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The growing role of In-System Programming activity in the electrical vehicle industry and its key players in the Chinese semiconductor market, with English-Chinese terminographic repertoire

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前言

此论文的目的是解释在线烧录的这个4.0工业活动。除了在线烧录以外，此论文也解释它的编程方法与编程语言、用在线烧录可编程的器件、生产这些可编程器件的基本原料、可编程器件在最终产品上的一个实际例如、以及中国半导体市场的现实情况。

第一章将介绍在线烧录如何成为电动汽车印制电路板编程的基础并得到巩固。电动汽车的定义是完全由电机与电力驱动的运输工具，店里可以来自电池、太阳能电池或燃料电池。使电动汽车有别于传统内燃汽车的独特部件有：电池、充电端口、直流/交流转换器、电动牵引电机、车载充电器、电力电子控制器、热系统、牵引电池组和变速器。在电动汽车的印制电路板上还有三个基本动力控制系统：1. 汽车控制器 （VCU）负责监管运作，和管理电力控制系统；2. 电机控制器 （MCU）在VCU的指令下运行，以传输车辆的交流电；3. 电池管理系统 （BMS）管理和控制电池单元。电动汽车的功率输出以千瓦 （kW）为单位，充电效率取决于所使用的充电器类型，根据行驶距离和可用时间进行分类： 1 级充电器，最方便，但也最慢；2 级充电器，比 1 级充电器快 6 到 8 倍；3 级充电器，也称为直流 （DC）快速充电器。此外，充电器还根据使用最多的地区进行划分。

采购一辆电动汽车的基本好处是：更低的运行成本、零尾气排放、税收和财务优惠、电动汽车没有速手排、零噪声污染、先进的电池、充满电后的行驶里程以及更好的转售价值。相反，在各种缺点中，可以发现：充电站有限、充电时间较长、初始购买成本较高、电池更换费用昂贵、对温度敏感、公寓居民充电选择有限以及生产对环境的影响。从环境角度来看，锂离子电池的制造需要使用化石燃料来开采锂、钴和镍，而用于充电的能源（如热能，包括化石燃料）对环境的影响比内燃汽车更大。幸亏可以通过下面的行为限制上面的影响：在汽车生产中增加可回收材料的使用，开发效率更高、寿命更长的电池，建设以可再生能源为动力的充电基础设施，为用户提供碳补偿计划，实施闭环生产流程以减少浪费，并减少供应链的碳足迹。

预测今年（2024年）国际电动汽车市场的收入将达到4.228亿美元，到2030年将达到9.519亿美元，年均复合增长率为13.7%；今年，中国将创造最多收入，没三辆汽车中就有一辆是电动汽车，其次是欧洲、北美、韩国与日本。这得益于环保意识的增强、政府政策与激励措施的支持以及电动汽车技术的进步。此外，价格下降、充电站扩建、充电插头兼容性提高也是电动汽车销售增加的原因。从全球来看，电动汽车市场未来的主要趋势是：1.中国、欧洲与美国将继续推动电动汽车的销

售；2.更多车型与汽车制造商进入市场；3.电动汽车价格下降；4.电池的改进和发展；5.充电更方便、更快捷；6.标准充电阳能与电动汽车技术的结合。到2030年，每四连新车中就有一辆是电动汽车，但要实现这一目标，需要汽车、公用事业、政府和私人业主共同努力，以应对消费者的不确定性。

印制电路板（PCB）是一种电子组件，通过使用铜导体在元件之间建立电气连接，为电子元件的安装和互联提供一个表面。印制电路板制造过程有六个步骤：设计、印刷、蚀刻法、钻探、电镀与焊接。设计印制电路板原型是测试和检查电路板是否功能良好的基础，它需要四个步骤：确定电路板规格、检查设计以纠正任何错误、生成Gerber文件和码放文件。印刷电路板由导电铜层和电绝缘材料层交替铺设而成，然后在机械结构上进行电镀并覆盖一层不导电的阻焊层，在阻焊层顶部印上丝网，为电子元件提供图例。最后，将 PCB 元件焊接到电路板上并进行测试。

随着技术的进步，印刷电路板在电动汽车制造过程中起着至关重要的作用，因为它们是使电动汽车不仅能运行，而且可靠耐用的关键部件。因此，电动汽车的印刷电路板需要满足一些要求，比如：重铜、电源组合板、绝缘金属基板、镶嵌技术、芯片嵌入技术、热阻和导通电阻、开关性能、微型化、更高可靠性和降低成本。电动汽车的印刷电路板有别于其他现有印刷电路板的主要特点是：适用于高温环境、在不同环境下性能可靠、耐污、小巧轻便、经久耐用、运行高效。印刷电路板对于创建智能充电系统、车辆传感器和控制系统（比如安全性和可靠性）也非常重要。

电动汽车很大程度上依赖于印刷电路板，事实上，电动汽车的印刷电路板数量是传统燃油汽车的六倍。因此，印制电路板制造商必须满足汽车行业的要求。随着电动汽车中电子元件数量的增加，印制电路板正朝着高集成度、高密度、多层和耐高压的方向发展。根据销售经济规律，印刷电路板需求的增加应降低元件和电路板的价格。预计到2030年，全球印刷电路板市场规模将至少达到133.9亿美元，这当然要归功于电动汽车的生产，目前许多中国印刷电路板制造商已进入特斯拉（Tesla）和比亚迪（BYD）等电动汽车公司的供应链。

第二章将继续分析用于生产印制电路板的主要原料，即硅，之后将通过在线烧录进行编程。硅是地壳中含量仅次于氧气的元素（27.7%），可以在土壤和岩石、然水、植物、大气与某些动物内找到，与氧、铝和镁形成化合物，因此需要提取和提纯。它呈深灰色固体，具有金刚石晶体结构，熔点为 1410°C，闷点为 2355°C，密度为 2.33/立方厘米。金属硅是由二氧化硅和碳材料（如焦炭、煤炭和木屑）制成的。硅的电导率介于导体与绝缘体之间，因此被广泛应用于电子工业。由于硅具有掺杂能力，它是制造芯片和微处理器常用的材料，事实上，它还可用于晶体管、集成电路和太阳能电池等多中设备。因此，硅的重要性与科技产业的发展和进步直接相关。

掺杂工艺用于改变硅的电学特性，即在硅晶格中引入杂质，杂质可以接受或捐赠电子，从而产生 p 型或 n 型半导体。 这种能力对于电子设备的制造至关重要，因为它可以控制电流的流动。n 型硅是通过引入具有五个价电子的供体杂质而产生的，它能提高导电性，在这种情况下电子带负电。p 型硅是通过从邻近原子中引入带有三个价电子的受体杂质而产生的，通过这种方法可以达到所需的导电水平。利用 n 型和 p 型半导体的不同组合，可以制造出具有有用特性的设备，如二极管、晶体管或集成电路。

Czochralski 工艺用于生产半导体器件，从硅锭（即大块硅）开始。这些铸锭被切成薄片，用于生产电脑、智能手机、压力传感器系统和移动设备中的芯片和其他电子设备。硅晶圆是一种超扁平的圆盘，表面呈镜面状，厚度在 0.2 至 1.5 毫米之间，直径从 1 英寸到超过 12 英寸不等。半导体制造是指从硅片开始生产半导体器件的过程，由 8 个步骤组成：硅开采、硅提纯、硅锭生产、硅片制造、分层工艺、掺杂扩散、蚀刻工艺以及测试和封装。

半导体制造工艺必须面对的主要挑战包括：微型化、产量管理、经济和环境挑战以及创新。所有这些挑战都在推动半导体行业向一些新兴趋势发展，如先进工艺节点、三维集成、新兴材料、专业应用和先进封装技术。

第三章专门介绍在线烧录活动及其历史，目前在4.0工业中的作用、不同的应用方法、使用测种编程方式的器件、编程所用的语言、以及两个编程器的实际例如。

在线编程是一种技术，用于对安装在印制电路板上的不同电子器件 （比如微控制器与芯片组）进行编程，而不是在安装前进行编程。

在这种编程方法的各种优势中，我们可以发现：简化了 PCB 上的设计工作；将固件更新直接发送到片上存储器；无需将微控制器和存储芯片从电路中移除即可对其重新编程；编程一体化；单一生产阶段测试；可在生产运行中期更改代码或设计，从而节省成本并减少生产延误。为了开展编程活动，ISP 需要一个桌面软件工具、一个编程适配器和一个专门的编程界面。

如前所述，最初生产的微控制器只能使用一次性可编程 (OTP) 或 EPROM 存储器。但在 1993 年，Microchip Technology Incorporated 推出了第一款带有 EEPROM 存储器的微控制器，通过这种方式，存储器可以被电擦除，无需擦除窗口，从而降低了生产成本，并实现了 ISP 技术。

根据要编程的微控制器类型，ISP 有不同的编程方法，例如 1. 编程软件；2.PC 端口；3.AVR 系统内编程；4.ARM 系统内编程；5.外部存储器 ISP；6.引导加载固件。引导加载固件。除编程方法外，ISP 还支持各种加载器，例如串行加载器、并行加载器、JTAG 加载器、SWD 加载器、以太网加载器、USB 加载器和通用加载器。当然，选择适当的编程方法和正确的加载程序，不仅取决于目标设备，还取决于对高速编程的要求、硬件接口的可用性和预算限制。

除了编程方法和加载器外，还需要选择编程语言，以保证最终产品的能力和功能，可以选择不同的编程语言，如 C、C++、Java、Assembly 和 Python。

根据产量的不同，ISP 最后阶段可以通过两种不同的方式进行：第一种方式适用于低产量，因为连接器是手动连接到编程器上的，然后编程器通过电缆连接到 PCB 上；第二种方式适用于中高产量，因为它使用 PCB 上的测试点，用于对 PCB 元件进行功能测试。本文还介绍了两个系统内编程器的例子：意大利 SMH Technologies 公司的 FlashRunner 和中国 Opted Technologies 公司的 SQ 高速编程器。

可以肯定的是，系统内编程为工业 4.0，尤其是汽车行业，提供了通过时间效率和灵活性、增强的质量控制、可扩展性、安全性和数据完整性以及成本优化对不同设备进行编程的可能性。

第四章介绍了中国市场上在线编程活动的实际情况，讨论了在线编程行业的主要合作伙伴，比如硅制造商、电子制造服务 （EMS）以及代工生产（OEM）。首先，硅制造商是指那些设计和制造半导体和半导体器件的公司，根据生产类型可分为四类公司：整合元件制造厂 （IDM）、 晶圆代工（Pure play-foundries）、 无厂 （fabless）和 OSAT。半导体行业还根据其在价值链中的作用分为四大部分：设计、制造、组装-包装-测试和半导体制造设备。此市场收到汽车、消费电子、电信、工业设备、航空航天和国防以及医疗保健行业的影响。21世纪初，半导体市场从四方国家转向亚洲，其中中国在亚太地区市场的份额超过50%，在全球市场的份额超过30%。事实上，中国与中国台湾、韩国、日本、美国、英国、马来西亚、荷兰和以色列一起，是最大的芯片制造国之一。中国也是全球最大的半导体消费国，购买了全球生产的50%以上的芯片。实际上，集成电路占中国市场收入的80%以上，是中国信息技术产业的主要组成部分。由于中国希望实现芯片制造的自给自足，中国的半导体产业近年来发展迅速，美国总统拜登 （Biden）从 2022 年 10 月开始实施限制措施，禁止美国公司向中国出售某些类型的半导体。事实上，中国半导体市场的主要问题是对外国供应商的依赖，因为中国缺乏芯片制造过程中必不可少的 EUV 技术（光刻技术），而且中国还是荷兰艾司摩尔公司（ASML Company）的净进口国。因此，中国政府希望通过 “中国制造 2025 ”和国家投资 500 多亿美元的 “大基金 ”来实现芯片生产的自给自足。今年，中国半导体市场收入预计将达到 1,989 亿美元，集成电路市场规模将达到 1,601 亿美元。广东、山东、河南、四川和江苏等省凭借其经济特区（SEZ）和工业开发区 （IDZ）在半导体市场占据主导地位。

其次，电子制造服务（EMS）是指那些提供并涵盖代工生产（OEM）的制造、设计、运输、测试、维修以及许多其他活动等特定广泛服务的行业和分包商或公司，如医疗、汽车、航空航天和国防、消费电子、电子元件、通信、新能源、物联网和家电等行业。电子制造服务提供商可根据其年度总收入、复杂性和数量、技术能力和提供的服务、生命周期阶段以及所服务的市场分为三个等

级。电子制造服务公司擅长在制造、原材料供应、汇集资源、工业设计专业知识以及创造保修和维修等增值服务方面创造巨大的规模经济效益，从而降低制造成本，缩短产品上市时间。中国电子制造服务市场的发展速度快于全球其他市场，因为它为海外企业提供了更多的投资和进入机会，如税收减免、土地出让、低进口关税以及建立完全股权的可能性。然而，中国的电子制造服务市场也面临着不同的挑战，如劳动力成本和关税提高、货币波动、监管负担加重、中美贸易战、与台湾的紧张关系以及知识产权保护制度。

最后一点，代工生产（OEM）是指那些专门为另一家公司生产特定产品或部件的制造商，而另一家公司则为其提供设计和规格。换句话说，代工生产零件是按订单生产的零件，在汽车、高端电子和半导体行业很常见。按产量计算，中国已连续十一年被视为全球最大的工业制造商，自 2008 年以来，中国也是全球最大的汽车市场和制造商，其产量占全球产量的 30%。中国汽车市场向新能源汽车转型的势头迅猛，中国汽车代工生产遍布发达国家和发展中国家，其中排名前五的中国整车厂分别是比亚迪（BYD）、吉利（Geely）、上汽（SAIC Motor）、长安（Changan）和宁德时代新能源科技股份有限公司 （CATL）。然而，代工生产不仅指汽车，还包括计算机、通信和医疗工具，其他领先的中国代工生产企业包括华为（Huawei）、中国航天科技集团（CASC）、中国电子科技集团公司（CETC）、美的集团（Midea Group）、海尔 （Haier)、格力（Gree）、联想（Lenovo）和中兴通讯（ZTE）。

本章最后讨论了始于2022年10月7日的中美芯片战，当时拜登（Biden）政府领导下的美国政府宣布了一系列对华出口限制措施，尤其是对人工智能和半导体技术的限制。第二年，中国作出回应，禁止美国公司英特尔（INTEL）和超威半导体公司（ADM - Advanced Micro Devices）生产的任何中英处理器（CPU）用于中国政府的计算机和服务器。2024年1月，中国半导体销售额的增长速度超过了美国和全球的增长速度，因此可以肯定连年后美国的限制措施仍在失效，而中国正在增强实现自给自足的能力。

从地缘政治的角度来看，两个世界超级大国之间的芯片战争使台湾处于尴尬境地，同时也影响了汽车工业。台湾是世界上生产最先进微芯片的领先国家（超过90%），事实上，半导体产业是台湾经济的支柱产业，而中国则是其出口的第一大国。这也是习近平主席寻求统一台湾的原因之一，同时也是美国为台湾独立提供保护的原因。

如果中国在不久的将来在芯片生态系统中完全独立，将会产生巨大的地缘政治影响，例如打乱现有的供应链，重塑全球电子产业的劳动分工和人力资本分布，中国芯片还可能被用来进行网络间谍活动。

最后，本文的第二部分是与在线编程领域有关的英-中语表组成，涉及在线编程的方方面面。最后，英-中和中-英概括词汇表完成论文。本文旨在强调在线编程在 4.0 这个与我们每个人都息息相关的行业中的重要性，并为任何希望从东方视角切入这一主题的人提供支持。

Index

PREFACE

This paper aims to explain the In-System Programming activity that is currently present in industry 4.0, as well as its programming methods and languages, the devices that can be programmed trough In-System programmers, the main raw material employed for the production of these programmable devices, a practical example of programmed device on final product, and the current state of semiconductor market in China.

The first chapter wants to report how In-System Programming is fundamental and already consolidated in the programming of PCB present in electric vehicles. The definition of all-electric vehicles is "means of transport powered exclusively through electric motors and electricity that can come from battery, solar panel, or fuel cell". The unique components that make EV different from the traditional combustion vehicles are: the battery, the charge port, the DC/AC converter, the electric traction motor, the on board charger, the power electronics controller, the thermal system, the traction battery pack, and the transmission. In EVs there are also three main power control systems built on their PCBs, that are: 1. Vehicle Control Unit (VCU) that governs and supervises the operations and decides for the power control system; 2. Motor Control Unit (MCU) that operates under the instructions of VCU in order to transmit the alternating current of the vehicle; 3. Battery Management System (BMS) that manages and controls the battery unit. The power output of an EV is quantified in kilowatts (kW) and the charging efficiency depends on the type of charger used, that are usually classified according to the distance to be traveled and on the time available: Level 1 charger , the most convenient but also the slowest; Level 2 charger, six to eight time faster than Level 1; and Level 3 charger, also known as DC fast chargers.

The main pros of purchasing an EV are: lower running costs, zero tailpipe emissions, tax and financial benefits, no gears, zero noise pollution, advanced batteries, full charge driving range, and better resale value. Instead among the different cons it is possible to find: limited availability of charging stations, longer charging times, higher initial purchase cost, expensive battery replacements, temperature sensitivity, limited charging options for apartment dwellers, and the environmental impact of production.

From an environmental point of view, the manufacturing of their lithium-ion batteries that requires fossil fuels in order to mine lithium, cobalt, and nickel, and the energy source used to charge them (like thermal source, including fossil fuel) have and higher impact on environment than internal combustion vehicles. Fortunately it is possible to limit this impact with the following actions: increasing the use of recycled materials in car production, developing more efficient and longer-lasting batteries, building renewable energy-powered charging infrastructure, offering carbon offset programs for users, to implement closed-loop manufacturing process to reduce waste, and reducing the carbon footprint of supply chains.

The global electric vehicles market is projected to reach a revenue of USD 422,8 billion this year (2024) and USD 951,9 billion by 2030 at CAGR of 13,7%; the most revenue will be generated in China this year where 1-in-3 cars are sold electric, followed by Europe, North America, South Korea, and Japan. This is mainly due to the increase of environmental awareness, supportive government policies and incentives, and advancements in EV technologies. In addition, the increase of EV sales are also motivated by lower selling prices, the expansion of charging stations, and greater charging plug compatibility. From a global point of view, the main future trend of EV market are: 1. China, Europe and US will continue to drive sales, 2. More models and automakers in the market, 3. Lower prices of EV, 4. Improvement and development of batteries, 5. Easier and faster charging, 6. Standard chargers, 7. Acceleration of commercial EV adoption, and 8. Combination of solar energy and EV technology. By 2030 one out of four new cars will be sold in EV, but it is needed a joint effort between automotive, utilities, government, and private property owners in order to face consumers uncertainty.

Printed circuit board (PCB) is an electronic assembly that creates electrical connections between components by using copper conductors, providing a surface for mounting and interconnecting electronics components. There are six steps in the PCB manufacturing process: design, printing, etching, drilling, plating, and soldering. Designing a prototype PCB is fundamental in order to test and check if PCB is well-functioning and it needs four steps: determine the specifications of PCB, check design to correct any errors, generate Gerber files, and stack up documents. PCBs are build alternating layers of conductive copper with layers of electrically insulating material, then the mechanical structure is plated and covered with a non-conductive solder mask, and a silk screen is printed on the top of the solder mask to provide a legend for electronic components. Last, the PCB components are soldered to the board and tested.

PCBs have a crucial role in the EV manufacturing process as technology advances, as they are the key components that make EVs possible function, not only for running but also to be reliable and durable. For these reasons, EVs' PCBs need to meet some requirements, such as: heavy copper, power combo-board, insulated metal substrate, inlay technology, chip embedded technology, thermal and on-state resistance, switching performance, miniaturisation, higher reliability, and cost reduction. The main features that distinguish EV's PCBs from the other existing PCBs are: suitable for high temperatures, reliable in different environments, dirt resistance, compact and lightweight, durable, and efficient operation. PCBs are important also for the creation of smart charging systems, vehicle sensors and control systems, like safety and reliability.

It is possible to affirm that electric cars heavily rely on PCBs, in fact they have 6 times more PCBs than traditional fuel vehicles. So it is necessary that PCB manufacturers meet the requirements from automotive industry. With the increase of the number of electronic components present in EVs, PCBs are developing in the direction of high integration, high density, multi-layer and withstand high-voltage. According to the law of the economy of scale, an increase in PCB demand should reduce the prices of components and boards. The global PCB market is expected to reach at least USD 13.39 billion by 2030, of course thanks to the production of EVs, and currently many Chinese PCB manufacturers have entered the supply chain of EV companies like Tesla and BYD.

The second chapter instead continue with the analysis of the main raw material used for the production of PCB, that will afterwards programmed through ISP, that is the silicon. Silicon is the second most abundant element in the Earth's crust (27,7%) after oxygen and can be found in soil and rock, natural water, plants, atmosphere and in certain animals, as compounds with oxygen, aluminium and magnesium, so it needs to be extracted and purified. It presents itself as a dark grey solid with a diamond crystalline structure, and its melting point is of 1410°C, boring point of 2355°C, and a density of 2.33/cm3. Silicon metal is crated from the creation of silica and carbon materials like coke, coal ad wood chips. Due to its electrical conductivity value between that of a conductor and an insulator, silicon is widely used in the electronic industry. Thanks to its ability to be doped, silicon is the most common material used for manufacturing chips and microprocessors, in fact it can fin a wide variety of devices' application, like transistors, integrated circuits and solar cells. For all these reasons, the importance of silicon is directly linked to the growth and the advancement of technology industry.

The process called doping is used to modify the electrical properties of silicon, and it means that impurities are introduced into silicon crystal lattice and they can accept or donate electrons, creating p-type or n-type semiconductors. This ability is essential for the manufacturing of electronic devices, as it can control the flow of electrical current. n-type silicon is created with the introduction of donor impurities with five valence electrons that improve electrical conductivity, and in this case electrons are negatively charged. p-type silicon is created with the introduction of acceptor impurities with three valence electrons from neighbouring atoms, and in this way it is possible to achieve the desired level of conductivity. With different combinations of n-type and p-type semiconductors, it is possible to create devices with useful properties, like diodes, transistors or integrated circuits.

The Czochralski process is used to produce semiconductor devices, starting from silicon ingots that are large blocks of silicon. These ingot are sliced into thin wafer, that are used for the production of chips and other electronic devices present in computers, smartphones, pressure sensor system, and mobile devices. Silicon wafers are super-flat disk with a mirror-like surface, a thickness between 0.2 and 1.5 mm and a diameter from 1 inch to over 12 inches. Semiconductor manufacturing is the process of producing semiconductor devices starting from silicon wafers, and it is made up of 8 steps: the silicon mining, the purification of silicon, the production of silicon ingots, the wafer fabrication, the layering process, the dopant diffusion, the etching process, and testing and packaging.

The main challenges that semiconductor manufacturing process has to face are: miniaturisation, yield management, economic and environmental challenges, and innovation. All these challenges are driving the semiconductor industry to some emerging trends, such as the advanced process nodes, the 3D integration, the emerging materials, the specialised applications, and the advanced packaging technologies.

The third chapter is dedicated to the activity of In-System Programming, as well as its history, its current role in industry 4.0, the different application methodologies, the devices that use this type of programming, the language used for programming, and two practical examples of programmers. In-System Programming is a technique applied to program different electronic devices such as microcontrollers and chipsets while they are installed on a printed circuit board, rather than programming them before installation. Among the different advantages of this programming methods, it is possible to find: the simplification of the design work on the PCB; the direct delivery of firmware updates directly to the on-chip memory; the possibility to re-program microcontroller and memory chips without removing them from the circuit; the integration of programming; the single production phase testing; the possibility to save money and reducing manufacturing delays by enabling code or design changes mid-production run. In order to conduct the programming activity, ISP needs for a desktop software tool, a programming adapter and a specialised programming interface.

As mentioned before, at the beginning microcontrollers could only be produced with one-time programmable (OTP) or EPROM memories. But in 1993, Microchip Technology Incorporated introduced the first microcontroller with EEPROM memory, and by this way memories could be electrically erased, reducing production costs by eliminating the need for erasing windows and enabling ISP technology.

According to the type of microcontroller to be programmed, ISP has different programming methods, such as: 1. Programming software, 2. PC ports, 3. AVR In-System Programming, 4. ARM In-System Programming, 5. ISP of external memory, and 6. Boot loading firmware. As well as programming methods, ISP supports also various loaders, for example serial loaders, parallel loaders, JTAG loaders, SWD loaders, ethernet loaders, USB loaders, and universal loaders. Of course the choice of the appropriate programming methods as well as the choice of the correct loader, depends not only on the target device, but also on the requirement for high programming speeds, hardware interface availability, and the budget constraints.
Other than programming methods and loaders, there is also the programming language to be choose in order to guarantee the capabilities and functionality on the final product, and it is possible to choose among different programming languages, such as C, C++, Java, Assembly, and Python.

Depending on the production volumes, ISP final stage can be carried out in two different ways: the first one is suitable for low production volumes, because the connector is manually attached to the programmer, which is then connected to the PCB via a cable; the second one is suitable for medium and high production volumes, as it uses test points on the PCB, that are used for conducting functional test on the PCB components. This paper introduces also two example of In-System Programmers: the Italian SMH Technologies' FlashRunner and the Chinese Opted Technologies' SQ High-Speed Programmer.
It is possible to affirm that In-System Programming offers to industry 4.0, especially to the automotive industry, the possibility to program different devices through time efficiency and flexibility, enhanced quality control, scalability, security and data integrity, and cost optimisation.

The fourth and last chapter deals with the actual state of ISP activity in the Chinese market, discussing the key partners in the In-System Programming industry, such as silicon produces, EMS and OEM. First, silicon producers are those companies that design and fabricate semiconductors and semiconductor devices, and are divided into four types of companies according to the type of production: IDM, Pure play-foundries, fabless and OSAT. Semiconductor industry is also divided into four major segment according to their role in the value chain: design, manufacture, assembly-packaging-testing, and semiconductor manufacturing equipments. This market is influenced by automotive, consumer electronics, telecommunication, industrial equipment, aerospace and defence, and healthcare industries. At the beginning of 21st century, the semiconductor market made a shift from Western countries to Asian ones, where China contributes with more than 50% to the regional APAC market and more than 30% globally. Actually China, together with Taiwan, South Korea, Japan, USA, UK, Malaysia, The Netherlands and Israel, is one of the biggest chip manufacturing countries. China is also the largest consumer of semiconductor at global scale, purchasing more than 50% of globally manufactured chips. In fact, in Chinese market the IC account for more than 80% of revenue, being the major part of the county's information technology industry.

Chinese semiconductor industry is growing fast in recent years because China wants to reach self-sufficiency in chip manufacturing, as from October 2022 US President Biden applied restriction that prohibit American companies from selling certain types of semiconductors to China. In fact, the main problem of Chinese semiconductor market is the dependance on foreign providers, as China lacks of EUV technology (lithography) essential in the chipmaking process, and the country is a net importer from the Dutch ASML. For these reasons, China government wants to achieve self-sufficiency through different initiatives as "Made in China 2025" and the state investment of more than USD 50 billion named the "Big Fund" for chip production. This year (2024) the Chinese semiconductor market revenue is projected to reach USD 198.90 billions and ICs reach a volume of USD 160.10 billions. Chinese provinces that dominate the semiconductor market are Guangdong, Shandong, Henan, Sichuan and Jiangsu thanks to their SEZ and IDZ.

Second, EMS short for Electronic Manufacturing Services, refers to those industries and subcontractors or companies that provide and cover a specific wide range of services, like manufacturing, design, shipping, testing, repairs, and many other activities of OEM and ODM, such as medical, automotive, aerospace and defence, consumer electronic, electronic components, communications, new energy, IoT, and home appliances industries. EMS providers can be categorised into three tiers according to their total annual revenue, but also according to the complexity and volume, to the technical capability and service offering, to lifecycle stage, and to the markets served. EMS companies are specialised in creating large economies of scale in manufacturing, raw materials supplying, gather together resources, industrial design expertise, and creating added value services like warrant and repairs, by this way it is possible to reduce manufacturing costs and time to market. Chinese EMS market is developing faster than the rest of the global market, as it provides more investment and entry opportunity to overseas players, like tax credits, land grants, low import duties and the possibility to establish full provate equity ownership. However, Chinese EMS market is also facing different challenges, such as raising labour costs and tariffs, currency fluctuations, more regulatory burdens, the US-China trade war, the tense relations with Taiwan and the intellectual property protection system.

Third and last, OEM short for Original Electronic Manufactures, refers to those manufacturers specialised in the production of particular products or parts for another company that provides them with the design and specifications. In other words, an OEM part is a manufacture to order and it is common in automotive, high-end electronic and semiconductor industries. China is considered the world's largest industry manufacturer by output for more than eleven years, and since 2008 China is also the world's largest automotive market and manufacturer as it produces the 30% of global production. Chinese automotive market have seen a huge transition to new energy vehicles and Chinese automotive OEMs are present both in developed and developing countries, and the top 5 Chinese OEMs are BYD, Geely, SAIC Motor, Changan and CATL. However, OEM does not only means automotive, but also computers, communications and medical tools, and the other leading Chinese OEMs are Huawei, CASC, CETC, Midea Group, Haier, Gree, Lenovo and ZTE.

This chapter concludes with a discussion about the US-China chip war that started on October the 7th 2022, when U.S. Government under Biden administration announced a set of export restrictions towards China, especially on AI and semiconductor technologies. The year after China responded with a ban of any CPU made by the American companies Intel and ADM (Advanced Micro Devices) for Chinese government computers and servers. On January 2024, semiconductor's sales in China reached a growth rate that is faster than US and global ones, so it is possible to affirm that after two years the US restrictions are still failing and China is increasing its capacity in achieving self-sufficiency. From a geopolitical point of view, the Chip War between the two world superpowers is putting Taiwan into an uncomfortable position and affecting automotive industry at the same time. Taiwan is the country leader in the production of world's most advanced microchips (more than 90%), in fact semiconductor industry makes up the country economy and China represents the first country for its export destination. This is one of the reasons way President Xi

Jinping is seeking for reunification with Taiwan, and why at the same time the US is offering protection to the independence of the country.

If China in the near future will be completely independent in the chip ecosystem, there will be massive geopolitical repercussions, for instance upset the existing supply chains, reshape the division of labour, the distribution of human capital in the global electronics industry, and Chinese chips could be exploited to conduct cyber espionage.

Finally, the second section of the paper consists of an English-Chinese terminographic repertoire relating to the sphere of In-System Programming, plumbed in its most diverse facets. An English-Chinese and Chinese-English glossary concludes the work. The paper aims to highlight the importance of In-System Programming in an industry that affects us all very closely, that of 4.0, and to be of support to anyone wishing to approach the subject from an Eastern perspective.

SECTION I

CHAPTER 1
PRINTED CIRCUIT BOARDS FOR ALL-ELECTRIC VEHICLES

1.1 All-electric vehicles

All-electric vehicles (also called pure-electric vehicles) are means of transport powered exclusively through electric motors and electricity that can come from battery (in this case it will be a battery electric vehicle), solar panel (in this case it will be called solar vehicle) or fuel cell (fuel cell vehicle). Fully electric car has neither petrol or diesel engine, or gears, so it is sufficient to place the car in “drive” mode to make it accelerates, just like an automatic vehicle. As EVs (short for electric vehicles) don’t have gears, they accelerate faster than traditional fuel engines cars. When the user presses the accelerator, the power is transferred from the battery to the electric motor and the motor is powered, and the drive shafts turn the wheels. When the user brakes the car, it begins to decelerate and the motor generates power, like an alternator, and this power is sent back to the battery.

EVs are influencing the present and the future of the automotive industry, as they are getting ready for a clear energy future. As a demonstration of this, many countries are preparing for the phasing out of petrol and diesel vehicles and car manufacturers are focusing on making EVs the eco-friendly alternatives to fossil-fueled cars[1].

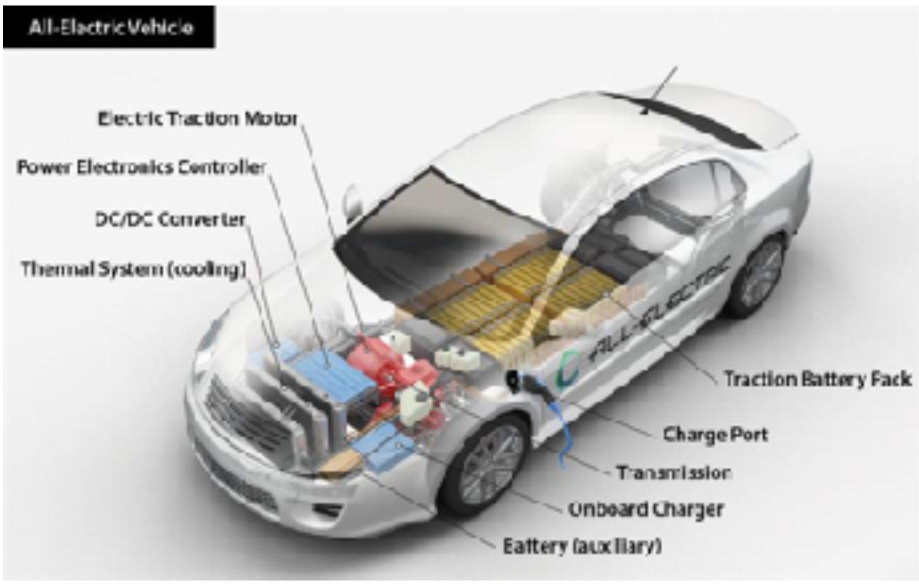

Figure 1: Example of all-electric car and its key components

[1] The sustainability of electric cars (2023-06-13), in “octopuses.com", https://octopusev.com/ev-hub/the-sustainability-of-electric-cars , 21-05-2024.

The figure 1 shows how an EV present itself and here below there is a list of the unique components that make this kind of vehicles different from the traditional internal combustion vehicles (ICV)[2]:

- **Battery**: it provides electricity to power vehicle accessories;

- **Charge port**: it allows the vehicle to connect to an external power supply in order to charge the traction battery pack;

- **DC/AC converter**: it is a device that converts higher-voltage DC (short for direct current) power from the traction battery pack to the lower-voltage AC (short for alternating current) power needed to run vehicle accessories and recharge the auxiliary battery;

- **Electric traction motor**: it drives the wheels of the vehicles using power from the traction battery pack;

- **On board charger**: it takes the AC electricity coming from the charge port and converts it to DC power for charging the traction battery. In addition, it communicates with the crashing equipment and monitors battery characteristics, such as voltage, current, temperature, and state of charge while charging the pack;

- **Power electronics controller**: it manages the flow of electrical energy delivered by the traction of the battery, and also controls the speed of electric traction motor and the torque it produces;

- **Thermal system (cooling)**: it maintains an appropriate operating temperature rage of vehicle's components such as the engine, electric motor, power electronics, and others;

- **Traction battery pack**: it stores electricity used by the electric traction motor;

- **Transmission (electric)**: it transfers mechanical power from the electric traction motor to drive the wheels.

In electric vehicles it is also possible to find three main power control systems that are built on the printed circuit boards (PCBs) of electric vehicles, that are[3]:

1. **VCU - Vehicle Control Unit**: it is a module that controls circuits and algorithms software, and its job is to govern and supervise vehicle operations and make decisions for the power control system. It occupies an area of approximately 0.03 square meters;

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[2] U.S. Department of Energy, Energy Efficiency & Renewable Energy, How do all-electric cars work?, in "afdc.energy.gov", https://afdc.energy.gov/vehicles/how-do-all-electric-cars-work , 21-05-2024.

[3] PCBs in electric vehicles: powering the future of transportation, in "ablcircuits.co.uk", https://www.ablcircuits.co.uk/blog/pcbs-in-electric-vehicles/ , 21-05-2024.

2. **MCU - Motor Control Unit**: it is similar to VCU as it controls circuits and algorithm software, but it operates under the instruction of VCU in order to facilitate the motor's transmission of alternating current of the vehicle. It occupies an area of approximately 0.15 square meters;

3. **BMS - Battery Management System**: it has a crucial role in the battery system of EVs, as it manages and controls the battery unit. BMS has various functions, for instance collecting and analysing voltage, current and State of Charge (SOC) data to control battery discharge and recharge. It is composed of hardware components that prevent battery damage, such as the BCU, that controls relays, estimates SOC and provides electrical protection, and the Battery Management Unit (BMU) that supervises voltage, data, battery current and ensures balance control on the vehicle's power system. Given its complexity, BMS requires several PCBs and it occupies an area of 0.24 square meters of PCB space for the master control unit, and an area of 2 and 3 square meters for individual management systems.

The power output of an all-electric car's motor, like other machinery, is quantified in kilowatts (kW) and electric motors can maintain their peak torque across a broad range of revolutions per minute (RPM)[4]. Consequently, a vehicle equipped with a 100 kW electric motor outperforms one with a 100 kW internal combustion engine, which can only deliver its maximum torque within a restricted range of engine speeds[5].

Charging efficiency varies significantly depending on the type of charger used, with energy lost during the conversion process from electrical to mechanical energy. Normally, direct current electricity is directed into a DC/AC inverter, where it is transformed into alternating current electricity before being supplied to a 3-phase AC motor. DC motors are commonly used in electric trains, forklift trucks, and certain types of electric cars. In some cases, universal motors are employed in order to allow the utilisations of both AC and DC power.

Electric cars, like all electrical devices, can be charged by plugging it into a charge point, where it takes electricity from the grid. EVs first store the electricity in rechargeable batteries and then these batteries power the electric motor, which turns the wheels. It is also important to notice that charging an EV is not fast as refuel a gasoline or diesel powered car and actually there are three main classifications of EV charging, depending on how long it will be the distance to be traveled and on the time available[6]:

1. **Level 1 charger**: it is an equipment normally provided with all new EVs and it plugs into an ordinary 120 volts household outlet. This is the most convenient but also the slowest way to charge the vehicle, as this type of chargers add roughly three to six kilometres of a range per hour. This means that using Level 1 charging can take days to fully replenish a depleted battery pack. It is the best solution if users drive no ore than thirty kilometres per day as they can plug in every night;

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[4] Electric vechile, în "en-wikipedia.org", https://en.wikipedia.org/wiki/Electric_vehicle , 21-05-2024.

[5] Sanjay C.P., (2023-02-16), Electric vehicles, in "linkedin.come", https://www.linkedin.com/pulse/electric-vehicles-sanjay-c-p-j7boc/ , 21-05-2024.

[6] Electric vehicles explained, in "windsor.ie", https://www.windsor.ie/electric-hybrid/electric-vehicles-explained/ , 21-05-2024.

2. **Level 2 charger**: it is also known as home charging and it can support up to 240 volts at triple the amperage of Level 1, making it six to eight time faster than Level 1. This means that it add 18 and 48 kilometres of range per hour, for this reason it makes full overnight charging easier even if you didn't charge the vehicle for a couple of days. It is the best solution for users that are also homeowner that can purchase standalone Level 2 home charge equipment. However it is possible to find Level 2 charge also in public spaces, workplaces, and shopping malls. Of course charge the EV at home costs notably less than filling, especially if users have solar panels that feed a series of batteries called an energy storage system, that collect energy from the sun during the day and store it for later uses;

3. **Level 3 charger**: it is also known as DC fast chargers and it can charge EV more rapidly than Level 1 and Level 2 chargers. It is useful in case of long trips that require intermediate charges to reach the destination. This kind of charger uses a different socket on the vehicle side, with extra pins in order to add higher voltage. It can charge the equivalent of 150-375 kilometres of rage in less than an hour. There are three types of Lever 3 chargers: 1. CHAdeMO, 2. SAE Combo and 3. Tesla Supercharger.

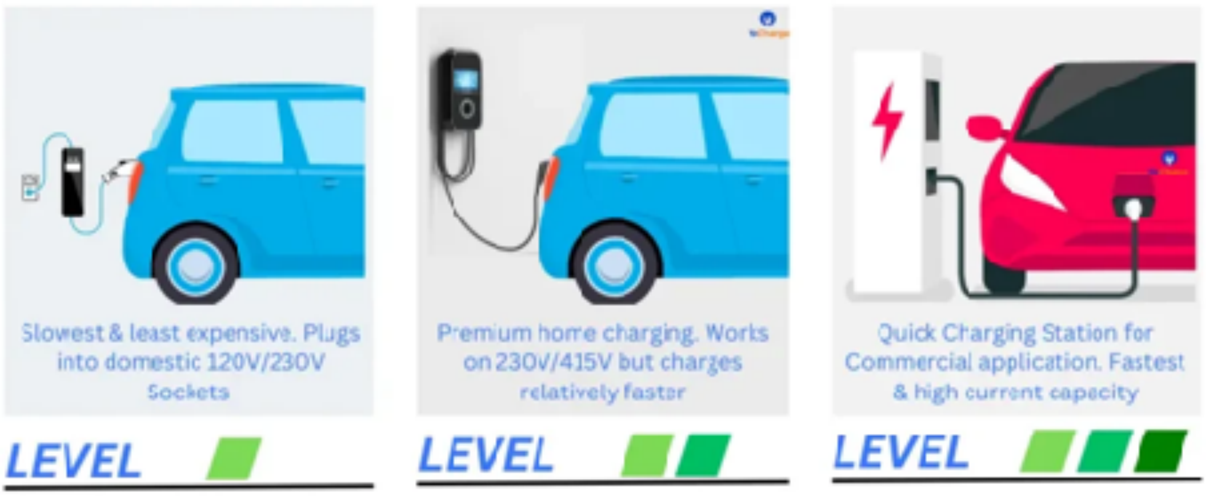

Figure 2: The three types of EV charging stations

As it happens with every new technology (just think to mobile phones), each manufacturer uses and develops his own charger. It is possible to divide chargers according to the region where they are used the most. For AC charging stations, the user is needed to carry the cable that fits his car, by this way the problem of different type of connector is eliminated. Instead, DC fast charging stations always have their own cable attached due to many reasons, such as security, amount of current, cable's price and weight. In this case the user needs to select a station that has the appropriate connector[7].

[7] Evexpert, Connector types for EV charging around the world, in "evexpert.eu", https://www.evexpert.eu/eshop1/knowledge-center/connector-types-for-ev-charging-around-the-world , 21-05-2024.

Figure 3: DC fast charging stations' connector types for EV charging around the world

Currently, the electric vehicle market is dominated by several companies around the world, such as Chinese BYD, American Tesla, German Volkswagen AG, Chinese SAIC Motors, and the Dutch Stellantis. These companies work with others players in the EV ecosystem and develop the best in class EV technology. At the moment, it is possible to consider BYD company to be the biggest EV-manufacturing rival to Tesla, and so China to be the U.S.' economic rival[8].

[8] Electric vehicle market, in "marketsandmarkets.com" https://www.marketsandmarkets.com/PressReleases/ev-component-and-infrastructure.asp , 21-05-2024.

1.1.1 The history of electric vehicles

The history of electric vehicles is a journey that started more than 200 years ago, making its genesis at the beginning of 19th century. Electric cars have emerged as a result of various factors, and the most significant is the development of railways, which revolutionised long-distance transportation. However, despite this advancement, the individual transportation of people remained predominantly reliant on horse-drawn carriages. Moreover, in 19th century took place a monumental revolution with the introduction of electricity, that completely transformed industries and later influenced housing, transportation, and public spaces.

The first electric motor was built in 1827 by an Hungarian priest named Ányos Jedlik, and it was used the year after to power a small model car. In 1835, a Dutch professor named Sibrandus Stratingh made a small electric car. Between 1832 and 1839, the first basic electric carriage was created by the Scottish entrepreneur Robert Anderson, however the vehicle could not recharge. In 1835, Thomas Davenport, an American blacksmith, created an electric locomotive toy and in 1838, while Robert Davidson build a faster electric train in Scotland.

The big advancement came in 1859, when the French scientist Gaston Plant invented the rechargeable lead-acid batteries, and this means that from that moment cars did not have to stay plugged in all the time. Then in 1881, Camille Faure made batteries better at charging, and the same year in Paris, the French engineer Gustave Trouvé presented an electric tricycle[9].

Electric cars begun to become more practical in the 1870s: the first electric car (called Flocken Electrowagen) was constructed in 1888 by a German inventor named Andreas Flocken, and it looked like a buggy and could reach 15km/h (figure 4). Around 1890, the American chemist William Morrison created a six-passenger electric vehicle similar to a wagon with a simple design. In 1899 the Belgian pioneer Camille Jenatzy broke the global speed record of electric cars, hitting over 100km/h[10].

Figure 4: 1888 Flocken Electrowagen, the first electric car

[9] History of the electric vehicle, in “en.wikipedia.org", https://en.wikipedia.org/wiki/History_of_the_electric_vehicle , 21-05-2024.

[10] Matulka, R. (2014-09-15), The history of electric car, in “energy.gov", https://www.energy.gov/articles/history-electric-car , 21-05-2024.

At the beginning of 20th century, Studebacker Automobile, a company which made both electric and gasoline cars, for the first time mass-produced electric vehicles in America, starting in 1902. As electricity became more available in the 1910s, it got easier to charge electric cars, and this make them more appealing, especially for New York taxi drivers. However, electric cars lost their popularity when Ford Motor company started making affordable gasoline cars in assembly lines in 1913. Actually there were not enough electric charging stations, and the batteries did not last long enough. In addition, roads got better, gas become cheap, and gasoline cars got better thanks to electric starter and muffler inventions, that made them easier and quieter to use[11].

Electric trains become more popular and common than electric cars in this period, because they were economical and fast, but they were not used as much for regular transportation. In fact, they were useful for carrying coal because they did not use up oxygen like steam trains did. In particular, Switzerland started using electric trains because they didn't have many fossil fuels. Instead, electric cars were used for special jobs like platform trucks, forklift trucks, ambulances, tow tractors, and urban delivery vehicles like the renowned British milk float. The next thirty years, electric cars didn't see much progress and were almost forgotten.

However in the late 1960s and early 1970s, people started thinking about using less foreign oil and finding other ways to power cars in the United States, because the oil price went up and there was not enough gas, especially during the 1973 Arab Oil Embargo[12]. For this reason the U.S. Congress in 1976 made the Electric and Hybrid Vehicle Research, Development, and Demonstration Act that helped the Department of Energy pay for research on electric and hybrid cars[13].

During this period, big and small car companies started looking into producing electric cars, as General Motors[14] that made a city electric car in 1973. Instead, the American Motor Corporation[15] in 1971 manufactured an electric delivery jeep for the United States Postal Service, and even NASA sent an electric car to the moon the same year. Despite all these efforts, electric cars in the '70s still had problem compared to gasoline vehicles, for instance they could not go as fast and did not go as far before needing to the recharged.

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[11] Matulka, R. (2014-09-15), The history of electric car, in "energy.gov", https://www.energy.gov/articles/history-electric-car , 21-05-2024.

[12] During the 1973 Arab-Israeli War, Arab members of the Organization of Petroleum Exporting Countries (OPEC) imposed an embargo against the United States in retaliation for the U.S. decision to re-supply the Israeli military and to gain leverage in the post-war peace negotiations. The embargo was extended also to Netherlands, Portugal, and South Africa. The embargo both banned petroleum exports to the targeted nations and introduced cuts in oil production. Oil Embargo, 1973-1974 (2024), in "history.state.gov", https://history.state.gov/milestones/1969-1976/oil-embargo , 21-05-2024.

[13] Matulka, R. (2014-09-15), The history of electric car, in "energy.gov", https://www.energy.gov/articles/history-electric-car , 21-05-2024.

[14] General Motor Company (GM) is an American multinational automotive manufacturing company located in Detroit, Michigan, United States. The company is most known for owing and manufacturing four automobile brands, that are Chevrolet, GMC, Cadillac and Buick. General Motors, in "en.wikipedia.org", https://en.wikipedia.org/wiki/General_Motors , 21-05-2024.

[15] American Motors Corporation (AMC) was an American automobile manufacturing company formed by the merger of Nash-Kelvinator Corporation and Hudson Motor Car Company on May 1, 1954. At the time, it was the largest corporate merger in U.S. history. American Motors Corporation, in "en.wikipedia.org", https://en.wikipedia.org/wiki/American_Motors_Corporation , 21-05-2024.

In January 1990, the President of General Motors presented a new electrical car called the "Impact" at the Los Angeles Auto Show and from September of the year after, the state of California approved a rule under which big car companies had to start selling electric cars in 1998. Between 1996 and 1998, General Motors made 1,117 EV1 model electric cars, and 800 of them were leased for three years. Also other car companies like Chrysler, Ford, Honda, and Toyota begun producing electric cars for people in California during this time.

But in 2003, General Motors' leases for the EV1 model ended, the company stopped manufacturing them and the reasons were: car industry won a court case against California's rule for zero-emission cars, government make a rule making General Motors keep spare parts for the EV1 cars, and a media campaign by the oil and car industries made people less interested in electric cars[16].

In the late 20th century and in the early 21st century, as people started worrying more about how gasoline cars can hurt environment and how oil would soon run out, they become interested in electric cars. But the big rebound for electric vehicles happened in the early 2000s, due to two important circumstances.

The first scenario took place in 1997, when Toyota introduced a large number of the world's first hybrid electric car named Prius, that from 2000 started to be sold globally becoming really popular. Prius showed that hybrid cars were a good idea, especially with gas prices going up and people worrying about pollution. The car used a battery called nickel metal hydride, that was developed with the help of research from the American Energy Department[17].

Figure 5: 1997 Toyota Prius

[16] Who killed the electric car? (2024), in "en.wikipedia.org", https://en.wikipedia.org/wiki/Who_Killed_the_Electric_Car%3F , 21-05-2024.

[17] Clifford, J., (2015-02-10), History of the Toyota Prius, in "mag.toyota.co.uk", https://mag.toyota.co.uk/history-toyota-prius/ , 21-05-2024.

The second scenario took place in 2006, when the famous Silicon Valley based Tesla Motors[18] started its activity as a start up. Its objective was to make a luxurious electric sports car that could go over 300 kilometres on one charge, and this got the attention from government, which finance the research with a huge loan. Tesla's success inspired other car companies to start making their own electric cars to be faster, for instance Chevrolet with its Chevy Volt which used both gas and electricity, and the full electric Nissan LEAF.

In September 2016, car dealers sold more than one million full electric cars and vans worldwide and Norway even had 100,000 electric cars registered by the end of that year. Then, in March 2020 Tesla has been reordered as the first company to produce one million electric cars, and by the end of the same year, over 10 million electric cars and vans had been sold since 2010.

Today, it is possible to choose from a lot of different electric cars, raging from small city cars like the Smart EQ to fancy SUVs like the BMW i3, and with the gas prices going up and electric cars becoming cheaper, more and more people are choosing electric vehicles. In the United States alone, there are over 234,000 plug-in electric cars and 3.3 million hybrids driving on the roads[19].

[18] Tesla Motors was founded in July 2023 by Martin Eberhard and Marc Tarpenning to create efficient electric cars for people who love to drive. The Chairman of Tesla Motors, a privately held company, is Elon Musk, who has led or co-led three round of investment resulting in USD 60 million in founding. Musk has been instrumental in both corporate and product development at Tesla Motors. About Tesla Motors (2010-04-20), in "tesla.com", https://www.tesla.com/blog/tesla-motors-receives-prestigious-'breakthrough-award'-popular-mechanics , 21-05-2024.

[19] History of the electric vehicle (2024), in "en.wikipedia.org", https://en.wikipedia.org/wiki/History_of_the_electric_vehicle , 21-05-2024.

1.1.1 Pros and cons of electric vehicles

As for the purchase of any new technology device, before proceeding with the purchase it is better to evaluate all the pros and the cons given the high initial cost.

The initial upfront purchase price of an electric car can be higher, however it is usually offset by lower running costs and many other advantages, that are listed here below[20]:

- **Lower running costs**: compared to fossil fuel cars, electric cars are more efficient and charging them is cheaper, especially if charging is done through renewable energy sources installed at home, like solar panels. In addition, EVs have fewer mechanical components than traditional cars, and this means that lower servicing and maintenance costs are needed, as they suffer less damage;

- **Zero tailpipe emissions**: drive an EV can help users to reduce their carbon footprint because there will be zero tailpipe emissions. It is possible to further reduce the environmental impact of charging the vehicle, by choosing renewable energy options for home electricity;

- **Tax and financial benefits**: registration fees and road taxes on purchasing EVs are lesser and lower than when buying petrol or diesel vehicles. Moreover, there are multiple policies and incentives offered by governments depending on which country and state the user is in;

- **Electric vehicles do not have gears**: EVs are convenient to drive, as there are no complicated controls, just accelerate, brake and steer. They are also better in performance as they are lighter, have faster acceleration and tend to have a low centre of gravity, which improves handling, comfort and safety;

- **Zero noise pollution**: EVs have no engine under the hood, and this allow them to have the silent functioning capability. In fact, the electric motor functions are so silent that users need to peek into instrument panel to check if it is ON. In addition, EV manufacturers have to add false sounds in order to make them safe for pedestrians;

- **Advanced batteries**: nowadays EVs have advanced batteries that are designed for extended life of 8 to 10 years, that correspond to about 150,000 kilometres[21]. Moreover, battery prices are expected to keep on declining as battery technologies improve and production volume increase;

[20] Benefits of electric vehicles, (2024), in "e-amrit.niti.gov.in", https://e-amrit.niti.gov.in/benefits-of-electric-vehicles , 21-05-2024.

[21] U.S. Department of Energy, (2024), Electric vehicles benefits and considerations, in "afdc.energy.gov", https://afdc.energy.gov/fuels/electricity-benefits , 21-05-2024.

- **The driving range on a full charge**: in recent years, the range of electric cars has increased with battery technology, and they can reach an effective range over 300 kilometres. As a demonstration of this, there is the 2021 Bolt EV that can reach 390 kilometres on a full charge, and the Tesla S model has listed a range between 580 and 780 kilometres on a full charge. For comparison, gas powered cars can boast a range around 600 kilometres per tank of gas[22];

- **Better resale value**: if people are looking to make the switch from petrol or diesel car, second-hand electric cars could be a great affordable option and cost-effective alternative. It is also worth to remember that the sale of new petrol and diesel vehicles will be banned from 2030 in UK and other countries like Germany and Canada. However, the sale and purchase of second hand internal combustion engine and hybrid cars will still be allowed[23].

Other than advantages, electric vehicles still present some disadvantages, such as[24]:

- **Limited availability of charging stations**: EVs charging stations are still fewer and further between than gas stations, making it challenging to find a place to recharge;

- **Longer charging times**: to fully recharge an EV can take hours and the time will depend on the model of the car, but also on the type of level of the charger. However, new fast chargers are rate for a thief wattage and can charge up a battery to around 80% in about 30 minutes[25]. Of course as the technology keep on maturing, this time should continue to decrease;

- **Higher initial purchase cost**: the current price gap between equivalent models seems to be around USD 10,000, but is should continue to decease as technology matures. However there are often states incentives and rebates that can close this purchase gap[26];

- **Expensive battery replacements**: batteries are one of the main reason that EVs have an higher initial cost and a full battery replacement can exceed USD 6,000[27]. However these prices are falling as the technology advances and this issue is mitigated by the fact that a full battery replacement is not commonly needed, and overall, EVs remain cheaper to operate over their lifetime;

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[22] Good, C., (2017-07-08), The Chevy Bolt just bested Tesla's model S in range test, in "futurism.com", https://futurism.com/the-chevy-bolt-just-bested-teslas-model-s-in-a-range-test , 21-05-2024.

[23] Benefits of electric cars (2024), in edfenergy.com", https://www.edfenergy.com/electric-cars/benefits , 21-05-2024.

[24] Tallodi, J., (2022-12-15), Seven disadvantages of electric cars, in "carlow.co.uk", https://www.carwow.co.uk/guides/choosing/disadvantages-of-electric-cars#gref , 21-05-2024.

[25] U.S. Department of Transportation (2023-06-22), Charger types and speeds, in "transportation.gov", https://www.transportation.gov/rural/ev/toolkit/ev-basics/charging-speeds , 21-05-2024.

[26] U.S. Department of Energy, (2024), Electric vehicle benefits and considerations, in "afdc.energy.gov", https://afdc.energy.gov/fuels/electricity-benefits , 21-05-2024.

[27] Witt, J., (2024-03-11), Electric car battery replacement costs, in "recurrentauto.com", https://www.recurrentauto.com/research/costs-ev-battery-replacement , 21-05-2024.

- **Temperature sensitivity**: extreme wether conditions, such as cold winters and hot summers, can significantly reduce and EV's range and performance. In fact, batteries do not like cold weather. However, this effects are temporary and improve as temperature normalises[28];

- **Limited charging options for apartments**: the world is experiencing a serious housing problem, not only because of increased populations, but also because of countries inflation exceeding the cost of leaving. In order to compensate this situation, different governments are building more apartment complex in order to give people the access to housing. However, many of these apartment complexes lack the necessary infrastructure for EV charging, making it difficult for residents to charger their cars conveniently[29];

- **Environmental impact of production**: EVs production process involves mining raw materials and emitting greenhouse gases during refining and manufacturing, similar to gas-powered cars. What differentiates EVs production process from fossil fuel vehicles, is the battery production that adds the environmental footprint relating a higher amount of CO2 than petrol or diesel car.

Concluding, there are a lot of factors that people should take into considerations when think to buy an electric vehicle. The most important of course is the distance of charging station from home. However, if people have a two-car household and are concerned about sustainability, carbon footprint, and clean transportation, they are in the best position to invest in electric vehicles.

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[28] Garberson, A., (2024-01-02), Winter & cold weather EV range 10,000+ cars, in "recurrentauto.com", https://www.recurrentauto.com/research/winter-ev-range-loss , 21-05-2024.

[29] Enphase (2024), EV Charging for apartment dwellers, in "anaphase.com", https://enphase.com/ev-chargers/articles/ev-charging-apartment-dwellers , 21-05-2024.

1.1.3 The environmental impact of electric vehicles

After having take into consideration all the pros and cons analysed in the previous part, now it is time to pass to analyse the environmental impact of electric vehicles. The main question related to this topic is: are EVs really better for the climate than gas-powered cars? It is common to believe that full electric cars are "zero emissions" vehicles as they do not emit greenhouse gases from their tailpipes. However, some emissions are still created in the process of building and charging these cars. Nevertheless, EVs are clearly a lower-emissions option than internal combustion cars and in time this comparative advantage is going to grow.
In fact, considering EVs to be worse for the climate than gasoline cars because of their power plant emissions and their battery manufacturing, are some of the several myths associated with the impact that EVs have on environment. Actually, EVs have smaller footprint than gasoline cars, even when taking into consideration both the energy used for charging the batteries and the manufacturing process, in addition the greenhouse gas emissions of EVs over their lifetime are still lower than those produced by gasoline-powered vehicles.

One source of EV emissions is the production of their lithium-ion batteries, as the use of lithium, cobalt, and nickel, that are essential for modern EV batteries, requires using fossil fuels in order to mine and heat them to high temperatures[30]. This means that building a new EV can produce around 80% more emission than building a gas-powered car[31], and require more energy intensive. In addition, the cost of transporting these batteries results in a higher carbon footprint than ICE (short for Internal Combustion Engine) vehicles. The processes of extraction and manufacturing of producing EV batteries negatively affect the environment, with pollution, habitat destruction, and carbon emissions, due to the toxic fumes released during the mining process and the water-intensive nature of this activity (one tonne of lithium requires approximately 2 million tonnes of water[32]). Currently, Argentina is the country that holds the highest number of lithium reserves in the worlds (around 21%), and it is planned to open 13 more mines, that could cause extensive harm to the vulnerable ecosystem and exploit nation's natural resources[33]. However, a lot of manufactures are now fighting the environmental impact of EV batteries, for instance Tesla has installed a large solar array at its factory, generating enough energy to power the facility, and EV batteries now last a long time, around 10-20 years[34].

Secondly, the main source of EV emissions is the energy source used to charge their batteries, that can vary also depending on where the car is driven. For example, using hydropower, solar energy, and others

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[30] Moseman, A., Paltsev, S., (2022-10-13), Are electric cars definitely better for the climate than gas-powered cars?, in "climate.mit.edu", https://climate.mit.edu/ask-mit/are-electric-vehicles-definitely-better-climate-gas-powered-cars , 24-05-2024.

[31] This estimate comes from Argonne National Laboratory's GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) Model, sponsored by the U.S. Department of Energy. It assumes comparable models of EV and gas-powered car, and that the EV has a battery with a range of 300 miles, similar to a Tesla Model 3. Different assumptions about battery manufacture would offer different comparisons; in this model, the battery of the EV entails close to 12 metric tons of CO_2 emissions. Moseman, A., Paltsev, S., (2023-04-26), Are electric vehicles definitely better for the climate than gas-powered cars?, in "congress.gov", https://www.congress.gov/118/meeting/house/115654/documents/HHRG-118-II10-20230426-SD003.pdf , 24-05-2024.

[32] Lakshmi, R.B., (2023-01-11), The environmental impact of battery production for electric vehicles, in "earth.org", https://earth.org/environmental-impact-of-battery-production#:~:text=Furthermore%2C%20producing%20one%20tonne%20of,an%20extremely%20water%2Dintensive%20practice , 24-05-2024.

[33] Parva, C., (2023-09-13), How can we deal with environmental challenges associated with the electric vehicle boom?, in "azocleantech.com", https://www.azocleantech.com/article.aspx?ArticleID=1727 , 24-05-2024.

[34] Octopus electric vehicles, (2023-05-24), The future of sustainable EV manufacturing, in "octopusev.com", https://octopusev.com/ev-hub/the-future-of-sustainable-ev-manufacturing , 24-05-2024.

green energy sources to charge EVs can reduce a lot the carbon footprint. According to the MIT's Insights Into Future Mobility study, gasoline cars emit on average more than 500 grams of CO2 per kilometre driven over their lifetimes, while a fully electric cars create just 300 grams. In addition, the study find out that EVs can emit 61% less carbon footprint than hybrid vehicles if use green energy source to charge[35]. However, in developing economies like India, EVs are still charged with the use of electricity coming from thermal source, including fossil fuel like coal. The use of coal leads to health issues due to noxious fumes, higher CO2 emissions, loss of forests, and water pollution. But also in this case, electric cars still have a smaller carbon footprint than gasoline cars[36]. The development of charging stations also presents environmental challenges, as they require energy, resources, and land to construct new infrastructures and facilities.

For all these reasons, the production phase of EVs has a higher impact on environment than ICVs due to battery manufacturing. Fortunately, there are some solutions and sustainability initiatives that electric cars manufacturers are using in order to reduce and minimise the environmental impact of EVs, and contribute to a more sustainable future. Among these actions it is possible to find: to increase the use of recycled materials in car production, to develop more efficient and longer-lasting batteries, to build renewable energy-powered charging infrastructure, to offer carbon offset programs for users, to implement closed-loop manufacturing process to reduce waste, and to reduce the carbon footprint of supply chains.

However, the recycling process of end-of-life EV batteries is still evolving, and in future it could potentially supply a significant portion of global cobalt (60%), lithium (53%), manganese (57%), and nickel (53%) by 2040[37]. Nevertheless, there are some challenges as EV batteries are not as easy to recycle as an aluminium car, and the price of recycled battery minerals is still high. As the market of EVs is growing, more companies are now trying to solve the problem of recycling batteries, by creating battery recycling plants. For example, Volkswagen announced a plan for battery recycling, and Nissan is using retired EV batteries for back-up power at Amsterdam ArenA[38]. In addition, European Union is about to introduce the digital product passport in order to improve transparency, traceability, and accountability throughout the battery life cycle. This could play a crucial role in providing accurate data, ensuring transparent supply chains, and enabling collaboration among value-chain participants[39].

Unfortunately, no vehicle is going to solve environmental problems, as they produce waste and require components that produce CO2 emissions. But if people are in a position that allows them to invest in an electric car over conventional one, this will be a good choice as EVs are approximately 50% better for the environment than gas-powered cars because they produce fewer total emissions[40].

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[35] Moseman, A., Paltsev, S., (2022-10-13), Are the electric vehicles definitely better for the climate than gas-powered cars?, in "climate.mit.edu", https://climate.mit.edu/ask-mit/are-electric-vehicles-definitely-better-climate-gas-powered-cars , 24-05-2024.

[36] Lakshmi, R.B., (2023-01-11), The environmental impact of battery production for electric vehicles, in "earth.org", https://earth.org/environmental-impact-of-battery-production/ , 24-05-2024.

[37] Xia, X., & Li, P. (2022-03-25). A review of the life cycle assessment of electric vehicles: Considering the influence of batteries, in "sciencedirect.com", https://www.sciencedirect.com/science/article/pii/S0048969721079493 , 24-05-2024.

[38] Octopus electric vehicles, (2023-06-13), The sustainability of electric cars, in "octopusev.com", https://octopusev.com/ev-hub/the-sustainability-of-electric-cars , 24-05-2024.

[39] Neligan, A., Schleicher, C., Engels, B., Kroke, T., (2023-09-22), Digital Product Passport as enabler for the circular economy, in "circular economy.europa.eu", https://circulareconomy.europa.eu/platform/sites/default/files/2024-02/IW-Report_2023-Digitaler-Produktpass-englisch.pdf , 24-05-2024.

[40] U.S. Environmental Protection Agency (EPA), (2024), Electric Vehicle Myths, in "era.gov", https://www.epa.gov/greenvehicles/electric-vehicle-myths , 24-05-2024.

Concluding, also users can apply few but basic measures, in order to make their electric cars to be as sustainable as possible. For instance, they can choose a renewable energy supplier for their home electricity if they are charging at home; they can minimise their car's energy consumption by driving efficiently and avoiding unnecessary trips; they can maintain their car's battery and use it for as long as possible; they can recycle their car's battery at the end of its life; and they can consider the entire lifecycle of their car, from production to disposal, and choose a vehicle with a low environmental impact.

1.1.4 Trends and developments of electric vehicles

It is already evident that the global vehicle market is turning toward electric vehicles, even if the sales started from a low base but now are growing quickly in many markets. Globally, around 1-in-5 new cars was sold electric in 2023, where in Norway, the share is well over 4-in-5, and in China is around 1-in-3[41].
But what are the future trends of electric vehicles market? Historically, EV sales have increased annually, and this trend is expected to continue throughout 2024.

From a revenue point of view, the global Electric Vehicles market is projected to reach USD 422,8 billion in 2024, and USD 951,9 billion by 2030 at CAGR (short for Compound Annual Growth Rate) of 13,7%[42]. Instead, unit sales are expected to reach 13.47 million vehicles in 2028 and the average price of electric vehicles market in 2024 is expected to amount to USD 49,100[43]. From an international point of view, the most revenue will be generated in China with USD 208,800 million in 2024, followed by Europe, North America, South Korea, and Japan. In fact, six out of ten EV sales are from China, where the competition is driving down costs and manufacturers profits[44].

Not only in China, but also the Asia Pacific region is expected to be the largest and the fastest growing EV market by value, as it is projected to reach 29,653 thousand units by 2030, at a CAGR of 19%[45]. This is mainly due to the increase of environmental awareness, supportive government policies and incentives, and advancements in EV technologies. In fact, the countries are planning to reduce emissions in the coming years: China had set a target of over 20% EV sales by 2025 and is also investing in the production of commercial vehicles, with plans for export; India have planned to have 30% of its passenger car sales to be electric by 2030; South Korea and Japan are among to be among the world's top 5 EV producers by 2030[46]. Chinese OEMs (short for Original Equipment Manufacturers, that will be discussed in the last chapter), like BYD automaker, are planning to open plants in other countries to manufacture electric buses and trucks to meet regional demand, and China offers also subsidiary for buying EVs and build charging infrastructure.

41 Ritchie, H., (April 2024), Tracking global data on electric vehicles, in "ourworldindata.org", https://ourworldindata.org/electric-car-sales , 24-05-2024.

42 Statista, (2024), Electric vehicles - Worldwide, in "statista.com", https://www.statista.com/outlook/mmo/electric-vehicles/worldwide , 24-05-2024

43 Statista, (2024), Battery electric vehicles - Worldwide, in "statista.com", https://www.statista.com/outlook/mmo/electric-vehicles/battery-electric-vehicles/worldwide , 24-05-2024.

44 IEA, (2023), Trends in electric cars, global EV outlook 2024, in "iea.org", https://www.iea.org/reports/global-ev-outlook-2024/trends-in-electric-cars , 24-05-2024.

45 Statista, (2024), Electric vehicles - Worldwide, in "statista.com", https://www.statista.com/outlook/mmo/electric-vehicles/worldwide , 24-05-2024.

46 Bharadwaj, R., (2023-08-31), China's EV market: opportunities, challenges, and future scope, in "bolt.earth" , https://bolt.earth/blog/ev-landscape-in-china , 24-05-2024.

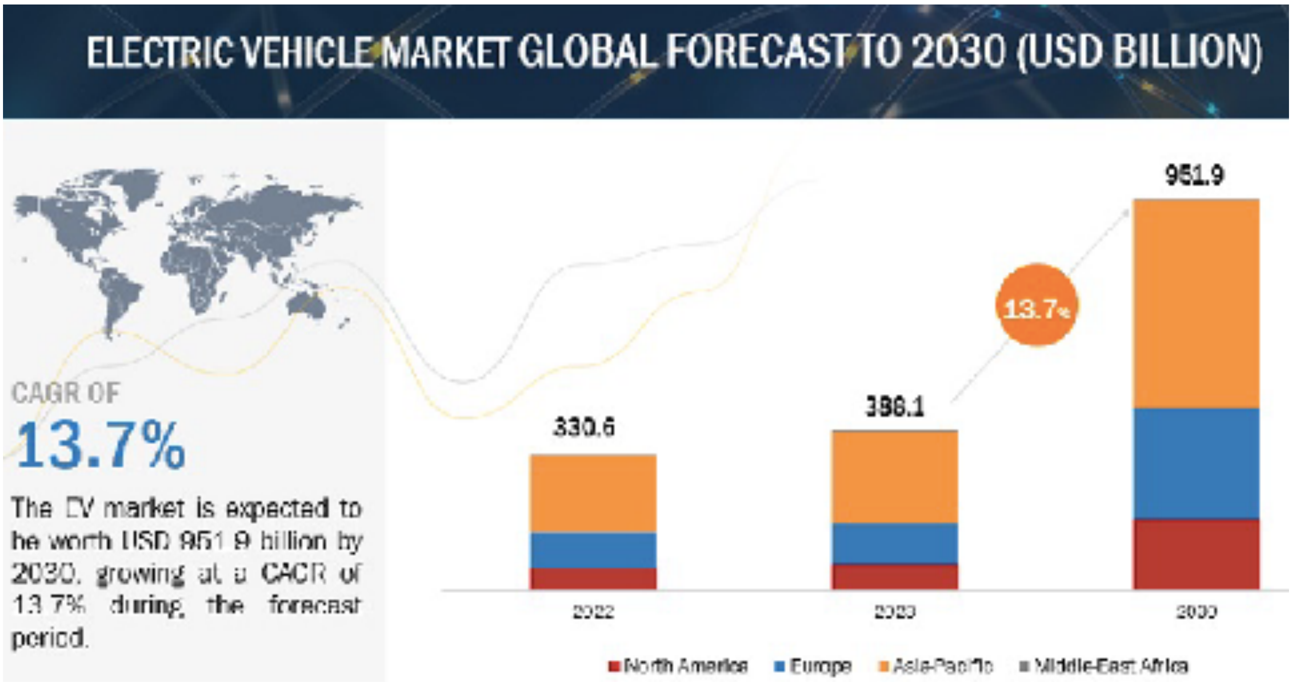

Figure 6: Chart of electric vehicle market global forecast to 2030 (USD billion)

From a practical point of view, the increase of electric car sales in 2024 is also motivated by lower prices, an expansion of charging stations, and a greater charging plug compatibility that make them increasingly affordable. In fact, prices of electric cars will continue to decrease due to technology advancements, especially related to the battery that make up around 40% of EVs total cost[47].

In addition, some gas stations companies, as Shell and BP, have projected to install a great number of high-powered fast-charging stations at their gas stations by 2025-2030, acquiring numerous EV charging companies[48]. The expansion of charging stations, subsequently creates opportunities for the installers, electricians and technicians, thanks to the increase need for skilled professionals.

However, there will be an imbalance because the demand may overload the supply side, and this means that automakers and infrastructure specialist will have to work overtime to accommodate the next generation of drivers. One thing is clear: over next few years, electric cars will displace gas-powered vehicles, and the trends of electric vehicles are going to unfold faster than ever before. Here below are listed the main eight future trends of EV market from a global point of view:

[47] Lozanova, S., (12-01-2022), What to expect in the electric vehicle industry: EV trends for 2024, in "greenlancer.com", https://www.greenlancer.com/post/ev-market-trends , 24-05-2024.

[48] Winokur Munk, C., (2023-08-19), How gas station economics will change in the electric vehicle charging future, in "cnbc.com", https://www.cnbc.com/2023/08/19/how-gas-station-economics-will-change-in-the-ev-charging-future.html , 24-05-2024.

1. **China, Europe and the US will continue driving sales**

By 2030, the global new EV sales will reach 35%, with China, United States, and Europe as the big three markets. Among them, China is the leading market with roughly 60% of EV sales in 2022, surpassing its 2025 target for new energy vehicle sales. This has been possible thanks to over a decade of policy support for early adopters[49].

In comparison, the growth of Europe's EV sales in 2022 have been slower than China, but still occupy the second place for global EV market share. In the continent, electric cars made up 21% of new vehicle sales, and this accounted for 25% of EV sales across the globe. This is due to the aggressive vehicle emissions policies, that will continue to be present in the next years[50]. Lately, United States EV sales have grown rapidly, with sales that have jumped by 55% and its global market share that reached the 10%. The country EV sales are driven by the availability of different and less expensive lineup of electric cars, and tax policies that reduce the initial purchasing cost and charging equipment[51].

In addition, Chinese automakers are trying to capitalise on their success in their domestic market by expanding their production and sales abroad. China is the fifth largest EV share on passenger vehicle (behind Norway at 80%, Iceland at 41%, Sweden at 32%, and Netherlands at 24%) according to World Resources Institute[52]. However, China is the world's largest car market, and it leads by far in direct sales. In 2022, China registered 4.4 million sales of EVs, with a market share of 22% and the rest of the world reached 3 million sales[53].

In 2024, China sees also the opportunity to make strategic investments in EVs by exporting batteries and vehicles to international markets. Thanks to Made in China 2025 (a national strategic plan and industrial policy of Chinese Communist Party), China has set a goal for BYD and XPeng, as these two companies are country's two largest EV manufacturers, to generate 10% of their sales abroad by 2025. BYD started delivering a European version of its Sedan model and has planned to launch a mid-size SUV in Europe in 2024. XPeng sells vehicles in four European markets and plans to enter the German market in 2024[54]. Dutch automaker Stellantis has acquired a 20% of Chinese automaker Leapmotor in order to form a joint venture with the objective of helping the Chinese EV startup expand into Europe. The deal includes an option to manufacture vehicles in Europe, reflecting Chinese automakers' plans to start local production to avoid import tariffs and shipping costs[55].

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[49] IEA (2024), Global EV Outlook 2023, Executive summary, Electric car sales break new records with momentum expected to continue through 2023, in "iea.org", https://www.iea.org/reports/global-ev-outlook-2023/executive-summary , 26-05-2024.

[50] IEA (2024), Global EV Outlook 2024, Trends in electric cars, Nearly one in five cars sold in 2023 was electric, in "iea.org", https://www.iea.org/reports/global-ev-outlook-2024/trends-in-electric-cars , 26-05-2024.

[51] IEA (2024), Global EV Outlook 2024, Trends in electric cars, Nearly one in five cars sold in 2023 was electric, in "iea.org", https://www.iea.org/reports/global-ev-outlook-2024/trends-in-electric-cars , 26-05-2024.

[52] Jaeger, J., (2023-09-14), These countries are adopting electric vehicles the fastest, in "wri.org", https://www.wri.org/insights/countries-adopting-electric-vehicles-fastest , 26-05-2024.

[53] IEA (2024), Global EV Outlook 2024, Trends in electric cars, Nearly one in five cars sold in 2023 was electric, in "iea.org", https://www.iea.org/reports/global-ev-outlook-2024/trends-in-electric-cars , 26-05-2024.

[54] Bharadwaj, R., (2023-08-31), China's EV market: opportunities, challenges, and future scope, in "bolt.earth", https://bolt.earth/blog/ev-landscape-in-china , 26-05-2024.

[55] Stellantis, (2024-05-14), Leapmotor international begins operations to expand global electric vehicle sales starting September 2024 in nine European countries, followed bu other key growth regions, in "stellantis.com", https://www.stellantis.com/en/news/press-releases/2024/may/leapmotor-international-begins-operations-to-expand-global-electric-vehicle-sales-starting-september-2024-in-nine-european-countries-followed-by-other-key-growth-regions , 26-05-2024.

2. More models and automakers in the market

According to the IEA (short for International Energy Agency)[56], the number of electric car models available in 2019 is more than doubled by 2022, reaching the number of 500 models.

On the contrary, the number of gas-powered car models has dropped from 1,500 models around 2015, to 1,300 in 2022. However, the number of gas-powered models are still far more than electric vehicle models.

EV models may double over the next few years and this shift is due to the established vehicle makers and the new players that will bring new and innovative models to the market[57].

3. Lower pieces of electric vehicles

Battery costs, tax incentives, and competition are driving down the cost of EVs. Thanks to the improvement of technology and the increase of volume, EV prices continue to drop from USD 71,000 in 2016 to USD 69,000 in 2023 and continuing toward USD 68,000 in 2028. Tesla in 2022 sold its Model Y to an average cost of all new cars and trucks in the U.S. (USD 45,000), and several other automakers are planning to sell cheaper EV models in the next few years[58]. In the meantime, many countries are supporting EV sales through policies and generous tax credit for the purchase of both new and used electric cars.

The price of EV batteries is expected to reach around USD 80 per kWh by 2025, and this will bring the price of EVs to the same lever as that of ICE vehicles and start a big shift to EVs. From 2025, it is expected to find some EVs to get cheaper than some ICE vehicles[59]. However, the cost of EV insurance could remain expensive, because many EVs are luxury vehicles as they are pricey and built with expensive components.

[56] The International Energy Agency (IEA) is a Paris-based autonomous intergovernmental organisation, established in 1974, that provides policy recommendations, analysis and data on the global energy sector. The 31 member countries and 13 association countries of the IEA represent 75% of global energy demand. In “en.wikipedia.org", https://en.wikipedia.org/wiki/International_Energy_Agency , 26-05-2024.

[57] IEA (2024), Global EV Outlook 2023, Executive summary, Electric car sales break new records with momentum expected to continue through 2023, in “iea.org", https://www.iea.org/reports/global-ev-outlook-2023/executive-summary , 26-05-2024.

[58] IEA (2024), Global EV Outlook 2024, Trends in electric cars, Nearly one in five cars sold in 2023 was electric, in “iea.org", https://www.iea.org/reports/global-ev-outlook-2024/trends-in-electric-cars , 26-05-2024.

[59] Tretheway, C., Current trends shaping the cost of electric vehicles in 2024, in “fool.com", https://www.fool.com/the-ascent/insurance/auto/articles/current-trends-shaping-the-cost-of-electric-vehicles-in-2024/ , 26-05-2024.

4. Improvement and development of batteries

Automakers and battery manufacturers are working hard to improve the quality and the durability of EV batteries. As a demonstration of this, venture capital investments in EV and battery technology increased by 30% in 2022, focusing on new battery technology and alternatives to lithium-ion materials[60]. Currently, a few top-end EV models have reached the 600-kilometres mark for battery range and many can be charged at outstanding speeds. Next-generation batteries is expected to provide more energy, and last longer than current ones. The cost of battery production will decline 11% each year on average through 2030, this thanks also to the falling of lithium cost[61].

5. Easier and faster charging

Other than battery improvement, easier and faster charging is another key target for policy-markers, battery manufacturers, and charging networks. The initial investment in setting up a fast-charging system is significantly higher compared to petrol, CNG, or LPG fuel stations, and this is due to the higher equipment costs and the requirement for an additional fast charger to install a transformer to connect the grid and charging system.

Currently, several energy companies are investing in order to improve the charging technology and in order to offer a variety a products that suit different customer needs. Some countries are also applying policies with the aim of expanding the nation's charging infrastructure, particularly into rural and underserved areas. In addition, taxpayers and companies can access to tax credit for purchasing and installing EV charging equipment, making it much easier to charge at home or at work and avoiding any concerns about discharging the battery.

Of course, public charging station availability is still an issue that presents opportunities for new players that aim to enter the EV charging market, and they can approach the business in two ways: the first is to partner with an established EV charging service provider in order to set up the EV charging operation; the second is to become an EV charging service provider lock, stock, and barrel[62].

6. Standard chargers

Tesla will dominate the charging landscape because at the end of 2022, the company lost the control of their charging connector NACS (short for North American Charging Standard) by adding it to the list of open standards in the EV industry. This connector represents a step forward in charging accessibility, as it eliminates the need for different EV charging plugs[63]. In fact, by the end of 2025 automakers as General Motors, Ford, Fisker, Rivian, Polestar, Volvo, Nissan, and Mercedes-Benz, will switch their EVs to the NACS plug. Also Enel X Way will support NACS EV charging connectors across its product line of chargers

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[60] [60] IEA (2024), Global EV Outlook 2023, Executive summary, Electric car sales break new records with momentum expected to continue through 2023, in "iea.org", https://www.iea.org/reports/global-ev-outlook-2023/executive-summary , 26-05-2024.

[61] Goldman Sachs, (2023-11-01), Electric vehicle battery prices are falling faster than expected, in "goldmansachs.com" , https://www.goldmansachs.com/intelligence/pages/electric-vehicle-battery-prices-falling.html , 26-05-2024.

[62] Honig, R., (2024-02-18), Top EV charging industry trends in 2024: new players getting into the game, in "driivz.com", https://driivz.com/blog/ev-industry-trends/, 26-05-2024.

[63] Lintec of America, Inc. (2023-12-01), 6 electric vehicle trends to watch in 2024 and beyond, in "blog.lintecauto.com", https://blog.lintecauto.com/6-electric-vehicle-trends-to-watch-in-2024-and-beyond , 26-05-2024.

by the end of 2024. This move will make the Tesla Supercharger network available to customer of these automakers from 2024 onwards. This improvement will give to EV drivers a unified charging experiences and increase EV adoption and compatibility.

Tesla's Supercharger is the largest rapid EV charging station network, but it's difficult to predict if non-Tesla EV drivers will have the same smooth vehicle charging experience as Tesla EV drivers when the networks become available to them.

7. Acceleration of commercial EV adoption

Even if commercial vehicles have lagged behind in electrification, government and manufacturers are making this a higher priority. According to IEA, light-duty commercial EV sales reached 90% globally in 2022. Electric buses and trucks, still represent less than 5% of sales in their respective classes, but their share is much larger in markets with a strong commitment to electrifying public transport and reducing emissions[64]. 27 countries have planned to reach 100% zero emission for public transport and trucks by 2040[65].

Thanks to the pressure to electrify vehicles for the public sector and commercial fleets, there will be a higher volume of large EVs hitting the market in the next few decades.

8. Combination of solar energy and EV technology

If solar energy and electric vehicle charging technology are used together, the two can become a powerful solution for decentralising and strengthening electrical grids. EV and solar energy markets have grown rapidly together, thanks to robust policy support over the past decade. The two energy-saving technology have a symbiotic relationship, as solar chargers allows vehicles to charge at peak sun times when solar energy is readily available.

In addition, vehicle-to-grid (V2G)[66] technology allows EVs to sent excess energy back to the grid, and coupled with solar, makes an EV its own kind of solar battery to store extra solar energy that can be used when needed. This technology can reduce costs and decrease strain on the electrical grid, and offer a variety of incentive programs to make solar panels and EV charging more attractive and affordable. Used together, these two technologies can reduce dependence on fossil fuels while easing the pressure on increasingly strained municipal electrical grids.

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64 IEA 50, (2024), Trucks nd buses, in "iea.org", https://www.iea.org/energy-system/transport/trucks-and-buses , 26-05-2024.

65 IEA, (2024), Global EV outlook 2023, policy developments, in "iea.org", https://www.iea.org/reports/global-ev-outlook-2023/policy-developments#:~:text=In%202022%2C%2011%20countries%20signed,and%20bus%20sales%20by%202040 , 26-05-2024.

66 Vehicle-to-grid (V2G) describes a system in which plug-in electric vehicles (PEV) sell demand response services to the grid. Demand services are either delivering electricity or reducing their charging rate. Demand services reduce pressure on the grid, which might otherwise experience disruption from load variations. In "en.wikipedia.org", https://en.wikipedia.org/wiki/Vehicle-to-grid , 26-05-2024.

Figure 7: Example of solar EV charging

It is evident that the transition to EVs is accelerating and the year 2026 will be an important year for the acceleration in EV adoption that will drive automotive electrification trends ahead. By 2030 one out of four new cars sold will be an EV, in fact top automakers are expected to account for more than 70% of global EV production by this year (in comparison, in 2002 they represented only 10% of all EV manufacturers)[67].
However it is needed a joint effort between automotive, utilities, government, and private property owners, in order to face consumers uncertainty linked to having no garage or traveling long distance for instance. As this cooperation happens, vehicle electrification trends will increase exponentially and we may see the end of ICE vehicles era.

In conclusion, in 2024 it will be possible to see more model available, more affordability, more range, more and better technologies, and more charging options. All these advancement together with government incentives, will play an important role in encouraging consumer adoption.
However not every automotive company can be the best, as some technologies will work out better than others, so understanding and monitoring these trends is crucial in helping pick potential winners on the stock market. While there could be a short-term reduction in the rate of uptake in 2024, global EV sales are forecast to continue growing as part of the broader energy transition to reduce carbon emissions.

[67] S&P Global Mobility, (2024), Electric vehicle trends, in "a-global.com", https://www.spglobal.com/mobility/en/topic/electric-vehicle-trends.html , 26-05-2024.

1.2 Features and benefits of electric vehicles' printed circuit boards

Before discussing about electric vehicles' printed circuit boards, first it is better to see briefly what PCBs are and how they are manufactured. A PCB (short for printed circuit board) is an electronic assembly that creates electrical connections between components by using copper conductors. The main purpose of PCBs is to provide a surface for mounting and interconnecting electronic components, for instance battery, motor controller, charging systems, air conditioning and infotainment systems[68]. PCB manufacturing process is complex and involves six steps that are:

1. **Design:** it involves laying out the circuitry and determining the placement of the components on the board;

2. **Printing:** the circuitry is printed onto the board using a special printer that uses a process called photolithography;

3. **Etching:** involves removing the unwanted copper from the board using a chemical solution;

4. **Drilling:** holes are drilled into the board to allow for the placement of the components;

5. **Plating:** holes are then plated with copper to provide a connection between the different layers of the board;

6. **Soldering:** components are then soldered onto the board, which involves melting a special metal alloy onto the copper pads on the board to create a permanent connection.

In order to test and check whether PCB is well-functioning, manufacturers first need to design a prototype PCB with the use of a designing software that helps to meet industry requirements. These are the steps to be followed in order to create electric vehicle PCB prototype:

1. **Determine the specifications of PCB**, in order to design precisely and meet the requirements of the vehicle, such as the thickness of the board, the number of layers, the type of material, impedance, finishing for the plate, minimum pitch, holes size, castellated holes and spacing parameters;

2. **Check design to correct any errors**, with the help of the design software in order to meet all the PCB specifications;

3. **Generate Gerber files**[69], that help to arrange neatly the entire process;

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[68] Peterson, Z., (2024-01-30), What is a PCB and intro to PCB design, in "resources.altium.com", https://resources.altium.com/p/what-is-a-pcb , 27-05-2024.

[69] Gerber file format is a de-facto standard used in PCB manufacturing, to trace electrical connections such as tracks, via, and pads. In addition, the file contains information for drilling and milling the PCB. In "en.wikipedia.org", https://en.wikipedia.org/wiki/Gerber_format , 27-05-2024.

4. **Stack up documents**, PCBs are produced with multi-layers that are bound together in order to form a single unit, and this process is called lamination. Lamination helps the board withstand high temperature and pressure and function at an optimum level. Once this operation is completed, the next step is the creation of the prototype that is followed from various tests in order to verify it functions as required.

All PCBs are built alternating layers of conductive copper (as copper traces, pads, and conductive panels) with layers of electrically insulating material (as fibreglass and plastic). Last, the mechanical structure is plated and covered with a non-conductive solder mask, and a silk screen is printed on the top of the solder mask to provide a legend for electronic components[70]. After all these steps, the PCB is sent into a printed circuit board assembly, where all the components are soldered to the board and the PCBA (short for Printed Circuit Board Assembly) can be tested. During the manufacturing process, the inner copper layers are etched, leaving the intended traces of copper for connecting components in the circuit board stack-up is complete.

PCBs have a crucial role in the automotive industry for long time, and their presence increased thanks to the growing dominance of electrical vehicles in the market and to the advancement of EV technology. In fact, PCBs are essential for all the various functions of modern cars, as general operations, safety features, dashboard alters, transmission control, engine and heating management, GPS navigation, entertainment, and many more, as they all rely on intricate electric systems embedded within PCBs. So it is possible to affirm that PCBs are the key components that make EVs possible to function, and single car can have hundreds of PCBs that them reliable and durable. For all these reasons PCB manufacturers are daily facing challenges in order to offer innovative solutions, as efficient miniaturisation and effective high-current handling by integrating new technologies (such as chip embedding) and incorporating multiple thin bare dies of semiconductors within PCB layers. PCBs are crucial for regulating and checking the power flow between the battery and all the various components of EV, in fact PCB manufacturers use power modules built up from substrates to efficiently manage high currents and regulate heat dissipation within PCBs.

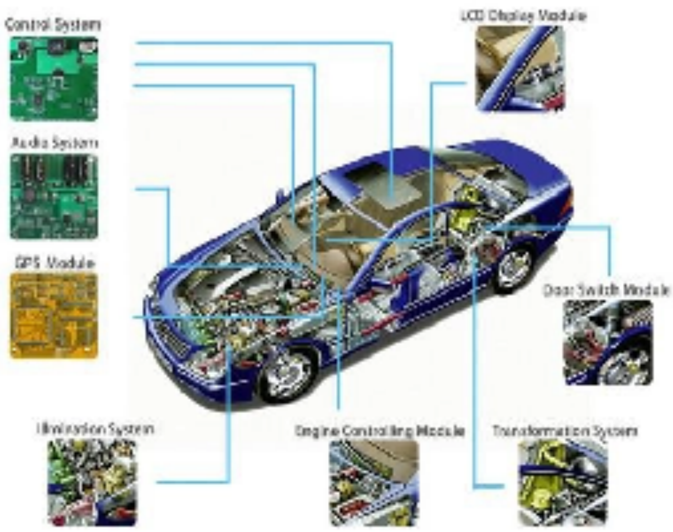

Figure 8: Applications of electric vehicle PCBs

[70] Peterson, Z., (2020-10-05), Cos'è un PCB? Significato e funzionamento di una scheda PCB, in "resources.altium.com", https://resources.altium.com/it/p/what-is-a-pcb#:~:text=All PCBs are built from alternating layers of,insulating material laminated between the layers of conductors , 27-05-2024.

In order to meet the evolving requirements from automotive industry, PCBs are undergoing modifications and adaptations specific to applications requirements, such as:

- **Heavy copper PCBs**, for an extensive duration;
- **Power combi-board**, that is assembled with a standard copper thickness;
- **Insulated metal substrate**, featuring a metal heat sink and thin insulation layer;
- **Inlay technology**, to minimise thermal resistance;
- **Chip embedded technology**, for integrating certain components inside the board;
- **Thermal and on-state resistance**;
- **Switching performance**;
- **Miniaturisation**;
- **Higher reliability;**
- **Cost reduction.**

The main challenge that EV's PCB have to face is the way in which EVs are made and how they run, as they must be able to handle high-voltage systems, rapid charging, temperature changes, and the general wear and tear that comes with being on road. Here are some of the unique features that distinguish EV's PCB from the other existing PCBs:

- **Suitable for high temperatures**: their lower density helps in heat dissipation and they incorporate unique properties that enable them to function effectively under elevated temperatures;

- **Reliable in diverse environments**: they use high-quality and robust materials in order to endure the hard working conditions of vehicles, maintaining functionality even in varied environmental circumstances;

- **Dirt resistance**: manufactures employ various laminations to protect the PCBs from dirt in order to ensure optimal performance and longevity, as the accumulation of dirt could lead to adverse effects, such as short-circuiting and malfunctioning.

Instead, the main benefits of using high-quality PCBs in EVs are:

1. **Compact and lightweight**, as the whole weight of the vehicle has a significant impact on the battery life and the distance that can travelled between charges, the battery packs required are big and heavy. For all these reasons PCBs are often made from light and electrically-insulating materials;

2. **Durable**, because of road conditions such as vibration and shock resistance as EVs are not intended to go off-road, temperature tolerance as many EVs component generate a lot of heat, and minimum lifespan of 10 years. The main factors that can impact the lifespan of PCB are the quality of material used, the stress it comes under during day-to-day use, whether or not it requires maintenance, and the lifespan of PCB's individual components;

3. **Efficient operation**, as PCBs control, monitor and optimise the various internal EV systems and help to maximise their energy efficiency, for example with their regenerative braking and the Battery Management Systems (BMS), which monitor the health of battery cells. In addition, PCBs involved in charging control have an important purpose as EVs charging quickly and efficiently is the key to encourage more people to go electric.

PCBs facilitate also the creation of smart charging systems adaptable to diverse power sources and charging rates. Due to the transition towards standard EV charging, PCB technology is enabling seamless and intelligent charging experiences for EV users, regardless their vehicles's model.

PCB is the central computing hub as it processes data from a range of vehicle sensors and systems, including the regenerative braking system. In addition, PCBs can enable smooth connectivity, allowing EVs to communicate with external networks, infrastructure, and the grid via Vehicle-to-Grid (V2G) technology[71]. This connectivity improves driving experiences and facilitates smart grid integration, allowing EVs to supply excess energy back to the grid during peak demand periods. The intelligence and the efficiency of EVs is due to the fact that PCBs coordinate all these complex data processing and communication tasks.

EVs rely hugely on PCBs integration in order to guarantee safety and reliability to the drivers and passengers, and for this reason PCBs are fundamental for the efficient operation of critical safety systems, like airbag deployment, anti-lock braking systems (ABS), and traction control[72]. In airbag deployment, PCBs manage sensor inputs to determine the precise moment and force necessary to activate airbags in collision scenarios, offering a potential life-saving protection. In the same manner, ABS relies on PCBs to monitor wheels speed and regulate brake pressure to prevent skidding and maintain steering control during sudden stops[73]. Furthermore, PCBs play a pivotal role in traction control systems by processing data coming from wheels sensors in order to optimise power distribution and prevent wheel spin on slippery surfaces.

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71 Henry, (2023-09-22), How PCB technology is revolutionising electric vehicles, in "theengineeringknowledge.com", https://www.theengineeringknowledge.com/role-of-pcb-board-in-evs/ , 27-05-2024.

72 Henry, (2023-09-22), How PCB technology is revolutionising electric vehicles, in "theengineeringknowledge.com", https://www.theengineeringknowledge.com/role-of-pcb-board-in-evs/ , 27-05-2024.

73 Henry, (2023-09-22), How PCB technology is revolutionising electric vehicles, in "theengineeringknowledge.com", https://www.theengineeringknowledge.com/role-of-pcb-board-in-evs/ , 27-05-2024.

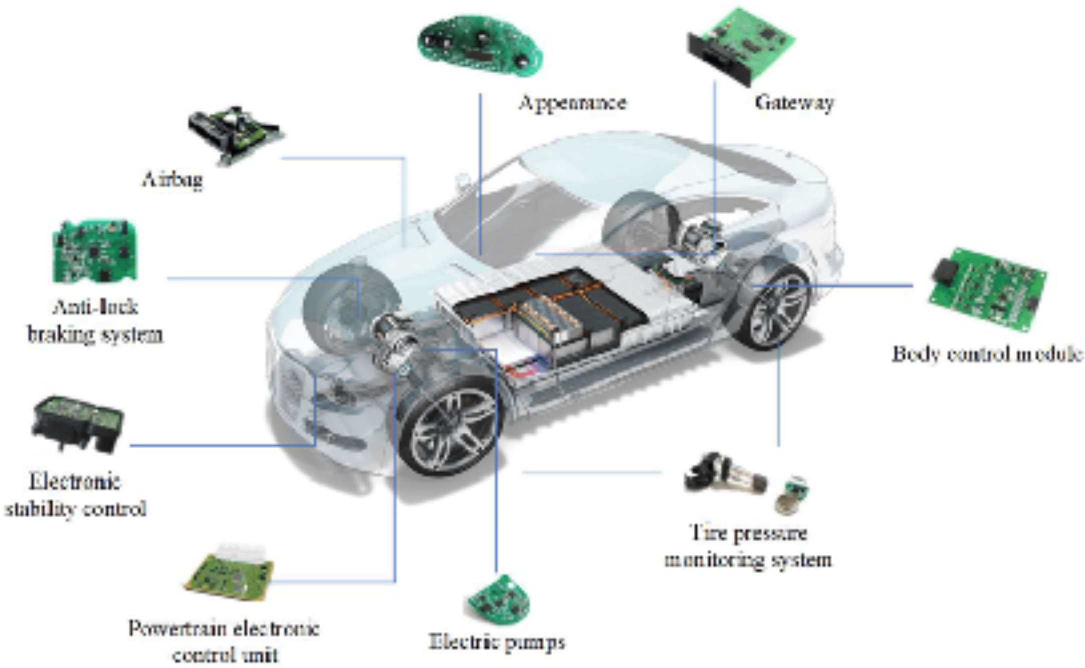

Figure 9: Example of PCBs present in electric vehicle

1.2.1 The impact of electric vehicles on PCB industry

Currently, PCBs are playing a more significant role in the production of electric vehicles, and in the near future it will be possible to see even more PCBs used in the automotive industry, in design and manufacture than before.

Automotive technology is evolving fast, requiring increasingly complex and intricate components and smart system. This is mainly due to the rise of electric cars which heavily rely on PCBs, in fact the average PCB value per electric vehicles is about 6 times that of traditional fuel vehicles. For this reason it is important that PCBs' manufacturers and suppliers are able to meet the requirements of the automotive industry. For example, following the trend of lightweight EVs, FPC (short for Flexible Printed Circuit) will be gradually adopted in the near future, and will also increase the PCB value content of the electronic control system[74].

Automotive PCBs are at the centre in ensuring important requirement for EVs that have already been analysed in the previous subchapter, such as reliability, ability to provide entertainment features, ability for use in navigation features, safety and security.

As EVs technology increases, the need of electronic products such as cameras and radars will increase at the same pace, which require HDI boards (short for High Density Interconnect). HDI boards have a price that is about three times that of PCBs commonly used in automotive, the 4-8 layer boards. For this reason, it will also be the main source of future automotive PCB output value increase. It is protected to see a drop of 4-8 layer boards from 40% to 32% by 2026, and an increase of HDI boards from 15% to 20%[75].

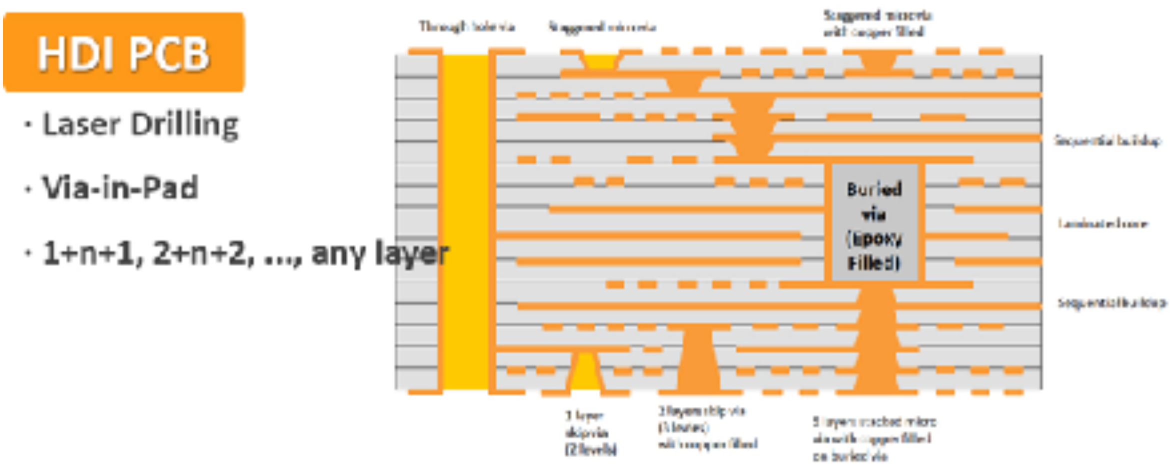

Figure 10: Example of HDI board

[74] IBE Electronics, (2022), EV penetration raises automotive PCB production value against the trend, in "pcbaaa.com", https://www.pcbaaa.com/ev-penetration-raises-automotive-pcb-production-value-against-the-trend/ , 27-05-2024.

[75] Li, T., (2023-07-17), Automotive PCBs are bucking the trend with a forecast of 12% CAGR from 2022 to 2026, says TrendForce, in "trendforce.com" , https://www.trendforce.com/presscenter/news/20230717-11767.html , 27-05-2024.

With the increase of the amount of electronic components present in EVs, PCBs are developing in the direction of high integration, high density, multi-layer and withstand high-voltage. In addition, smart vehicles have high requirements on the transmission rate, that need to use of high-frequency and high-speed PCBs.

According to the laws of economics, an increase in PCB demand should reduce prices of components and boards as demand increases the opportunity for companies to take advantage of economies of scale[76]. However, the introduction of EVs is not likely to be all good news for PCB manufacturers. Recently, the copper industry is under pressure due to the increase in battery-powered goods. According to an IDTechEx report, commissioned by the International Copper Association (ICA), PCB industry is expected to see a 9-fold increase in copper demand due by 2027, mainly driven by the increase in electric vehicles[77]. This is influenced by China's decision to ban waste imports, that is an important source of recycled copper. Last, as cars contain up to six kilometres of copper wiring, the copper industry is even more under pressure. In addition, the increase demand for solar powered cars will add further pressure to PCB industry.

In conclusion, the advancement of PCB technology will improve and affect connectivity, data processing, and vehicle-to-grid interactions, building the future of transportation towards a more sustainable ecosystem. In fact, all these technologies can support e-mobility systems by minimising form factors, increasing the systems performance and by reducing the system cost when determined on the system level. Embedded devices of power electronic are able to replace conventional power modules, significantly improve system performance and reliability and are useful for low voltage applications with highest currents as well as for wide band gap devices in high voltage applications.

PCB manufacturers are expected to take advantage of networking and intelligence, in fact many Chinese PCB manufacturers, such as Shiyun Circuit, Shanghai Electric Power, Dongshan Precision, and Shenghong Technology have now entered the supply chain of electric vehicles companies such as Tesla or BYD. When China's automotive brands will reach the centre of the global stage, also China's PCB brand will go global[78].

The global PCB market is expected to reach at least USD 13.39 billion by 2030[79], and of course the production of EVs will contribute to this number. Indeed, PCB manufacturers are pushed to compete with each other and produce great technological advancement, due to EV demands for compact, handle clean energy conversion, and support the IoT boards.

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[76] Economies of scale are cost advantages reaped by companies when production becomes efficient. Companies can achieve economies of scale by increasing production and lowering costs. This happens because costs are spread over a larger number of goods. Costs can be both fixed and variable. In "investopedia.com", https://www.investopedia.com/terms/e/economiesofscale.asp , 27-05-2024.

[77] Garner, M., (2018-01-19), Electric cars by 2040 - How will it affect the PCB industry?, in "LinkedIn.com", https://www.linkedin.com/pulse/electric-cars-2040-how-affect-pcb-industry-mike-garner , 27-05-2024.

[78] IBE Electronics, (2022), EV penetration raises automotive PCB production value against the trend, in "pcbaaa.com", https://www.pcbaaa.com/ev-penetration-raises-automotive-pcb-production-value-against-the-trend/ , 27-05-2024.

[79] Automotive industry news updates, (2024-04-15), A deep dive into the automotive PCB industry an powering innovation, in "LinkedIn.com", https://www.linkedin.com/pulse/deep-dive-automotive-pcb-industry-powering-24tyf#:~:text=A Market on the Move,(CAGR) of 5.6% , 27-05-2024.

CHAPTER 2
SILICON AS A SEMICONDUCTOR MATERIAL

2.1 Silicon Is

Silicon is a chemical element with the symbol Is and the atomic number 14, and it is the second most abundant element in the Earth's crust with about 27,7% of crust by mass, after oxygen[80]. Together with carbon germanium, tin and lead, silicon is a IVA group element. The majority of silicon can be found in soil and rock, but also in natural water, plants, atmosphere, and even in certain animals. However, in nature it is found as compounds with oxygen, aluminium and magnesium, for this reason it needs be extracted from the compound and purified. Pure silicon is a dark grey solid with the same crystalline structure as diamond. Its melting point is of 1410°C, boring point of 2355°C, and a density of 2.33/cm3[81]. Silicon metal is created from the creation of silica (also known as silicon dioxide, SiO_2) and carbon materials like coke, coal and wood chips.

In 1824 a Swedish chemist named Jons Jacob Berzelius first isolated and described silicon as an element and crystalline silicon was first produced in 1854 with the use of electrolysis[82]. The first electric arc furnace used to make silicon was invented in 1899 by Paul Louis Toussaint Heroult, a French inventor[83]. At the beginning, the first electronic devices used bulky, power-hungry vacuum tubes that burned out frequently. In 1947, with the development of transistor there has been a radical shift: silicon stood out among all the other semiconductors.

Thanks to its electrical properties and characteristics, as small energy gap, silicon is widely used in the electronic industry because it is ideal for a range of applications. In fact, due to its electrical conductivity value between that of a conductor and an insulator, silicon is the heart of semiconductors, playing a vital role in the development of modern technology. Semiconductors instead are the most important part of modern electronics, as they power the devices we rely on everyday, from smartphones to cars.

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[80] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in "wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[81] Wikipedia, (2024), Silicon, in "en.wikipedia.org", https://en.wikipedia.org/wiki/Silicon , 04-06-2024.

[82] Britannica, (2024-05-14), Silicon, in "britannica.com", https://www.britannica.com/science/silicon , 04-06-2024.

[83] Made how, (2024), Silicon, in "madehow.com", https://www.madehow.com/Volume-6/Silicon.html , 04-06-2024.

Silicon has the peculiar ability to be intentionally contaminated, called doping, and this means that it can be intentionally contaminated with other elements in order to alter its electrical properties. This is the reason why silicon is the most used material for chips and microprocessor's manufacturing. In fact, silicon allows the development of high-performance electronic devices through low power consumption, and making chips suitable for computers, smartphones, and many others devices. Thanks to the capacity of fabrication complex electronic circuits on a small area of silicon, the electronic industry has revolutionised with the development of smaller, faster, and more powerful electronic devices. These are all the reasons why the growth and the advancement of technology industry is directly linked to the importance of silicon[84].

Figure 11: Pure silicon

[84] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in "wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

A semiconductor is an organic or inorganic material with electrical conductivity properties between conductor and insulator, and with the ability to conduct electricity under certain conditions, the capacity to be doped with impurities to modify its electric behaviour, and its temperature-dependent conductivity[85]. Semiconductors fall between conductors[86] and insulators[87] in terms of electrical properties, as they have a moderate resistance to the flow of current. They have a smaller band gap[88] than insulators (about 1eV, electron volt), that allows for some electron movement between the valence of conduction bands, enabling them to conduct electricity under specific conditions. Semiconductors' electrons need to obtain energy to cross the band gap and reach the conduction band, with ionising radiation for instance. The properties of semiconductors are usually determined by the energy gap between valence and conduction bands.

Semiconductors can be intrinsic, if they are made up of a single element (for instance silicon), and have no intentional doping with impurities, and also extrinsic, if they are intentionally doped with impurities in order to change their electronic properties, and can be classified in p-type and n-type, that will be discussed later. Another material employed for manufacturing semiconductors are thin films, that create conductive and insulating layers. In order to create different layers and components needed to build a semiconductor device, insulators, conductors, and other electronic components, these thin films are deposited on a silicon wafer.

When manufacturing insulators, the thin films are placed on a silicon wafer in order to create a layer that block the flow of electric current, as transistors[89] and integrated circuits[90]. Instead in the case of semiconductors, thin films of silicon or germanium[91] are placed on a substrate, with the purpose of creating a layer with semiconductors properties[92].

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[85] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in "wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[86] Conductors are materials like copper and aluminium, that allow the free flow of electric current, with low resistance to the movement of electrons. The valence band in conductors containing the outermost electrons, overlaps with the conduction band, allowing electrons to move freely and conduct electricity. Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and its use in semiconductor technology, in "wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[87] Insulators are materials like rubber and glass, that impede the flow of electric current, with high resistance to the movement of electrons. The band gap in insulator prevents the flow of electric current. Wikipedia, (2024), Insulator (electricity), in "en.wikipedia.org", https://en.wikipedia.org/wiki/Insulator_(electricity) , 04-06-2024.

[88] The band gap, also known as energy gap, is a large energy gap present in insulator, conductor and semiconductor. It is an energy range between the valence band and conduction band where electron states are forbidden. Wikipedia, (2024), Band gap, in "en.wikipedia.org", https://en.wikipedia.org/wiki/Band_gap , 04-06-2024.

[89] A transistor is a semiconductor device used to amplify or switch electrical signals and power. It is composed of semiconductor material with al least three terminals for connection to an electronic circuit. Wikipedia, (2024), Transistor, in "en.wikipedia.org", https://en.wikipedia.org/wiki/Transistor , 04-06-2024.

[90] An integrated circuit, also known as a microchip, chip or IC, is a small electronic device made up of multiple interconnected electronic components such as transistors, resistors, and capacitors. All these components are etched onto a small piece of silicon. They are used in a wide range of electronic devices and have impacted the electronic industry by enabling device miniaturisation and improved functionality. Wikipedia, (2024), Integrated circuit, in "en.wikipedia.org", https://en.wikipedia.org/wiki/Integrated_circuit , 04-06-2024.

[91] Germanium is a chemical element, its symbol is Ge and its atomic number is 32. In appearance is similar to silicon, as it is a metalloid in the carbon group that is chemically similar to the group of silicon and tin. Wikipedia, (2024), Germanium, in "en.wikipedia.org", https://en.wikipedia.org/wiki/Germanium , 04-06-2024.

[92] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in "wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

Several factors, such as the abundance in the Earth's crust, its ability to form high-quality insulating oxide layers, and its compatibility with different fabrication processes, make silicon very popular in the electronic industry[93]. In fact, its temperature-dependent conductivity and its capability to be doped with impurities, make silicon to be a perfect material for different electronic applications. In addition, silicon has a high melting point that reaches 1414°C, can tolerate temperatures up to 150°C, and has a low band gap energy of 1.1 eV (short for electron volt), and for these reasons it needs less energy to free the valence electrons in the crystal structure and create charge carriers[94].

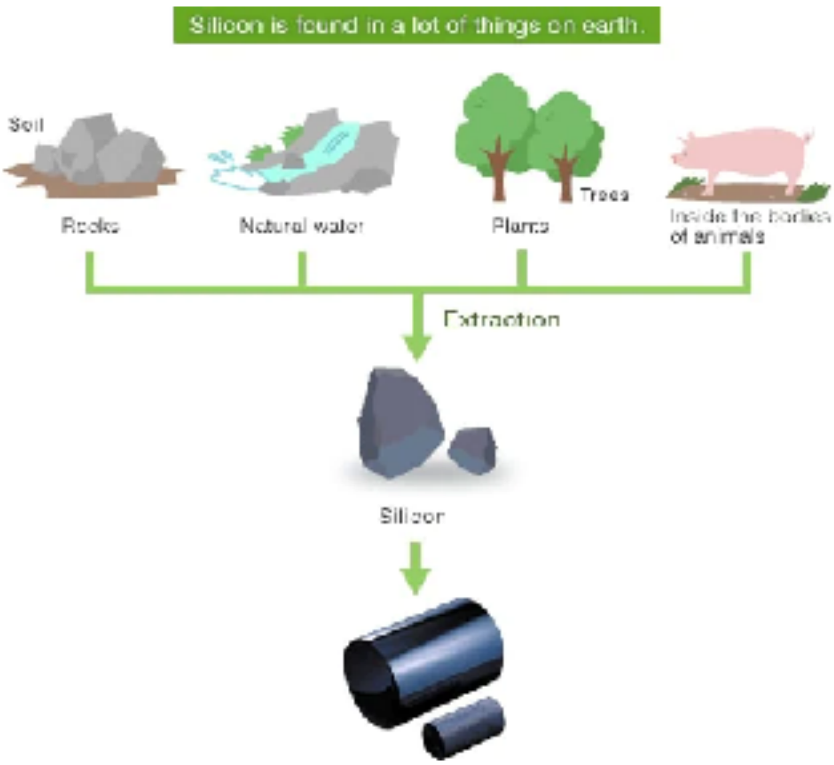

Figure 12: Where silicon can be found on earth

[93] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in "wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[94] Electrical4U, (2023-06-18), What is silicon semiconductor?, in "electrical4u.com", https://www.electrical4u.com/silicon-semiconductor/?utm_content=cmp-true , 04-06-2024.

Silicon semiconductors find a wide variety of devices' application, for instance transistors, integrated circuits, and solar cells. Silicon semiconductors allowed to produce smaller, faster and more powerful electronic devices in the electronics industry. However, a limitation of silicon is its low electron mobility compared to those of other semiconductor material as gallium arsenide and gallium nitride. This is a limit for its performance in high-frequency and high-power electric devices.

From an atomic structure point of view, silicon is a tetravalent element, that means it has four valence elections in its outermost electron shell. This make it able to form covalent bonds with adjacent silicon atoms, and create a stable crystal lattice structure. This makes difficult for electrons to move freely within the crystal lattice, due to the silicon semiconducting properties[95]. When silicon is doped with impurities, there is the creation of n-type and p-type semiconductors due to the alteration of its electrical behaviour.

From chemical point of view, silicon forms a diamond cubic crystal lattice, characterised by a repeating pattern of atoms in a three dimensional arrangement[96]. Each silicon atoms is covalently bonded to four adjacent atoms, creating an ordered and stable lattice. This arrangement of atoms allows the formation of energy bands, which give the ability to conduct electricity. The valence band and the conduction band are separated by a small band gap of 1.12 electron volts (eV) at room temperature[97]. When silicon is exposed to oxygen at high temperatures, it forms a thin layer of silicon dioxide (SiO2) on its surface. This layer act as insulator, preventing the flow of electric current between adjacent silicon regions, and it is important for the fabrication of integrated circuits. If silicon is doped with impurities such as boron or phosphorus, free electrons are introduced in the crystal lattice, which determines the electrical properties of semiconductor, that can be controlled by applying a voltage or current to the device[98].

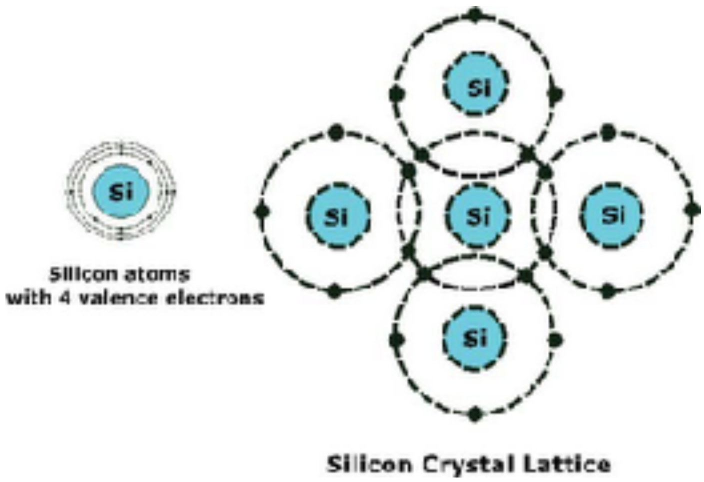

Figure 13: Structure and lattice of a normal pure crystal of silicon

[95] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in "wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[96] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in "wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[97] Abiola, A., (2023-08-10), Silicon Semiconductor: a comprehensive guide to silicon and its use in semiconductor technology, in "wevolver.com",, https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[98] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in "wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

2.1.1 Main functions of silicon semiconductor[99]

The electrical properties of silicon can be modified with a process called doping, with which impurities are introduced into silicon crystal lattice. The impurities donate or accept electrons, by this way it is possible to create n-type or p-type semiconductors. This ability is essential for the manufacturing of electronic devices, because it forms junctions that control the flow of electrical current.

n-type silicon is created with the introduction of donor impurities, that are elements from V group of the periodic table, as phosphorus or arsenic, with five valance electrons. In this case covalent bonds are formed with four adjacent silicon atoms, leaving one extra electron available for conduction[100]. Extra electrons increase the number of charge carries that improve electrical conductivity, and in this case they are electrons that are negatively charged. In fact, the “n” of n-type refers to the negative charge of carriers. Of course the concentration of donor impurities can be controlled in the doping process in order to reach the desired level of conductivity. An example of n-type silicon is the Phosphorus-doped Silicon (n-Si).

p-type silicon is created with the introduction of acceptor impurities, that are elements from the II group of the periodic table, as boron or aluminium, with three valence electrons. In this case covalent bonds are formed with four adjacent silicon atoms, but it lacks one electron to complete the bond. For this reason there is the creation of a hole, that is a positive charge carrier, in fact, it can accept electrons from neighbouring atoms and this is the reason why they are called “p-type”. When an electron fills a hole, it leaves behind a new hole that moves through the lattice. Also in this case, the concentration of acceptor impurities can be controlled during the doping process in order to achieve the desired level of conductivity. An example of p-type silicon is Boron-doped Silicon (p-Si).

Through different combinations of n-type and p-type semiconductors, it is possible to create devices with useful properties, such as diodes, transistors, or integrated circuits[101].

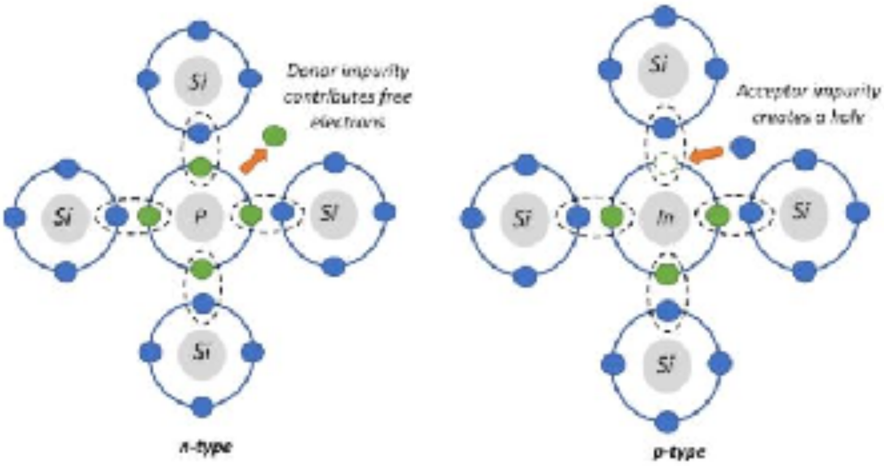

Figure 14: structure of n-type and p-type silicon

[99] This paragraph is based on “wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[100] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in “wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[101] Abiola, A., (2023-08-10), Silicon Semiconductor: A comprehensive guide to silicon and its use in semiconductor technology, in “wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

2.1.2 Main applications of silicon semiconductor

Silicon ingots are large blocks of silicon used for producing semiconductor devices, and are created by melting high-purity silicon and then cooling it from a single crystal structure[102]. The ingot is then sliced into thin wafers, that are used for producing chips and other electronic devices, and this process is called Czochralski process[103]. The process requires precise temperature control and a carefully controlled environment to ensure the purity and the uniformity of the resulting ingot[104]. Silicon ingots are important in microelectronics[105], in fact the wafers are used for the production of chips and other electronic devices.

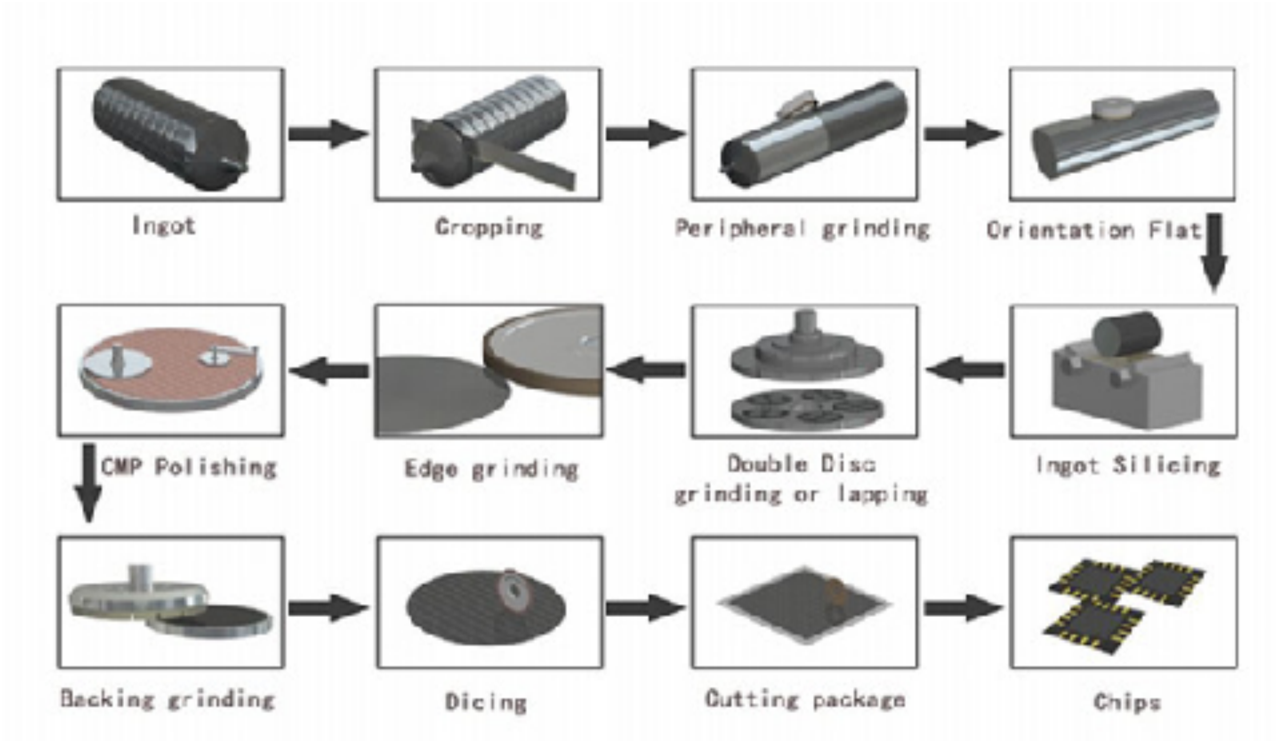

Figure 15: Silicon wafering process

[102] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in “wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[103] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and its use in semiconductor technology, in “wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[104] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in “wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[105] Microelectronics is the study and development of electronic components and devices that are extremely small in size, typically on the order of micrometer and nanometers. Wikipedia, (2024), in “en.wikipedia.org", https://en.wikipedia.org/wiki/Microelectronics , 04-06-2024.

Silicon wafers are a material used for the production of semiconductors, and it is possible to find them various electronic devices like computers, smartphones, pressure sensor system, and mobile devices. Silicon wafers present themselves as a super-flat disk with a mirror-like surface, and it is the flattest object in the world, with a thickness between 0.2 and 1.5 mm, and a diameter from 1 inch to over 12 inches[106]. They are used for the production of both chips and microchips, especially ICs (integrated circuits) due to their electrical currents. Silicon wafers are a thin slice of semiconductor material that act as a substratum for microelectronic devices fitted in and above the wafer[107].

[106] WaferPro, (2024-01-04), What is a silicon wafer? What is it used for?, in "waferpro.com", https://waferpro.com/what-is-a-silicon-wafer/ , 04-06-2024.

[107] WaferPro, (2024-01-04), What is a silicon wafer? What is it used for?, in "waferpro.com", https://waferpro.com/what-is-a-silicon-wafer/ , 04-06-2024.

Silicon wafers are used as a canvas on which to fabricate also other devices, such as:

- **Microprocessors**, that are the central chips that power computers and smartphones;
- **DRAM & flash memories**, that are silicon-based memory cells on chips;
- **CMOS sensors**, that are image sensors that capture light in the camera of smartphones and other devices;
- **Power devices**, that manage electricity in systems;
- **MEMS**, that are tiny mechanical and electromechanical silicon systems;
- **Optical circuits**, that are waveguides and photonics devices which integrate optics.

Silicon is the primary material for the fabrication of transistors, that normally consist of a p-n junction formed by overlaying a thin layer of doped silicon (either n-type or p-type) between two layers of the opposite type[108]. This structure let the transistor to be a switcher or an amplifier, as there is a controlled flow of electrical current between the layers. Silicon transistors have different advantages, such as: 1. Higher thermal stability, that allows to operate in higher temperatures without degrading its performances; and 2. Excellent insulation between different components, thanks to the high quality silicon dioxide layer on the silicon's surface. According to Moore's Law[109], the continuous miniaturisation of silicon transistors has permit the creation of more powerful and efficient electronic devices, like computers, smartphones, medical equipment and renewable energy systems[110].

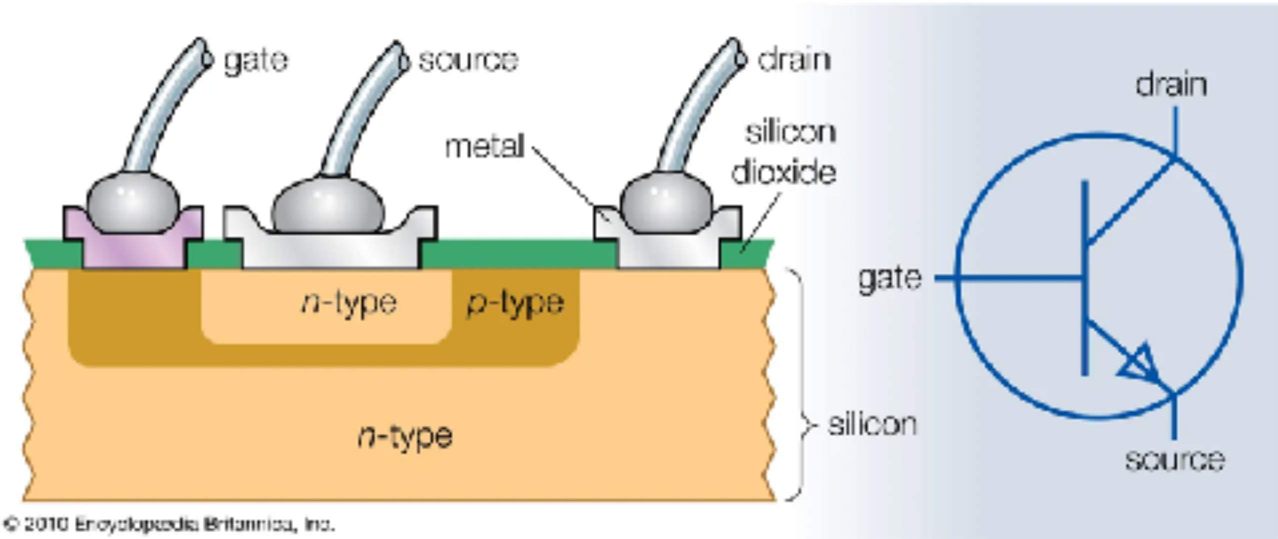

Figure 16: Representation of a silicon transistor's cross section

[108] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in "wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[109] Moore's Law states that the number of transistors in an integrated circuit doubles about every two years at a minimal cost. It is an empirical relationship linked to gains from experience in production. It is not actual science, but an observation and extrapolation held steady since 1965. Wikipedia, (2024), Moore's Law, in "en.wikipedia.org", https://en.wikipedia.org/wiki/Moore%27s_law , 05-06-2024.

[110] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in "wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

Thanks to its semiconductor properties, its ability to form high-quality insulating oxide layers, and its compatibility with different manufacturing processes, silicon is also employed to fabricate integrated circuits (ICs). The manufacturing process of ICs includes: 1. Photolithography, that creates intricate patterns on the silicon wafer and defines the layout of IC components; 2. Etching, that removes unwanted silicon material in order to reach the desired structures; and 3. Doping, that introduces impurities into specific parts of silicon, creating n-type or p-type materials.
The different advantages of silicon ICs are:

1. Excellent insulation between different components, due to the high-quality silicon dioxide layer;
2. Compatibility with a wide range of manufacturing processes;
3. Abundance of silicon in the Earth's crust, that makes the material cheap and available.

Finally, silicon is also used for the production of power electronics as thyristors[111], MOSFETs[112], and IGBTs[113], that are devices are used to control the flow of electric power in different applications, like power suppliers, motor drivers, and renewable energy systems. In fact, the application of silicon in power electronics has become increasingly important due to the increasing demand for energy-efficient systems and renewable energy sources of last years. Concluding, silicon semiconductor has a large market share and economy of scale, for this reason it is low cost and increases the availability of silicon-based devices.

[111] Thyristor is a solid-state semiconductor device that allows the passage of current in only one direction, and under the control of a gate electrode, that is used in high power applications like inverters and generators. Wikipedia, (2024), Thyristor, in "en.wikipedia.org", https://en.wikipedia.org/wiki/Thyristor , 05-06-2024.

[112] MOSFET (short for metal-oxide-semiconductor field-effect transistor) is a field-effect transistor (FET) with an insulated gate, that determines the conductivity of the device. In fact, it is used to amplify or switch electronic signals. Wikipedia, (2024), MOSFET, in "en.wikipedia.org", https://en.wikipedia.org/wiki/MOSFET , 05-06-2024.

[113] 113 IGBT (short for insulated-gate bipolar transistor) is a three-terminal power semiconductor device that creates electronic switch. Wikipedia, (2024), Insulated-gate bipolar transistor, in "en.wikipedia.org", https://en.wikipedia.org/wiki/Insulated-gate_bipolar_transistor , 06-05-2024.

2.2 Semiconductor production process: from silicon dioxide to semiconductor[114]

The process of producing semiconductor devices from silicon wafers is known as semiconductor manufacturing, where semiconductors are manufactured through a complex process that involves multiple steps, stating from the silicon mining to the production of finished devices. The fabrication process takes place in specialised semiconductor fabrication plants, also called foundries or fabs, and can take from few weeks to several months, depending on the specificity of the device to be produced (for instance integrated circuits, computer processors, microcontrollers, and memory chips). Due to its complexity and highly technical requirements, this process needs for specialised equipment, facility, and trained personnel.

The first step in semiconductor production is the silicon mining. Silica, also known as silicon dioxide (SO2), is the source of silicon and it is possible to find it in sand and quartz. During this process of mining, sand extraction takes place and countries abundant of sand resources, like United States, China, and Australia are silicon's top producers[115]. Sand is first extracted from the Earth through open pit mining or dredging[116]. Then the sand follows cleaning and filtering processes in order to remove unwanted materials, and after this passage, the refined sand follow the step of the carbothermic reduction, where it is heated in a high-temperature furnace with the presence of carbon. As a result it is possible to obtain metallurgical grade silicon with a purity level of about 98%[117].

However in this passage, silicon sill has impurities as iron, aluminium, and other metals, and semiconductors need for a higher degree of purity. For this reason the second step is the purification of silicon, through which the material has to reach the 99.9999999% of purity level[118]. In fact, silicon crystal structure is also called "eleven nines", due to this ultra-high-purity level that has to reach in order to be used in semiconductor industry. It is important to remember that even a small trace of impurities can impact their functionality. During purification, there is another sub-process called Siemens process[119], where metallurgical grade silicon reacts with hydrochloric acid in order to produce trichlorosaliane (HCl3Si), which is a more volatile compound. Trichlorosilane is then further purified through CVD process (short for chemical vapour deposition), and become highly pure silicon and hydrogen chloride, and the silicon reaches a polycrystalline form with the purity level needed for the semiconductor manufacturing. Other than Siemens process, in recent years has been developed an alternative method called Fluidised Bed Reactor (FBR), which is more efficient and reduces the cost of production.

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114 This paragraph is based on "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 06-05-2024.

115 Khan, M., (2023-06-02), How are semiconductors made? A comprehensive guide to semiconductor manufacturing, in "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 06-05-2024.

116 Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in "wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

117 Khan, M., (2023-06-02), How are semiconductors made? A comprehensive guide to semiconductor manufacturing, in "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 06-05-2024.

118 Khan, M., (2023-06-02), How are semiconductors made? A comprehensive guide to semiconductor manufacturing, in "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 06-05-2024.

119 The Siemens process is usually used to produce pure (or almost pure) silicon ready for use in electronics and especially in the production of photovoltaic cells. Wikipedia, (2024), Processo Siemens, in "it.wikipedia.org", https://it.wikipedia.org/wiki/Processo_Siemens , 05-06-2024.

The third step is the production of silicon ingots, that are large and cylindrical pieces of silicon. At the beginning of this step there is a small piece of silicon, called seed crystal, that through the Czchralski process[120] takes the form of a cylindrical silicon ingot. This ingot takes also the name of mono crystalline silicon and it ensures the uniformity of the crystal lattice structure, that is important for the functionality of the semiconductor. The ingot need to be shaped and sized in order to meet the specifications for chip manufacturing, in fact it can be cut with the use of a special saw into wafers usable in semiconductor devices. The silicon wafer is then polished to a mirror finish, in order to ensure that any remaining microscopic irregularities is removed.

The fourth step of semiconductor production is wafer fabrication, that is a process with the aim of transforming a simple silicon disc into a platform for various microscopic electronic components, and this process include: oxidation, lithography, etching, doping, and metallisation[121].

During oxidation step, the wafer is heated with oxygen and the result is a layer of silicon dioxide. Instead with lithography, the silicon dioxide layer is imprinted of intricate circuit patterns and determines how small the transistor on a chip can be. The chip wafer is inserted into a lithography machine where it is exposed to deep ultraviolet (DUV) or extreme ultraviolet (EUV) light[122].

Next, etching is employed in order to remove the exposed silicon dioxide and leave behind the desired pattern. Following etching, the wafer goes through doping in order to modify its electrical properties by introducing impurities into specific areas of the wafer, and this brings to the creation of p-n junctions[123].

Finally, metallisation provides an electrical connection between the different elements of the integrated circuit and the wafer is then coated with a protective layer against damage and contamination.

Chemical-mechanical planarization (CMP), also known as polishing or cleaning, is an essential process where the combination of chemical and mechanical processes reduce the topographical variations, yielding a flat, smooth surface[124]. At this point the wafer is placed on a rotating platen where a pad and a chemically active slurry remove the material from the high points on the wafer, levelling out the surface.

The fifth step is the layering process, also known as film deposition, and involves the deposit of different material into the silicon wafer. These materials have specific properties and functions, and are classified into: insulators, semiconductors, and conductors.

Insulator layers electrically isolate the different part of the circuit and protect the underlying layers from environmental contamination[125]. Thermal oxidation is the process of forming an insulator layer where the silicon wafer is heated in order to form a thin layer of silicon dioxide. Exist two types of oxidation process:

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[120] The Czochralski Process (CZ) is a crystal growth technology that starts with insertion of a small seed crystal into a melt in a crucible, pulling the seed upwards to obtain a single crystal. Science Direct, (2011), Czochralski Process, in "sciencedirect.com", https://www.sciencedirect.com/topics/chemistry/czochralski-process , 05-06-2024.

[121] Abiola, A., (2023-08-10), Silicon semiconductor: a comprehensive guide to silicon and is use in semiconductor technology, in "wevolver.com", https://www.wevolver.com/article/silicon-semiconductor , 04-06-2024.

[122] Li,A., (2023-10-04), 6 crucial steps in semiconductor manufacturing, in "asml.com", https://www.asml.com/en/news/stories/2021/semiconductor-manufacturing-process-steps , 05-06-2024.

[123] Khan, M., (2023-06-02), How are semiconductors made? A comprehensive guide to semiconductor manufacturing, in "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 05-06-2024.

[124] Khan, M., (2023-06-02), How are semiconductors made? A comprehensive guide to semiconductor manufacturing, in "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 05-06-2024.

[125] Khan, M., (2023-06-02), How are semiconductors made? A comprehensive guide to semiconductor manufacturing, in "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 05-06-2024.

the wet one, where steam is passed over the wafer at high temperatures, and the dry one, where dry oxygen at similar temperature is used to produce thinner, denser, and higher quality oxide layer.
The semiconductor layers are the active region of the device as here takes place the electrical activity, and epitaxy is the process through which layers of semiconductor are grown in the silicon wafer.
Instead, conductor layers, like aluminium or copper, create connection between different parts of the circuit, that allow the flow of electricity through the device. After layering, there is the post-deposition cleaning, where all the small particles adhering to the wafer resulting to the film deposition are removed with the use of brushed or nanospray containing demonised water, or other physical methods.

The sixth fundamental step in semiconductor fabrication is the dopant diffusion, that give them the property of change control. During this process there is the incorporation of dopants (that are the impurity atoms) into the silicon wafer, and according to the type of dopant it is possible to have an n-type, where the majority of carriers are electrons or a p-type, where the majority of carriers are holes. Silicon atoms in the crystal lattice are replaced by these impurities, that significantly influence the electrical properties of the silicon. The dopant diffusion process is carried out at high temperatures, between 900 and 1200° C, the wafer is placed in a furnace, and the dopant is introduced in the form of gas and takes up positions within the silicon's crystal lattice[126]. This process is highly controlled because it directly impacts the electrical characteristics of the device.

Then, there is the seventh process called etching process, that is used to removed selected layers from the surface of the wafer (for instance silicon dioxide, poly silicon, metal layers), and creates intricate patterns that form the basis for the miniaturised circuits of electronic devices. During this process, photolithography[127] is used to define the patterns and there are two methods: wet etching, where a liquid called Ethan dissolves the material, and dry etching, where a gas phase etchants in a vacuum chamber in order to control the etch process. This process is controlled through the etch rate, that is measured in nanometers per minute and temperature, pressure, and the composition of etching agent are factors that can affect this rate. This control allow to produce nanoscale structures and this is fundamental for the miniaturisation of electronic circuits.

The final steps are testing and packaging. Testing stage, also known as quality control, is part of the manufacturing process and it aims to ensure that all the circuits on the wafer function correctly[128]. During the electrical test each wafer's die is connected with an array of tiny problems that are connected to a tester. This tester (normally is a ATPG software, short for automatic test pattern generation) checks parameters like current, voltage, resistance, and capacitive or inductive properties, in order to ensure that the device meets the requirements. In addition, wafer test metrology equipment is employed in order to verify if wafer has been damaged in previous processing steps.

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[126] Khan, M., (2023-06-02), How are semiconductors made? A comprehensive guide to semiconductor manufacturing, in "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 06-05-2024.

[127] Photolithography, also known as optical lithography, is a process used in the manufacturing of integrated circuits and it involves the use of light to transfer a pattern into a substrate, normally a silicon wafer. Wikipedia, (2024), Photolithography, in "en.wikipedia.org", https://en.wikipedia.org/wiki/Photolithography , 05-06-2024.

[128] Khan, M., (2023-06-02), How are semiconductors made? A comprehensive guide to semiconductor manufacturing, in "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 05-06-2024.

Following, there is the dicing process, that uses a precision diamond saw to cut the wafer into chips. Then the chips are mounted into a protective package, that can be plastic or ceramic with thin wires connecting the chip to the external leads, or CSP (short for chip scale package) where the chip can be soldered directly to the package leads.

Finally, there is the final test that ensures the packaging process didn't intact the correct functioning of the chips. The test can be done under different environmental conditions, like high or low temperature and humidity and it is considered a time-consuming process, as it account for up to 25% of the total manufacturing time[129]. The test coverage exceeds 99% for high-reliability applications and the average chip yield[130] has a range from 50% to 90%[131].

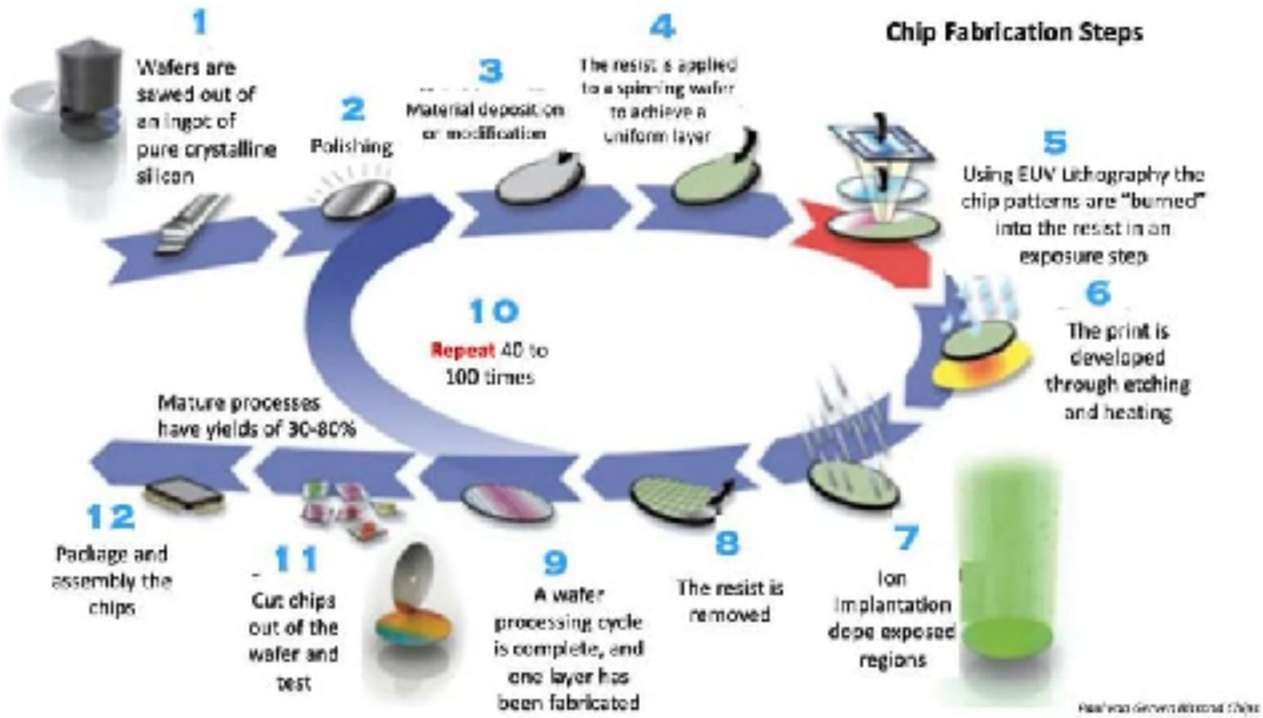

Figure 17: Stages of semiconductor production

[129] Khan, M., (2023-06-02), How are semiconductors made? A comprehensive guide to semiconductor manufacturing, in "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 05-06-2024.

[130] The average chip yield is the percentage of functional chips on a wafer.

[131] Khan, M., (2023-06-02), How are semiconductors made? A comprehensive guide to semiconductor manufacturing, in "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 06-05-2024.

2.2.1 Challenges and future trends in semiconductor manufacturing[132]

In order to include technical, economic, and environmental aspects, semiconductor manufacturing process has to face several challenges, such as:

- **Miniaturisation**, due to the demand for higher transistor density and lower power consumption;
- **Yield management**, as chips become more complex and small, the defect increases and several techniques are employed in order to mitigate the impact of defects;
- **Economical challenges**, in fact new technology development leads to high costs;
- **Environmental challenges**, as manufacturing a single silicon wafer requires thousand of litres of ultra-pure water, large amounts of electricity, and a variety of chemicals;
- **Innovation**, as existing semiconductor technologies are facing limits, new technologies need to be developed and there is also need for investment in new manufacturing process and equipment.

Driven by the challenges, semiconductor industry is constantly evolving and its future is shaped by the following emerging trends:

- **Advanced process nodes**, Moore's law trend is expected to continue with the development of advanced process nodes, like 5 nanometers and beyond[133];
- **3D integration**, that involves the stacking of multiple layers of chips vertically, in order to increase the functionality and the performance;
- **Emerging materials**, like Gallium Nitride (GaN), silicon Carbide (SiC), and 2D materials as Graphene are now gaining prominence and will lead to enhanced device performance and efficiency;
- **Specialised applications**, including artificial intelligence (AI) chips, Internet of Things (IoT) devices, autonomous vehicles, and advanced sensors, all need for specialised chips able to meet their unique requirements, as low power consumption, high computational power, and robust connectivity[134];
- **Advanced packaging technologies**, like fan-out wafer-level packaging (FOWLP), system-in-package (SiP), and chipsets, offer improved performance, smaller form factors, and increased flexibility in integrating different functions into a single package[135].

Due to the intersection of different scientific and engineering discipline, semiconductor manufacturing is a complex and technologically advanced process that involves several stages and that operates on a microscopic scale. For this reason, it requires advanced lithography technique. Despite the many challenges to face, semiconductor industry keep on driving forward, with constant innovation leading to more powerful and efficient devices.

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[132] This paragraph is based on "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 06-05-2024.

[133] Khan, M., (2023-06-02), How are semiconductors made? A comprehensive guide to semiconductor manufacturing, in "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 05-06-2024.

[134] Khan, M., (2023-06-02), How are semiconductors made? A comprehensive guide to semiconductor manufacturing, in "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 05-06-2024.

[135] Khan, M., (2023-06-02), How are semiconductors made? A comprehensive guide to semiconductor manufacturing, in "wevolver.com", https://www.wevolver.com/article/how-are-semiconductors-made-a-comprehensive-guide-to-semiconductor-manufacturing , 05-06-2024.

CHAPTER 3
IN-SYSTEM PROGRAMMING

3.1 In-System Programming[136]

In-System Programming (abbreviation ISP), also known as In-Circuit Serial Programming (ICSP), is a technique applied to program different electronic devices such as microcontrollers[137] and chipsets[138] while they are installed on a printed circuit board (PCB), rather than programming them before installation (also known as Pre-programming technique). ISP refers to the process of flashing a processor during production, typically done towards the end of the assembly line. Following this, there is usually either a one-site test or a functional test, with ISP occurring just prior to the functional test. Over the past 15 years, different EMS (short for Electronic Manufacturing Services, that will be discussed in chapter 4) have moved from pre-programming methods to ISP solutions due to the various advantages that they offer.

Among the different benefits of this programming technique, it is possible to find the simplification of the design work as it doesn't need for specialised programming circuitry on the PCB; then there is the direct delivery of firmware[139] updates directly to the on-chip memory and the fact that today's microcontroller and memory chips can be re-programmed without being removed from the circuit, by this way it's possible to streamline the process. In fact, ISP boosts manufacturing by removing the extra step of programming devices on an external programmer before placing them on the PCB, reducing also the risk of damaging delicate leads or the device itself from electrostatic discharge. ISP also permits Automatic Test Equipment (ATE)[140] to perform ISP operations on ISP devices, integrating them into the normal production test flow.

As there are no standards for ISP protocols, manufacturers implement their owns that often differ even for devices from the same manufacturer. Modern protocols aim to minimise pin usage, in fact some protocols use as few as 2 pins or even a single pin, while others employ up to 4 pins for a Joint Test Action Group (JTAG) interface[141].

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[136] This paragraph is based on "smh-tech.com", https://smh-tech.com/corporate-blog/what-is-in-system-programming/ , 18-06-2024.

[137] A microcontroller is a compact integrated circuit designed to govern a specific operation in an embedded system. A typical microcontroller includes a processor, memory and input/output (I/O) peripherals on a single chip. Lutkevich B., (2024): Microcontroller (MCU), in "tech target.com", https://www.techtarget.com/iotagenda/definition/microcontroller , 09-05-2024.

[138] A chipsets is a collection of electronic components what work together to enable the functioning of a computer system. It is typically made up of two main parts: the Northbridge and the Southbridge. The Northbridge handles high-speed communication between the processor, memory, and graphic cards, while the Southbridges manages the slower, peripheral devices such as USB ports, hard drives, and audio interfaces. What is a chipset?, in "lenovo.com", https://www.lenovo.com/us/en/glossary/chipset/?orgRef=https%253A%252F%252Fwww.google.com%252F , 09-05-2024.

[139] Firmware is a form of microcode or program embedded into hardware devices to help them operate effectively. It is often referred to as "software of hardware". What is firmware? Types and examples, in "fortinet.com", https://www.fortinet.com/resources/cyberglossary/what-is-firmware , 09-05-2024.

[140] Automated test equipment (ATE), or automatic testing equipment, is computerised machinery that uses test instruments to carry out and evaluate the results of functionality, performance, quality, and stress test performed on electronic devices systems. As its name implies, ATE automates traditionally manual electronic test equipment and processes, and requires minimal human interaction. Brett D., Feb 11, 2021 : What is automatic test equipment (ATE)?, in "trentonsystems.com", https://www.trentonsystems.com/en-us/resource-hub/blog/automatic-test-equipment-overview , 09-05-2024.

[141] JTAG is an integrated method for testing interconnects on printed circuit boards (PCB) that are implemented at the integrated circuit (IC) level. What is JTAG? Introduction, in "corals.com", in https://www.corelis.com/education/tutorials/jtag-tutorial/what-is-jtag/ , 09-05-2024.

Others advantages are the integration of programming, the single production phase testing, saving money and reducing manufacturing delays by enabling code or design changes mid-production run. In addition, ISP ensures the use of latest firmware in production, in order to facilitate the implementation of new features and bug[142] fixes without delays associated with pre-programmed microcontrollers. Another advantage that allows to save time and money during development and software updates in the field, is the elimination of physical chip removal that reduces also the risk of device damage. Chips that support ISP can generate necessary internal programming voltage and communicate with the programmer via a serial protocol.

As programming devices have become more popular due to decreasing cost, the variety of devices and programming methods require that users to acquire and maintain different types of In-System Programmers for each device manufacturer, resulting in inefficient use of engineering resources. For this reason, engineers may purchase cost-effective development tools from device manufacturers or specialised programmers, which focus on fast programming speed and compatibility with various devices.

The necessary components that are needed to conduct In-System Programming are:

- **A desktop software tool,** capable of managing the programming interface via any standard port;
- **A programming adapter,** enabling the connection of the programming interface to various standard ports on the PC, such as USB, RS-232, or printer port;
- **A specialised programming interface,** like SPI (Serial Programming Interface), JTAG (Joint Test Action Group), etc.

All the three elements need to be met in some way, but there exists a wide range of implementations in practice. For instance, the programming adapter might be integrated into the target board itself and in this case USB cable could directly link the PC to the target board. Occasionally, the programming interface is accessible through specific microcontroller instructions or registers, facilitating the loading of new firmware.

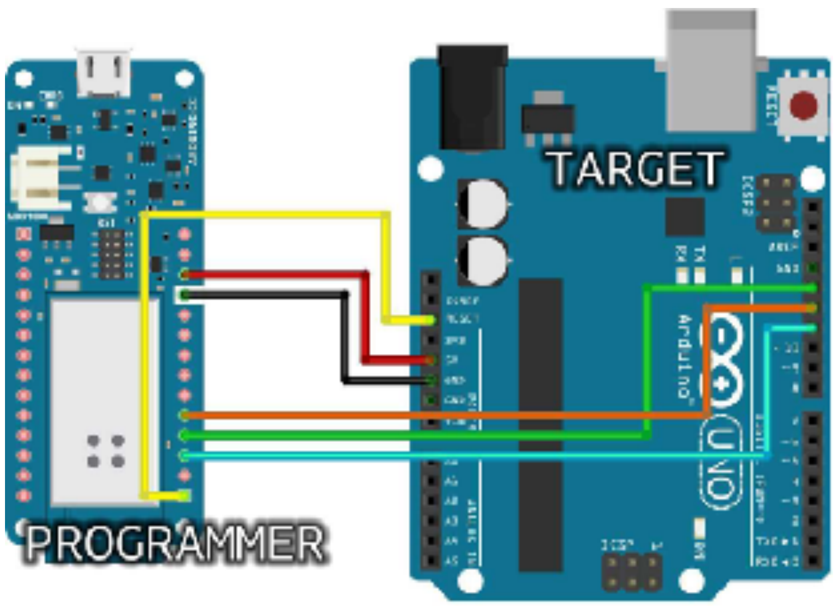

Figure 18: The wiring between a programmer (MKR1000) and a target device (UNO).

[142] In computing, a bug is considered a mistake or a problem in a computer program. In "dictionary.cambridge.org", https://dictionary.cambridge.org/dictionary/english/bug , 09-05-2024.

3.1.1 History of In-System Programming[143]

At the beginning microcontrollers could only be produced with either OTP (short for one-time programmable) or EPROM memories[144], that require the exposure to ultraviolet light through a specific window for memory erasure. But in the early 1990s there has been a significant advancement in microcontroller architecture.

In 1993, Microchip Technology Incorporated[145] introduced the first microcontroller with EEPROM memory, the PIC16C84. EEPROM memories could be electrically erased, reducing production costs by eliminating the need for erasing windows and enabling in-system programming (ISP) technology. This advancement allowed flashing processes to be performed directly on the board post-production, unifying programming and functional testing phases and enabling preliminary board production before firmware development completion. Additionally, bugs could be corrected or changes made later on. At the same time, Atmel[146] developed the first microcontroller with flash memory, which was easier and faster to program and had a longer lifecycle compared to EEPROM memories.

Microcontrollers supporting ISP typically have pins for serial communication with the programmer, flash/EEPROM memory, and voltage supply circuitry for programming. The communication peripheral connects to a programming peripheral issuing commands to operate on the memory.

To keep the process with a reliability it requires to pushing some guidelines when creating electronic boards and this is earthed in ISP programming as well. Due to the fact that some microcontrollers have programming lines shared with I/O (input-output) line, it will be necessary take care during this phase of programming so as not to damage any component in I/O. High impedance buffer circuitry should not be loaded down by and ISP lines for the purpose of ensuring that no damage would occur and supplying enough current to drive a line. Certain microcontrollers require a separate RESET line or higher voltage to enter Programming Mode, which calls for careful preparation regarding the current supply of line driving, checking for watchdogs connected to this reset line causing unwanted reset that can fail programming and avoiding direct forwarding the entire on-board in-circuit-voltage.

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[143] This paragraph is based on “en.wikipedia.org", https://en.wikipedia.org/wiki/In-system_programming , 18-06-2024.

[144] EEPROM (electrically erasable programmable read-only memory) is a memory chip that does not lose data after power failure. EEPROM can be erased and reprogrammed on a computer or dedicated device. Apr 18, 2013: What is EEPROM?, in “en.gianctec-semi.com", https://en.giantec-semi.com/Newsroom/What-Is-EEPROM-and-How-Does-it-Work 09-05-2024.

[145] Microchip Technology Incorporated is a publicly listed American corporation that manufactures microcontroller, mixed-signal, analog, and Flash-IP integrated circuits. In “en.wikipedia.org", https://en.wikipedia.org/wiki/Microchip_Technology , 09-05-2024.

[146] Founded in 1984, Atmel Corporation was a creator and manufacturer of semiconductors before being subsumed by Microchip Technology in 2016. The company focused on embedded systems built around microcontrollers. In “en.wikipedia.org", https://en.wikipedia.org/wiki/Atmel , 09-05-2024.

3.1.2 The role of In-System Programming in Industry 4.0[147]

ISP is a practice that makes live and up&running devices smarter by providing Industry 4.0[148] with the most effective way to update and MANAGE firmware, software using In-System Programming on interconnected (via IoT) systems, devices, sensors, and managers. For example, in some pre-programming systems that are used to flash devices installed on boards, updating the firmware after installation is next-to-impossible. Again, In-System Programming addresses this and allows for updates right on the board (through test points), translating to an automatic programming process rendering enough productivity and fast adaptability.

ISP key-points are:

- **Time efficiency and flexibility**: ISP allows for swift and seamless firmware updates without needing device disassembly. This enables manufacturers to concurrently develop hardware and firmware, reducing downtime and ensuring optimal productivity. Moreover, programming and updates can be executed on multiple devices simultaneously, saving time and effort;

- **Enhanced quality control**: ISP is crucial for maintaining high-quality standards. Manufacturers can conduct comprehensive firmware testing and validation before deployment, minimising the risk of quality issues and customer dissatisfaction;

- **Scalability and flexibility**: ISP facilitates the automated programming of thousands or even millions of devices, ensuring efficient management of large-scale deployments;

- **Security and data integrity**: Advanced ISP solutions offer security features such as encryption of customer data and integrity checks to protect against unauthorised modifications, ensuring the integrity of firmware and software;

- **Cost optimisation**: ISP simplifies the programming process, allowing for simultaneous flashing of multiple devices. Additionally, programming devices directly on the board eliminates the need to store pre-programmed devices, reducing costs associated with inventory management and firmware version control;

[147] This paragraph is based on “smh-tech.com", https://smh-tech.com/corporate-blog/empowering-industry-4-0-the-significance-of-in-system-programming/ , 18-06-2024.

[148] Industry 4.0, which is synonymous with smart manufacturing, is the realisation of the digital transformation of the field, delivering real-time decision making, enhanced productivity, flexibility and agility to revolutionise the way companies manufacture, improve and distribute their products. What is Industry 4.0?, in “ibm.com", in https://www.ibm.com/topics/industry-4-0 , 09-05-2024.

There are ways to apply ISP application in various industries in particular in the automotive one, especially when the complexity of the boards is evolving as self-driving cars, largely with their microscopic parts. More developed ISP technologies use security controls and permit many devices to be programmed at the same time thereby increasing output. In the domestic and industrial IoT landscapes, Insulating solid polymer ensures connected devices work continuously with reduced downtime for carrying out repairs. The incorporation of automation within ISP results in higher yield and also better process control for manufacturers making it possible for them to cope with new demands without halting production.

Industry 4.0 enables the transformation of production processes through smart and well-connected network systems. The ISP will advance this revolution by ensuring that a secure method for managing both firmware and software on the attached devices is provided. Proper management of ICT allows the incorporation of an ISP in the dynamics and even structure of organisations which reduces disruption of business activities and time taken to restore normal functioning of the business.

3.1.3 Examples of In-System Programmers

The first example of In-System programmer is the FlashRunner, that is the main product of the Italian SMH Technologies company[149], and it is a universal and production In-System Programmer that develops programs and debugging solutions for microcontrollers. This type of In-System Programmer has been designed to supports multiple device manufacturers, to lower production cost by reducing also programming time, to be applied to any programming configuration and to ensure data integrity and uninterrupted production flow.

Figure 19: FlashRunner 2.0

The main components of FlashRunner are:
A: **Top panel,** it protects the main hardware and replicates status LEDs. It can be easily removed if space is an issue when integrating in programming/testing system;

B: **Built-in timekeeper/calendar**, it allows for detailed, timestamped logs. Production problems can thus be traced back to the exact moment that happened;

C: **Secure digital card** (up to 2GB), it is standard and removable and it needed to store binary image, files, projects and log files;

D: Mounts easily inside ATE and test fixtures. Compatible with Agilent, Teradyne, SPEA, Gerard and other systems;

[149] SMH Technologies is an Italian company located in Friuli Venezia Giulia, specialized in the production of universal In-System Programmer and operates at a worldwide level. In “smh-tech.com", in https://smh-tech.com/company/ , 09-05-2024.

E: **Connection layer**, it provides connectors to interface to your programming/testing system. It includes optoisolation circuity[150] and an Ethernet connector to interface to host system;

F: The programmer engine layer contains all of the FlashRunner electronics in a compacts footprint.

The FlashRunner 2.0 technology marks a significant advancement not only in rapid programming speed but also in enhancing production efficiency and quality. With its remarkable flexibility and universality, this product range offers a diverse selection of 1 to 32 independent and parallel channels to meet various needs. Accompanied by a comprehensive set of peripheral features (listed below), its evolution reflects the transformative shifts in information and communication technology, transitioning from simple tools to interconnected smart systems.

In conclusion, the main key features of FlashRunner are:

- **Built for speed**: Hardware and firmware collaborate to eliminate efficiently communication bottlenecks. With fast Programming Algorithms, FlashRunner can reach the memory technology speed limit to the target device, making it one of the fastest universal In-System Programmers on the market, significantly reducing production costs[151];

- **Extensive device coverage**: FlashRunner's hardware is fully reconfigurable and flexible, capable of programming a vast array of Flash-based reconfigurable and serial memories. With over 5000 supported devices and constantly updated, FlashRunner offers extensive device coverage;

- **Compact and robust**: FlashRunner offers high integration flexibility in a compact footprint, engineered to withstand harsh product environments. Optoisolation, ESD protection, CRC on data transfers, and detailed reports make FlashRunner the ideal choice when programming flow certainty is crucial[152];

- **Easy ATE and fixture integration**: FlashRunner features a simple and versatile interface system for seamless integration into Automatic Test Equipment (ATE) systems. It can operate standalone or be driven by a host system via Ethernet or RS-232 connections;

- **Data protection system**: FlashRunner includes an optional data protection system that programs the binary file contents to the target devices, making them unreadable by unauthorised individuals.

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[150] An optoisolator is an electronics device that transfers electrical energy from one circuit to another through a short optical transmission path while providing electrical isolation between two circuits. Optoisolator, in "sunpower-uk.com", in https://www.sunpower-uk.com/glossary/what-is-an-optoisolator/ , 09-05-2024.

[151] FlashRunner High Speed, in "unites-systems.com", https://unites-systems.com/product/flashrunner-high-speed-0-88#:~:text=FlashRunner%20has%20been%20built%20for%20speed.%20Both%20the,memory%20technology%20speed%20limit%20of%20the%20target%20device , 09-05-2024.

[152] FlashRunner High Speed, in "unites-systems.com", https://unites-systems.com/product/flashrunner-high-speed-0-88#:~:text=FlashRunner%20has%20been%20built%20for%20speed.%20Both%20the,memory%20technology%20speed%20limit%20of%20the%20target%20device , 09-05-2024.

Additionally, the protection system extends to the programming cycle to prevent tampering by production personnel;

- **Paneled PCB programming**: FlashRunner offers multiple ISP outputs, enabling programming of multiple devices on a single board or distributed across multiple boards in a panel assembly[153].

The second and last example of In-System programmer, is the Chinese Opteeq Technologies[154]' S1 High-Speed Programmer, that is an advanced industrial-grade programmer known for its exceptional speed and reliability. It has a variety of support interfaces, plenty of extensive programming algorithms, steady performance, and whole protection of the target circuit. Due to its small dimensions and individual constriution, it can be easily embedded into various testing devices like ATE, ICT, FCT, as well as tooling and fixtures. It works efficiently in both manual and automatic modes, therefore it is applicable for testing, production, and other electronic devices tasks across industries such as manufacturing, home appliances, automotive, and automation engineering.

The main features of Opteeq S1 In-System Programmer are:

- Ultra-high programming speed;
- General-purpose programmer, supporting tens of thousands of devices from dozens of semiconductor companies;
- Able to work in standalone manner;
- Being combined with various testing devices (such as ATE, ICT and FCT) easily and quickly;
- Compact outline; being embedded in various clamps, fixtures and tooling easily;
- Being controlled by an external device to work automatically, or operated manually;
- Quick response to user needs, Chinese and English product manual and technical support;
- Input Power: 12 V 24 V (DC)
- Programming Signal Interface J5: is a programming interface that consists of a D-type connector (plug) with 15 pins. This interface connects to the programming interface of the target chip either through the programming signal interfaces of J5 or via the programming wire provided by the company. Different chips necessitate distinct programming wiring schematic diagrams.

[153] FlashRunner High Speed, in "unites-systems.com", https://unites-systems.com/product/flashrunner-high-speed-0-88#:~:text=FlashRunner%20has%20been%20built%20for%20speed.%20Both%20the,memory%20technology%20speed%20limit%20of%20the%20target%20device , 09-05-2024.

[154] Founded in 2010, OPTEEQ Technologies is a high-tech enterprise specialising in the research and development, production and sales of automotive electronic tool chain products. About OPTEEQ Technologies, professional tool chain for automotive electronics, in "opteeq.com", in http://www.opteeq.com/en/about-us/ , 09-05-2024.

Figure 20: Top View of Opteeq's S1 High-Speed Programmer

- LED indicator used by programmer during operation to convey its status as follows:
  - FAIL: Illuminates when programming fails;
  - READY/PASS: Lights up to indicate successful programming;
  - BUSY: Illuminates during programming and turns off upon completion;
  - STOP: Not utilised;
  - START: Initiates programming when signal is set to 0;
  - LINK: Indicates connection to PC, lights up when connected and turns off when disconnected;
  - STATUS: Not utilised;
  - POWER: Indicates power status, lights up when system is powered on and turns off when powered off.

3.2 In-System Programming methods[155]

There are new various In-System Programming methods used with the AVR and AMR microcontroller families, and the main differences between the two are linked to their architecture, the set of instructions, the speed, the cast, the memory, the power consumption and the bus width.

AVR microcontrollers were first introduced in 1996 by Atmel corporation and then acquired by Microchip Technology. It is categorised in the RISC (short for Reduced Instruction Set Computer) family which means efficiency from instruction point of view and simplicity from a practical point of view. Harvard architecture is used in these controllers, where separate storage is available for program code and program data, and both are accessed at the same time making the processor carry out the operation faster. Mostly employed in occasions where level of performance required is not too high, AVR is best for usages that have no need of multitasking or heavy processing like simple robotic or house control systems. Of importance, although the TinyAVR and MegaAVR series are small sized, and targeted towards applications that require low power, they take advantage of this fact to enhance this with extra features like sleep modes. The branded Atmel Studio is the main IDE for the AVR family of microcontrollers while The Arduino IDE of kindergarten level has built a huge grass root movement around AVR. Even though many varieties of microcontrollers are made with many requirements in focus, more and more AVR range can be covered with less budget than ARM. In all cases costs and performance wise AVR microcontrollers have been effective, thus remain attractive to hobbyists and students who tend to gravitate towards building things. It appears in a range of applications from in DIY projects[156], to industrial sensors, agricultural automation, and basic consumer electronics.

ARM microcontroller comes from Advanced RISC microcontroller, it was fist developed by the British company ARM Holdings[157] and now it is the most popular and cheap microcontroller in embedded systems. Actually, it has branches in wireless network, sensor, automotive body control and industrial management system, tablets, smartphones and other mobile equipment including adding rings. The ARM architecture employs a load/store architecture. It is possible to use the memory only for loading and storing data while the processing will be performed in internal registers. Such a method facilitates handling of computations that are even more complicated. ARM implemented top performance cores, especially belonging to the Cortex family A or M including core, chips are supplied into from mobile phones and the servers. ARM cores strive for low power consumption. For example, Cortex-M0 is designed for such applications as IoT where very minimal power consumption is needed. Due to the wide-spread acceptance of ARM, it has a healthy community backed by powerful development tools like ARM Development Studio and Keil MDK. It has become prevalent and well-known nature of the ARM ecosystem that powered by a licensing structure has resulted growth of ARM's microcontroller over different professional backgrounds. In spite of these different explications there are still differences in prices depending on the spectrum.

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155 This paragraph is based on "ethernut.de", http://www.ethernut.de/en/tools/in-system-programming.html , 18-06-2024.

156 DIY is the activity of making or repairing things yourself, and is an abbreviation for do-it-yourself. In "collinsdictionary.com", in https://www.collinsdictionary.com/us/dictionary/english/diy#:~:text=DIY%20is%20the%20activity%20of,for%20do%2Dit%2Dyourself , 10-05-2024.

157 ARM Holdings is the leading technology provider of processor IP, offering the widest range of processors to address the performance, power, and cost requirements of every device. In "arm.com", 10-05-2024.

After having analysed the main differences of the two microcontrollers, here below are listed the six different In-System Programming methods used with AVR and ARM microcontrollers:

1. Programming Software

For this type of programming method, many tools with their own set of programming adapters, interfaces and targets are available. However, not every tool is available for every desktop operating system and each of them can run on a command line (CLI) or can provide a graphical user interface (GUI).

CLI tools are suitable for automation, and the large number of available options are easier to handle manually with GUI tools. Some tools offer both a graphical interface controls an underlying command line tool, which can alternatively run without the GUI.

Some programming adapters have an integrated programming software, being controlled by a web interface, which makes them practically independent from the operating system of the desktop computer.

2. PC Ports

Basic programming adapters designed for the parallel printer port are quite straightforward, and they consist of little more than a logic buffer or level converter connected to the parallel printer port, sometimes supplemented with a few resistors. Although modern PCs rarely feature this outdated interface, some companies still produce adapter cards for the PCI bus.

Even if the RS-232 (COM port) interface still remain popular in embedded systems, it has largely been superseded by USB. Advanced programming adapters often utilise microcontrollers, many of which include at least one UART for RS-232 communication. Consequently, programming adapters with RS-232 ports continue to be utilised. While numerous companies offer USB to RS-232 converters, not all of them function flawlessly.

USB presents greater complexity compared to the parallel printer port or RS-232, but an increasing number of microcontrollers now support this interface. For this reason, there is a growing availability of programming adapters for the USB port, as it is present on nearly all PCs. Following the introduction of specialised chips by FTDI capable of JTAG programming via USB without requiring firmware development, the prices of JTAG programming adapters for USB have significantly decreased.

However, prices vary widely, ranging from a few dollars to several thousand dollars, and this is due by factors such as higher programming speeds, unique features, and robust support. One downside of USB is its restricted cable length, but advanced programming adapters now offer Ethernet connectivity, enabling remote programming and debugging via the Internet.

3. AVR In-System Programming

There are various methods available for programming the internal flash memory of AVR microcontrollers, such as:

- In-System Programming (ISP), sometimes referred to as SPI due to its reliance on the serial peripheral interface;
- JTAG programming, which is offered on larger devices as an alternative to ISP;
- DebugWire, utilised on many devices with low pin counts;
- PDI, present on the newer XMEGA chips.

The STK200 dongle, originally part of Atmel's now discontinued STK200 starter kit, serves as a straightforward and economical ISP programming adapter for the parallel printer port. Despite the unavailability of the starter kit, numerous companies still produce clones of this adapter, and various schematics are accessible.

Atmel provides two programming adapters for AVR microcontrollers: the first one is the cost-effective AVR ISP mkII, equipped with an ISP programming interface and connecting to the PC via USB. The second one is the more advanced JTAGICE mkII, which offers JTAG and debugWIRE programming capabilities through USB and RS-232.

The SP Duo by Embedded Creations[158] and the AVR DUO ICE from MCU ProShop provide both ISP and JTAG programming functionalities. The SP Duo uses an RS-232 interface and features its own firmware, albeit lacking JTAG debugging support. Instead, the AVR DUO ICE features a USB interface and supports JTAG debugging.

Despite several attempts by the Open Source community[159] to use the FT2232 in order to create a low-cost JTAG adapter, the success has been limited. The speed programming is slow, and JTAG debugging is not reliable due to Atmel's policy of keeping AVR debugging information proprietary.

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[158] Embedded Creation is an Indian company specialised in the production of embedded systems focused on microcontroller based application, that find application in different industries, such as product development, academic training and project based solutions. In “embedded creation.in", 10-05-2024.

[159] A loosely organised, ad-hoc community of contributors from all over the world who share an interest in meeting a common need, ranging from minor projects to huge developments, which they carry out using a high-performance collaborative development environment, allowing the organisational scheme and processes to emerge over time. The concept represents one of the most successful examples of high-performance collaboration and community-building on the internet. Soriano J., (2008), Collaborative development environments, chapter 30, in “igi-global.com", https://www.igi-global.com/dictionary/collaborative-development-environments/21213 , 10-05-2024.

4. ARM In-System Programming

Usually, ARM microcontrollers with internal flash memory are programmed in-system using JTAG. From an hardware point of view, one of the simplest JTAG adapters is the Macraigor Systems[160]' Wiggler, designed for the parallel printer port, that now have numerous clones, and various schematics are available online.

The Turtelizer programming adapter serves as an example of a JTAG adapter designed for the RS-232 port, and its design relies on either an ATmega8 or ATmega168 microcontroller, and its firmware is distributed under the BSD License. Today, many JTAG adapters use the FT2232 chip, that provides two USB devices, and certain programming adapters utilise the second USB device to offer an additional RS-232 port.

Zylin AS[161] offers the ZY1000 programming adapter, that is considered one of the most sophisticated JTAG adapters currently available built on Open Source software, and it functions as a miniature Linux system with Ethernet and JTAG interfaces, integrating OpenOCD and a web server.

5. In-System Programming of External Memory

Because of the Harvard architecture's composition incorporating both 8-bit data and 16-bit instruction code bus, the execution of programs on all members of the 8-bit AVR family is confined to internal flash memory, even when an external bus interface is accessible. However, external flash memory can still be employed as non-volatile data memory and it is possible to use two primary methods for in-system programming of external memory devices.

The first method uses JTAG boundary scan, enabling the manipulation of nearly any pin on a JTAG-enabled device. By connecting all programming pins of the memory chip to such a device, the JTAG boundary scan can be employed to execute the programming sequence on the memory chip. This method boasts the advantage of requiring no initial software on the target board since JTAG boundary scan operates purely in hardware. However, it can be time-consuming.

The second method involves using the JTAG debugging interface, which permits the CPU to execute individual instructions. Trough this approach, a programming sequence for the external memory chip can be executed incrementally. This method is faster than the boundary scan method but necessitates that the CPU is initialised and operational. A variation of this method can be employed when some RAM is available, where the entire procedure is uploaded and then executed by the CPU. The data that needs to be programmed into the external memory chip can be transferred through another interface or via the JTAG cable itself if a "JTAG COMM" interface is provided.

160 Macraigor Systems is a leading supplier of BDM / JTAG connection solutions for onchip debugging of 32 and 64-bit embedded microprocessors. In "embeddedinindia.com", https://www.embeddedindia.com/macraigor-systems.html#:~:text=Macraigor%20Systems%20is%20a%20leading,designed%20for%20price%2Dsensitive%20customers , 10-05-2024.

161 Zylin AS is a Norwegian company which provides qualified and objective development services. In "opersource.zylin.com", in https://opensource.zylin.com , 10-05-2024.

6. Boot Loading Firmware

Boot loaders are needed to transfer an executable binary from an external source to the on-board memory and then proceed to execute it from a specified entry point. Usually, this action occurs either upon powering on the system or resetting it, and it is relatively straightforward when using RAM. A standard boot loader loads the binary image into volatile memory each time the system starts.

Firmware boot loaders have the capability to program non-volatile memory and are solely necessary during firmware updates, hence they are activated only when required. If internal flash memory is used, the device must possess self-programming capabilities.

Depending on the type of microcontroller involved, there are two types of firmware boot loaders:

- **AVR Firmware Boot Loaders**

On the AVR platform the program code can only run from internal flash, and if try to program the same flash memory, the flashing code would fail, as during programming cycles, the CPU wouldn't be able to fetch the subsequent instruction code. Fortunately, the flash memory is partitioned into two sections: the application area and the boot area, and a program executing in either of these areas can program the other area.

- **ARM Firmware Boot Loaders**

The majority of AT91SAM devices come equipped with a boot loader stored in internal ROM, known as SAM-BA. A programmable, non-volatile bit within the chip determines whether the CPU initiates the boot loader or the previously uploaded firmware after a hardware reset. When the device is erased, the boot loader becomes active.

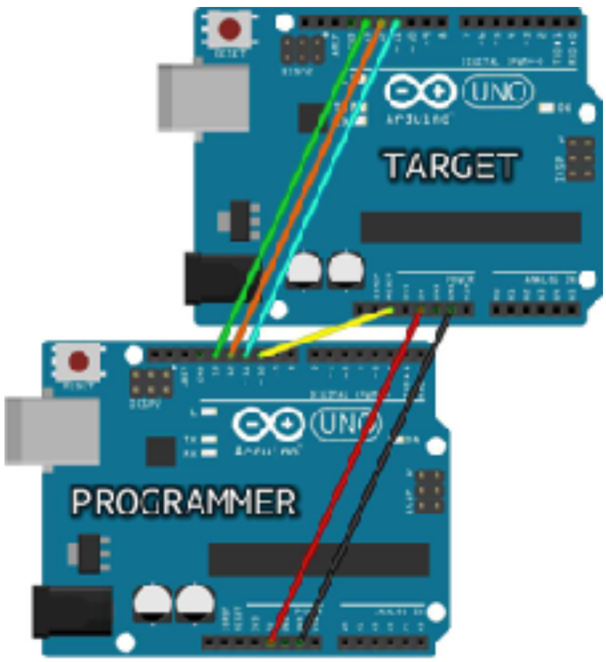

Figure 21: Boot loader of two UNO boards, where the top one is the target and the bottom one is the programmer

3.2.1 Loaders of In-System Programming[162]

Nowadays, it is important to find effective and adaptable programming solution for the electronics and embedded systems environments, and engineering are facing increasing pressure in order to develop reliable and scalable solutions because of the advancement of technology[163]. For this reason, In-System Programming is relevant as it allows the programming of microcontrollers and other programmable devices after their integration onto a circuit board or within a system. This permit to eliminate the need for manual programming during manufacturing, reducing the production processes and facilitating updates and maintenance.

Loaders are the core component of ISP, and are a mix of software and hardware that manage the transfer of binary code or firmware from a programming source, like a computer or storage device, to the target device requiring programming. Loaders are a sort of intermediaries connecting the gap between the programming source and the target device, ensuring a smooth and efficient programming process[164]. Loaders decide the way of transmission of programming data and the way the target device is managed throughout the programming cycle[165]. There are different types of loaders with distinct features and advantages, making them suitable for specific applications and scenarios:

1. **Serial Loaders** are among the simplest loader types used in In-System Programming, as they use serial communication protocols like UART or SPI to transfer programming data from the source to the target device. They are preferred for their simplicity and cost-effectiveness, requiring minimal hardware components and wiring, thus suitable for various applications;

2. **Parallel Loaders** transfer data in parallel, enabling the simultaneous transmission of multiple bits of data. These loaders excel in speed and are ideal for applications requiring rapid programming. However, they may necessitate more complex hardware interfaces and be less versatile compared to serial loaders;

3. **JTAG Loaders** are renowned for their versatility and widespread use in the ISP domain, and as the name suggests, they use the JTAG interface. These loaders offer access to various functionalities of a target device, including debugging and boundary scanning, making them ideal for both programming and debugging tasks in embedded systems;

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[162] This paragraph is based on "smh-tech.com", https://smh-tech.com/corporate-blog/in-system-programming-understanding-the-different-types-of-loaders/ , 18-06-2024.

[163] In-System Programming: understanding the different types of loaders, in "smh-tech.com", https://smh-tech.com/corporate-blog/in-system-programming-understanding-the-different-types-of-loaders/#:~:text=These%20loaders%20make%20use%20of%20the%20JTAG%20interface,,a%20target%20device,%20including%20debugging%20and%20boundary%20scanning , 18-06-2024.

[164] In-System Programming: understanding the different types of loaders, in "smh-tech.com", https://smh-tech.com/corporate-blog/in-system-programming-understanding-the-different-types-of-loaders/#:~:text=These%20loaders%20make%20use%20of%20the%20JTAG%20interface,,a%20target%20device,%20including%20debugging%20and%20boundary%20scanning , 18-06-2024.

[165] In-System Programming: understanding the different types of loaders, in "smh-tech.com", https://smh-tech.com/corporate-blog/in-system-programming-understanding-the-different-types-of-loaders/#:~:text=These%20loaders%20make%20use%20of%20the%20JTAG%20interface,,a%20target%20device,%20including%20debugging%20and%20boundary%20scanning , 18-06-2024.

4. **SWD Loaders** employ a simpler two-wire serial interface known as Serial Wire Debug. They are chosen when space constraints or power consumption considerations are significant. SWD loaders are commonly used in programming ARM-based microcontrollers, offering a balance between versatility and resource efficiency;

5. **Ethernet Loaders** use Ethernet connectivity to transfer programming data to the target device. Of course they are ideal for remote programming scenarios where physical access to the target device may be limited. These loaders offer the convenience of programming over a network connection, making them valuable in situations where physical proximity is not feasible;

6. **USB Loaders** connect directly to a USB port on the target device, offering user-friendly plug-and-play functionality. They enjoy widespread compatibility with computers and are frequently used in consumer electronics and rapid prototyping environments;

7. **Universal Loaders** encompass all these programming interfaces, essentially performing the tasks of other specific loaders. They offer a versatile solution applicable across various In-System Programming tasks.

According to the nature of the target device, the requirement for high programming speeds, hardware interface availability, budget constraints and other several factors, it is important to choose the appropriate loader for different In-System Programming needs. This because it is important to ensure the chosen loader lines up with various needs of the specific project. The best solution is to prefer a loader type that offers adaptability and can accommodate the future needs.

In conclusion, it is possible to affirm that In-System Programming (ISP) is a crucial tool for engineers that operates in the electronics and embedded systems industry. Understanding the different types of loaders available, together with their pros and cons, is essential in order to select the right loader for precise programming tasks. By this way, engineers can ensure project success and contribute to technological advancement across various applications[166].

[166] In-System Programming: understanding the different types of loaders, in “smh-tech.com", https://smh-tech.com/corporate-blog/in-system-programming-understanding-the-different-types-of-loaders/#:~:text=These%20loaders%20make%20use%20of%20the%20JTAG%20interface,,a%20target%20device,%20including%20debugging%20and%20boundary%20scanning , 18-06-2024.

3.2.2 The industrial application of In-System Programming

During the final production stage, the In-System Programming process can be carried out in two different ways, depending on the production volumes.

The first method is suitable for low production volumes, where there is a connector that is manually attached to the programmer, which is then connected to the electronic board via a cable. The second method uses test points[167] on the board, which are specific areas on the printed circuit board (PCB) electrically linked to some electronic components. Test points are used for conducting functional tests on the board's components and, as they are directly connected to certain microcontroller pins, they are highly effective for ISP. This method is optimal for medium to high production volumes, as it enables the integration of the programming phase into an assembly line.

In production lines, boards are placed on a bed of nails called fixture[168]. These fixtures, integrated into semi-automatic or automatic test systems known as ATE (automatic test equipment), vary based on production volumes. Each fixture is custom-designed for a specific board, allowing for interchangeability within the system environment. Once the board and fixture are in place, the test system engages a mechanism to make contact between the fixture's needles and the test points on the board for testing purposes. The system is connected to or contains an integrated ISP programmer, responsible for programming the device or devices mounted on the board.

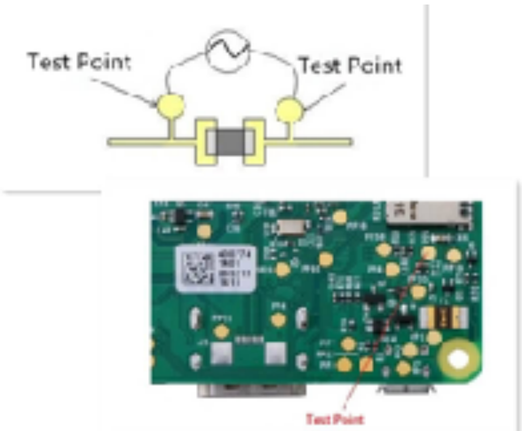

Figure 22: Example of test points on PCB

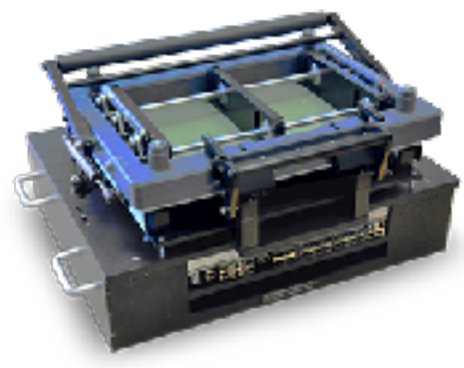

Figure 23: Example of functional PCB test fixture

[167] In a PCB with surface-mount components, a test point PCB is a short wire loop utilsed for test probes. They allow the user to monitor the circuitry of the board or introduce test signals during manufacturing. Test points are available in a range of sizes, colours, and materials. What is a test point PCB, in "raypcb.com", in https://www.raypcb.com/test-point-pcb/ , 10-05-2024.

[168] A test fixture is a device used to consistently test some item, device, or piece of software. Test fixtures are used in the testing of electronics, software and physical devices. In "en.wikipedia.org", in https://en.wikipedia.org/wiki/Test_fixture , 10-05-2024.

3.3 In-System Programming for flash memories[169]

Technology industry is constantly changing, and the demands for code and data storage in applications keep increasing. For this reason, In-System Programming engineers are searching for efficient and reliable methods to enhance memory in their projects, involving both the use of external memories and internal memory of microcontrollers.

There are two types of external flash memories[170], that are NOR flash and NAND flash, which play crucial roles in storing data and code in various applications, and each memory has distinct features, making them suitable for specific functions and programs.

NOR flash memory is appreciated for its random-access capabilities, that allow it to read and write individual bytes without erasing entire blocks. This makes NOR flash suitable for applications requiring fast read times and code execution, such as boot code storage and microcontroller firmware. Even if NOR flash can ensures higher storage reliability than NAND flash, however it is more expensive and offers lower storage densities.

Instead, NAND flash memory is cheaper as it can store data in pages, organised into blocks. Like NOR flash, NAND flash also needs to erase entire blocks before writing new data, known as "erase-before-write" process, making it appropriate for applications involving large data transfers and storage needs. NAND flash is commonly used in automotive or multimedia projects where cost-effectiveness and higher storage capacities are crucial.

Each of these two flash memories has its own programming methods in ISP: due to its random-access capabilities, NOR Flash Programming follows an easy and flexible approach. With byte-level reads and writes, programming data into NOR flash is simple and efficient, as developers can modify specific bytes without block erasures.

The advantages of NOR Flash Programming are:

- **Simplified programming**: Byte-level access simplifies programming, facilitating easier firmware updates and managing small data sets. This speeds up the development and debugging, leading to faster time-to-market;
- **Read-While-Write (RWW) capability**: NOR flash permits simultaneous reading and writing operations, enabling seamless updates and data modifications without interrupting ongoing processes;
- **Fast execution**: Direct code execution from NOR flash reduces boot-up time and enhances system performance, particularly beneficial for real-time systems and microcontrollers.

[169] This paragraph is based on “smh-tech.com", https://smh-tech.com/corporate-blog/in-system-programming-of-nor-and-nand-flash-memories-a-comprehensive-guide/ , 18-06-2024.

[170] Flesh memory, also known as flash storage, is a type of nonvolatile memory that erases data in unit called blocks and rewrites data at the bite level. This kind of memory is widely used for storage and data transfer in consumer devices, enterprise systems and industrial applications. Flash memory restrains data for an extended period regardless of whether a flash-equipped device is powered on or off. Kinza, Y., (2024), Definition - Flash memory, in “techtarget.com", https://www.techtarget.com/searchstorage/definition/flash-memory , 12-05-2024.

Opposite, **NAND Flash Programming** involves a more intricate process due to its block-based architecture, and specific procedures must be followed for effective data updates.

The challenges of NAND Flash Programming are:

- **Erase-Before-Write**: NAND flash requires entire blocks to be erased before writing new data, leading to increased write amplification and affecting memory lifespan;
- **Wear levelling**: to prevent uneven wear, wear levelling algorithms are crucial, evenly distributing write and erase cycles across the memory
- **Error correction**: NAND flash is more suitable to read and write errors, necessitating advanced error correction techniques to maintain data integrity.

Considering application requirements, memory access, updates, system complexity, costs, and many other factors, it is important to choose the appropriate flash memory type and programming method in order to achieve the success of the project.

NOR flash programming offers fast execution and simplified programming, suitable for real-time systems and firmware storage, while NAND flash programming, with its block-based architecture, is preferred for applications with large data volumes, like multimedia.

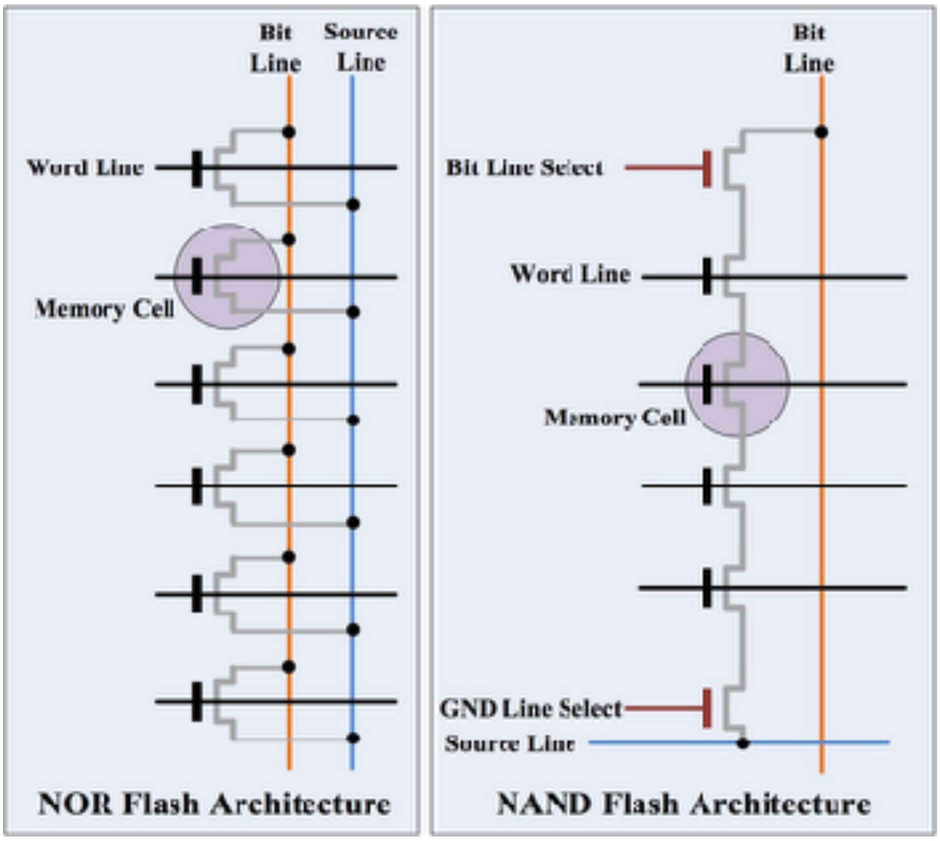

Figure 24: NOR Flash (left) has an architecture resembling a NOR gate. Similarly, NAND Flash (right) resembles a NAND gate.

3.3.1 eMMC in In-System Programming[171]

The environment of electronic manufacturing is constantly changing and for this reason engineers need to improve their programming methods in order to achieve efficiency and productivity. In fact, electronic devices are downsizing while enhancing in power and features, like Embedded MultiMediaCard (eMMC)[172] that has emerged as a favoured flash memory programming solution. This memory help with the storage of seamless data and it is found in compact and advanced devices.

eMMC is used as a non-volatile memory storage solution for embedded applications, and it is widely employed in devices like smartphones, tablets, digital cameras, automotive infotainment systems, and IoT. eMMC design is efficient, it recedes footprint, and ensures optimal performances and reliability as it integrates flash memory and a controller into a single package. eMMC operates following NAND flash memory standards, using memory cells arranged in a grid to store binary data. A flash memory controller within the eMMC chip manages data operations, including read, write, and erase.

Here below there are the different eMMC operations:

1. **Controller operation**: The controller facilitates communication between the eMMC and the host device, managing data transfer protocols, wear levelling[173], error correction, and bad block management. Wear levelling ensures even distribution of data across memory cells to prevent premature wear;

2. Data read operation: Upon a data request from the host device, the controller locates and retrieves data from corresponding memory cells, sending it back for processing;

3. Data write operation: When storing data, the controller identifies a suitable memory cell, erases existing content if necessary, and writes new data using a "program and erase" cycle;

4. Error correction: To maintain data integrity and reliability, the controller employs error correction algorithms to detect and rectify errors.

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[171] This paragraph is based on "smh-tech.com", https://smh-tech.com/corporate-blog/demystifying-emmc-understanding-its-functionality-in-in-system-programming/ , 18-06-2024.

[172] The term eMMC is short for "embedded Multi-Media Card" and refers to a package consisting of both flash memory and a flash memory controller integrated on the same silicon die. The eMMC solution consists of al toast three components - the MMC (multimedia card) interface, the flash memory, and the flash memory controller - and is offered in an industry-standard BGA (Ball Grid Array) package. It is smaller than a typical postage stamp and it is ideal for many electronic devices, including smartphones, small laptops, smart TVs, wearable technology and smart home appliances.
Grahm, (2024-05-07), What is eMMC? (Embedded Multi-Media Card), in "simms.co.uk", https://www.simms.co.uk/tech-talk/what-is-emmc-embedded-multi-media-card/#:~:text=The%20term%20eMMC%20is%20short,on%20the%20same%20silicon%20die , 13-05-2024.

[173] Wear levelling is a technique for prolonging the service life of some kinds of erasable computer storage media, such as flash memory, which is used in solid-state drivers (SSDs) and USB flash drivers, and phase-change memory. There are several wear levelling mechanism that provide varying levels of longevity enhancement in such memory systems. Wear levelling, in "en-wikipedia.org", https://en.wikipedia.org/wiki/Wear_leveling , 13-05-2024.

In-System Programming is important for updating firmware or software in embedded systems and eMMC simplifies ISP through:

1. **Seamless integration**: eMMC devices integrate smoothly with ISP methods, using existing physical connectors for connection, minimising disruptions, and eliminating the need for memory chip removal;

2. **Manufacturing efficiency**: In-system programming accelerates production by allowing programming before sealing devices, reducing handling. Additionally, high storage capacity and controller management enhance efficiency;

3. **Faster programming speeds**: eMMC's 8-bit data bus and high communication frequency accelerate programming, minimising downtime and saving time and resources.

The integration of eMMC devices with ISP solutions can shows up the advancements in electronics, simplifying programming, enhancing efficiency, data security, and remote accessibility.

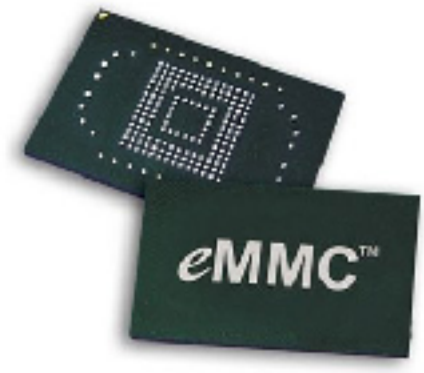

Figure 25: example of eMMC

3.4 In-System Programming in Embedded Systems[174]

An Embedded System is a microprocessor-based processing system integrated within an object or a larger framework, equipped with specialised software tailored in order to execute specific functions in real-time operations. Embedded Systems have a decisive role in technological progress, as they are the core of the modern automated solutions. The complexity of an Embedded System depends on its intended function, ranging from a single microcontroller to a network of processors interconnected with peripherals and interfaces, including anything from basic user interfaces to intricate graphical displays.

Embedded Systems are developed in order to execute specific tasks in efficient way, and they find wide application across various devices, from household appliances like vacuum cleaners and microwave ovens, to more complex ones, such as automotive and medical devices.

The components that build an Embedded Systems are a processor, power supply, memory, and communication ports, that are configured according to the complexity of the task at hand. These systems ensure optimal performance while conserving resources. In other terms, communication ports relay data to the processor, acting as intermediaries between peripherals, which then prompt the processor to interpret the data.

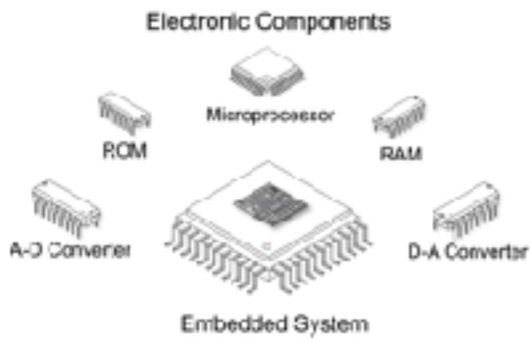

Figure 26: Embedded System's components

There are different types of Embedded Systems, that are categorised according to their performance and functionalities, underlining their diversity and adaptability, providing a wide group of industrial and consumer requirements. They vary from small-scale to sophisticated-scale systems, according to the chosen microcontroller architecture (8, 16, 32-bit, etc.) or to the functionalities like Standalone, Mobile, Network, or Real-time Embedded Systems.

[174] This paragraph is based on "smh-tech.com", https://smh-tech.com/corporate-blog/mastering-the-art-of-in-system-programming-a-comprehensive-exploration-of-microcontroller-programmers-in-embedded-systems/ , 18-06-2024.

The configuration of an Embedded System depends on different factors related to its tasks and operations, with the purpose of minimise human intervention and maximising efficiency of tasks. The constant evolution of Embedded Systems need a continuous efficiency redefinition, in order to make more efficient everyday operations and enhancing the experience of the users.

Among the key benefits it is possible to find the ease of use, optimised performance in terms of execution times, energy consumption, and memory usage, as well as facilitating size reduction and offering enhanced flexibility.

Due to the pursuit of efficiency and adaptability, Embedded systems have evolved significantly and In-System Programming has emerged as a pivotal solution, transforming microcontroller programming with direct programming within circuits. This has reduced production costs and accelerated the development of electronic devices, that are important in industries like automotive and Internet of Things (IoT).

ISP involves programming microcontrollers directly within their circuits, reorganising production and preparing for advanced capabilities in modern embedded systems:

- **JTAG programmers**, based on the Joint Test Action Group standard, excel in boundary scanning and debugging. They offer versatility and real-time debugging capabilities without disrupting device operation;

- **SPI programmers** use a synchronous serial communication protocol for rapid programming and data exchange, ideal for applications requiring high-speed operations;

- **I2C programmers** use a serial communication protocol suitable for connecting multiple devices on the same bus, facilitating seamless connectivity;

- **UART programmers** provide simple serial communication, suitable for scenarios requiring lower data transfer rates;

- **SWD programmers** leverage a two-wire protocol for efficient programming and debugging, striking a balance between speed and precision;

- **Universal programmers** offer versatility and efficiency, catering to the diverse communication interfaces present in modern embedded systems.

The main advantages of ISP in Embedded Systems are:

1. Efficiency: ISP reduces production time and costs by programming microcontrollers in-circuit, particularly beneficial for large-scale manufacturing;

2. Flexibility: ISP allows firmware updates and code changes without physical access to the microcontroller, crucial for devices in remote locations;

3. Debugging: Advanced debugging features like JTAG and SWD empower engineers to identify and rectify issues directly on the target board, enhancing efficiency in embedded system development.

Instead, security is the main disadvantage of ISP in Embedded Systems due to the ability to program microcontrollers in-circuit. In order to face this problem, strict measures must be taken to safeguard against unauthorised access and potential risks, especially in the context of connected devices and IoT.

In conclusion, Microcontroller Programmers play a pivotal role in modern embedded systems, as they combine technological intricacies with efficiency and cost-effectiveness.

3.4.1 Main programming languages used in Embedded Systems[175]

Programming languages have an important role in In-System programming as they offer the instructions to the microprocessor, in order to allow it to execute operations. Compilers also have a pivotal role as they act as a link between instructions and the executing microcontroller. The choice of the right programming language impact the capabilities and functionality of the final product in embedded systems.

The prevalent embedded programming languages include:

C: A compiled language tailored for crafting low-level applications for microcontrollers, prominently employed in industrial settings. Mastery of intricate coding techniques is requisite due to its efficiency and granular control over system resources;

C++: An efficient language boasting a robust standard library, facilitating streamlined and expedited coding processes. Despite its steep learning curve, its object-oriented features empower developers to construct complex and modular code;

Java: Renowned for Internet-based applications owing to its efficiency, adaptability, and cross-platform compatibility. Offers enhanced hardware interaction capabilities and is preferred for network-dependent embedded systems;

Assembly: Less prevalent due to its complexity and long-term maintenance challenges, yet indispensable for scenarios demanding absolute system control or custom OS development. Typically reserved for critical applications prioritising performance and efficiency;

Python: Widely embraced in automation, involving machine learning, AI, and data analysis, attributed to its versatility, open-source nature, and ease of use. Although slower in execution and subject to design constraints, its accessibility and extensive libraries render it increasingly popular in embedded systems, particularly in prototyping and IoT.

The choice of an embedded programming language depend on programmer familiarity, project type, industry context, and specific requirements, so it is needed a strategic approach in order to match system demands with language capabilities and constraints.

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[175] This paragraph is based on “smh-tech.com", https://smh-tech.com/corporate-blog/embedded-systems-what-programming-languages-are-used-in-the-industry/ , 18-06-2024.

3.4.2 Main microcontrollers in Embedded Systems[176]

A microcontroller programmer, also called device programmer, is a tangible tool that help with the installation of software or firmware onto a microcontroller chip, allowing the execution of operational instructions by the device. This procedure is crucial for the development and fine-tuning of embedded systems, making the selection of both microcontroller and programmer a fundamental decision for engineers and developers.

There are different families of microcontroller in the market, each with distinct characteristics:

PIC (Peripheral Interface Controller) Microcontroller: Widely used in electronics design, computer robotics, and similar applications, a PIC integrates memory, a data bus, and a dedicated microprocessor for I/O operations and methods. The versatility and efficiency of PIC microcontrollers make them indispensable in both hobbyist projects and professional endeavours;

ARM (Advanced RISC Machine) Microcontroller: Particularly popular in the industrial sector due to its blend of quality, performance, and cost-effectiveness. Its advantages include compact size, high performance, and energy efficiency. ARM's architecture allows low power consumption and swift processing capabilities, making it a preferred choice for portable devices;

8051 Microcontroller: Introduced by Intel in the 1980s, it is an 8-bit microcontroller capable of processing 8 bits of data simultaneously. It finds application in various embedded systems, including robotics, remote controls, automotive, medical devices, telecommunications, power tools, and consumer appliances. The long-lasting popularity of the 8051 depends on its reliability and ease of integration across a wide range of applications;

AVR (Alf and Vegard's RISC Processor) Microcontroller: Among the first microcontroller families to use internal flash memory for storing program content, enabling seamless erasure and rewriting with new versions without the need for microcontroller removal from the board;

MSP (Mixed Signal Processor) Microcontroller: Tailored specifically for low-cost and low-power dissipation in embedded applications. MSPs are 16-bit mixed-signal processors designed for ultra-low-power RISC-based systems. The fusion of analog and digital capabilities presents opportunities for innovative embedded system designs.

It is important to choose the appropriate microcontroller, because the environment of Embedded Systems progresses day by day, and keeping alongside the latest advancements in microcontroller technology can significantly enhance the performance and capabilities of different projects.

[176] This paragraph is based on "smh-tech.com", https://smh-tech.com/corporate-blog/types-of-microcontrollers-a-basic-guide-to-the-most-popular-in-the-embedded-system-field/ , 18-06-2024.

CHAPTER 4
THE MARKET OF SEMICONDUCTOR MANUFACTURERS IN CHINA

4.1 Silicon producers

In this chapter will be discussed the three main players that are also the key partners in the In-System Programming industry, such as silicon producers, EMS (short for electronic manufacturing services) and OEM (short for original electronic manufacturers) from the Chinese semiconductor market point of view.

Starting with silicon producers, also known as semiconductor manufacturers, are those companies specialised in the design and fabrication of semiconductors and semiconductor devices. Usually, semiconductor industry market is divided into four types of companies that operates in this sector, that are:

1. **IDM** (short for Integrated Devices Manufacturers), are companies specialised in the process of producing semiconductors from planning to the final product. Chinese YMTC company (Yangtze Memory Technologies Corp 长江存储 *Chángjiāng cúnchǔ*) is a good example;
2. **Pure play-foundries**, are semiconductor fabs that do not produce their own IC products and Chinese SMIC company (Semiconductor Manufacturing International Corporation 中芯国际 *Zhōngxīn guójì*) is a good example;
3. **Fabless**, are semiconductor companies that design and market semiconductors, while outsourcing the hardware's fabrication to a third-party partner, which produces them in foundries. Chinese HiSilicon 海思, *Hǎisī*, and Unisoc 紫光展锐, *Zǐguāng zhǎnruì* companies are good examples;
4. **OSAT** (short for Outsourced Semiconductor Assembly and Test), are companies that offer third-party IC packaging and test services. Chinese JCET company 长电科技 *Chángdiàn kējì* is a good example.

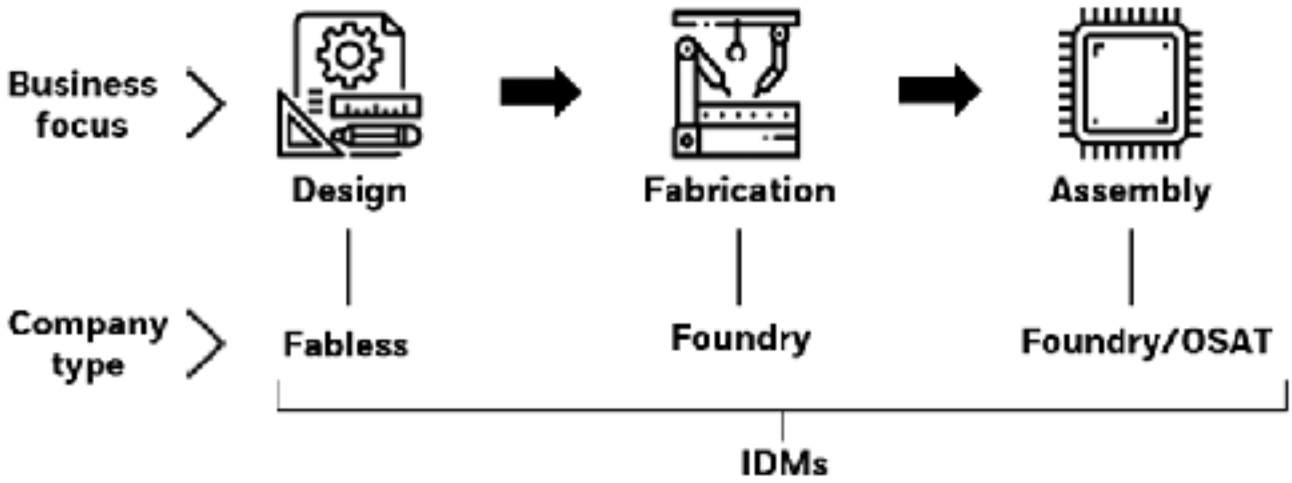

Figure 27: Illustration of semiconductors' steps and firms

Semiconductor industry is also divided into four major segments based on their role in the value chain, and are:

1. **Design**, the process of producing an implementation ready to be laid out into a chip, a board or both;
2. **Manufacture**, the process used to produce semiconductor devices;
3. **Assembly, packaging, and testing**, are the processes of combining individual components into a single substrate, that is then encapsulated in a protective package, and finally tested in order to assess the functionality, the performance, and the reliability of semiconductor devices before they are integrated into electronic final products;
4. **Semiconductor manufacturing equipments**, are machines needed to make semiconductors like dicing machines, probing machines, plush and edge grinders, chemical mechanical planarization (CMP), photolithography machines, and sliced wafer demounting cleaning machines.

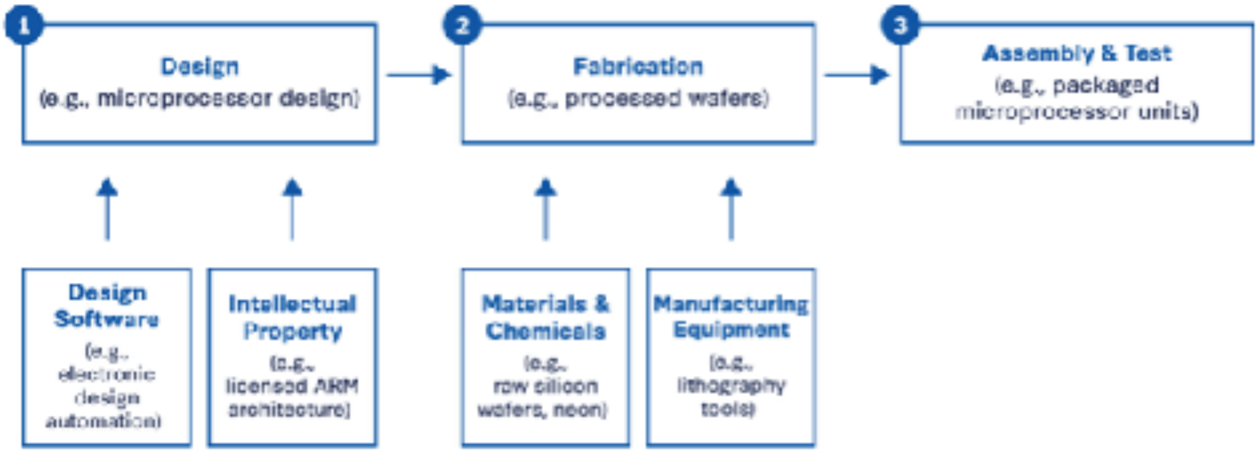

Figure 28: Simplified description of the semiconductor value chain

Semiconductor market is strongly influenced by automotive, consumer electronic (as smart home, smartphones, laptop, tablets, and wearable for instance), telecommunication, industrial equipment market (like smart cities, solar panels, wind turbines, and energy storage systems), aerospace and defence, and healthcare industries.

In 2022 the global semiconductor manufacturing industry was evaluated USD 580.1 billion and it is expected to reach USD 1,883.7 billion in the next 10 years[177]. In order to estimate the manufacturing sector of each country, what is take into consideration is the capability to produce semiconductors. Actually, only 10 countries are manufacturing semiconductors that empower the entire world (see the figure 28 below) and the major semiconductor companies are expanding their operations even more in the top production countries[178]. Malaysia, Israel, and the Netherlands have the lowest number but a huge potential for semiconductor manufacturing. In addition, companies like the Taiwan based FOXCONN and the American Intel are planning to expand their operations in emerging countries like India and Vietnam[179].

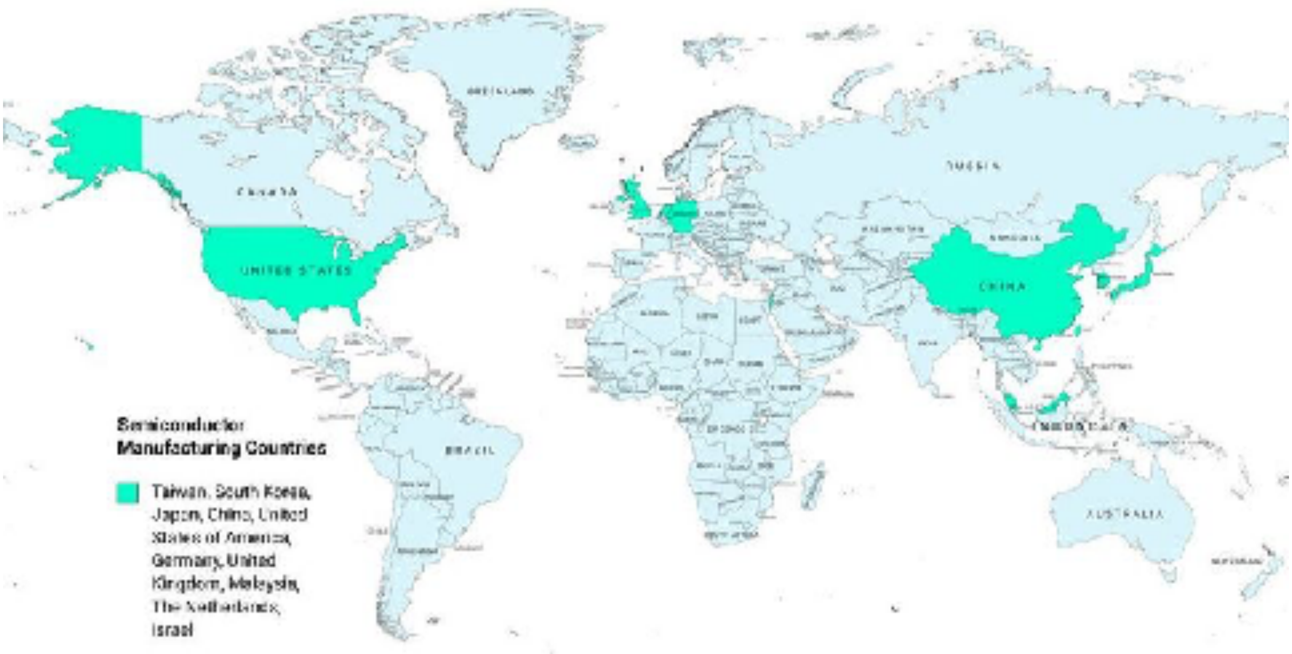

Figure 29: Biggest chip manufacturing countries

[177] Kohli, V., (2023-09-13), Introduction to semiconductor manufacturing, in "power-and-beyond.com", https://www.power-and-beyond.com/semiconductor-manufacturing-steps-explained-a-ebfb8f22238e055c7f98329eed1af49e/ 22-04-2024.

[178] Kohli, V., (2023-09-13), Introduction to semiconductor manufacturing, in "power-and-beyond.com", https://www.power-and-beyond.com/semiconductor-manufacturing-steps-explained-a-ebfb8f22238e055c7f98329eed1af49e/ 22-04-2024.

[179] Kohli, V., (2023-09-13), Introduction to semiconductor manufacturing, in "power-and-beyond.com", https://www.power-and-beyond.com/semiconductor-manufacturing-steps-explained-a-ebfb8f22238e055c7f98329eed1af49e/ 22-04-2024.

At the beginning of 21st century, the semiconductor market made a shift from American and European countries to Asian ones, thanks to the increase in electronic equipment production in this continent, in fact in 2001 Asia Pacific region become the leading region in semiconductor sales[180]. In this part of the world, China is the largest country market contributing with 55% to the regional APAC market and 31% globally. In 2020, the semiconductor industry in China consumed about 24% of the global semiconductor-enabled electronic devices[181]. China is also the top revenue generator on global scale, reaching USD 179.50 billion in 2023 and is expecting a Compound Annual Growth Rate (CAGR) of 7.31%. Moreover, China is the largest consumer in the world of semiconductors and purchases more than 50% of globally manufactured chips[182]. In this market, the integrated circuits account for more than 80% of revenue, and logic integrated circuits are the major share of the revenue. So it is possible to say that the Chinese semiconductor industry is the major part of the country's information technology industry.

The reason why Chinese semiconductor industry is growing so fast in recent years, is also due to the restriction applied by Biden administration started in October 2022[183] and then updated the year after, that prohibit American companies from selling certain types of semiconductors, AI, and computing chips to China. In 2023 also Japan and The Netherlands joined and followed the same restrictions. This leads China to develop independent chip manufacturing capabilities and attain self-sufficiency, and TMSC (Taiwan Semiconductor Manufacturing Company 台積電 *Táijī diàn*) become the largest foundry fab in the world, from which China imports integrated circuits without imposing sanctions.

As demonstration of this, recently Huawei (华为 *Huáwéi)* produced the chip for Mate 60 Pro smartphone and in August 2023 the Shanghai based SMIC produced Huawei's Kirin 9000S processor, that is a second-generation 7-nanometer chip designed by HiSilicon, which is a Huawei's subsidiary. This type of chip is only two generation behind the Apple's 3-nanometer chip, and Huawei is expected to reach the 5-nanometer chip production by 2025[184]. Despite US restrictions on chip exports and investment, Chinese semiconductor sales keep growing outpaced the global average, with a growth of 26.6% year-on-year. The growth includes also its capacity in chip manufacturing and its accelerated pace in achieving self-reliance. In fact, self-sufficiency in chip production grew from 5% in 2018 to 30% in 2023[185].

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180 Semicondcutors: market data & analysis, in "statista.com", https://www.statista.com/study/146704/semiconductors-market-data-and-analysis/ , 23-04-2024

181 Daxue consulting, (2024-01-04), China's semiconductor industry: Seeking for self-sufficiency amid global political tensions, in "daxueconsulting.com", https://daxueconsulting.com/china-semiconductor-industry/ , 23-04-2024.

182 Daxue consulting, (2024-01-04), China's semiconductor industry: Seeking for self-sufficiency amid global political tensions, in "daxueconsulting.com", https://daxueconsulting.com/china-semiconductor-industry/ , 23-04-2024.

183 On October 2022, the 46th American President Joe Biden started issuing restrictions on selling semiconductors and chip-making equipment to China.

184 Araya, D., (2024-01-08), Will China dominate the global semiconductor market? Chip design and manufacturing are the heart of the US-China rivalry, in "cigionline.org", https://www.cigionline.org/articles/will-china-dominate-the-global-semiconductor-market/#:~:text=The%20Chinese%20market%20is%20already,of%20the%20US%20tech%20sector , 23-04-2024.

185 GT staff reporters, (2024-03-05), China's Jan semiconductor sales growth outpaces global level, as self-sufficiency improves amid US clampdown, in "globaltimes.cn" , https://www.globaltimes.cn/page/202403/1308245.shtml , 23-04-2024.

The main problem of Chinese's semiconductor market is the dependance on foreign providers, as the Dutch ASML (Advanced Semiconductor Materials Lithography) and the Taiwan based TSMC (Taiwan Semiconductor Manufacturing Company). It is important to notice that TSMC produces the 90% of world's most advanced and sophisticated microchips, while ASML is the global market leader for deep ultraviolet (DVU) photolithography machines and extreme ultraviolet (EUV) machines. The lack of EUV technology is a huge problem for Chinese semiconductor market as lithography is an essential step in the chipmaking process, which determines the dimensions of chips. For this reason, the Shanghai based SMEE (Shanghai Micro Electronic Equipment 上海微电子装备 *Shànghǎi wēi diànzǐ zhuāngbèi*) company is focusing and specialising in the production of advanced lithography machines.

The production of integrated circuit in China has accounted for 16% of world total production, placing the country at the third place in the world. However, China is still a net semiconductor importer, especially for semiconductor equipment from the Dutch ASML, which had a rise sales revenue from China, doubling from 24% to 46% in 2023[186].

Semiconductor development is a key part of China government agenda to grow its chip and IC industry and in order to work towards self-sufficiency, the government also applied different initiatives as "Made in China 2025 (中国制造2025 *Zhōngguó zhìzào èrlíng'èrwǔ*)[187]", tax exemptions and import duty exemptions for advanced technology nodes, and a state investment named the "Big Fund (国家大基金 *Guójiā dàjījīn*)[188]" for chip production, which exceeds USD 50 billion.

The growth in the Chinese semiconductor equipment market is focused in the extensive expansion of foundries. According to TrendForce[189], the country currently has 44 fabs, where 25 of them are 12-inch fabs, 4 are 6-inch fabs, and 15 are 8-inch fabs. In addition, there are 22 fabs under construction and companies like SMIC, Nexchip (晶合集成 *Jīnghé jíchéng*) and Silan Micro (士兰微电子 *Shì Lán wéi diànzǐ*) are planning to built 10 additional fabs. By the end of 2024, China is expected to establish 32 large-scale fabs focused on advanced and mature process. This mature process is projected to increase from 29% of 2023 to 33% by 2027.

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186 Daxue consulting, (2024-01-04), China's semiconductor industry: Seeking for self-sufficiency amid global political tensions, in "daxueconsulting.com", https://daxueconsulting.com/china-semiconductor-industry/ , 23-04-2024.

187 Made in China 2025 (中国制造2025 *Zhōngguózhìzào èrlíng'èrwǔ*) is a national strategic plan and industrial policy of the Chinese Communist Party in May 2015, in order to further develop the manufacturing sector of China.

188 The China Integrated Circuit Industry Investment Fund (ICF; 国家集成电路产业投资基金 *Guójiā Jíchéng Diànlù Chǎnyè Tóuzī Jījīn*), also known as the National Integrated Circuit Industry Investment Fund and the Big Fund (国家大基金 *Guójiā Dàjījīn*), is a China Government Guidance Fund. The fund aims to help China reach its national goal of achieving self-sufficiency in the semiconductor industry (as part of the Made in China 2025 plan) by investing in domestic semiconductor companies. It has played a significant role with regards to the semiconductor industry in China by funding companies such as SMIC, Hua Hong Semiconductor, and YMTC. Wikipedia, (2024), China Integrated Circuit Industry Investment Fund, in "en.wikipedia.org", https://en.wikipedia.org/wiki/China_Integrated_Circuit_Industry_Investment_Fund , 23-04-2024.

189 Trendforce, (2024-02-17), Overview of China's Semiconductor Equipment Industry, in "trendforce.com", https://www.trendforce.com/news/2024/02/17/news-overview-of-chinas-semiconductor-equipment-industry/ , 23-04-2024.

Demand for chips is projected to drive a trillion-dollar industry by 2030, and China now leads the world in terms of the number of new fabs under construction[190]. The emergence of a completely independent Chinese semiconductor industry would have huge geopolitical repercussions. China is just at the beginning of dominating the world's technology value chain and its potential to become the leader in the global semiconductor market is high.

Figure 30: China's 2023 Semiconductor Projects Map

According to Statista outlook[191], in 2024 the semiconductor market revenue in China is projected to reach USD 198.90 billions and ICs dominate the market (about more than 80%) with a projected market volume of USD 160.10 billions in the same year (the rest of the market shares is occupied by discrete semiconductors, optoelectronics, and sensors and actuators). The Chinese semiconductor market is expected to show an annual growth rate of 6.16%, and in global comparison the most revenues will be generated in China, following USA, Japan, Singapore and Mexico. China is also the largest consumer of semiconductor among other countries, in fact more than 50% of semiconductors are imported from multinational suppliers.

[190] Araya, D., (2024-01-08), Will China dominate the global semiconductor market? Chip design and manufacturing are the heart of the US-China rivalry, in "cigionline.org", https://www.cigionline.org/articles/will-china-dominate-the-global-semiconductor-market/#:~:text=The%20Chinese%20market%20is%20already,of%20the%20US%20tech%20sector , 23-04-2024.

[191] Statista, (2024), Semiconductors - China, in "statista.com", https://www.statista.com/outlook/tmo/semiconductors/china , 24-04-2024.

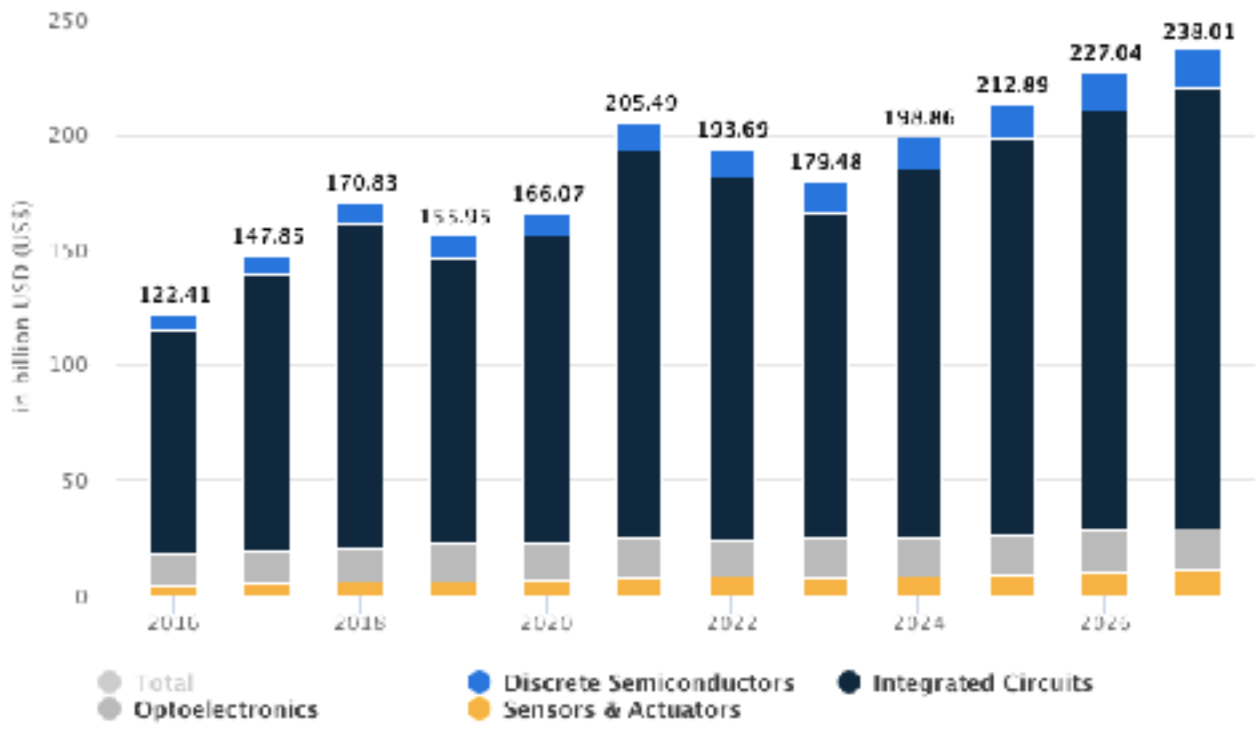

Figure 31: Revenue by segment of Chinese's semiconductor market (August 2023)

Currently, Chinese provinces that dominate the semiconductor market are Guangdong, Shandong, Henan, Sichuan, and Jiangsu. In fact, in China there are 4 special economic zones (SEZ), and 3 of them are located in Guangdong province and are Shenzhen (the so called "Chinese Silicon Valley"), Zhuhai and Shantou. Guangdong province has a strategic location and now after years has also gained higher administrative and fiscal autonomy. In addition, also Shanghai Pudong district had become a SEZ in the latest years.

SEZs are a medium for introducing technology, management, and knowledge, and Shenzhen become the technological capital of China and for this reason it is considered the first special economic zone, as it was built for the sole purpose of rapid production of electronics.

Other than SEZ, until 2010 in China there were also Industrial Development Zones (IDZ) that apply different preferential policies according to the industrial sector that they are specialised in, for example Economic and Technological Development Zones, High-Tech Industrial Development Zones and Industrial Parks. Of course, the province that counted the major number of IDZs is Guangzhou with 70 IDZs. However, after 2010 there has been a stop of these zones because several studies underlined that there were too many specialised IDZ (known as the "booming IDZ" phenomena) and the government decided to slow down, also motivated by the changes after the 2008 economical crisis.

Due to its strategic area, perfect industrial eco-environment and skilled workforce, Guangdong province plays a dominant role in China semiconductor market as it is considered a key hub for semiconductor manufacturing, design, and research[192]. Here is where some of the largest semiconductor companies of China (both domestic and intentional players) have their headquarters, thanks to the significant investments in the Chinese chip industry. In fact, this province is powered by the efforts made to strengthen collaboration among industry, academia and research institutions, besides measures implemented for semiconductor development and investments. It is possible to affirm that the favourable environment, together with the proximity to the major consumer electronics manufacturers and export channels, have raised Guangdong as the province leader in the Chinese semiconductor market.

Currently, the most important silicon semiconductor manufacturer companies in China are:

- **SMIC** 中芯国际 (Semiconductor Manufacturing International Corporation), the first Chinese chip maker and the fifth global chip maker with headquarter (HQ) in Shanghai;
- **HiSilicon** 海思, a fabless company specialised in chip design with HQ in Shenzhen;
- **YMTC** 长江存储科技 (Yangtze Memory Technologies Corporation), is the China's leading memory chip manufacturer with HQ in Wuhan;
- **UNISOC** 紫光展锐, is the largest mobile phone chip designer with HQ in Shanghai;
- **Naura Technology Group** 北方华创, is China's largest chip production equipment manufacturer with HQ in Beijing;
- **Will Semiconductor** 韦尔半导体, is a fabless semiconductor design company with HQ in Shanghai;
- **Wingtech** 闻泰科技, is a pure-play foundry integrated device manufacturer (IDM) with HQ in Shanghai;
- **GigaDevice Semiconductor** 兆易创新, is a fabless chip design company with HQ in Beijing;
- **JCET** 长电科技 (Jiangsu Changjiang Electronics Tech), is an OSAT company with HQ in Jiangyin;
- **Hua Hong Semiconductor** 华虹集团, is the sixth-largest foundry company at a global level with HQ in Shanghai.

Other than these top 10 Chinese's semiconductor manufacturers, China have tens of thousands of other semiconductor companies. However, China remains dependent on foreign suppliers and foreign-owned technologies for the advanced semiconductors needed. In fact, in the county there also are a large number of foreign semiconductor companies that operate in fabrication plants and design facilities, for instance the South Koreans SK Hynx and Samsung, the Taiwaneses TSMC and UMC, and the Americans Texas Instruments and Micron[193].

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[192] China semiconductor market report by industry type, end user, material used, functions, and region 2024-2032, in "imarcgroup.com", https://www.imarcgroup.com/china-semiconductor-market , 24-06-2024.

[193] Hope, A., (2023-02-03), China's top 10 semiconductor firms, in "thechinaproject.com", https://thechinaproject.com/2023/02/03/chinas-top-10-semiconductor-firms/#:~:text=Jiangsu%20Changjiang%20Electronics%20Tech%20(JCET) , 24-06-2024.

In order to end this reliance on foreign companies, Chinese government established the National Integrated Circuit Industry Investment Fund (国家集成电路产业投资基金 *Guójiā Jíchéng Diànlù Chǎnyè Tóuzī Jījīn*) in 2014[194], with which Beijing has invested in 2,793 entities, and the majority are semiconductor firms. In fact, according to the Semiconductor Industry Association's 2022 State of Industry Report[195], China's share of the global chip design market is projected to rise to 23% by 2030[196].

[194] The China Integrated Circuit Industry Investment Fund (ICF; 国家集成电路产业投资基金 *Guójiā Jíchéng Diànlù Chǎnyè Tóuzī Jījīn*), also known as the National Integrated Circuit Industry Investment Fund and the Big Fund (国家大基金 *Guójiā Dàjījīn*), is a China Government Guidance Fund. The fund aims to help China reach its national goal of achieving self-sufficiency in the semiconductor industry (as part of the Made in China 2025 plan) by investing in domestic semiconductor companies. It has played a significant role with regards to the semiconductor industry in China by funding companies such as SMIC, Hua Hong Semiconductor, and YMTC. Wikipedia, (2024), China Integrated Circuit Industry Investment Fund, in "en.wikipedia.org", https://en.wikipedia.org/wiki/China_Integrated_Circuit_Industry_Investment_Fund , 23-04-2024.

[195] SIA Semiconductor Industry Association: 2022 state of the U.S. semiconductor industry, in "semiconductors.org" , "https://www.semiconductors.org/wp-content/uploads/2022/11/SIA_State-of-Industry-Report_Nov-2022.pdf", 24-05-2024.

[196] Hope, A., (2023-02-03), China's top 10 semiconductor firms, in "thechinaproject.com", https://thechinaproject.com/2023/02/03/chinas-top-10-semiconductor-firms/#:~:text=Jiangsu%20Changjiang%20Electronics%20Tech%20(JCET) , 24-06-2024.

4.2 EMS: Electronic Manufacturing Services

The second player and key partner in the In-System Programming industry are the Electronic Manufacturing Services, commonly known as EMS. With the abbreviation EMS, technicians refer to an overall industry and to a specific class of subcontractors or companies, that provide and cover a wide range of services, such as manufacturing, design, shipping, testing, repairs, and many other activities for Original Electronic Manufacturers (OEMs) or Original Design Manufacturers (ODMs). Examples of OEMs that benefit from EMS work are: medical, automotive, aerospace and defence, consumer electronic, electronic components, communications, new energy, IoT, and home appliances industries.

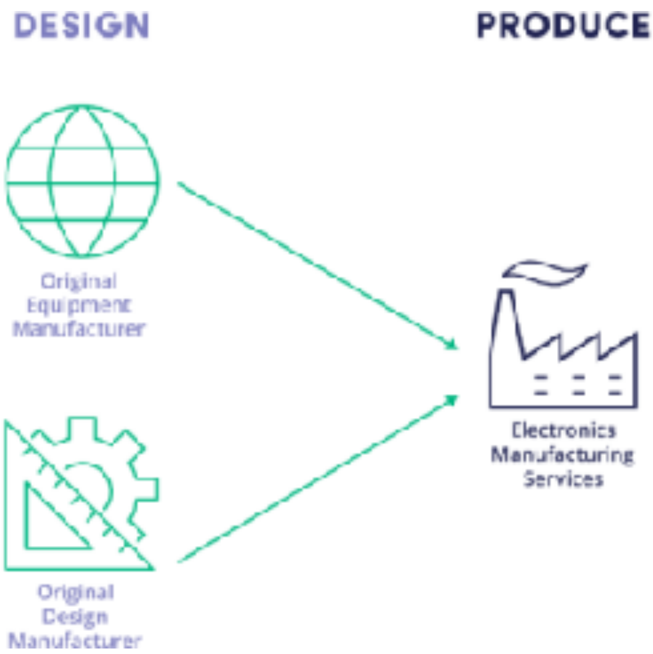

Figure 32: Representation of EMS activity

EMS companies are specialised in creating large economies of scale[197] in manufacturing, raw materials supplying, gather together resources, industrial design expertise, and creating added value services like warrant and repairs. By this way it is possible to satisfy customers who do not need to keep huge inventories and respond quickly and efficiently to sudden demands from customers. For these reasons, by the mid-1990s several OEMs started selling their assembly plants to EMSs.

[197] According to the Scottish economist Adam Smith (1723-1790) and the English economist Alfred Marshall (1842-1924), with the term "economies of scale" we refer to the technique where cost advantage experienced by a firm when it increases its level of output. The advantage comes from the inverse relationship between the per-unit fixed cost and the quantity produced: the greater the quantity of output produced, the lower the per-unit fixed cost.

Usually, EMS providers are categorised into three tiers, according to their total annual revenue:

- **1st Tier**: more than USD 3 billion;
- **2nd Tier**: between USD 300 million to USD 3 billion;
- **3rd Tier**: less than USD 300 million[198].

There are also other four ways to classifying EMS providers, that are:

- **Complexity and volume**, where complexity refers to the number of component parts in a product and the number of man/machine hours it takes in order to manufacture it, and volumes refers to the number of units built;
- **Technical capability and service offering**, that can distinguish them from others;
- **Lifecycle stage**, that is where the product are in their life cycle;
- **Markets served**, that can be medical, automotive, or communication for instance[199].

In addition, thanks to EMS job, it is possible to reduce manufacturing costs and time to market, as many consumer electronics are built in China, due to low maintenance costs, availability of materials, and speed. In fact, cities as Shenzhen and Penang have become important production centres for the industry, attracting many consumer electronics companies, like the American Apple Inc[200].

According to Global Information research, China is the leading country in the Asia Pacific EMS market since 2022 and it is expected to continue to dominate the market until 2030, with a projected market value of USD 88,181.6 million by 2030[201]. This is motivated by the great number of manufacturing units of consumer electronics, semiconductors, and other telecommunications devices and machinery manufacturing, that increased especially during the COVID-19 pandemic.

Compared to the global market, the Chinese EMS market is developing much faster, providing more investment and entry opportunities to overseas players. In fact, the market size is expected to increase from USD 141,216 million in 2023 to reach USD 208,333 million by 2029, at a CAGR of 6.7%[202]. This is mainly due to the significant incentives, like tax credits, land grants, low import duties and the possibility to establish full private equity ownership, that Chinese government is providing in order to encourage the internal EMS market.

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198 Sharp, N., (2016-01-28), 4 different ways to categorise EMS providers, in "escatec.com", https://www.escatec.com/blog/4-different-ways-to-categorise-ems-providers , 09-06-2024.

199 Sharp, N., (2016-01-28), 4 different ways to categorise EMS providers, in "escatec.com", https://www.escatec.com/blog/4-different-ways-to-categorise-ems-providers , 09-06-2024.

200 Electronic manufacturing services, in "en.wikipedia.org", https://en.wikipedia.org/wiki/Electronics_manufacturing_services , 09-06-2024.

201 KBV Research, (2024-02-09), Asia Pacific Electronic Manufacturing Services Market Size, Share & Trends Analysis Report By Service, By Industry, By country and Growth Forecast, 2023-2030, in "giiresearch.com" , https://www.giiresearch.com/report/kbv1431366-asia-pacific-electronic-manufacturing-services.html , 28-04-2024.

202 QY Research (29-05-2023), Global Electronic Manufacturing Services (EMS) Market Insights, Forecast to 2029 (2023-05-29), in "giiresearch.com" , https://www.giiresearch.com/report/qyr1280772-global-electronics-manufacturing-services-ems.html , 28-04-2024.

Other than government incentives, there are also other several factors that make the Chinese EMS production profitable and are: the extreme low labour costs, the low taxation and custom duties, the competitive currency procedures, a laid-back approach to regulatory compliance, and a rapidly growing business ecosystem. Moreover, China become a key global business hub thanks to the access of a fast-growing number of consumers from Southeast Asia and the global transformation, and adjusted its production capacity and grew specialised industries.

Currently, the top 10 EMS providers in China are[203]:

- **Hon Hai Technology Group** (鴻海科技集團 *Hóng hǎi kējì jítuán*) is part of the Taiwanese Foxconn, and provides software and hardware devices for electric vehicles, digital health, robotics, artificial intelligence (AI), and new generation communications;
- **Kaifa Technology** (开发科技 *Kāifā kējì*), located in Shenzhen, provides services like supply chain, research and development, designing and prototyping, management and logistics maintenance and their final products can be used in many electronic devices;
- **KINPO Group** (金仁寶總部大樓 *Jīnrénbǎo zǒngbù dàlóu*), their electronic products find application in consumer electronics, printing and imaging, communications, semiconductors, AI, power management, and precision parts;
- **3CEMS Group** (三希集团 *Sān xī jítuán*) is specialised in complete device assembly, electronic assembly, schematic designs, IC programming, optimisation, corner bonding, and component sourcing;
- **RYDER Industries**, offers solutions related to EMS and PCB, that can find application in audio industry, consumer electronics, safety and security, and IoT;
- **Viasion Technology**, is specialised in PCB production and electronic services as turnkey PCB assembly, consignment assembly, box building, electromechanical assembly, components sourcing, IC programming, testing, wire bonding, and custom PCB design and assembly;
- **MOKO Technology**, is specialised in electronic, mechanical, embedded, and manufacturing designs, PCBs' assembly and prototyping, that can benefit industries like automotive, communications, LED, industrial electronics, IoT, medical, and green energy;
- **IBE Electronics**, has great experience in industrial design, research and development, PCB manufacturing;
- **ZOWEE** (卓翼科技 *Zhuó yì kējì*) offers different services such as development and manufacturing of mold, spray printing, printed circuit board manufacturing and assembly, product assembly, and packaging, system integration and testing, supply chain management, and production track systems;
- **ABP Electronics**, offers different services for PCB manufacturing and services supporting every PCB and PCBA projects.

[203] Ranjeet, (2024), Top 10 EMS Manufacturers and suppliers in China in 2024. In "viasion.com", https://www.viasion.com/blog/top-10-ems-manufacturers-and-suppliers-in-china/ , 09-10-2024.

As per Silicon Producers, the regions and cities which count the major number of EMS companies are Guangdong, Jiangsu, Shanghai and Shenzhen, due to the presence of SEZ and IDZ.

However, in recent years China is facing numerous challenges that are affecting its EMS market, that are: rising labour costs and tariffs, Covid-19 pandemics, currency fluctuations, more regulatory burdens, the US-China trade war, and the tense relations with Taiwan. For all these reasons, EMS business are planning to move out of the country. In addition, there is also the issue of the Chinese intellectual property (IP) protection system that is causing tensions between China and the countries that have experiences this kind of problem. Although in recent years the country has made significant progress in strengthening its IP protection system, through stricter enforcement, increased penalties for infringements, and by setting specialised IP courts, however foreign enterprises still face difficulties[204].

[204] Integra, G., (2023-07-13), Intellectual property protection in China: an essential overview, in "integra-group.cn", https://www.integra-group.cn/intellectual_property_ip_protection_china/ , 09-10-2024.

4.3 OEM: Original Electronic Manufacturer

The last and third key players for the In-System Programming activity are OEMs. The abbreviation OEMs refers to Original Electronic Manufacturers, that are manufacturers specialised in the production of particular products or parts (normally called OEM product) for another company (also known as VAR - valued-added reseller) that provides them with the design and specifications. The company that uses the parts can mark them with their brand or name. In synthesis, the product comes from the end company but uses the OEM components. OEMs can provide products of good quality at a lower price trough economies of scale and can outsource complicated production tasks and focus on what they do best. An OEM part therefore is manufactured to order and this is commonly observed in industries like the automotive, high-end electronic and semiconductor.

From automotive industry point of view, OEM normally refers to the company manufacturer of the original equipment, which are the auto parts assembled and installed during the construction of the vehicles. Instead, from a software point of view, PC companies manufacturers (like Lenovo or ASUS) normally purchase processors or graphic cards from OEM companies (like Intel, Nvidia or Microsoft).

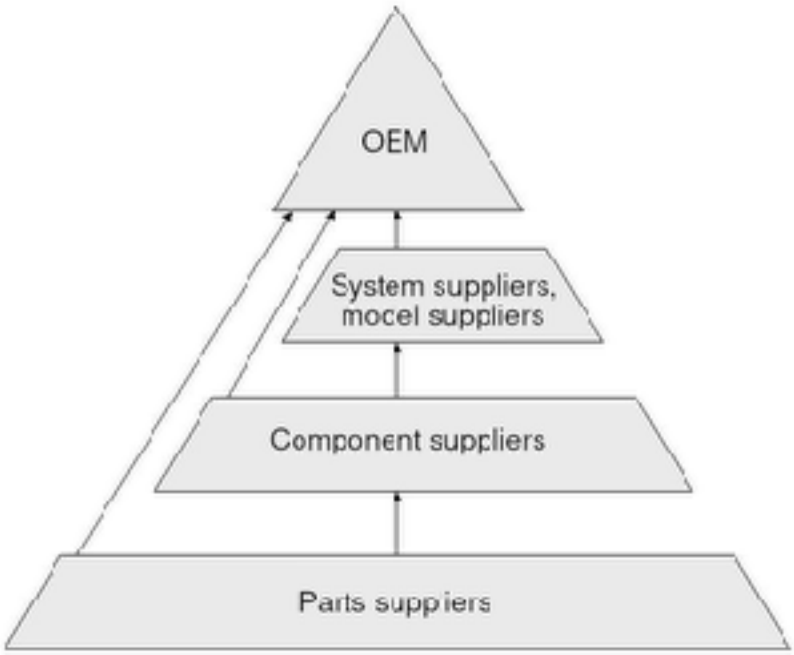

Figure 33: Example of OEM supply chain

China holds the position of the world's largest industry manufacturer by output for more than eleven years, contributing USD 4 trillion to the nation's overall economic output, this is the main reason why it is called the "World's factory"[205]. Since 2008, China is also the world's largest automotive market and manufacturer as it produces more vehicles in a year than United States, Europe and Japan taken together, accounting for 30% of global production[206]. The success of the county in the automotive industry is due to the good performances of in-land OEMs companies. In fact, China's auto parts industry is estimated to be worth USD 550 billion[207]. In addition, the Chinese automotive market is continually evolving and the last few years have seen a huge transition to new energy vehicles, as fully electric cars and plug-in hybrid cars.

According to SBD Automotive, Chinese OEMs are present both in developed and in developing countries and in 2022 their export volume reached more than 2.5 million[208]. What is expected in the near future is that Chinese OEMs will be present in many other countries, especially those of Western Europe that will become the key area and the primary market for the future expansion.

According to the E-magazine "Direct Industry"[209], the top 5 Chinese OEMs leader in the automotive industry, based on sales volume and market capitalisation, currently are:

- **BYD** (比亚迪汽车 *Bǐyàdí Qìchē*) is one of the most vertically integrated car manufacturer in the world, developing and producing their own batteries, that supply also to other car producers. In 2020 started its expansion outside the country first in Norway, and two years after in other European countries like the Netherlands, Sweden, Germany, and Denmark;
- **Geely** (吉利汽车 *Jílì Qìchē*) is the owner of Volvo and many other EV producers, as Polestar, Smart, Zeek, and radar;
- **SAIC Motor (**上海汽车集团 *Shànghǎi Qìchē Jituan*), is the first Chinese state-owned automaker for sales, reaching 5.02 million units in 2003. It is also the Chinese largest car export company thanks to the acquisition of the British MG and the joint ventures with Volkswagen and General Motors;
- **Changan (**长安汽车 *Chángān Qìchē*), is a state-owned car manufacturer that recently set up partnerships with Huawei, NIO, and CATL in order to promote their EV models;
- **CATL** (宁德时代新能源 *Níngdé Shídài Xīnnéng Yuán*), produces batteries for new energy vehicles and is the world EV battery market leader with 37.4% of global share in 2023[210].

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[205] Bajpai, P., (2024-05-24), Why China is "the world's factory", in "investopedia.com", https://www.investopedia.com/articles/investing/102214/why-china-worlds-factory.asp , 09-06-2024.

[206] Tomaia, L.L., (2024-01-04), Automotive manufacturing industry in China - statistics & facts, in "statistia.com", https://www.statista.com/topics/1050/automobile-manufacturing-in-china/#topicOverview , 09-10-2024.

[207] Editorial Team, (2023-02-28), OEM China - What to expect and what to look out for, in "sourcingalliances.com", https://www.sourcingallies.com/blog/oem-china , 09-06-2024.

[208] Atkinson, C., (2023-03-2): Chinese OEMs expanding into new market, in "sbdautomotive.com" , in "https://www.sbdautomotive.com/post/chinese-oems-expanding-into-new-markets" , 1-05-2024.

[209] Andrews, M., (2024-02-19): The Top 5 Chinese Automotive OEMs to Know in 2024, in "mag.directindustry.com", in https://emag.directindustry.com/2024/02/19/the-top-5-chinese-automotive-oems-to-know-in-2024-byd-geely-catl-saic-changan/ , 29-03-2024.

[210] Ren, D., (2024-01-21): Chinese EV battery market CATL expects 2023 profit to jump as much as 48 per cent as it maintains huge advantage over rivals, in "sump.com", in https://www.scmp.com/business/china-business/article/3250390/chinese-ev-battery-maker-catl-expects-2023-profit-jump-much-48-cent-it-maintains-huge-advantage-over , 29-04-2024.

Moreover, another important Chinese OEM is the multinational automobile manufacturer **Nio (**蔚来 *Wèilái*) with its headquarter in Shanghai. The company is specialised in the production of electric vehicles equipped with AI technology, and its goal for 2025 is to be globally present in 25 different countries and regions. After Nio, there are also other important automotive companies, such as **Chery** (奇瑞汽车 *Qíruì Qìchē*) that is a state-owned firm with headquarter in Wuhu and it is considered the third largest Chinese automobile manufacturer; **Dongfeng** (东风汽车 *Dōngfēng Qìchē*), that is the smallest state-owned car company with headquarter in Wuhan and it cooperates also with foreign automotive companies; **Xpeng** (小鹏汽车 *Xiǎopéng Qìchē*) is specialised in the manufacturing of electric vehicles, has its headquarters in Guangzhou and it is listed both in New York stock Exchange and in Hong Kong Stock Exchange; and **GWM** (Great Wall Motor - 长城汽车 *Chángchéng Qìchē*) that is a privately owned company with headquarter in Baoding, is specialised in the manufacturing of SUVs and pick-up trucks, and it is ranked as the eight largest Chinese car manufacturer.

It is easy to understand that thanks to EVs expansion, China's automotive industry is rapidly growing, trying to access new markets like India, Africa and Western Europe. The key motivations that push Chinese OEMs to expand globally are: *new business opportunities*, as in Europe cars have an higher price, and this give China opportunity to realise higher margins; *brand image*, because being present in Western market could remove the bad reputation for cheap low-quality products; *improvement for both product and service*, as Chinese product need to meet Western audience's needs and expectations; *preferential industrial policies*, as many foreign market provide numerous incentives for the purchase of EVs; and *leverage EV expertise advantage*, since Chinese OEMs already gained the largest share of domestic market, now have enough expertise to approach developed and competitive markets like Europe. This made China to be the third-largest car exporter in the world, reaching the leader countries that are United States, France and Italy.

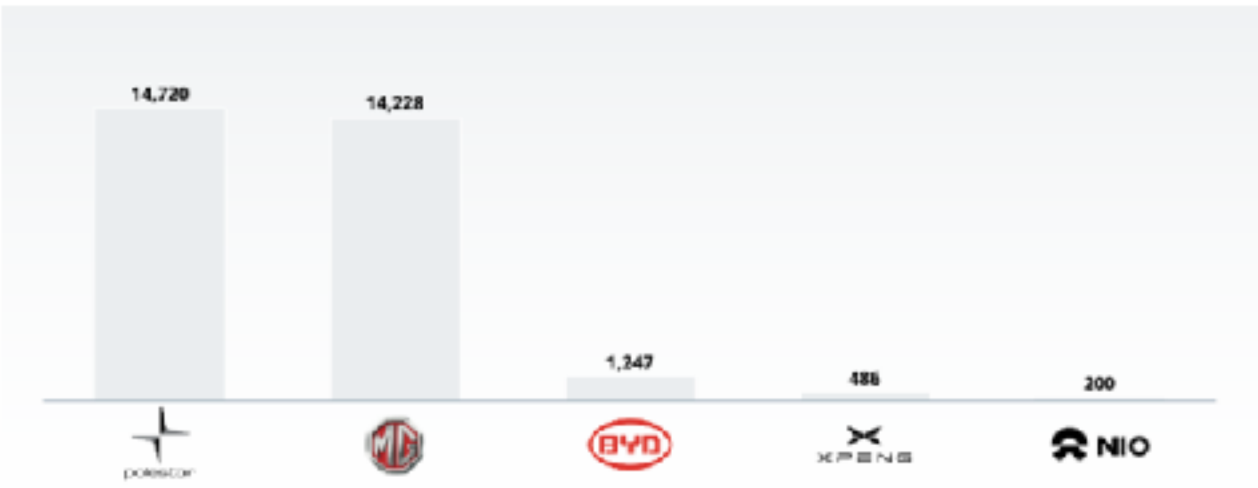

Figure 34: Chinese OEM sales in Europe in 2021 (in vehicle units)

Even if the biggest number of Chinese OEM companies do business in the automotive industry, OEM does not only means car manufacturing, but also many other products like computers, communications and medical tools. In fact, other leading Chinese OEMs are:

- **Huawei** (华为 *Huáwéi*), is specialised in the production of telecommunications equipment, consumer electronics, smart devices and rooftop solar products;
- **China Aerospace Science and Technology Corporation** (CASC - 中国航天 *Zhōngguó Hángtiān*), is the main state-owned company employed in the Chinese space program, concentrated in the design, development and manufacture of spacecraft, launch vehicles, and ground equipment;
- **China Electronics Technology Group Corporation** (CETC - 中国电子技术 *Zhōngguó diànzǐ jìshù*), is a state-owned company producing communication equipment, computers, electronic equipment, IT infrastructure, networks, software development, research services, investment and asset management applications[211];
- **Midea Group** (美的集团 *Měidì Jítuán*), is a company manufacturing electrical appliances, like lighting, water appliances, floor care, kitchen, laundry and refrigerator appliances, heating, ventilation and air conditioning, industrial robots and appliances;
- **Haier Smart Home** (海尔 *Hǎiěr*), is a multinational company manufacturing home appliances and consumer electronics, as refrigerators, air conditioners, washing machines, dryers, microwave ovens, mobile phones, computers, and televisions;
- **Gree Electric Appliances** (格力电器 *Gélì diànqì*), is a company specialised in the production of home appliances, like air conditioners, electric fans, water dispensers, heaters, rice cookers, air purifiers, water kettles, humudifiers, and induction cookers[212];
- **Lenovo** (联想 *Liánxiǎng*), is a Chinese-American multinational company specialised in the production of technologies like desktop computers, laptops, tablet, smartphones, workstations, servers, data storage devices, IT management software, and smart TVs;
- **ZTE Corporation** (中兴通讯 *Zhōngxīng tōngxùn*), is a partially state-owned company concentrated in telecommunication, in fact its product portfolio includes wireless, exchange, optical transmission, data telecommunications gear, telecommunication software, and mobile phones.

China is both the largest manufacturer and the largest consumer market of electronic product in the world, and together with low-cost supply base, well-organised infrastructure, and a great number of talented engineers, it can be easily considered a good partner for foreign electronic corporations and also the best country where to establish manufacturing facilities for foreign corporations[213].

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211 Semiconductor industry in China, in "en.wikipedia.org", https://en.wikipedia.org/wiki/Semiconductor_industry_in_China , 01-05-2024.

212 Gree Electric, in "en.wikipedia.org", https://en.wikipedia.org/wiki/Gree_Electric , 01-05-2024

213 Read, J., (2021-08-12): OEM Electronics Manufacturing in China, in "emsnow.com", https://www.emsnow.com/oem-electronics-manufacturing-in-china/ , 1-05-2024.

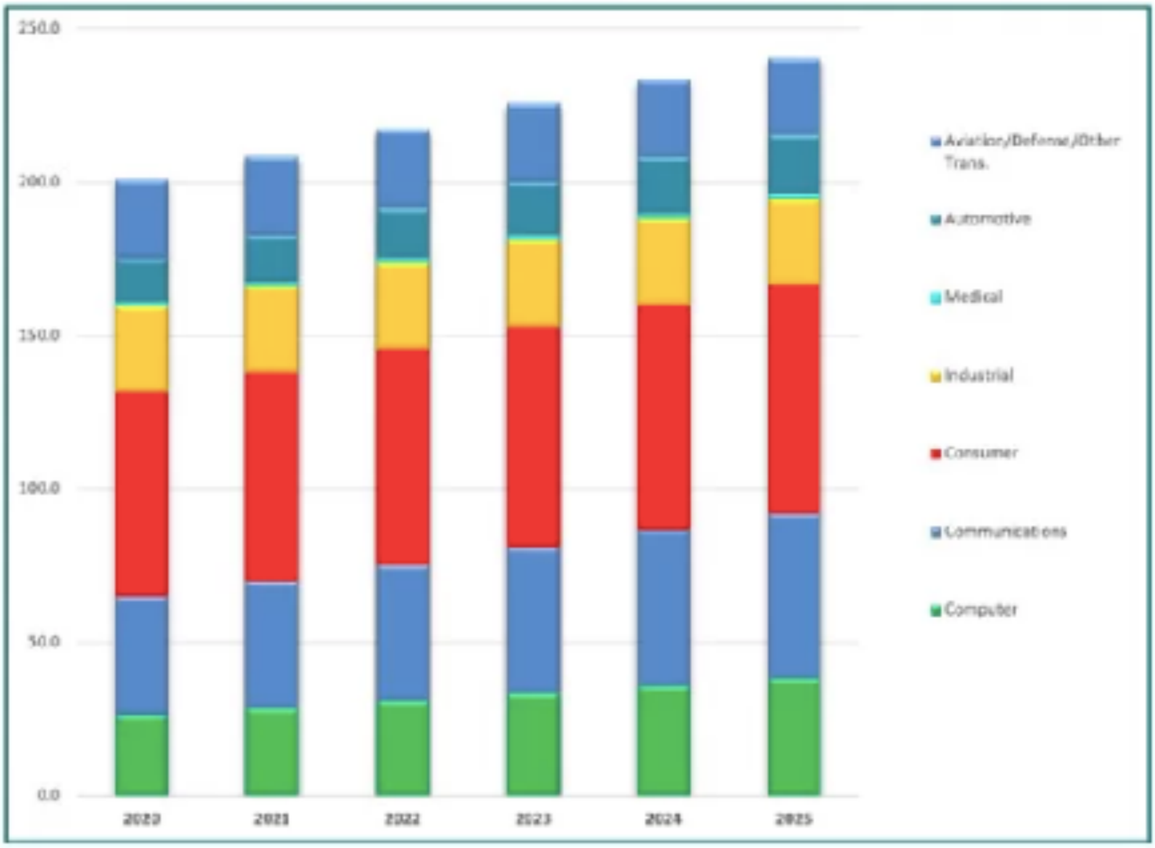

Figure 35: Forecast of China OEMs' assembly value by industry segment for 2020-2025 (in USD billion)

In conclusion, the figure below is a simple representation of how the structure of electronic and high-technology market present itself: at the beginning there are component and semiconductor manufacturers, then there are the electronics manufacturers for third parties (such as EMS and ODM, Original Design Manufacturer[214]), and in the final stage there are the consumer electronic manufacturers and other OEMs.

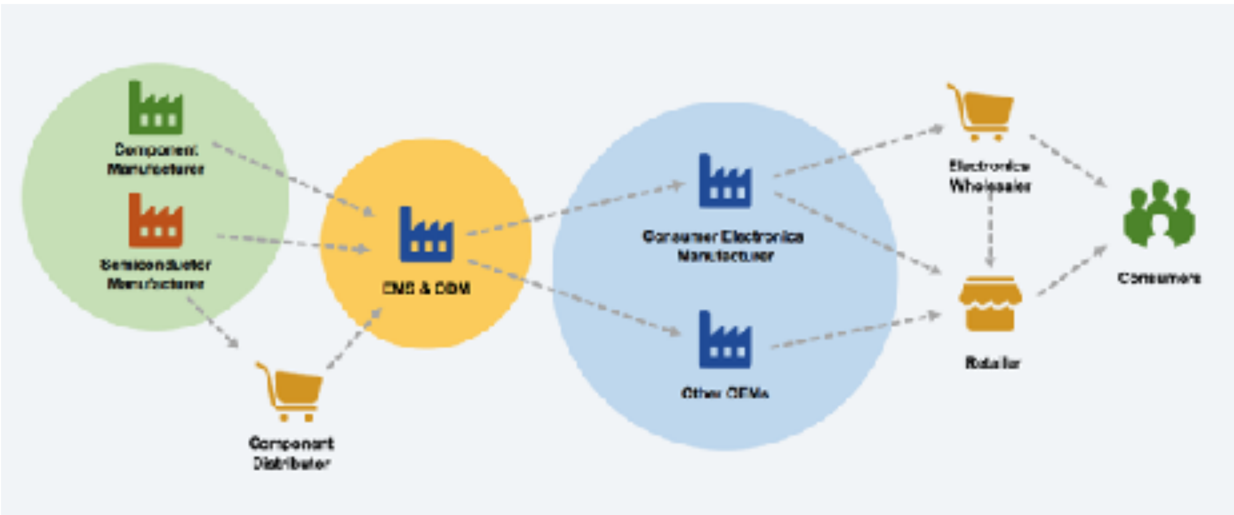

Figure 36: Explanation of electronic and technology markets' supply chain structure

[214] ODMs are companies specialised in the design and manufacturing of specific products, that are following branded by another company, which normally is an OEM.

4.4 USA - China chip war and the role of Taiwan

As anticipated at the beginning of this chapter, on October the 7th 2022, the U.S. Government, under Biden administration, announced a set of export restrictions toward China, especially on AI and semiconductor technologies, with the purpose of interfering with the development of Chinese semiconductor industry. Three months later, on January 2023, also Japan and the Netherlands joined the American restrictions, by banning the sale of semiconductor equipment to China. On August 2023, President Biden set up a screening mechanism on outbound investment and restricting US companies from investing in semiconductor industry in China. On March 2023, United States passed the CHIPS and Science Act[215] with the aim of improving the US tech sector, through USD 39 billion of incentives for manufacturing. In addition, the Biden administration is also planning to expand the construction of plants for chip, EV batteries, consumer goods, and renewables. However, the main problem of this operations is the construction cost that is estimated to be about five times greater than those of Asia[216]. The US sustain that China may use the chips from Nvidia and other American companies for military purpose. In fact, in 2022 Chinese President Xi Jinping announced his vision for the settlement of a “world-class” Chinese military and want to develop advanced dual-use technologies that could surpass the American ones[217]. Currently, according to the ranking of the world’s 500 most powerful supercomputers “TOP500”[218], China is just behind the US for the number of supercomputers, with 134 supercomputers for China and 150 for the US.

On July 2023, Chinese Government announced the need of a license requirement for the export of gallium and germanium, that are raw materials employed for the manufacture of semiconductors, and Japan and the Netherlands in 2022 were the first importers of these rare-earth metal from China[219].

After the update of these restrictions on October 2023, the Chinese government responded with a ban of any CPU made by the American companies Intel and Advanced Micro Devices (also known as AMD) for Chinese government computers and servers at the end of the same year. In fact, Beijing substituted the previous American CPU with Chinese companies Loongson and Phylum ones, and charged State-owned companies to transition towards Chinese hardware by 2027. These actions are all part of the strategy for reaching the Chinese self-sufficiency on semiconductor industry.

As response, Chinese tech giant Huawei released the new Mate 60 smartphone in August 2023, which uses 7 nanometer process chip made by the Chinese SMIC company (Semiconductor Manufacturing International Corporation). This type of chip is highly advanced, and this showed how American restrictions have failed since the beginning. However, China is still employing old chipmaking technology to producing these complex and new-age chips, and the US has limited the access of China to the most sophisticated chip

[215] The CHIPS and Science Act is a U.S. federal statute enacted by the 117th United States Congress and signed into law by President Joe Biden on August 9, 2022. The aim of this act is to boost domestic research and manufacturing of semiconductor, through USD 280 billion in funding. In “en.wikipedia.org", “https://en.wikipedia.org/wiki/CHIPS_and_Science_Act", 03-05-2024.

[216] Mullaney, T., (2023-03-09): How manufacturing chips in the US could make smartphones more expensive, in “nbc.com", https://www.cnbc.com/2023/03/09/why-manufacturing-chips-in-us-may-make-smartphones-more-expensive.html , 03-05-2024.

[217] U.S. Deartement of Defense, Military and security developments involving the People’s Republic of China 2022, in “media.defense.gov" , “https://media.defense.gov/2022/Nov/29/2003122279/-1/-1/1/2022-MILITARY-AND-SECURITY-DEVELOPMENTS-INVOLVING-THE-PEOPLES-REPUBLIC-OF-CHINA.PDF" , 4-05-2024.

[218] in “top500.org".

[219] Al Jazeera, (2023-07-12), Costlier cars? Why China’s gallium, germanium export curbs matter (2023-07-12), in “aljazeera.com", in https://www.aljazeera.com/news/2023/7/12/costlier-cars-why-chinas-gallium-germanium-export-curbs-matter , 04-05-2024.

making equipment, like the extreme ultraviolet lithography system of the Dutch ASML Holding (Advanced Semiconductor Materials Lithography). Other concerns like the low yield of older chip technology, intellectual property issues, and the corruption present in founding for chip research and development programmes, all have contributed to the slow down of the domestic chip manufacturing process. In order to solve this negative situation, Chinese government allocated one trillion yuan trough the Big Fund and high political priority.

Among the several effort that China is applying in order to renew the semiconductor manufacturing industry, it is possible to find design tools, advanced materials, advanced packaging techniques, and systems engineering approaches designed to improve performance via a system-led approach[220]. For instance, SMEE company (Shanghai Micro Electronic Equipment) is going to launch new lithography equipment that will be suitable for the production process of 28-nm (nanometre) chips[221]. However, China is still not making any improvement in etching equipment, and for this reason Chinese companies like NAURA and AMEC, are specialising in trailing and in mature nodes that need less this kind of equipment. Because of the great demand coming from emerging areas, China is also trying to expand rapidly in mature notes, such as 28-nm chips used for electric vehicles.

On January 2024, China's semiconductor sales growth has reached the 26.6%, and this means first that its growth is faster than the US rate (20.3%) and the global average[222], and second that after two years the US restrictions are still failing. So currently it is possible to affirm that China is succeeding in its intent of increasing its capacity in chip manufacturing and in achieving self-sufficiency. The capabilities of chip manufacturing of the country are improving, in fact the internal production of chips is surpassing the imported ones, mobile chips are becoming localised, and there are also advancement in AI chip research. Instead, self-sufficiency rate went from 5% in 2018 to 17% in 2022, and it is expected to reach the 30% in 2023[223]. According to Ministry of Industry an Information Technology data, the total output of integrated circuits increased of 7% in 2023, and this brought a drop of ICs imports rate of 10.8% compared with 2022. According to the Ministry of Finance, over the past six years the fiscal expenditure on science and technology development has increased by 6.4%, in order to boost semiconductor self-reliance and strength[224]. This overall growth is mainly due to the strong manufacturing capabilities, the size of the domestic market, and of course the government support.

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220 Kennedy, S., (2024-03-07), China's semiconductor industry advances despite U.S. export controls, in "csis.org", https://www.csis.org/analysis/chinas-semiconductor-industry-advances-despite-us-export-controls . 04-05-2024.

221 Kuo, M.A., (2023-10-02), The State of China's Semiconductor Industry, in "thediplomat.com", https://thediplomat.com/2023/10/the-state-of-chinas-semiconductor-industry/ , 04-05-2024.

222 GT staff reporters, (2024-03-05), China's Jan semiconductors sales growth outpaces global level, as self-sufficiency improves amid US clampdown, in "globaltimes.cn", https://www.globaltimes.cn/page/202403/1308245.shtml , 03-05-2024.

223 Liang, X., director-general of the Beijing-based Information Consumption Alliance, (2024-03-05), in "globaltimes.cn", https://www.globaltimes.cn/page/202403/1308245.shtml , 03-05-2024.

224 GT staff reporters, (2024-03-05), China's Jan semiconductors sales growth outpaces global level, as self-sufficiency improves amid US clampdown, in "globaltimes.cn", https://www.globaltimes.cn/page/202403/1308245.shtml , 03-05-2024.

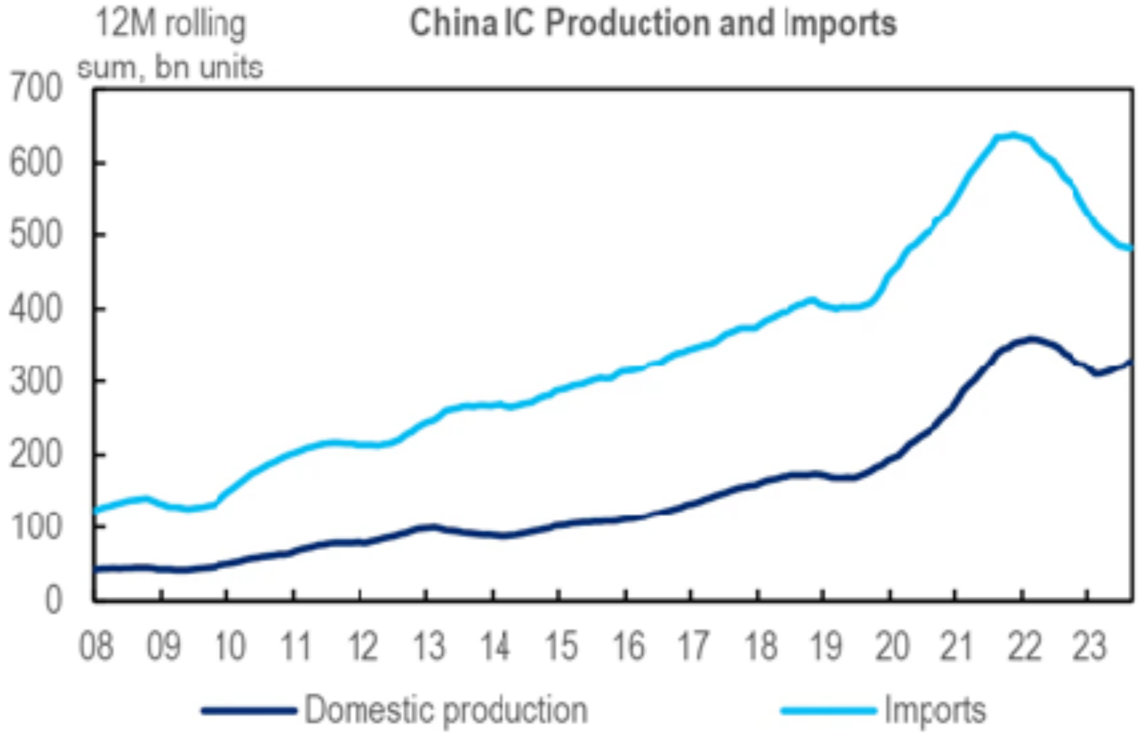

Figure 37: Graphic representation of China's IC imports and IC domestic production in unit terms

The implications of the run for the silicon supremacy between the first two world's economic super powers, are affecting the global community, especially Taiwan. As the country produce more than 90% of the world's most advanced microchips[225], the Chip War is putting Taiwan into an uncomfortable position in the evolving geopolitical landscape. In addition, this struggle is also affecting several industries, like automotive electric-vehicles industry, where China is the leading country.

The economy of Taiwan is made up of semiconductor manufacturing and exporting, and China is the first country for Taiwan's export destination. However, President Tsai Ing-wen published the "New Southbound Policy[226]", according to which Taiwan has to move its investment and trade away from China. For China is difficult to quickly replace the supply of semiconductor from Taiwan.

[225] Palmer, A.W., (2023-08-11), An Act of War: Inside America's Silicon Blockade Against China, in "nytimes.com" , https://www.nytimes.com/2023/07/12/magazine/semiconductor-chips-us-china.html , 04-05-2024.

[226] The New Southbound Policy (新南向政策 *Xīn Nán Xiàng Zhèngcè*) launched on 5 September 2016, is an initiative that aims to enhance cooperation and exchange between Taiwan and 18 countries in Southeast Asia, South Asia and Australasia, in order to make Taiwan less dependent on China. In "en.wikipedia.org", https://en.wikipedia.org/wiki/New_Southbound_Policy#:~:text=9%20External%20links-,History,Taiwan's%20cooperation%20with%20other%20countries , 11-06-2024.

The success of Taiwan in manufacturing semiconductors is due to the contributions of key individuals and a strategic approach to development, with investment in R&D, build up knowledge and expertise, training workforce, and prompt companies to operate independently. All these efforts, lead Taiwan to be the most innovative and competitive country in the world of semiconductor manufacturing industry[227].

TSMC (Taiwan Semiconductor Manufacturing Company, 台灣積體電路製造 *Táiwān jītǐ diànlù zhìzǎo*) shapes the global position of the country, as it is the global leader in advanced semiconductor manufacturing process and recently become the main target from both the US and China for help in growing their chip sectors. In fact, the most advanced semiconductors of the American Apple Inc. are produced by TSMC.

Taiwan need to ensure economic interactions with countries other than China and the US, in order to maintain its economic growth.

It is possible to affirm that Taiwan has a strategic role in the current geopolitical environment, as semiconductor industry is capable of shaping international politics, the world economy, and the global balance of power. This is of course one of the reasons why President Xi Jinping is seeking for reunification with Taiwan, and why at the same time the US is offering protection to the independence of the country.

From one side, some economists think that China could be tempted to use force against Taiwan in order to replicate the success of Taiwan in semiconductor manufacturing; from the other side, some other economists affirm that the reliance that China have in chips manufactured in Taiwan will prevent an attack, as the destruction of Taiwan's foundries would negatively affect the Chinese economy and also the rest of the world.

[227] Liu, M., Managing Editor & English website editor at CommonWealth Magazine, Wu, M., Founder & Chairman of Macronix International Co., Ltd, (2023-02-23), What's Taiwan's role in the chip war? Taiwanology Ep.1, in "open.firstory.me", https://open.firstory.me/story/clefivqel00wj01v58cn90wtd , 04-05-2024.

4.5 Future trends and development of Chinese semiconductor industry

It is difficult to predict the long-term capability of Chinese semiconductor industry, but it is almost certain how the advanced manufacturing capabilities will develop. Currently, China is the leading country for number of new fabs under construction, and the demand for chips is projected to reach the trillion-dollar by 2030. But what will be the consequences if China would succeed in producing advanced chips at scale? One thing is sure, if China will be completely independent in the chip ecosystem, there will be massive geopolitical repercussions. However, one thing is clear: the global order is chaining, with China that is just at the beginning of its domination on world's technology value chain, and there are high possibilities that the country would absorb the semiconductor market. Even if China at the moment do not have access to advanced lithography tools, the county still have vast domestic capacity and unexploited engineering skills.

Currently, Chinese wafer fabs are self-sufficient in 22/28 nanometer and previous process technologies. Thanks to government policies and subsidies, China is expected to reach mature process market by 2030 and reach the 40% of share (in 2023 was 30%)[228].

In 2023, the capacity of silicon carbide crystal (SiC) continued to grow in China, with an industrial influence that cannot be ignored. However, on semiconductor equipment side, the country is still dependent on import, and won't be easy to achieve self-reliance in the next five years. For this reason, the development of Chinese semiconductor industry is expected to be a gradual process.

Despite the US ban, the chips production capacity of China is still growing rapidly, and in order to maintain this growth rate, the country is offering competitive pricing. Moreover, Chinese bargaining power will be influenced by industrial and automotive industries, that will require mature processes.

From an economic point of view, the emergence of China to become a major semiconductor player could upset the existing supply chains, reshape the division of labour and the distribution of human capital in the global electronics industry[229]. Instead from a security point of view, with the rise of China in semiconductor market, there is also the risk that chips made in China could be exploited to conduct cyber espionage. In addition, the status of Taiwan as leading manufacturer of semiconductors could be undermined by the Chinese self-sufficiency in semiconductor design and manufacturing.

[228] Araya, D., (2024-01-08), Will China Dominate the Global Semiconductor Market?, in "cigionline.org", https://www.cigionline.org/articles/will-china-dominate-the-global-semiconductor-market/ , 04-05-2024.

[229] Sauer, N., (2024-02-13), China's chip industry is gaining momentum - it could alter the global economical security landscape, in "the conversation.com", https://theconversation.com/chinas-chip-industry-is-gaining-momentum-it-could-alter-the-global-economic-and-security-landscape-222958 , 04-05-2024.

SECTION II

TERMINOGRAPHIC REPERTOIRE

<Subject>Computer science, knowledge, and systems

<Subfield>Systems

<en>Embedded system

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^Zhang/Li 2023^:01

<Lexica>Found in ^dictionary.cambridge.org, dictionary^

<Definition>A computer system that does a particular task inside a machine or larger electrical system.

<Source> ^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/embedded-system (2024)

<Context> The complexity of an Embedded System varies widely based on its intended function, ranging from a single microcontroller to a network of processors interconnected with peripherals and interfaces, encompassing anything from rudimentary user interfaces to intricate graphical displays.

<Source>^Fedrigo 2024^

<Concept field>Systems engineering

<Equivalence en-zh>There is full conceptual identity between “Embedded systems” and “嵌入式系统” terms

<zh>嵌入式系统

<Morphosyntax>noun group, inv., count.

<Usage label>main term

<Source>^李/刘/王 2006^:01

<Definition>嵌入式系统是用来控制、监视或辅助设备、机器或工厂运行的装置。一词表明嵌入式系统是以上大规模系统中不可或缺的一部分。

<Source>^李/刘/王 2006^:01

<Context>嵌入式系统是计算机软件与硬件的综合体，它是以应用为中心，以计算机技术为基础，软硬件可裁剪，从而能够适应实际用中对功能、可靠性、成本、体制、功耗等严格要求的专用计算系统。

<Source>李/刘/王 2006^:01

<Concept field>系统工程

**

<Subject>Computer science, knowledge, and systems

<Subfield>Data processing and computer science

<en>Microprocessor

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Jia/Valavi/Tang/Zhang/Verma 2020^:2609

<Lexica>Found in^dictionary.cambridge.org, dictionary^

<Definition>A part of a computer that controls its main operations.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/microprocessor (2024)

<Context>Intel 4004 is known as the first microprocessor, though it was not very powerful, as it could only perform simple 4-bit arithmetic operations. Meanwhile, Texas Instrument (TI) also filed a patent on microprocessors, which was issued in 1973 . TI's first microprocessor was introduced in 1974, with the name TMS1000, which was also a 4-bit microprocessor with 32 byte RAM and 1 KB ROM. It initiated an avalanche of research and development in this field. Continued interest in improvement in IC technology led to a diverse range of 8- and 16-bit microprocessors within the next few years.

<Source>^Khan/Pasha/Masud 2021^:06

<Concept field>Processors

<Equivalence en-zh>There is full conceptual identity between "Microprocessor" and "微处理器" terms

<zh>微处理器

<Morphosyntax>noun

<Usage label>main term

<Source>^张/张/高 2005^:01

<Definition>微处理器又称为中央处理器 (Central Processing Unit, CPU) 。它利用半导体集成技术，将运算器 (Arithmetic Logic Unit, ALU) 、控制器 (Control Unit, CU) 和寄存器组 (Registers) 等功能部件通过内部总线集成在一块硅片上。它虽然不是一台计算机，却是成微型机的核心部分。

<Source>^张/张/高 2005^:01

<Context>嵌入式微处理器 (Embedded Microprocessors) 是由微处理器来的，它不附加内部存储器，依靠三总线与片外存储器连接起来，使用原微处理器的指令系统，不需要重新学习。

<Source>^张/张/高 2005^:06

<Concept field>处理器

**

<Subject>Computer science, information, and general works

<Subfield>Special computer methods

<en>Artificial intelligence (AI)

<Morphosyntax>noun, uncount,

<Usage label>main term

<Source>^britannica.com, encyclopaedia^

<Lexica>Found in^dictionary.cambridge.org, dictionary^

<Definition>The ability of a digital computer or computer controlled robot to perform task commonly associated with intelligent beings.

<Source>^britannica.com, encyclopaedia^ , https://www.britannica.com/technology/artificial-intelligence (2024)

<Context>Managing artificial intelligence involves communicating, leading, coordinating, and controlling an ever-evolving frontier of computational advancements that references human intelligence in addressing ever more complex decision-making problems.

<Source>^Berente/Gu/Recker/Santhanam 2021^:1433

<Concept field>Computer activity

<Equivalence en-zh>There is full conceptual identity between “Artificial intelligence” and “工人职能” terms

<zh>人工智能

<Morphosyntax>noun

<Usage label>main term

<Source>^郑 2019^:201914-1

<Definition>人工智能（Artificial Intelligence），英文缩写为AI。是新一轮科技革命和产业变革的重要驱动力量，是研究、开发用于模拟、延伸和扩展人的智能的理论、方法、技术及应用系统的一门新的技术科学。

<Source>^baike.baidu.com, 网络百科全书^ , https://baike.baidu.com/item/人工智能/9180 (2024）

<Context> 当前的人工智能系统在不同层次上都依赖大量的样本训练完成有监督的学习，真正的通用智能会在经验和知识积累的基础上灵巧地无监督学习。

<Source>^郑 2019^:201914-1

<Concept field>计算机活动

**

<Subject>Computer science, knowledge, and systems

<Subfield>Knowledge

<en>Internet of Things (IoT)

<Morphosyntax>noun

<Usage label>main term

<Source>^Rose/Eldridge/Chapin 2015^:1

<Lexica>Found in^dictionary.cambridge.com, dictionary^ , https://dictionary.cambridge.org/dictionary/english/internet-of-things (2024)

<Definition>The term Internet of Things generally refers to scenarios where network connectivity and computing capability extends to objects, sensors and everyday items not normally considered computers, allowing these devices to generate, exchange and consume data with minimal human intervention.

<Source>^Rose/Eldridge/Chapin 2015^:1

<Context>Despite the global buzz around the Internet of Things, there is no single, universally accepted definition for the term. Different definitions are used by various groups to describe or promote a particular view of what IoT means and its most important attributes. Some definitions specify the concept of the Internet or the Internet Protocol (IP), while others, perhaps surprisingly, do not.

<Source>^Rose/Eldridge/Chapin 2015^:11

<Concept field>Internet and telecoms

<Equivalence en-zh>There is full conceptual identity between “Internet of Things” and “物联网” terms

<zh>物联网

<Morphosyntax>noun

<Usage label>main term

<Source>^刘/崔/陈 2010^:2

<Definition>物联网起源于传媒领域，是信息科技产业的第三次革命。物联网是指通过信息传感设备，按约定的协议，将任何物体与网络相连接，物体通过信息传播媒介进行信息交换和通信，以实现智能化识别、定位、跟踪、监管等功能。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/物联网/7306589 (2024)

<Context>物联网具有其基本属性，实现了任何物体、任何人在任何 时间、任何地点，使用任何路径／网络以及任何设备的连接。因此，物联网的相关属性包括集中、内容、收集、计算、通信以 及场景的连通性

<Source>^刘/崔/陈 2010^:2

<Concept field>互联网与电信

**

<Subject>Computer science, knowledge, and systems

<Subfield>Computer programming, programs, and data

<en>To encrypt

<Morphosyntax>verb

<Source>^Abdullah 2017^:10

<Lexica>Found in^dictionary.cambridge.org, dictionary^

<Definition>To change electronic information or signals into a secret code (system of letters, numbers, or symbols) that people cannot understand or use on normal equipment.

<Source>^dictionary.cambridge.org, dictionary^ , https://dictionary.cambridge.org/dictionary/english/encrypt?q=to+encrypt (2024)

<Context>Various kind of algorithms are exist to encrypt data. Advanced encryption standard (AES) algorithm is one of the efficient algorithm and it is widely supported and adopted on hardware and software.

<Source>^Abdullah 2017^:10

<Concept field>Programming language

<Equivalence en-zh>There is full conceptual identity between “To encrypt” and “加密” terms

<zh>加密

<Morphosyntax>verb

<Source>^黄/桂/余/庄 2011^:2392

<Lexica>按^baike.baidu.com, 网络百科全书^

<Definition>通过某种特殊的算法，来改变原有的信息数据，使得未授权的用户即使获得了已加密的信息，但因不知解密的方法，仍然无法了解信息的内容。

<Source>按^baike.baidu.com, 网络百科全书^，https://baike.baidu.com/item/加密?fromModule=lemma_search-box (2024)

<Context>加密是一种常用的保护用户隐私数据的方法，但目前的大多数加密方案都不支持对密文的运算，如对加密的文件进行模糊检索、对加密的公司财务信息进行统计分析等，因而严重妨碍了云服务商为用户提供更进一步的数据管理和运算服务，从而削弱了云计算的优势．针对上述问题，本文提出了一个基于矩阵和向量运算的可计算加密方案 CESVMC (Computable Encryption Scheme based on Vector and Matrix Caltulations)。

<Source>^黄/桂/余/庄 2011^:2392

<Concept field>程序设计语言

**

<Subject>Computer science, knowledge, and systems

<Subfield>Computer programming, programs, and data

<en>To decrypt

<Morphosyntax>verb

<Source>^Ako/Roza 2016^:12

<Lexica>Found in^dictionary.cambridge.org, dictionary^

<Definition>To change electronic information or signals that were stored, written, or sent in the form of a secret code (a system of letters, numbers, or symbols) back into a form that you can understand and use normally.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/decrypt?q=to+decrypt (2024)

<Context>The message could not be decrypted without using encrypting key. One of the issue is appeared with cryptography is that the message always clear to intermediate person that the message is encrypted form. This means that the sender of the message does not want it to be read by unauthorized person. Today, there are many cryptography techniques which are capable of encrypting data, one of the most widely technique is Affine algorithm.

<Source>^Abdullah/Aziz 2016^:12

<Concept field>Programming language

<Equivalence en-zh>There is full conceptual identity between “To decrypt” and “解密” terms

<zh>解密

<Morphosyntax>verb

<Source>^毕 2024^144

<Lexica>按^baike.baidu.com, 网络百科全书^

<Definition>加密过程的逆过程称为解密，即将该编码信息转化为明文的过程。

<Source>按^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/数据加密与解密/7112126?fromModule=search-result_lemma-recommend (2024)

<Context>数据加密技术是一种通过特定的算法将明文数据转换为密文数据的过程。在解密时，使用相同的密钥或算法将密文数据还原为明文数据。加密和解密的过程都需要密钥，且密钥需要保密。通过数据加密，可以防止未经授权的人员获取敏感信息，从而保护网络通信的安全

<Source>^毕 2024^144

<Concept field>程序设计语言

**

<Subject>Computer science, information, and general works

<Subfield>Computer programming, programs, and data

<en>Flash memory

<Morphosyntax>noun, count.

<Source>^Gal/Toledo 2005^:138

<Lexica>Found in^britannica.com, encyclopedia^

<Definition>Is a data-storage medium used with computers and other electronic devices. Unlike previous forms of data storage, flash memory is an EEPROM (electronically erasable programmable read-only memory) form of computer memory and thus does not require a power source to retain the data.

<Source>^britannica.com, encyclopedia^, https://www.britannica.com/technology/flash-memory (2024)

<Context>The read/write/erase behaviours of flash memory is radically different than that of other programmable memories such as volatile RAM and magnetic disks. Perhaps more importantly, memory cells in a flash device (as well as in other types of EEPROM memory) can be written to only a limited number of times, between 10,000 and 1,000,000, after which they wear out and become unreliable.

<Source>^Gal/Toledo 2005^:138

<Concept fiedl>Electronics

<Equivalence en-zh>There is full conceptual identity between “Flash memory” and “快闪存储器” terms

<zh>快闪存储器 （闪存）

<Morphosyntax>noun

<Source>^王/赖/孟 2013^:1550

<Lexica>按^baike.baidu.com, 网络百科全书^

<Definition>快闪存储器是一种电子式可清除程序化只读存储器的形式，允许在操作中被多次擦或写的存储器。这种科技主要用于一般性数据存储，以及在计算机与其他数字产品间交换传输数据，如储存卡与U盘。闪存是一种特殊的、以宏块抹写的EPROM。早期的闪存进行一次抹除，就会清除掉整颗芯片上的数据

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/闪存?fromModule=lemma_search-box (2024)

<Context>闪存是一种全电设备，通过电子电路来读取数据，具有非易失、极高的读写速度、抗震、低功耗、体积小等特性，目前已经广泛应用于嵌入式系统、航空航天、消费电子等领。

<Source>^王/赖/孟 2013^:1550

<Concept field>电子学

**

<Subject>Computer science, information, and general works

<Subfield>Computer programming, programs, and data

<en>In-system programming

<Morphosyntax>noun group

<Source>^Bonnet 1999^:253

<Definition>In-System Programming (abbreviation ISP), also known as In-Circuit Serial Programming (ICSP), is a technique applied to program different electronic devices such as microcontrollers and chipsets while they are installed on a printed circuit board (PCB), rather than programming them before installation (also known as Pre-programming technique).

<Source>^Fedrigo 2024^

<Context>The benefits of ISP are becoming widely known andaccepted, but many times they are not realized in new designs because designers have not anticipated the problems that may occur. ISP requires a new approach to design, just as test must be considered during design. There are many issues that must be considered to ensure that you gain all the benefits of ISP throughout the product life cycle.

<Source>^Bonnet 1999^:253

<Concept field>Programming language

<Equivalence en-zh>There is full conceptual identity between “In-system programming” and “在线烧录” terms

<zh>在线烧录

<Morphosyntax>noun group

<Source>^张 2012^:65

<Definition>在线烧录是可以烧录已焊接在印刷电路板上的可程式化逻辑装置、单片机或是其他嵌入式系统的技术。传统的烧录方式是在元件安装之前先烧录韧体，烧录后再焊接到电路板上。透过在线烧录技术，也可以烧录微控制器以及其他处理器上的记忆体，不需专用的烧录硬体，因此可以简化设计工作。

<Source>^zh.wikipedia.org，百科全书^, https://zh.wikipedia.org/zh-hans/在線燒錄 （2024）

<Context>Atmel公司的AVR系列单片机具有高速度、低功耗、ISP在线烧录、BootLoader等功能，受到工程师和学生们的喜爱。

<Source>^张 2012^:65

<Concept field>程序设计语言

**

<Subject>Computer science, information, and general works

<Subfield>Engineering

<en>Microchip

<Morphosyntax>noun, cout.

<Usage label>main term

<Source>^Kricka/Wilding 2003^:823

<Lexica>Found in^dictionary.cambridge.org, dictionary^

<Definition>A very small piece of semiconductor, especially in a computer, that contains extremely small electronic circuits and devices, and can perform particular operations.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/chip (2024)

<Context>An advantage of the oxide method is that it can be performed at the wafer stage during microchip fabrication and it does not interfere with subsequent capping of the microchips with Pyrex glass using an anodic bonding process. Other examples of this type of passivation are silanization of internal surfaces. This is accomplished by filling a chip with a silanizing agent and incubating the filled microchip for a period of time, then emptying and washing the microchip.

<Source>^Kricka/Wilding 2003^:823

<Concept field>Electronics

<Equivalence en-zh>There is full conceptual identity between “Microchip” and “微芯片” terms

<zh>微芯片

<Morphosyntax>noun

<Usage label>main term

<Source>^张 2023^:209

<Lexica>按^Il dizionario di Cinese, Zanichelli^:865

<Definition>微芯片（有时简称芯片）是一片包起来的计算机电路（一般叫集成电路），它是用一种原料例如硅在很小的体积上制成的。微芯片是用来进行程序逻辑（逻辑或微处理器芯片）和计算机存贮（存贮器或可存期存贮器）的。微芯片也用来既包括逻辑又包括存贮，还可能为了特殊目的，例如模拟数字转化、位片和网关。

<Source>^baike.daidu.com, 网络百科全书^, https://baike.baidu.com/item/微芯片?fromModule=lemma_search-box (2024)

<Context>芯片专业称为半导体集成电路是所有电子整机设备的 心脏，芯片一般分类为数字芯片、模拟芯片和其他芯片几个 大类，芯片具有存储、逻辑电路、电源管理、信号处理等各 种功能，被广泛地应用在手机、汽车、家电、可穿戴设备、 工业智能装备、人工智能物联网、自动驾驶、航空航天等产 业中，芯片因其在制造业中的巨大作用也被称为工业制造品 中的皇冠，在电子制造业中具有不可替代的核心作用，芯片 安全事关产业安全、芯片供应稳定事关经济发展的稳定。

<Source>^张 2023^:209

<Concept field>电子学

**

<Subject>Technology

<Subfield>Engineering

<en>Integrated circuit (IC)

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Wanhammar 1999^:25

<Lexica>Found in^britannica.com, encyclopedia^

<Definition>integrated circuit (IC) is an assembly of electronic components, fabricated as a single unit, in which miniaturized active devices (e.g., transistors and diodes) and passive devices (e.g., capacitors and resistors) and their interconnections are built up on a thin substrate of semiconductor material (typically silicon). The resulting circuit is thus a small monolithic "chip," which may be as small as a few square centimetres or only a few square millimetres. The individual circuit components are generally microscopic in size.

<Source>^britannica.com, encyclopedia^, https://www.britannica.com/technology/integrated-circuit (2024)

<Context>The integrated circuit design phase can be more or less sophisticated, from fully automatic chip generation, down to hand-crafted design of every transistor.

<Source>^Wanhammar 1999^:25

<Concept field>Electronics

<Equivalence en-zh>There is full conceptual identity between "Integrated circuit" and "集成电路" terms

<zh>集成电路

<Morphosyntax>noun group

<Usage label>main term

<Source>^何/编 2002^:i

<Lexica>按^youdao.com，词典^

<Definition>集成电路是一种将多个电子元件（如晶体管、电容、电阻等）集成在一起形成的微小电路，通常被用于计算机、手机、电视等电子设备中。

<Source>^youdao.com，词典^, https://www.youdao.com/result?word=integrated%20circuit&lang=en (2024)

<Context>集成电路的体积小，可靠性高，调试方便，使用灵活，越来越受人们的重视。要想设计出高质量的电子产品，除了总体方案最佳外， 还离不开集成电路构成的性能优良的单元电路。

<Source>^何/编 2002^:i

<Concept field>电子学

**

<Subject>Computer science, information, and general works

<Subfield>Computer programming, programs, and data

<en>Network protocol

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^Zander/Branch 2007^:44

<Lexica>Found in^britannica.com, encyclopaedia^

<Definition>In computer science, a set of rules or procedures for transmitting data between electronic devices, such as computers. In order for computers to exchange information, there must be a preexisting agreement as to how the information will be structured and how each side will send and receive it.

<Source>^britannica.com, encyclopedia^ , https://www.britannica.com/technology/protocol-computer-science (2024)

<Context>Covert channels in computer network protocols are similar to techniques for hiding information in audio, visual or textual content (steganography). While steganography requires some form of content as cover, covert channels require some network protocol as carrier.

<Source>^Zander/Branch 2007^:44

<Concept field>Programming language

<Equivalence en-zh>There is full conceptual identity between “Network protocol” and “网络协议” terms

<zh>网络协议

<Morphosyntax>noun group

<Source>^李/张/刘李 2011^:243

<Lexica>按^youdao.com, 词典^

<Definition>计算机网络协议是为了实现计算机网络中不同平台、不同网络、不同操作系统之间的通信而规定的一系列规则、标准和约定，它是正确进行通信的基础。

<Source>^youdao.com, 词典^, https://www.youdao.com/result?word=网络协议&lang=en (2024)

<Context>在网络协议逆向工程领域，国内外进行了较为深入的研究，主要分为两个大的方向：一个方向是单纯利用网络流量来推测网络协议，这类方法也称为基于“Network Trace”的方法；另外一个方向是对实现网络协议的服务器程序进行二进制的动态跟踪分析，通过跟踪二进制文件对报文的处理流程对报文进行解析，这种方法也称为基于“Tainted Data”的方

<Source>^李/张/刘李 2011^:243

<Concept field>程序设计语言

**

<Subject>Technology

<Subfield>Engineering

<en>Wire rod

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Laber 2024^:1

<Definition>Wire rod is a long steel semi-finished product manufactured by hot rolling billets on continuous rolling mills. It has a round cross-section and is wound up in coils.

<Source>^Fedrigo 2024^

<Context>The quality of a wire rod is mainly determined by the temperature–strain rolling parameters in the finishing rolling blocks and the cooling rate of the wire rod on the roller conveyor using blown air.

<Source>^Laber 2024^:1

<Concept field>Metallurgy

<Equivalence en-zh>There is full conceptual identity between “Wire rod” and “线材” terms

<zh>线材

<Morphosyntax>noun group

<Source>^张 2024^:1

<Lexica>按^youdao.com, 词典^

<Definition>用于拉制线材的金属棒

<Source>^youdao.com, 词典^, https://www.youdao.com/result?word=wire%20rod&lang=en (2024)

<Context>Bi-2212线材是目前唯一能够制备成圆线的高温超导材料，因其具有高临界磁场、高电流密度等优异性能已成为超导科学与技术领域的研究热点。

<Source>^张 2024^:1

<Concept field>冶金学

**

<Subject>Technology

<Subfield>Engineering

<en>Programmer

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Moyer 1999^:167

<Definition>The process used to writing programs for integrated circuits

<Source>^Fedrigo 2024^

<Context>This means that a programming environment - whether a device programmer or an embedded system - no longer has to wait for a long development of a particular programming algorithm for new device.

<Source>^Moyer 1999^:167

<Concept field>Computing

<Equivalence en-zh>There is full conceptual identity between “Programmer” and “编程器” terms

<zh>编程器

<Morphosyntax>noun group

<Source>^王/王 2008^:58

<Lexica>按^baike.baidu.com, 百科全书^

<Definition>编程器为可编程的集成电路写入数据的工具,编程器主要用于单片机（含嵌入式）/存储器(含BIOS)之类的芯片的编程（或称刷写）。编程器主要修改只读存储器中的程序，编程器通常与计算机连接，再配合编程软件使用。

<Source>^baike.baidu.com, 王百科全书^, https://baike.baidu.com/item/编程器?fromtitle=烧录器&fromid=1975398&fromModule=lemma_search-box (2024)

<Context>目前，编程器的设计方案主要有两种131：一种是直接采用Freescale公司提供的技术手册中的监控模式编程电路。通过PC机的串行口直接对目标MCU编程；另一种是基板一适配器方案，PC机通过基板上主控MCU实现对适配器上目标MCU的编程，此时目标MCU必须处于监控状态。

<Source>^王/王 2008^:58

<Concept field>计算

**

<Subject>Technology

<Subfield>Electronics

<en>Power dissipation

<Morphosyntax>group noun, uncount.

<Usage label>main term

<Source>^Srivastva/Sarkar^:117

<Definition>The process in which an electric or electronic device produces heat (or other waste energy) as an unwanted byproduct of its primary action.

<Source>^en.wikitionary.org, dictionary^ https://en.wiktionary.org/wiki/power_dissipation#:~:text=power%20dissipation%20(uncountable),central%20concern%20in%20computer%20architecture (2024)

<Context>the power dissipation for a QCA circuit can be expressed as the sum of power estimates computed on a per cell basis. Each cell in a QCA circuit sees three types of events: 1) clock going from low to high so as to "depolarize" a cell; 2) input or cells in previous clock zone switching states; and 3) clock changing from high to low, latching and holding the cell state to the new state.

<Source>^Srivastva/Sarkar^:117

<Concept field>Energy

<Equivalence en-zh>There is full conceptual identity between "Power dissipation" and "功耗" terms

<zh>功耗

<Morphosyntax>noun

<Source>^刘/杨/李/吕/孙 2024^:201

<Lexica>按^youdao.com, 词典^

<Definition>电力或电子设备在其主要作用的同时产生热量（或其他废能）作为其不需要的副产品的过程。

<Source>^youdao.com, 词典^ , https://www.youdao.com/result?word=功耗&lang=en (2024)

<Context>具体而言,装备平台开发时面临众多的约束条件,如便携装备要求整体体积尽量小,应尽量缩小器件体积,减少部署所需器件数量,同时也对低功耗提出了极端苛求。

<Source>^刘/杨/李/吕/孙 2024^:201

<Concept field>能源

**

<Subject>Computer science, knowledge, and systems

<Subfield>Data processing and computer science

<en>Cloud computing

<Morphosyntax>noun, uncount.

<Usage label>main term

<Source>^Boss/Malladi/Quan/Legregni/Hall 2007^:4

<Lexica>Found in^britannica.com, encyclopedia^

<Definition>method of running application software and storing related data in central computer systems and providing customers or other users access to them through the Internet.

<Source>^britannica.com, encyclopedia^ , https://www.britannica.com/technology/cloud-computing (2024)

<Context>Cloud computing also describes applications that are extended to be accessible through the Internet. These cloud applications use large data centers and powerful servers that host Web applications and Web services. Anyone with a suitable Internet connection and a standard browser can access a cloud application.

<Source>^Boss/Malladi/Quan/Legregni/Hall 2007^:4

<Concept field>Computing

<Equivalence en-zh>There is full conceptual identity between “ ” and “ ” terms

<zh>云计算

<Morphosyntax>noun

<Source>^baike.baidu.com, 百科全书^

<Lexica>按^youdao.com, 词典^

<Definition>将经常使用的计算机数据存储在多个服务器上，并通过互联网进行访问的一种实践。

<Source>^youdao.com, 词典^, https://www.youdao.com/result?word=云计算&lang=en (2024)

<Concept field>计算

**

<Subject>Computer science, information, and general works

<Subfield>Special computer methods

<en>Augmented reality (AR)

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^en.wikitiorary.org, dictionary^

<Definition>The merging of a view of the real-world environment upon a digital image in real time.

<Source>^en.wikitiorary.org, dictionary^, https://en.wiktionary.org/wiki/augmented_reality (2024)

<Context>We define Augmented Reality (AR) as a real-time direct or indirect view of a physical real-world environment that has been enhanced by adding virtual computer-generated information to it.

<Source>^Carmigniani 2011^

<Concept field>Technological innovations

<Equivalence en-zh>There is full conceptual identity between “Augmented reality” and “增强现实” terms

<zh>增强现实

<Morphosyntax>noun

<Source>^朱/姚/蒋 2004^:766

<Definition>增强现实技术是一种将虚拟信息与真实世界巧妙融合的技术，广泛运用了多媒体、三维建模、实时跟踪及注册、智能交互、传感等多种技术手段，将计算机生成的文字、图像、三维模型、音乐、视频等虚拟信息模拟仿真后，应用到真实世界中，两种信息互为补充，从而实现对真实世界的“增强”。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/增强现实/1889025 (2024)

<Context>与传统虚拟现实技术所要达到的完全沉浸的效果不同;增强现实技术致力于将计算机生成的物体叠加到现实景物上。

<Source>^朱/姚/蒋 2004^:766

<Concept field>技术革新

**

<Subject>Computer science, information, and general works

<Subfield>Special computer methods

<en>Virtual reality (VR)

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^Zheng/Chan/Gibson 1998^:20

<Definition>A set of images and sounds, produced by a computer, that seem to represent a place or a situation that a person can take part in .

<Source>^dictiornary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/virtual-reality?q=virtual+reality+ (2024)

<Context>Virtual reality (VR) is an advanced, human-computer interface that simulates a realistic environment. The participants can move around in the virtual world. They can see it from different angles, reach into it, grab it and reshape it.

<Source>^Zheng/Chan/Gibson 1998^:20

<Concept field>Technological innovations

<Equivalence en-zh>There is full conceptual identity between “Virtual reality” and “虚拟现实” terms

<zh>虚拟现实

<Morphosyntax>noun group

<Source>^张 2001^:1

<Lexica>按^baike.baidu.com, 百科全书^

<Definition>增强现实技术是一种将虚拟信息与真实世界巧妙融合的技术，广泛运用了多媒体、三维建模、实时跟踪及注册、智能交互、传感等多种技术手段，将计算机生成的文字、图像、三维模型、音乐、视频等虚拟信息模拟仿真后，应用到真实世界中，两种信息互为补充，从而实现对真实世界的“增强”。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/增强现实/1889025 (2024)

<Context>虚拟现实通常是指用头盔显示器和传感手套等一系列新型交互设备构造出的一种计算机软硬件环境， 人们通过这些设施以自然的技能（如头的转动、身体的运动等） 向计算机送入各种命令， 并得到计算机对用户的视觉、听觉及触觉等多种感官的反馈。

<Source>^张 2001^:1

<Concept field>技术革新

**

<Subject>Computer science, knowledge, and systems

<Subfield>Computer programming, programs, and data

<en>Software

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Leveson 1986^:125

<Definition>The instruction that control what a computer does, computer programs.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/software (2024)

<Context>Both computer scientists and system engineers are finding themselves faced with difficult and unsolved problems regarding the safety of the software used in these systems.

<Source>^Leveson 1986^:125

<Concept field>Computer program

<Equivalence en-zh>There is full conceptual identity between “Software” and “软件” terms

<zh>软件

<Morphosyntax>noun

<Source>^梅/申 2006^:1257

<Lexica>按^youdao.com, 词典^

<Definition>软件是一系列按照特定顺序组织的计算机数据和指令的集合。一般来讲软件被划分为系统软件、应用软件和介于这两者之间的中间件。

<Source>^baike.baidu.com, 网路百科全书^, https://baike.baidu.com/item/软件/12053 (2024)

<Context>作为控制软件复杂性、提高软件系统质量、支持软件开发和复用的重要手段之一,软件体系结构自提出以来,日益受到软件研究者和实践者的关注,并发展成为软件工程的一个重要的研究领域。

<Source>^梅/申 2006^:1257

<Concept field>计算机程序

**

<Subject>Computer science, knowledge, and systems

<Subfield>Computing

<en>Hardware

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Rowson 1994^:439

<Definition>computer machinery and equipment, including memory, cabling, power supply, peripheral devices, and circuit boards. Hardware design specifies the computer’s capability.

<Source>^britannica.com, encyclopedia^, https://www.britannica.com/technology/hardware-computing (2024)

<Context>If the software and the hardware communicate through asynchronous communication methods such that time between communications has no effect on functionality, then an even faster method of simulation is available.

<Source>^Rowson 1994^:439

<Concept field>Computer parts

<Equivalence en-zh>There is full conceptual identity between “Hardware” and “硬件” terms

<zh>硬件

<Morphosyntax>noun

<Source>^李/鄂/葛/钱 2006^:2404

<Definition>硬件是计算机硬件的简称是指计算机系统中由电子，机械和光电元件等组成的各种物理装置的总称。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/硬件?fromModule=lemma_search-box (2024)

<Context>随着各种新的应用的出现，基于软件的实现已经不能充分满足对匹配速度日益增长的需求，因此，基于硬件的多模式匹配的实现逐渐出现，并成为当前的研究热点。

<Source>^李/鄂/葛/钱 2006^:2404

<Concept field>计算机零部件

**

<Subject>Computer science, information, and general works

<Subfield>Knowledge

<en>Hacker

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^McKenzie 2006^:320

<Definition>Information technology professionals or enthusiasts who compromise the security of computers.

<Source>^britannica.com, encyclopedia^, https://www.britannica.com/topic/hacker (2024)

<Context>The figure of the “hacker” is a new and distinctive one in the social history of the late 20th century. The hacker probably first emerged out of the electrical engineering labs at the Massachusetts Institute for Technology (MIT).

<Source>^McKenzie 2006^:320

<Concept field>Software professionals

<Equivalence en-zh>There is full conceptual identity between “Hacker” and “黑客” terms

<zh>黑客

<Morphosyntax>noun

<Source>^海 2022^:3

<Lexica>按^赵 2020^:357

<Definition>黑客是热心于计算机技术,水平高超的电脑专家,尤其是程序设计人员。他们要对计算机了如指掌对网络很精通才能算一个黑客高手。

<Source>^youdao.com, 词典^, https://www.youdao.com/result?word=Hacker&lang=en (2024)

<Context>黑客对有趣的事情也充满激情，这使他们精神振奋纪60年代的麻省理工学院开始，早期的黑客每天下午打醒来，就开始充满激情的编程。

<Source>^海 2022^:3

<Concept field>软件专业

**

<Subject>Technology

<Subfield>Hardware and household appliances

<en>Adapter

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Dorofeev/Cheng/Guedes/Ferreira/Profanter/Zoitl 2017^:3

<Definition>A type of plugs that makes it possible to connect two or more pieces of equipment to the same electrical supply.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/it/dizionario/inglese/adapter (2024)

<Context>After the device is being plugged in the production system, the device adapter should start the communication to the middleware. The adapter should be informed about: (1) the IP address of the middleware controller, (2) the entities who initiate the communication, and (3) the methods how to perform registration.

<Source>^Dorofeev, Cheng, Guedes, Ferreira, Profanter, Zoitl 2017^:3

<Concept field>Device

<Equivalence en-zh>There is full conceptual identity between “Adapter” and “适配器” terms

<zh>适配器

<Morphosyntax>noun

<Source>^付/肖/周/孔^:228

<Definition> 适配器是一个接口转换器，它可以是一个独立的硬件接口设备，允许硬件或电子接口与其它硬件或电子接口相连，也可以是信息接口。比如：电源适配器、三角架基座转接部件、USB与串口的转接设备等。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/适配器/908851#:~:text=适配器是一个接口转换,的转接设备等%E3%80%82 （2024）

<Context>采用RTUA 可以减少适配器的数量、降低测试系统的构建成本，有效解决了资源专用和适配器重复开发问题。

<Source>^付/肖/周/孔 2009^:228

<Concept field>器件

**

<Subject>Computer science, information, and general works

<Subfield>Data processing and computer science

<en>Asymmetric cryptography

<Morphosyntax>group noun, uncount.

<Usage label>main term

<Source>^Pointcheval 2002^:45

<Definition>Asymmetric cryptography is the field of cryptography systems that use pairs of related keys. Each key pair consists of a public key and a corresponding private key. Key pairs are generated with cryptographic algorithms based on mathematical problems termed one-way functions.

<Source>^en.wikipedia.org, encyclopedia^ , https://en.wikipedia.org/wiki/Public-key_cryptography (2024)

<Context>On the other hand, an attacker can play many kinds of at-tacks, according to the available information:since weare considering asymmetric encryption, the adversary can encrypt any plaintext of her choice, granted the public key, hence the chosen-plaintext attack (CPA).

<Source>^Pointcheval 2002^:45

<Concept field>Telecommunication

<Equivalence en-zh>There is full conceptual identity between “Asymmetric encryption” and “非对称加密” terms

<zh>非对称加密

<Morphosyntax>noun group

<Source>^卓/赵/曾 2010^:562

<Definition>公钥加密，也叫非对称（密钥）加密，属于通信科技下的网络安全二级学科，指的是由对应的一对唯一性密钥（即公开密钥和私有密钥）组成的加密方法。它解决了密钥的发布和管理问题，是商业密码的核心。在公钥加密体制中，没有公开的是私钥，公开的是公钥。

<Source>^baike.baidu.com, 网路百科全书^, https://baike.baidu.com/item/公钥加密?fromtitle=非对称加密&fromid=9874417&fromModule=lemma_search-box (2024)

<Variant of>公钥加密

<Context>非对称加密技术使用不同的密钥进行加密和解密操作, 不同于对称加密, 在非对称加密中, 加密密钥仅用于加密而对解密完全无用; 解密密钥仅用于解密而对加密无用。

<Source>^卓/赵/曾 2010^:562

<Concept field>通信

**

<Subject>Computer science, information and general works

<Subfield>Systems

<en>Automotive advanced driver-assistance system

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^Choi/Thalmayr/Wee/Weig 2016^:1

<Definition>Advanced driver-assistance systems (ADAS) are technologies that assist drivers with the safe operation of a vehicle. Through a human-machina interface, ADAS increase car and road safety. ADAS use automated technology, such as sensors and cameras, to detect nearby obstacles or driver errors, and respond accordingly. ADAS can enable various levels of autonomous driving.

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/Advanced_driver-assistance_system (2024)

<Context>Demand for advanced driver-assistance systems (ADAS)—those that help with monitoring, warning, braking, and steering tasks—is expected to increase over the next decade, fueled largely by regulatory and consumer interest in safety applications that protect drivers and reduce accidents.

<Source>^Choi/Thalmayr/Wee/Weig 2016^:1

<Concept field>Automotive

<Equivalence en-zh>There is full conceptual identity between "Automotive advanced driver-assistance system" and "先进驾驶辅助系统" terms

<zh>先进驾驶辅助系统

<Morphosyntax>noun group

<Source>^孙 2009^:4

<Lexica>按^zgbk.com, 中国大百科全书^, https://www.zgbk.com/ecph/words?SiteID=1&ID=554592&Type=bkzyb&SubID=230809 (2024)

<Definition>利用安装在车上的各式各样传感器，在汽车行驶过程中随时感应周围的环境，收集数据，进行静态、动态物体的辨识、侦测与追踪，并结合导航仪地图数据，进行系统的运算与分析，从而预先让驾驶者察觉到可能发生的危险，有效增加汽车驾驶的舒性和安全性的主动安全技术。

<Source>^zgbk.com, 中国大百科全书^, https://www.zgbk.com/ecph/words?SiteID=1&ID=554592&Type=bkzyb&SubID=230809 (2024)

<Context>先进驾驶辅助系统（Advanced Driver Assistance Systems） 简称ADAS， 是利用安装于车上各式各样的传感器， 在第一时间收集车内外的环境数据， 进行静、动态物体的辨识、侦测与追踪等技术上的处理， 从而能够让驾驶者在最快的时间察觉可能发生的危险。

<Source>^孙 2009^:4

<Concept field>汽车

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>Binary code

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^Meng/Miller 2016^:24

<Definition>Code used in digital computers, based on a binary number system in which there are only two possible states, off and on, usually symbolised by 0 and 1.

<Source>^britannica.com, encyclopedia^, https://www.britannica.com/technology/binary-code (2024)

<Context>Binary code analysis is used in a wide range of applications, including performance analysis, software reverse engineering, debugging, software reliability, software forensics and security.

<Source>^Meng/Miller 2016^:24

<Concept field>Data

<Equivalence en-zh>There is full conceptual identity between “Binary code” and “二进制编码” terms

<zh>二进制编码

<Morphosyntax>noun group

<Source>^刘/路/文/肖/严/刘 2023^:3

<Definition>由两个基本字符'0'、'1'组成的代码。其中，码元："一位"二进制代码。码字：N个码元可以组成的不同组合，任意一个组合称一个码字。

<Source>^baidu.baike.com, 网络百科全书^, https://baike.baidu.com/item/二进制代码/4879654 （2024）

<Context>二进制编码建立在相移法的基础上，使用进制转换的方式得到多幅二值条纹，并将其代替灰度正弦条纹。

<Source>^刘/路/文/肖/严/刘 2023^:3

<Concept field>数据

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>Bit error rate

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^Kumar/Gupta 2011^:11

<Definition>The bit error rate (BER) is the number of bit errors per unit time.

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/Bit_error_rate (2024)

<Variant of>BER

<Context>During digital data transmission and storage operations, performance criterion is commonly determined by bit error rate (BER) which is simply: Number of error bits / Number of total bits.

<Source>^Kumar/Gupta 2011^:11

<Concept field>Data

<Equivalence en-zh>There is full conceptual identity between “bit error rate” and “比特误码率” terms

<zh>比特误码率

<Morphosyntax>noun group

<Source>^张/范/赵/李/古 2024^:69

<Definition>是指单比特时间差错比特的数量。比特差错率是一段时间内差错比特的数量除以传输的总比特数。BER是一种无单比特的性能指标，通常以百分比的形式表示。

<Source>^baidu.baike.com, 网络百科全书^, https://baike.baidu.com/item/比特误码率?fromModule=lemma_search-box (2024)

<Context>系统使用Xilinx官方提供的集成比特误码率测试工具IBERT(integrated bit error ratio tester)来测试链路的误码率和眼图。

<Source>^张/范/赵/李/古 2024^:69

<Concept field>数据

**

<Subject>Computer science, information and general works

<Subfield>Systems

<en>Chipset

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Gringoli/Link/Schulz/Hollick 2019^:22

<Definition>A set of extremely small electronic circuits that performs a particular task in a computer or other piece of electronic equipment.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/chipset (2024)

<Context>Recenty, Quantenna Communications, a division of On Semiconductor that manufacturers Wi-Fi chipsets for high-end/enterprise Access Points, released a solution for exporting CSI data from 11ac APs serving stations.

<Source>^Gringoli/Link/Schulz/Hollick 2019^:22

<Concept field>Device

<Equivalence en-zh>There is full conceptual identity between “chipset” and “芯片组” terms

<zh>芯片组

<Morphosyntax>noun

<Source>^刘/王/李/安 2009^:38

<Lexica>按^zgbk.com, 中国大百科全书^, https://www.zgbk.com/ecph/words?SiteID=1&ID=216417&Type=bkzyb&SubID=81429 （2024）

<Definition>一系列相互关联的芯片组合。它们相互依赖、组合在一起能发挥更大的作用，比如计算机里面的处理器和南北桥芯片组，手机里面的射频、基带和电源管理芯片组。

<Source>^zgbk.com, 中国大百科全书^, https://www.zgbk.com/ecph/words?SiteID=1&ID=216417&Type=bkzyb&SubID=81429 （2024）

<Context>通过曙光5000芯片组”可以将两颗CPU聚合成为HPP计算单元"多个计算单元之间通过曙光5000高速网络接口及交换机进一步聚合成为HPP超节点。

<Source>^刘/王/李/安 2009^:38

<Concept field>器件

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>Connector

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Satoh 2017^:177

<Definition>A device or part of a device that makes it possible to connect one piece of electrical equipment to another by allowing contact between wires, electrical components, etc.

<Source>^dictionary.cambridge.com, dictionary^ https://dictionary.cambridge.org/it/dizionario/inglese/connector (2024)

<Context>The spatial connector that is connected to the virtual counterpart corresponding to his/her smart phone enables services that may be executed at pervasive computing devices and cloud computing platforms to access services provided in the virtual counterparts corresponding to the room.

<Source>^Satoh 2017^:177

<Concept field>Device

<Equivalence en-zh>There is full conceptual identity between “connector” and “连接器” terms

<zh>连接器

<Morphosyntax>noun

<Source>^王/赵/张 2024^:222

<Lexica>按^zgbk.com, 中国大百科全书^，https://www.zgbk.com/ecph/words?SiteID=1&ID=32630&Type=bkzyb&SubID=81429 （2024）

<Definition>把不同的电路（如印制电路）连接在一起的导电装置。在中国国内又称接插件、插头、插座。

<Source>^zgbk.com, 中国大百科全书^，https://www.zgbk.com/ecph/words?SiteID=1&ID=32630&Type=bkzyb&SubID=81429 （2024）

<Variant of>接插件、插头、插座。

<Context>PCB 走线可以通过走线的线宽、线距、叠层高度很好控制，而SMA 连接器是3D 模型，其阻抗控制难度较高。本文则对SMA 连接器做了重点研究设计，在SMA 下方挖平面的基础上，创新性的在SMA 连接器走线附近多处优化。

<Source>^王/赵/张 2024^:222

<Concept field>器件

**

<Subject>Computer science, information and general works

<Subfield>Systems

<en>Controller

<Morphosyntax>noun, count.

<Usage label>Main term

<Source>^Anderson/Liu 1987^:1

<Definition>A device used to operate or control a macine, a computer game, etc.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/it/dizionario/inglese/controller (2024)

<Context>Simple linear controllers are normally to be preferred to complex linear controllers for linear time-invariant plants: there are fewer things to go wrong in the hardware or bugs to fix in the software, they are easier to understand, and the computational requirements are less.

<Source>^Anderson/Liu 1987^:1

<Concept field>Device

<Equivalence en-zh>There is full conceptual identity between “Controller” and “控制器” terms

<zh>控制器

<Morphosyntax>noun

<Source>^郑/王/李/马 2013^:119

<Lexica>按^zgbk.com, 中国大百科全书^, https://www.zgbk.com/ecph/words?SiteID=1&ID=22750&Type=bkzyb&SubID=42669 （2024）

<Definition>控制器是一依据传感器信号，来调整发送至致动器的输出信号，用以改变受控体状况的装置。

<Source>^zh.wikipedia.org, 网络百科全书^, https://zh.wikipedia.org/zh-hans/控制器 (2024)

<Context>传统的方法中经常采用比例积分控制器，这类控制器实现简单，稳定性较好，但是控制的参数需要根据精确的控制模型参数来计算得到，其控制的性能往往受制于参数的准确度。

<Source>^郑/王/李/马 2013^:119

<Concept field>器件

**

<Subject>Computer science, information and general works

<Subfield>Computer programming, programs and data

<en>To debug

<Morphosyntax>verb, transit.

<Usage label>main term

<Source>^Vermeulen 2008^:208

<Definition>To remove bugs (=mistakes) from a computer program.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/debug (2024)

<Context>Traditionally, embedded-system debug is very difficult and time-consuming because of the intrinsic lack of internal system observability in the target environment.

<Source>^Vermeulen 2008^:208

<Concept field>Program

<Equivalence en-zh>There is full conceptual identity between “To debug” and “调试” terms

<zh>调试

<Morphosyntax>verb

<Source>^王 2024^:202

<Lexica>按^汉意-意汉 双解词典，词典^:778

<Definition>调试是保证所提供的设备能够正常运行的必须程序，所有费用由设备提供商负担。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/调试?fromModule=lemma_search-box (2024)

<Context>。然而，在实际工作中，一些安装人员可能缺乏必要的专业知识和技能，导致安装质量不佳或调试不准确。

<Source>^王 2024^:202

<Concept field>程序

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>Dedicated short-range communication

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^Nguyen/Shailesh/Sudhir/Kapil/Jiang/Wu/Malladi/Li 2017^:101

<Definition>Dedicated short-range communication (DSRC) is a technology for direct wireless exchange of vehicle-to-everything (V2X) and other intelligent transportation systems (ITS) data between vehicles, other road users (pedestrians, cyclists, etc.) and roadside infrastructure (traffic signals, electronic message signs, etc.).

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/Dedicated_short-range_communications (2024)

<Variant of>DSRC

<Context>Based on this study, one can see that Cellular V2X provides significant improvement over Dedicated Short Range Communication in terms of communication range, without suffering in other aspects. This improvement is equivalent to longer reaction time and more lives saved in the road.

<Source>^Nguyen/Shailesh/Sudhir/Kapil/Jiang/Wu/Malladi/Li 2017^:101

<Concept field>Communication

<Equivalence en-zh>There is full conceptual identity between “Dedicated short-range communication” and “专用短程通信” terms

<zh>交通专用短程通信

<Morphosyntax>noun group

<Source>^张 2024^:119

<Lexica>按^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/专用短程通信技术/6418494?fr=ge_ala (2024)

<Definition>用于智能交通系统领域车车、车路间的无线通信协议。简称DSRC。

<Source>^zgbk.com, 中国大百科全书^，https://www.zgbk.com/ecph/words?SiteID=1&ID=118494&Type=bkzyb&SubID=84209 （2024）

<Context>目前，常用的无线通信技术包括DSRC（专用短程通信）、WAVE（车辆环境无线接入）、LTE-V（长期演进-车辆）等。

<Source>^张 2024^:119

<Concept field>通讯

**

<Subject>Technology

<Subfield>Manufacturing

<en>Electronic manufacturing services

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^Valverde/Saadé 2013^:80

<Definition>Electronic manufacturing services (EMS) is a term used for companies that design, manufacture, test, distribute, and provide return/repair services for electronic components and assemblies for original equipment manufacturers (OEMs).

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/Electronics_manufacturing_services (2024)

<Variant of>EMS

<Context>The Electronic Manufacturing Services (EMS) suppliers are used by many companies as a strategic way to reduce time to market, decrease costs, improve quality, and improve overall customer satisfaction.

<Source>^Valverde/Saadé 2013^:80

<Concept field>Manufacture for specific use

<Equivalence en-zh>There is full conceptual identity between “Electronic manufacturing services” and “电子制造服务” terms

<zh>电子制造服务

<Morphosyntax>noun group

<Lexica>按^youdao.com, 词典^, https://www.youdao.com/result?word=electronic%20manufacturing%20services&lang=en (2024)

<Definition>...整体变更设立为股份公司，公司是深圳市高新技术企业，专门为国际客户提供电子制造服务(EMS，Electronic Manufacturing Services)，自从成立以来，一直专业从事PCBA控制板贴装业务，以及贴牌生产少量DVD、机顶盒、MP3等整机产品...

<Source>^youdao.com, 词典^, https://www.youdao.com/result?word=electronic%20manufacturing%20services&lang=en (2024)

<Concept field>为特定用途制造

**

<Subject>Computer science, information and general works

<Subfield>Systems

<en>Emulator

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Kesler/Ozdemir/Kisacikoglu/Tolbert 2014^:5806

<Definition>A computer system that is designed to behave in the same way as a different system.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/it/dizionario/inglese/emulator (2024)

<Context>Transmission network emulator, which is called the hardware testbed (HTB), is conceptualized to emulate the largescale power system by interconnected converters which emulate power generators and loads.

<Source>^Kesler/Ozdemir/Kisacikoglu/Tolbert 2014^:5806

<Concept field>System

<Equivalence en-zh>There is full conceptual identity between “Emulator” and “仿真器” terms

<zh>仿真器

<Morphosyntax>noun

<Lexica>按^youdao.com, 词典^, https://www.youdao.com/result?word=emulator&lang=en (2024)

<Definition>在线仿真器是调试嵌入式系统软件的硬件设备。

<Source>^zgbk.com, 中国大百科全书^, https://www.zgbk.com/ecph/words?SiteID=1&ID=32676&Type=bkzyb&SubID=81429 (2024)

<Concept field>系统

**

<Subject>Computer science, information and general works

<Subfield>Systems

<en>Electronic toll collection system

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^Lee/Tseng/Wang 2008^:2925

<Definition>Electronic toll collection (ETC) is a wireless system to automatically collect the usage fee or toll charged to vehicles using toll roads, HOV lanes, toll bridges, and toll tunnels.

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/Electronic_toll_collection (2024)

<Variant of>ETC

<Context>Electronic toll collection (ETC), also known as electronic payment and pricing system, is one of the major research topics in intelligent transportation system (ITS). ETC is an implementation of a road pricing concept in order to create benefits such as increasing the capacity of toll stations, reducing toll paying time, enhancing the convenience and safety of travelers, and minimizing air pollution and fuel consumption.

<Source>^Lee/Tseng/Wang 2008^:2925

<Concept field>System

<Equivalence en-zh>There is full conceptual identity between “Electronic toll collection system” and “电子不停车收费系统” terms

<zh>电子不停车收费系统

<Morphosyntax>noun group

<Source>^伟/琳 2008^:1

<Definition>ETC（Electronic Toll Collection），中文翻译是电子不停车收费（电子收费），是高速公路或桥梁自动收费。通过安装在车辆挡风玻璃上的车载电子标签与在收费站ETC车道上的微波天线之间进行的专用短程通讯，利用计算机联网技术与银行进行后台结算处理，从而达到车辆通过高速公路或桥梁收费站无需停车而能交纳高速公路或桥梁费用的目的。

<Source>^baidu.baike.com, 网络百科全书^, https://baike.baidu.com/item/ETC/563188?fromtitle=电子不停车收费系统&fromid=6594149&fromModule=lemma_search-box (2024)

<Context>电子不停车收费是ITS 服务领域中的一个特殊方面, 由于它涉及交通基础设施投资的回收, 又是缓解公路特别是高速公路收费站交通拥堵的有效手段, 同时在使用中收费卡的用量又很大, 因此各个国家的ETC作为ITS领域最先投入应用的系统来开发, 我国也不能例外。

<Source>^伟/琳 2008^:1

<Concept field>系统

**

<Subject>Computer science, information and general works

<Subfield>Computer programming, programs and data

<en>Error correcting code

<Morphosyntax>noun group, count.

<Usage label>main term

<Definition>Error correction code (ECC) checks read or transmitted data for errors and corrects them as soon as they are found. ECC is similar to parity checking except that it corrects errors immediately upon detection. ECC is becoming more common in the field of data storage and network transmission hardware, especially with the increase of data rates and corresponding errors.

<Source>^technolpedia.com, technology encyclopedia^, https://www.techopedia.com/definition/24161/error-correction-code--ecc (2024)

<Variant of>ECC

<Concept field>Codes

<Equivalence en-zh>There is full conceptual identity between “Error correcting codes” and “纠错码” terms

<zh>纠错码

<Morphosyntax>noun group

<Source>^王 2000^:112

<Lexica>按^youdao.com, 词典^, https://www.youdao.com/result?word=error%20correcting%20code&lang=en (2024)

<Definition>在传输过程中发生错误后能在收端自行发现或纠正的吗。

<Source>^zgbk.com, 中国大百科全书^, https://www.zgbk.com/ecph/words?SiteID=1&ID=147194&Type=bkzyb&SubID=98388 (2024)

<Context>虽然利用纠错码可以构造出一类数字签名方案, 但有以下一些弱点

<Source>^王 2000^:112

<Concept field>代码

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>Firmware

<Morphosyntax>noun, uncount.

<Usage label>main term

<Source>^Davidson/Shriver 1978^:22

<Definition>Set of instructions that form part of an electronic device and allow it to communicate with a computer or with other electronic devices.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/it/dizionario/inglese/firmware (2024)

<Context>The first step in any software or firmware project is the detailed specification of what is to be accomplished. This step involves interaction with the eventual users of the system and other efforts to obtain a clear understanding of such factors as acceptable cost, interfaces with other systems, and size of the system.

<Source>^Davidson/Shriver 1978^:22

<Concept field>Data

<Equivalence en-zh>There is full conceptual identity between “Firmware” and “固件” terms

<zh>固件

<Morphosyntax>noun

<Source>^张/司徒/王 2021^:142

<Lexica>按^youdao.com, 词典^, https://www.youdao.com/result?word=firmware&lang=en （2024）

<Definition>固件(Firmware)就是写入EPROM（可擦写可编程只读存储器）或EEPROM(电可擦可编程只读存储器)中的程序。

<Source>^baidu.baike.com, 网络百科全书^, https://baike.baidu.com/item/固件?fromModule=lemma_search-box (2024)

<Context>固件按照其是否内置操作系统、以及内置操作系统的类型可分如表1 所示的三类: (1)单片固件,通常采取单个二进制镜像的形式,无需底层操作系统,直接基于底层硬件驱动完成所有功能,或者只包含部分系统的库; (2)基于Linux 的固件, 以Linux 作为底层的系统, 基于Linux 进行开发; (3)基于RTOS 的固件。

<Source>^张/司徒/王 2021^:142

<Concept field>数据

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>EPROM

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Fiegna/Venturi/Melanotte/Sangiorgi/Riccò 1991^:603

<Definition>EPROM, form of computer memory that does not lose its content when the power supply is cut off and that can be erased and reused. EPROMs are generally employed for programs designed for repeated use but that can be upgraded with a later version of a program. EPROMs are erased with ultraviolet light. The capabilities of EPROMs were extended with EEPROM (electrically erasable programmable read-only memory); flash memory, which is extensively used in computers in the early 21st century, is an EEPROM.

<Source>^britannica.com, encyclopedia^, https://www.britannica.com/technology/EPROM (2024)

<Variant of>Erasable Programmable Read Only Memory

<Context>Erasable-Programmable Read Only Memories (EPROM) represent an important category of devices exploiting channel hot electrons for cell writing obtained by charging the floating gate (FG) with energetic carriers injected over the energy barrier at the Si-SiO, interface.

<Source>^Fiegna/Venturi/Melanotte/Sangiorgi/Riccò 1991^:603

<Concept field>Memories

<Equivalence en-zh>There is full conceptual identity between “Erasable Programmable Read Only Memory” and “可擦写可编程只读存储器” terms

<zh>可擦写可编程只读存储器

<Morphosyntax>noun group

<Source>^杨/于/赵/陈 2024^:143

<Lexica>按^youdao.com, 词典^, https://www.youdao.com/result?word=可擦写可编程只读存储器&lang=en (2024)

<Definition>EEPROM，或写作E2PROM，全称电可擦除可编程只读存储器（英语：Electrically-Erasable Programmable Read-Only Memory），是一种可以通过电子方式多次复写的半导体存储设备。相比EPROM，EEPROM不需要用紫外线照射，也不需取下，就可以用特定的电压，来抹除芯片上的信息，以便写入新的数据。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/电可擦除可编程只读存储器/22813237 (2024)

<Context>在对电力设备的状态监测和风险识别过程中，需要存储大量数据，本文采用AT2404 芯片作为可编程只读存储器（erasable programmable read-only memory，EPROM）的扩展芯片，这种芯片有较高的适应性，且保存数据的时间长。

<Source>^杨/于/赵/陈 2024^:143

<Concept field>存储器

**

<Subject>Computer science, information and general works

<Subfield>Special computer methods

<en>Test fixture

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Grelier/van Deursen/Storey 2013^:322

<Definition>A test fixture is a device used to consistently test some item, device, or piece of software. Test fixtures are used in the testing of electronics, software and physical devices.

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/Test_fixture (2024)

<Context>During the evolution of test code, developers have to make conscious decisions about how to set up the test fixture and adjust their fixture strategies, otherwise they end up with poor solutions to recurring implementation and design problems in their test code, so-called test smells.

<Source>^Grelier/van Deursen/Storey 2013^:322

<Concept field>Device

<Equivalence en-zh>There is full conceptual identity between “Test fixture” and “测试夹具” terms

<zh>测试夹具

<Morphosyntax>noun group

<Source>^陈/王/祝 2022^:1711

<Lexica>按^youdao.com, 词典^, https://www.youdao.com/result?word=test%20fixture&lang=en (2024)

<Definition>Fixtures 是测试中非常重要的一部分。他们的主要目的是建立一个固定/已知的环境状态以确保 测试可重复并且按照预期方式运行。Yii 提供一个简单可用的 Fixure 框架 允许你精确的定义你的 Fixtures 。

<Source>^yiichia.com 2024^, https://www.yiichina.com/doc/guide/2.0/test-fixtures (2024)

<Context>测试夹具的双口校准至少需要一个传输参数不为零的已知双口网络作为标准，如thru 或line 校准。 当两个测试端口相同时,这类传输标准容易得到,并且标准的精度也较高。

<Source>^陈/王/祝 2022^:1711

<Concept field>器件

**

<Subject>Computer science, information and general works

<Subfield>Systems

<en>Ground-loop

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Cai/Wang/Chen/Chen/Zhang/Kolditz/Shao 2022^:1

<Definition>In an electrical system, a ground loop or earth loop occurs when two points of a circuit are intended to have the same ground reference potential but instead have a different potential between them

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/Ground_loop_(electricity) (2024)

<Variant of>Earth loop

<Context>Therefore, the variation of long-term ground-loop temperature needs to be quantitatively evaluated in advance, and the system optimization is recommended to be conducted over the entire life cycle of the system.

<Source>^Cai/Wang/Chen/Chen/Zhang/Kolditz/Shao 2022^:1

<Concept field>Electrical system

<Equivalence en-zh>There is full conceptual identity between “Ground loop” and “接地回路” terms

<zh>接地回路

<Morphosyntax>noun group

<Lexica>按^youdao.com, 词典^, https://www.youdao.com/result?word=ground%20loop&lang=en (2024)

<Definition>接地回路（Ground Loop）的作用是利用共地线方式将线路多余回馈电流与干扰导入接地，以免造成线路与资料的错乱。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/接地回路?fromModule=lemma_search-box （2024）

<Concept field>电子系统

**

<Subject>Computer science, information and general works

<Subfield>Systems

<en>Guide rail

<Morphosyntax>noun. count.

<Usage label>main term

<Source>^Moon/Huh/Hong/Lee/Han 2015^:13

<Definition>A guide rail is a device or mechanism to direct products, vehicles or other objects though a channel, conveyor, roadway or rail system.

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/Guide_rail (2024)

<Context>In addition, with the rail expansion system, the built-in guide rail is connected with the transom rail of the building, for the horizontal robot to dock with the vertical robot.

<Source>^Moon/Huh/Hong/Lee/Han 2015^:13

<Concept field>Device

<Equivalence en-zh>There is full conceptual identity between “Guide rail” and “导轨” terms

<zh>导轨

<Morphosyntax>noun

<Source>^李/何/杜/肖/王 2016^:106

<Lexica>按^youdao.com, 词典^, https://www.youdao.com/result?word=guide%20rail&lang=en (2024)

<Definition>金属或其它材料制成的槽或脊，可承受、固定、引导移动装置或设备并减少其摩擦的一种装置。导轨表面上的纵向槽或脊，用于导引、固定机器部件、专用设备、仪器等。导轨又称滑轨、线性导轨、线性滑轨，用于直线往复运动场合，拥有比直线轴承更高的额定负载， 同时可以承担一定的扭矩，可在高负载的情况下实现高精度的直线运动。

<Source>^baidu.baike.com, 网络百科全书^, https://baike.baidu.com/item/导轨/4469954 (2024)

<Context>机床服役一段时间后，导轨一般会发生磨损，而导轨磨损影响因素较多，取决于导轨材料的硬度、承载重量、滑动速度和工作条件等多个方面

<Source>^李/何/杜/肖/王 2016^:106

<Concept field>器件

**

<Subject>Technology

<Subfield>Engineering and allied operations

<en>Screw

<Morphosyntax>noun, count.

<Usage label>main term

<Definition>In machine construction, a usually circular cylindrical member with a continuous helical rib, used either as a fastener or as a force and motion modifier.

<Source>^britannica.com, encyclopedia^, https://www.britannica.com/technology/transmission-engineering (2024)

<Concept field>Machine component

<Equivalence en-zh>There is full conceptual identity between “Screw” and “丝杠” terms

<zh>丝杠

<Morphosyntax>noun

<Source>^高/符/李 2024^:936

<Lexica>按^汉意-意汉 双解词典，赵秀英^:750

<Definition>在机械制造中，通常是指带有连续螺旋肋条的圆柱形部件，可用作紧固件或力和运动调节器。

<Source>^Fedrigo 2024^

<Context>为了维持质心与形心的一致，以六棱柱结构为卫星平台的缩比模型，提出了一种以丝杠导轨为调节组件的质心调节方案。

<Source>^高/符/李 2024^:936

<Concept field>机械部件

**

<Subject>Computer science, information and general works

<Subfield>Systems

<en>In-vehicle infotainment

<Morphosyntax>noun group, uncount.

<Usage label>main term

<Source>^Macario/Torchiano/Violante 2009^:257

<Definition>In-car entertainment (ICE), or in-vehicle infotainment (IVI), is a collection of hardware and software in automobiles that provides audio or video entertainment.

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/In-car_entertainment (2024)

<Variant of>IVI, in-car entertainment, ICE

<Context>The automotive infotainment industry is currently heavily pressured with a horde of requirements. The customers are used to the most breathtaking features on their mobile phones and they expect the same from their vehicles, which are, at any rate, bigger and more expensive.

<Source>^Macario/Torchiano/Violante 2009^:257

<Concept field>System

<Equivalence en-zh>There is full conceptual identity between “In-vehicle infotainment” and “车用娱乐系统应用服务” terms

<zh>车载信息娱乐系统

<Morphosyntax>noun group

<Source>^王 2020^:278

<Lexica>按^youdao.com, 词典^，https://www.youdao.com/result?word=车载信息娱乐系统&lang=en（2024）

<Definition>车载信息娱乐系统（In-Vehicle Infotainment 简称IVI），是采用车载专用中央处理器，基于车身总线系统和互联网服务，形成的车载综合信息处理系统。IVI能够实现包括三维导航、实时路况、IPTV、辅助驾驶、故障检测、车辆信息、车身控制、移动办公、无线通讯、基于在线的娱乐功能及TSP服务等一系列应用，极大的提升了车辆电子化、网络化和智能化水平。

<Source>^baidu.baike.com, 网络百科全书^, https://baike.baidu.com/item/车载信息娱乐系统/2338474 (2024)

<Variant of>车载综合信息处理系统

<Context>随着人们对驾驶、信息、娱乐、安全等方面的需求不断的提升，车载信息娱乐系统朝着功能集成化和模块化的趋势更加明显。多功能集成是未来车载信息娱乐系统发展的重心，将汽车的音视频、导航运用、网络传输、辅助驾驶进行有效的合成是当下车载信息娱乐流行的趋势。

<Source>^王 2020^:278

<Concept field>系统

**

<Subject>Social sciences, sociology and anthropology

<Subfield>Law

<en>Intellectual property

<Morphosyntax>noun, uncount.

<Usage label>main term

<Source>^Menell 2007^:1475

<Definition>Someone's idea, invention, creation, etc., that can be protected by law from being copied by someone else.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/it/dizionario/inglese/intellectual-property (2024)

<Variant of>IP

<Context>The digital revolution and other technological breakthroughs of the past several decades have brought intellectual property to the forefront of economic, social, and political interest.

<Source>^Menell 2007^:1475

<Concept field>Property

<Equivalence en-zh>There is full conceptual identity between "Intellectual property" and "知识产权" terms

<zh>知识产权

<Morphosyntax>noun group

<Source>^黄 2014^:153

<Lexica>按^youdao.com, 词典^，https://www.youdao.com/result?word=知识产权&lang=en （2024）

<Definition>排他性支配受保护的智慧产品和商事标记并享受其利益的一组权利。

<Source>^zgbk.com, 百科全书^, https://www.zgbk.com/ecph/words?SiteID=1&ID=464063&Type=bkzyb&SubID=48469 （2024）

<Variant of>智慧产权

<Context>知识产权, 其词源来自于英文 intellectual property。有学者考证,该词最早于17 世纪中叶由法国学者卡普佐夫提出,直到1967 年《世界知识产权组织公约》签订以后,该词才逐渐为国际社会所普遍使用。

<Source>^黄 2014^:153

<Concept field>产权

**

<Subject>Computer science, knowledge and systems

<Subfield>Systems

<en>Manual toll collection system

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^Lai/Hsiao/Yang/Lin/Lung 2021^:25

<Definition>Manual toll collection means a process for collection tolls using cash, credit card, or debit card to provide payment directly to the operator of the toll facility or his agents at the time a vehicle passes through the toll facility.

<Source>^lawinsider.com, library^, https://www.lawinsider.com/dictionary/manual-toll-collection (2024)

<Variant of>MTC

<Context>In addition to increasing the toll collection capacity and shortening the toll collection time, the ETC system can reduce air pollution and provide more convenient and safer services for highway users than a manual system.

<Source>^Lai/Hsiao/Yang/Lin/Lung 2021^:25

<Concept field>System

<Equivalence en-zh>There is full conceptual identity between “Manual toll collection system” and “人工收费系统” terms

<zh>人工收费系统

<Morphosyntax>noun group

<Lexica>按^youdao.com, 词典^, https://www.youdao.com/result?word=人工收费系统&lang=en (2024)

<Definition>人工收费系统是使用现金、信用卡或借记卡收取通行费的程序，在车辆通过收费设施时直接向收费设施运营商或其代理人付款。

<Source>^Fedrigo 2024^

<Concept field>系统

**

<Subject>Computer science, knowledge and systems

<Subfield>Computer programming, programs and data

<en>Microcontroller

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Yadav/Singh 2004^:2

<Definition>A microcontroller is a computer present in a single integrated circuit which is dedicated to perform one task and execute one specific application. It contains memory, programmable input/output peripherals as well a processor. Microcontrollers are mostly designed for embedded applications and are heavily used in automatically controlled electronic devices such as cellphones, cameras, microwave ovens, washing machines, etc.

<Source>^technopedia.com, technology encylopedia^, https://www.techopedia.com/definition/3641/microcontroller (2024)

<Context>A microcontroller is a highly integrated chip which includes, on one chip, all or most of the parts needed for a controller. The microcontroller could be called a “one-chip solution”. It typically includes: CPU (central processing unit), RAM (Random Access Memory), EPROM/PROM/ROM (Erasable Programmable Read Only Memory), I/O (input/output)—serial and parallel timers interrupt controller.

<Source>^Yadav/Singh 2004^:2

<Concept field>Device

<Equivalence en-zh>There is full conceptual identity between “Microcontroller” and “微控制器” terms

<zh>微控制器

<Morphosyntax>noun

<Source>^徐/陈/方 2006^:1

<Lexica>按^youdao.com，词典^, https://www.youdao.com/result?word=microcontroller&lang=en (2024)

<Definition>微控制器是将微型计算机的主要部分集成在一个芯片上的单芯片微型计算机。微控制器诞生于20世纪70年代中期，经过20多年的发展，其成本越来越低，而性能越来越强大，这使其应用

已经无处不在，遍及各个领域。例如电机控制、条码阅读器/扫描器、消费类电子、游戏设备、电话、HVAC、楼宇安全与门禁控制、工业控制与自动化和白色家电（洗衣机、微波炉）等。

<Source>^baike.baidu.com，网络百科全书^, https://baike.baidu.com/item/微控制器/6688343 (2024)

<Context>微控制器（microcontroller unit， MCU） 是专为控制和检测而设计制造的微型计算机， 因为它完全作嵌入式应用， 所以又被称为嵌入式微控制器（embedded microcontroller）； 又因为它在一片集成电路芯片上集成了计算机的三大部分： 中央处理器（ CPU ）、存储器（ RA M 和ROM）和输入输出端口（ I / O Port）， 在我国又被广泛称作单片机（ single chip microcomputer） 。

<Source>^徐/陈/方 2006^:1

<Concept field>器件

**

<Subject>Computer science, information and general works

<Subfield>Systems

<en>System on module

<Morphosyntax>noun group, count.

<Usage label>main term

<Definition>A system on a module (SoM) is a board-level circuit that integrates a system function in a single module. It may integrate digital and analog functions on a single board. A typical application is the area of embedded systems.

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/System_on_module (2024)

<Variant of>SoM, modular system

<Concept field>System

<Equivalence en-zh>There is full conceptual identity between “System on module” and “模块系统” terms

<zh>模块系统

<Morphosyntax>noun group

<Lexica>^youdao.com，词典^, https://www.youdao.com/result?word=模块系统&lang=en （2024）

<Definition>模块系统（SoM）是将系统功能集成在单个模块中的板级电路。它可以在一块电路板上集成数字和模拟功能。典型的应用领域是嵌入式系统。

<Source>^Fedrigo 2024^

<Concept field>系统

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>Motherboard

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Chang/Lin/Chen/Huang 2005^:1118

<Definition>The main printed circuit board that contains the CPU of a computer and makes it possible for the other parts of a computer to communicate with each other.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/it/dizionario/inglese/motherboard (2024)

<Context>To ensure the speed of new motherboard model introduction, manufacturing personnel must actively participate in new motherboard design and reliability testing in conformity with the principles of design for manufacturability (DFM).

<Source>^Chang/Lin/Chen/Huang 2005^:1118

<Concept field>Device

<Equivalence en-zh>There is full conceptual identity between “Motherboard” and “主板” terms

<zh>主板

<Morphosyntax>noun

<Source>^zgbk.com, 网络百科全书^, https://www.zgbk.com/ecph/words?SiteID=1&ID=32623&Type=bkzyb&SubID=81429 （2024）

<Lexica>^赵 2020^:997

<Definition>计算机中装载CPU和内存等关键元器件及外围设备相关的电子线路的印制电路板。又称主机板、系统板、母板。

<Source>^zgbk.com, 网络百科全书^, https://www.zgbk.com/ecph/words?SiteID=1&ID=32623&Type=bkzyb&SubID=81429 （2024）

<Variant of>主机版，系统班，母版

<Concept field>器件

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>Multi-chip package

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^Shimizu/Kaneda/Arisaka/Koizumi/Sunohara/Rokugawa/Koyama 2013^:2

<Definition>A multi-chip module is generically an electronic assembly (such as a package with a number of conductor terminals or "pins"), where multiple integrated circuits, semiconductor dies and/or other discrete components are integrated, usually onto a unifying substrate, so that in use it can be traced as if it were a larger IC.

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/Multi-chip_module (2024)

<Variant of>MCP, multi-chip module, MCM

<Context>The manufacturing of the Organic Multi Chip Package consists of three parts: (1) The first part is the build-up process of the PWB. TH (Through holes) are formed in standard CCL (Copper Clad Laminate) core, then three build-up layers are formed by the conventional semi-additive process on the core.

<Source>^Shimizu/Kaneda/Arisaka/Koizumi/Sunohara/Rokugawa/Koyama 2013^:2

<Concept field>Device

<Equivalence en-zh>There is full conceptual identity between "Multi-chip package" and "多芯片封装" terms

<zh>多芯片封装

<Morphosyntax>noun group

<Source>^潘/曹/李/刘 2013^:12

<Definition>内部包含了多个集成电路的封装形式。

<Source>^zgbk.com, 网络百科全书^, https://www.zgbk.com/ecph/words?SiteID=1&ID=32667&Type=bkzyb&SubID=81429 （2024）

<Context>多芯片封装 (MCP）技术作为SiP技术在封装中的一种典型应用已经变得越来越重要。

<Source>^潘/曹/李/刘 2013^:12

<Concept field>器件

**

<Subject>Computer science, information and general works

<Subfield>Systems

<en>Optical isolator

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Wang/Zhong/Li 2012^:2

<Definition>An optical isolator is a passive magneto-optic device that makes travel of light unidirectionally. The operation of the device is based on the Faraday effect. It is used in applications to avoid unwanted feedback to the system using the optical isolator.

<Source>^technopedia.com, technology encyclopedia^, https://www.techopedia.com/definition/14987/optical-isolator (2024)

<Context>Our theoretical and experimental study on the optical isolation performance of this silicon PC hetero junction diode leads to a totally different answer to the above question, namely, the spatial inversion symmetry breaking diode can construct an optical isolator in no conflict with any reciprocal principle.

<Source>^Wang/Zhong/Li 2012^:2

<Concept field>Device

<Equivalence en-zh>There is full conceptual identity between “Optical isolator” and “光隔离器” terms

<zh>光隔离器

<Morphosyntax>noun

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/光隔离器?fromModule=lemma_search-box (2024)

<Lexica>^youdao.com, 词典^, https://www.youdao.com/result?word=光隔离器&lang=en (2024)

<Definition>光隔离器是一种只允许单向光通过的无源光器件，其工作原理是基于法拉第旋转的非互易性。 通过光纤回波反射的光能够被光隔离器很好的隔离。光隔离器主要利用磁光晶体的法拉第效应。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/光隔离器?fromModule=lemma_search-box (2024)

<Concept field>器件

**

<Subject>Manufacture for specific uses

<Subfield>Hardware and household appliances

<en>Original equipment manufacturer

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^Herbig/O'Hara 1994^:38

<Definition>Original-equipment manufacturers incorporate the purchased goods into their final products, which are then sold to final consumers.

<Source>^britannica.com, enciclopedia^, https://www.britannica.com/topic/original-equipment-manufacturer (2024)

<Variation of>OEM

<Context>The original equipment manufacturer, or OEM, is a very important source of supply for most manufacturers. Items produced by these OEMs include fasteners, power transmission components, hydraulic equipment, and small rubber parts that eventually become part of the manufacturer's finished product.

<Source>^Herbig/O'Hara 1994^:38

<Concept field>Manufacturer

<Equivalence en-zh>There is full conceptual identity between "Original equipment manufacturer" and "代工生产" terms

<zh>代工生产

<Morphosyntax>noun

<Source>^尚/郑 2013^:62

<Lexica>^youdao.com, 词典^, https://www.youdao.com/result?word=代工生产&lang=en （2024）

<Definition>"代工"有两种模式，OEM和ODM。OEM生产，也称为定点生产，俗称代工（生产）。OEM特征是：技术在外，资本在外，市场在外，只有生产在内。OEM基本含义为品牌生产者不直接生产产品，而是利用自己掌握的关键的核心技术负责设计和开发新产品，控制销售渠道，具体的加工任务通过合同订购的方式委托同类产品的其他厂家生产。之后将所订产品低价买断，并直接贴上自己的品牌商标。这种委托他人生产的合作方式简称OEM，承接加工任务的制造商被称为OEM厂商，其生产的产品被称为OEM产品。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/代工生产?fromModule=lemma_search-box （2024）

<Context>但是，随着我国经济形势的变化，这种集中于国际产业链低技术含量环节的代工生产模式变得越来越难以为继，产业的转型升级日益成为突出的问题。

<Source>^尚/郑 2013^:62

<Concept field>厂家

**

<Subject>Manufacture for specific uses

<Subfield>Precision instruments and other devices

<en>Stepper

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Callafon/Van den Hof 2001^:381

<Definition>A stepper or wafer stepper is a device used in the manufacture of integrated circuits (ICs). It is an essential part of the process of photolithography, which creates millions of microscopic circuit elements on the surface of silicon wafers out of which chips are made.

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/Stepper (2024)

<Context> Wafer steppers combine a high accuracy positioning and a sophisticated lithographic process to manufacture integrated circuits (chips) via a fully automated process.

<Source>^Callafon/Van den Hof 2001^:381

<Concept field>Device

<Equivalence en-zh>There is full conceptual identity between “Stepper” and “光刻机” terms

<zh>光刻机

<Morphosyntax>noun

<Source>^姜/丁/丁/杨/徐 2022^:0922003-1

<Lexica>^mdbg.net, 词典^, https://www.mdbg.net/chinese/dictionary?page=worddict&wdrst=0&wdqb=光刻机&email= （2024）

<Definition>是一种将目标结构图样印刷到硅片等基底上的机器，其机理类似照片冲印过程。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/光刻机?fromModule=lemma_search-box （2024）

<Context>半导体工艺中的一道关键工艺步骤为光刻，而进行光刻工艺是通过光刻机来实现的。光刻机的作用是通过曝光的方式，将掩模内的集成电路版图转移到硅片面的光刻胶中，完成光刻工艺

<Source>^姜/丁/丁/杨/徐 2022^:0922003-1

<Concept field>器件

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>Port

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Kia/Shayan/Ghotb 2022^:533

<Definition>A part of a computer where wires can be connected in order to control other pieces of equipment, such as a printer.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/it/dizionario/inglese/port (2024)

<Context>In the last decade, proposed operational improvements and port developments were incrementally implemented by using simulation to test local terminal performance whilst maintaining the global perspective.

<Source>^Kia/Shayan/Ghotb 2022^:533

<Concept field>Parts

<Equivalence en-zh>There is full conceptual identity between “Port” and “端口” terms

<zh>端口

<Morphosyntax>noun

<Source>^王/赵/张 2024^:228

<Lexica>^赵 2020^:225

<Definition>端口是英文port的意译，可以认为是设备与外界通讯交流的出口。端口可分为虚拟端口和物理端口，其中虚拟端口指计算机内部或交换机路由器内的端口，不可见。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/端口?fromModule=lemma_search-box （2024）

<Context>为了区别每个S 参数所涉及的端口组合，使用两个下标值。第一个下标值是输出端口，第二个下标值是输入端口。

<Source>^王/赵/张 2024^:228

<Concept field>部件

**

<Subject>Computer science, information and general works

<Subfield>Systems

<en>Printed circuit board

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Petkov/Ivanova 2024^:2566

<Definition>A set of electrical connections made by thin lines of metal fixed onto a surface.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/it/dizionario/inglese/printed-circuit-board (2024)

<Variant of>PCB

<Context>Testing of printed circuit boards (PCBs) and printed circuit board assemblies (PCBAs) is an important procedure in manufacturing of electronic modules and devices that guarantee timely check for quality of the performed operations and finally the quality of the product.

<Source>^Petkov/Ivanova 2024^:2566

<Concept field>Device

<Equivalence en-zh>There is full conceptual identity between “ ” and “印刷电路板” terms

<zh>印制电路板

<Morphosyntax>noun

<Source>^李/高/舒 2024^:35

<Lexica>^赵 2020^:208

<Definition>用电子印刷术将覆盖在绝缘基材上的铜箔刻蚀为满足元器件连接要求的导电线路，从而形成的可安装并连接电子元器件的电路板。又称印刷电路板。

<Source>^zgbk.com, 网络百科全书^，https://www.zgbk.com/ecph/words?SiteID=1&ID=32626&Type=bkzyb&SubID=81429 （2024）

<Variant of>电路板， 线路板，印刷电路板

<Context>研究电子设备动态特性需要建立准确的印制电路板(Printed Circuit Board，PCB)有限元模型，关于PCB的有限元成型技术，Pitarresi等提出了6种方法：简单成型法、总质量等效法、总刚度等效法、总质量/刚度等效法、局部等效法和直接有限元成型法。

<Source>^李/高/舒 2024^:35

<Concept field>器件

**

<Subject>Technology

<Subfield>Engineering and allied operations

<en>Printed circuit board assembly

<Morphosyntax>noun group, uncount.

<Usage label>main term

<Source>^Petkov/Ivanova 2024^:2567

<Definition>A printed circuit board assembly (PCBA) describes the finished board after all the components have been soldered and installed on a printed circuit board (PCB).

<Source>^arenasolutions.com, glossary^, https://www.arenasolutions.com/resources/glossary/printed-circuit-board-assembly/ (2024)

<Variant of>PCBA

<Context>Testing of PCBAs is also a key step addressing the check whether all components are placed and mounted correctly on the PCB and whether the assembly functions are as it is expected. A wide variety of testing methods and methodologies exists in electronics as some of them are well accepted in practice, others are only in theoretical development.

<Source>^Petkov/Ivanova 2024^:2567

<Concept field>Activity

<Equivalence en-zh>There is full conceptual identity between “Printed circuit board assembly” and “印制电路板装配件” terms

<zh>印制电路板装配件

<Morphosyntax>noun

<Source>^李/高/舒 2024^:35

<Lexica>^youdao.com, 词典^，https://www.youdao.com/result?word=印制电路板装配件&lang=en（2024）

<Definition>印刷电路板装配（PCBA）是指将所有元件焊接并安装到印刷电路板（PCB）上后的成品电路板。

<Source>^Fedrigo 2024^

<Context>印制电路板装配件（Printed Circuit Board Assembly，PCBA）在航空航天设备中有广泛应用，分析和优化航空设备中电子设备振动可靠性的必要前提是建立准确的PCBA有限元模型

<Source>^李/高/舒 2024^:35

<Concept field>

**

<Subject>Law

<Subfield>Private law

<en>Property right

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Levine 2005^:62

<Definition>The right of people and companies to own and use land, capital, etc. and to receive profit from it.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/it/dizionario/inglese/property-rights (2024)

<Context>The law, property rights and contracting are inseparable. Statutes define property rights. At a broader level, legal systems consist of the entire apparatus of courts, procedures and institutions associated with enforcing property rights.

<Source>^Levine 2005^:62

<Concept field>Rights

<Equivalence en-zh>There is full conceptual identity between “Property law” and “产权” terms

<zh>产权

<Morphosyntax>noun

<Source>^周 2005^:2

<Lexica>^赵 2020^:116

<Definition>产权是经济所有制关系的法律表现形式。产权是指合法财产的所有权，这种所有权表现为对财产的占有、使用、收益、处分。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/产权?fromModule=lemma_search-box (2024)

<Context>经济学产权理论的基本命题是:“产权是一束权利”,即产权界定了产权所有者对资产使用、资产带来的收入、资产转移诸方面的控制权,为人们的经济行为提供了相应的激励机制,从而保证了资源分配和使用的效率。

<Source>^周 2005^:2

<Concept field>权利

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>QR code

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Soon 2008^:60

<Definition>A QR code is much like a bar code, except that because it carries data in two dimensions (horizontally and vertically), it is able to hold much more information than a one-dimensional bar code. In fact, compared to a bar code’s 20 alphanumeric character limit, a QR code can hold thousands of characters of data.

<Source>^technopedia.com, technology encyclopedia^, https://www.techopedia.com/2/27408/trends/an-introduction-to-qr-codes (2024)

<Context>QR Code is a two-dimensional symbol. It was invented in 1994 by Denso, one of major Toyota group companies, and approved as an ISO international standard (ISO/IEC18004) in June 2000. This two-dimentional symbol was initially intended for use in production control of automotive parts, but it has become widespread in other fields.

<Source>^Soon 2008^:60

<Concept field>Codes

<Equivalence en-zh>There is full conceptual identity between “QR code” and “二维码” terms

<zh>二维码

<Morphosyntax>noun

<Source>^杨/刘/杜 2002^:29

<Lexica>^mdbg.net, 词典^，https://www.mdbg.net/chinese/dictionary?page=worddict&wdrst=0&wdqb=二维码&email= （2024）

<Definition>二维码也称为二维条码、行动条码，是指在一维条码的基础上扩展出另一维具有可读性的条码，使用黑白矩形图案表示二进制数据，被设备扫描后可获取其中所包含的信息。

<Source>^zh.wikipedia.org, 网络百科全书^, https://zh.wikipedia.org/zh-hans/二維碼 （2024）

<Context>二维码是在一维码的基础上，在两个方向上进行的编码和解码。二维条码是用某种特定的几何图形按一定规律在平面(二维方向上)分布的黑白相间的图形记录数据符号信息的；这将极大地增大编码的容量，从而很好地解决一维码容量不足和编码加密机制过于简单的问题，从而增强了条码的容量和加密功能并拓展了它的应用范围。

<Source>^杨/刘/杜 2002^:29

<Concept field>代码

**

<Subject>Computer science, information and general works

<Subfield>Special computer methods

<en>Robotics

<Morphosyntax>noun, uncount.

<Usage label>main term

<Source>^Doncieux/Bredeche/Mouret/Eiben 2015^:1

<Definition>Robotics is the engineering and operation of machines that can autonomously or semi-autonomously perform physical tasks on behalf of a human.

<Source>^technopedia.com, technology encyclopedia^, https://www.techopedia.com/definition/32836/robotics (2024)

<Context>In designing a robot, many different aspects must be considered simultaneously: its morphology, sensory apparatus, motor system, control architecture, etc. One of the main challenges of robotics is that all of these aspects interact and jointly determine the robot's behavior.

<Source>^Doncieux/Bredeche/Mouret/Eiben 2015^:1

<Concept field>Robot

<Equivalence en-zh>There is full conceptual identity between "Robotics" and "机器人技术" terms

<zh>机器人技术

<Morphosyntax>noun

<Source>^谭/王 2013^:963

<Lexica>^赵 2020^:395

<Definition> 研究机器人设计、制造和应用一门学科。主要研究机器人的控制与被处理物体之间的相互关系，一项涵盖了机器人的设计、建造、运作以及应用的跨领域的学科。又称机器人技术、机器人工程学。

<Source>^zgbk.com, 网络百科全书^，https://www.zgbk.com/ecph/words?SiteID=1&ID=507586&Type=bkzyb&SubID=222709 （2024）

<Variant of>机器人学

<Context>21 世纪以来, 国内外对机器人技术的发展越来越重视. 机器人技术被认为是对未来新兴产业发展具有重要意义的高技术之一。

<Source>^谭/王 2013^:963

<Concept field>机器人

**

<Subject>Computer science, information and general works

<Subfield>Special computer methods

<en>Rugged computer

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Li/Gao 2024^:2

<Definition>A rugged computer or ruggedized computer is a computer specifically designed to operate reliably in harsh usage environments and conditions, such as strong vibrations, extreme temperatures and wet or dusty conditions.

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/Rugged_computer (2024)

<Context> A certain type of portable rugged computer needs to meet extreme environmental requirements such as high and low temperatures, humidity and heat, and anti-mould, so the design of the cooling structure needs to take full account of the actual working environment and performance requirements of the equipment, in order to achieve effective heat dissipation and ensure the stable operation of the equipment.

<Source>^Li/Guo 2024^:2

<Concept field>Computers

<Equivalence en-zh>There is full conceptual identity between “Rugged computer” and “强固计算机” terms

<zh>强固计算机

<Morphosyntax>noun

<Source>^baike.baidu.com, 网络百科全书^，https://baike.baidu.com/item/强固计算机?fromModule=lemma_search-box （2024）

<Definition>强固计算机是为适应某种恶劣环境，在计算机设计时对影响机器性能的各种因素，诸如系统结构、电气特性、机械结构等所采取的相应保证措施。也就是说，计算机要在各种恶劣环境下使用，都应采取相应措施，否则，机器难于正常运转，所采取的措施就是对机器进行强固。

<Source>^baike.baidu.com, 网络百科全书^，https://baike.baidu.com/item/强固计算机?fromModule=lemma_search-box （2024）

<Concept field>计算机

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>Secret key

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Kiya/Maung/Kinoshita/Imaizumi/Shiota 2022^:4

<Definition> A secret key is the piece of information or parameter that is used to encrypt and decrypt messages in a symmetric, or secret-key, encryption.

<Source>^technopedia.com, technology encyclopedia^, https://www.techopedia.com/definition/24865/secret-key (2024)

<Context>In addition, the use of a secret key allows us to embed unique features controlled with the key into images. From these properties, several transformation methods with a key have been proposed for adversarially robust defense, access control, and model watermarking.

<Source>^Kiya/Maung/Kinoshita/Imaizumi/Shiota 2022^:4

<Concept field>Codes

<Equivalence en-zh>There is full conceptual identity between “Secret key” and “密钥” terms

<zh>密钥

<Morphosyntax>noun

<Source>^张/余/王/贺 2024^:129

<Lexica>^赵 2020^:565

<Definition>密钥是密码和明码之间的对应替代关系，分为对称密钥与非对称密钥。如以00、01、02、03代替字母A、B、C、D，那么00译成A、01译成B、02译成C、03译成D就是密钥。

<Source>

<Context>车辆与提供IoV 服务的设施之间的认证与密钥协商被认为是解决上述问题的关键手段。目前的认证与密钥协商方案按照认证节点的选取， 分为基于云服务器或可信机构（TA, trusted authority）的认证方案和基于代理的认证方案。

<Source>^张/余/王/贺 2024^:129

<Concept field>代码

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>Serial port

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Axelson 2000^:2

<Definition>A serial port is an interface that allows a PC to transmit or receive data one bit at a time. It is one of the oldest types of interfaces and at one time was commonly used to connect printers and external modems to a PC. Modern serial ports are used in scientific instruments, shop till systems such as cash registers and applications like industrial machinery systems.

<Source>^technopedia.com, technology encyclopedia^, https://www.techopedia.com/definition/3665/serial-port (2024)

<Context>Different chips have different features and abilities, including serial ports of various types, varying amounts of memory for storing programs and data, and low-power modes for battery-powered circuits.

<Source>^Axelson 2000^:2

<Concept field>Accessory

<Equivalence en-zh>There is full conceptual identity between “Serial port” and “串行端口” terms

<zh>串行端口

<Morphosyntax>noun

<Source>^周/王 2005^:195

<Lexica>^youdao.com, 词典^，https://www.youdao.com/result?word=serial%20port&lang=en（2024）

<Definition>串行接口简称串口，也称串行通信接口或串行通讯接口（通常指COM接口），是采用串行通信方式的扩展接口。串行接口 （Serial Interface）是指数据一位一位地顺序传送。其特点是通信线路简单，只要一对传输线就可以实现双向通信（可以直接利用电话线作为传输线），从而大大降低了成本，特别适用于远距离通信，但传送速度较慢。

<Source>^baidu.baike.com, 网络百科全书^，https://baike.baidu.com/item/串行端口?fromtitle=串口&fromid=1250303&fromModule=lemma_search-box （2024）

<Context>McASP是TI TMS320C6000较TI的C5000系列DSP处理器新增加的一个专门用来实现多通道音频应用的通用串行端口，它包括收 / 发两个功能部件，收 / 发部件二者间即可完全同步，也可各自采用完全独立的主时钟、位时钟和帧同步时钟，以及不同的数据传输模式和位码流格式。

<Source>^周/王 2005^:195

<Concept field>附件

**

<Subject>Science

<Subfield>Chemistry and allied sciences

<en>Silicon carbide

<Morphosyntax>noun, uncount.

<Usage label>main term

<Source>^Abderrazak/Hmida 2011^:16

<Definition>Silicon carbide, exceedingly hard, synthetically produced crystalline compound of silicon and carbon.

<Source>^britannica.com, enciclopedia^, https://www.britannica.com/science/silicon-carbide (2024)

<Variant of>SiC

<Context>Silicon carbide is an important non-oxide ceramic which has diverse industrial applications. In fact, it has exclusive properties such as high hardness and strength, chemical and thermal stability, high melting point, oxidation resistance, high erosion resistance, etc. All of these qualities make SiC a perfect candidate for high power, high temperature electronic devices as well as abrasion and cutting applications.

<Source>^Abderrazak/Hmida 2011^:16

<Concept field>Crystallography

<Equivalence en-zh>There is full conceptual identity between “Silicon carbide” and “碳化硅” terms

<zh>碳化硅

<Morphosyntax>noun

<Source>^盛/任/徐 2020^:1741

<Lexica>^youdao.com, 词典^, https://www.youdao.com/result?word=silicon%20carbide&lang=en （2024）

<Definition>碳化硅在大自然以莫桑石这种稀罕的矿物的形式存在，由于其非常罕有，世界上几乎所有的碳化硅固体，包括莫桑石制成的珠宝都来自人工合成。纯的碳化硅是无色的，工业用碳化硅由于所含杂质种类和含量不同，而呈浅黄、绿、蓝乃至黑色，透明度随其纯度不同而异。晶体上彩虹般的光泽则是因为其表面产生的二氧化硅钝化层所致。

<Source>^zgbk.com, 网络百科全书^, https://www.zgbk.com/ecph/words?SiteID=1&ID=297073&Type=bkzyb&SubID=120534 （2024）

<Context>近20 多年来，以碳化硅(silicon carbide，SiC)为代表的宽禁带半导体器件，受到了广泛的关注。SiC 材料具有3 倍于硅材料的禁带宽度，10 倍于硅材料的临界击穿电场强度，3 倍于硅材料的热导率，因此SiC 功率器件适合于高频、高压、高温等应用场合，且有助于电力电子系统的效率和功率密度的提升。

<Source>^盛/任/徐 2020^:1741

<Concept field>晶体学

**

<Subject>Technology

<Subfield>Manufacturing

<en>Silicon producer

<Morphosyntax>noun group, count.

<Usage label>main term

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/List_of_silicon_producers (2024)

<Definition>Silicon producers, also known as semiconductor manufacturers, are those companies specialised in the design and fabrication of semiconductors and semiconductor devices.

<Source>^Fedrigo 2024^

<Concept field>Metal working and primary metal products

<Equivalence en-zh>There is full conceptual identity between “Silicon manufacturers” and “硅制造商” terms

<zh>硅制造商

<Morphosyntax>noun

<Lexica>^youdao.com, 词典^，https://www.youdao.com/result?word=硅制造商&lang=en （2024）

<Definition>硅生产商又称半导体制造商，是指专门设计和制造半导体和半导体器件的公司。

<Source>^Fedrigo 2024^

<Concept field>金属加工和初级金属产品

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>Device driver

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Cordbet/Rubini/Kroah-Hartman 2005^:1

<Definition>A device driver is a particular form of software application that allows one hardware device (such as a personal computer) to interact with another hardware device (such as a printer). A device driver may also be called a software driver.

<Source>^technopedia.com, technology encyclopedia^, https://www.techopedia.com/definition/6824/device-driver (2024)

<Variant of>Actuator

<Context>Device drivers take on a special role in the Linux kernel. They are distinct “black boxes” that make a particular piece of hardware respond to a well-defined internal programming interface; they hide completely the details of how the device works.

<Source>^Cordbet/Rubini/Kroah-Hartman 2005^:1

<Concept field>Software

<Equivalence en-zh>There is full conceptual identity between “Driver” and “驱动器” terms

<zh>驱动器

<Morphosyntax>noun

<Source>^杨/刘/聂/李/王 2024^:15

<Lexica>^zgbk.com, 网络百科全书^，https://www.zgbk.com/ecph/words?SiteID=1&ID=32611&Type=bkzyb&SubID=81429 （2024）

<Definition>驱动，计算机软件术语，是指驱使计算机里硬件动作的软件程序。驱动程序全称设备驱动程序，是添加到操作系统中的特殊程序，其中包含有关硬件设备的信息。此信息能够使计算机与相应的设备进行通信。驱动程序是硬件厂商根据操作系统编写的配置文件，可以说没有驱动程序，计算机中的硬件就无法工作。

<Source>^baidu.baike.com, 网络百科全书^，https://baike.baidu.com/item/驱动/2765136 （2024）

<Context>智能材料驱动器和柔性蒙皮是发展柔性机翼的关键技术。智能材料具有质量轻、结构简单、驱动力大等优点。使用智能材料驱动器取代传统驱动器，可有效减轻机翼质量，减少复杂机械机构的使用，具有非常好的应用前景。

<Source>^杨/刘/聂/李/王 2024^:15

<Concept field>软件

**

<Subject>Computer science, information and general works

<Subfield>Computer programming, programs and data

<en>Symmetric encryption

<Morphosyntax>noun group, uncount.

<Usage label>main term

<Source>^Bellare/Desai/Jokipii/Rogaway 1997^:396

<Definition>Symmetric-key algorithms are algorithms for cryptography that use the same cryptographic keys for both the encryption of plaintext and the decryption of ciphertext.

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/Symmetric-key_algorithm (2024)

<Variant of>Single-key cryptography, symmetric crypto-system

<Context>The construction of a pseudorandom generator from a one-way function provides a solution for symmetric encryption starting from a one-way function

<Source>^Bellare/Desai/Jokipii/Rogaway 1997^:396

<Concept field>Encryption methods

<Equivalence en-zh>There is full conceptual identity between “Symmetric encryption” and “对称加密” terms

<zh>对称加密

<Morphosyntax>noun

<Source>^毕 2024^:144

<Lexica>^youdao.com，词典^，https://www.youdao.com/result?word=symmetrical%20encryption&lang=en （2024）

<Definition>采用单钥密码系统的加密方法，同一个密钥可以同时用作信息的加密和解密，这种加密方法称为对称加密，也称为单密钥加密。

<Source>^baike.baidu.com, 网络百科全书^，https://baike.baidu.com/item/对称加密?fromModule=lemma_search-box （2024）

<Context>常见的加密算法。首先，对称加密算法：对称加密算法是指加密和解密使用相同密钥的算法。

<Source>^毕 2024^:144

<Concept field>加密方法

**

<Subject>Computer science, information and general works

<Subfield>Data processing and computer science

<en>Time server

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Mills 1991^:1482

<Definition>A time server is a server computer that reads the actual time from a reference clock and distributes this information to its clients using a computer network. The time server may be a local network time server or an internet time server.

<Source>^en.wikipedia.org, encyclopedia^, https://en.wikipedia.org/wiki/Time_server (2024)

<Variant of>Network time protocol, NTP

<Context>Local clocks are maintained at designated time servers, which are timekeeping systems belonging to a synchronization subnet, in which each server measures the offsets between its local clock and the clocks of its neighbor servers or peers in the subnet.

<Source>^Mills 1991^:1482

<Concept field>Computer

<Equivalence en-zh>There is full conceptual identity between “Time server” and “时间服务器” terms

<zh>时间服务器

<Morphosyntax>noun

<Source>^杨/郭/董 2013^:58

<Definition>**时间服务器**是一种计算机网络仪器，它从参考时钟获取实际时间，再利用计算机网络把时间信息传递给用户。

<Source>^baike.baidu.com, 网络百科全书^，https://baike.baidu.com/item/时间服务器/3765733 （2024）

<Context>在时间同步系统中，时间服务器为客服端提供精确时间同步服务，进而实现整个网络的时间同步。随着嵌入式技术的发展，嵌入式与网络时间同步技术的结合，无疑具有良好的发展前景。同时，这也对时间服务器性能提出了更高的要求。

<Source>^杨/郭/董 2013^:58

<Concept field>计算机

**

<Subject>Technology

<Subfield>Engineering and allied operations

<en>Servo motor

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Haidar/Benachaiba/Zahir 2013^:84

<Definition>A servo motor is a rotary actuator or motor that allows for a precise control in terms of angular position, acceleration and velocity, capabilities that a regular motor does not have. It makes use of a regular motor and pairs it with a sensor for position feedback. The controller is the most sophisticated part of the servo motor, as it is specifically designed for the purpose.

<Source>^technopedia.com, technology encyclopaedia^, https://www.techopedia.com/definition/13274/servo-motor (2024)

<Context>DC Servo Motors become an important device in a wide range of industrial applications that require high dynamics on position control such as numerically controlled machinery, robotics, automation and other mechanism where the starting and stopping functions are quickly and accurately.

<Source>^Haidar/Benachaiba/Zahir 2013^:84

<Concept field>Motors

<Equivalence en-zh>There is full conceptual identity between “Servo motor” and “伺服电机” terms

<zh>伺服电机

<Morphosyntax>noun

<Source>^王/唐 2009^:129

<Lexica>^youdao.com, 词典^，https://www.youdao.com/result?word=servo%20motor&lang=en （2024）

<Definition>自动控制系统中的执行元件。根据控制指令输出转矩和转速。

<Source>^zgbk.com，网络百科全书^，https://www.zgbk.com/ecph/words?SiteID=1&ID=406612&Type=bkzyb&SubID=200325 （2024）

<Context>为了满足机械设备对高精度、快速响应的要求，伺服电机应有较小的转动惯量和大的堵转转矩，并具有尽可能小的时间常数和启动电压，还应具有较长时间的过载能力，以满足低速大转矩的要求，能够承受频繁启动、制动和正、反转，如果盲目地选择大规格的电机，不仅增加成本，也会使得设计设备的体积增大，结构不紧凑，因此选择电机时应充分考虑各方面的要求，以便充分发挥伺服电机的工作性。

<Source>^王/唐 2009^:129

<Concept field>电机

**

<Subject>Technology

<Subfield>Engineering and allied operations

<en>Test machine

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Wang/Low/Che/Pang/Yeo 2003^:263

<Definition>Test machines are machines used to evaluate the quality and yield of blank printed circuit boards and aimed at ensuring that a project passes the assembly stage without defects.

<Source>^Fedrigo 2024^

<Context>The Lansmont Model 65181-shock test machine is used to provide the free-fall drop test of board-level mounted with the flip chip packages. This machine can provide two types of shock pulse: half sine pulse and trapezoid pulse.

<Source>^Wang/Low/Che/Pang/Yeo 2003^:263

<Concept field>Machinery

<Equivalence en-zh>There is full conceptual identity between “Test machine” and “测试机” terms

<zh>测试机

<Morphosyntax>noun

<Source>^徐/杨/赵 2024^:98

<Lexica>^youdao.com，词典^，https://www.youdao.com/result?word=test%20machine&lang=en（2024）

<Definition>一种用于测试和评估产品性能、功能或可靠性的设备或工具。

<Source>^youdao.com，词典^，https://www.youdao.com/result?word=test%20machine&lang=en（2024）

<Context>。相较于使用ATE 测试机台的存储器测试或通过用户层测试软件的测试方案，本文所采用的FPGA 嵌入特定自测试算法方案可以实现典型DDR 互连故障的高效覆盖，测试效率和测试成本均得到明显改善。

<Source>^徐/杨/赵 2024^:98

<Concept field>机器

**

<Subject>Technology

<Subfield>Engineering and allied operations

<en>Test point

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Huang/Cheng 2000^:977

<Definition>A PCB test point is a small wire loop used for test probes on a PCB that contains surface-mount parts.

<Source>^mclpcb.com, Millenium Circuits Limited^ https://www.mclpcb.com/blog/test-points-pcb/#:~:text=A%20PCB%20test%20point%20is,of%20materials%2C%20sizes%20and%20colors (2024)

<Context>In addition to finding the sets of test points that allow one to differentiate between the elements under diagnosis, the algorithm can serve as a design for testability (DfT) guide for circuit board design.

<Source>^Huang/Cheng 2000^:977

<Concept field>PCB

<Equivalence en-zh>There is full conceptual identity between “Test point” and “测试点” terms

<zh>测试点

<Morphosyntax>noun

<Source>^徐/李/姜/郭 2013^:1654

<Lexica>^youdao.com, 词典^，https://www.youdao.com/result?word=测试点&lang=en （2024）

<Definition>PCB 测试点是一个小导线环，用于在包含表面贴装部件的 PCB 上进行测试探针。

<Source>^Fedrigo 2024^

<Context>此外,利用了系统等效缩减/ 扩展方法,用模态置信准则和共位模态置信准则来揭示不恰当的测试点带来的误差.结合印制电路板案例分析了测试点的选择对相关性分析结果的影响.

<Source>^徐/李/姜/郭 2013^:1654

<Concept field>印刷电路板

**

<Subject>Technology

<Subfield>Manufacture for specific use

<en>To install

<Morphosyntax>verb

<Source>^Hasegawa/Takahara/Tabata/Tsukuda/Omura 2017^:1707

<Definition>To put furniture, a machine, or a piece of equipment into position and make it easy to use.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/install?q=to+install (2024)

<Context>The method will make it possible to install the PCB current sensors in an insulated-gate bipolar transistor (IGBT) module.

<Source>^Hasegawa/Takahara/Tabata/Tsukuda/Omura 2017^:1707

<Concept field>Hardware

<Equivalence en-zh>There is full conceptual identity between “To install” and “安装” terms

<zh>安装

<Morphosyntax>verb

<Source>^邱/张/张/赵 /徐^:580

<Lexica>^赵 2020^:43

<Definition>按照一定的程序、规格把机械或器材固定在一定的位置上。

<Source>^zdic.net, 词典^, https://www.zdic.net/hans/安装 （2024）

<Context>自动装配模式，就是在整个过程中都不需要操作人员来参与，装配机器人会自动地将舱板安装到位，操作人员只需要最后安装紧固件即可。

<Source>^邱/张/张/赵 /徐^:580

<Concept field>硬件

**

<Subject>Computing science, knowledge and systems

<Subfield>Data processing and computer science

<en>To leak

<Morphosyntax>verb

<Source>^Rivest/Shamir/Tauman 2001^:552

<Definition>To allow secret information to become generally known.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/leak?q=to+leak (2024)

<Context>Ring signatures provide an elegant way to leak authoritative secrets in an anonymous way, to sign casual email in a way which can only be verified by its intended recipient, and to solve other problems in multiparty computations.

<Source>^Rivest/Shamir/Tauman 2001^:552

<Concept field>Data

<Equivalence en-zh>There is full conceptual identity between “To leak” and “外泄” terms

<zh>外泄

<Morphosyntax>verb

<Source>^杨/刘 2024^:139

<Lexica>^zdic.net，词典^, https://www.zdic.net/hans/外泄 (2024)

<Definition>让秘密信息广为人知。

<Source>^Fedrigo 2024^

<Context>在设备研发使用的技术层面，在对患者进行数据收集或存储时，采用去身份化或匿名化的方式来降低患者隐私信息外泄的风险，同时配备强大的机制来保证设备使用的基本安全属性，如机密性、完整性和可用性

<Source>^杨/刘 2024^:139

<Concept field>数据

**

<Subject>Technology

<Subfield>Manufacture for specific uses

<en>To solder

<Morphosyntax>verb

<Source>^Primavera 1999^:1

<Definition>To join pieces of metal together using solder.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/solder?q=to+solder (2024)

<Context>This paper discusses some of the basic assembly and Printed Circuit Board (PCB) parameters that influence the success of CSP assembly and solder joint robustness.

<Source>^Primavera 1999^:1

<Concept field>Hardware

<Equivalence en-zh>There is full conceptual identity between “To solder” and “焊接” terms

<zh>焊接

<Morphosyntax>verb

<Source>^王/赵/张 2024^:227

<Lexica>^赵 2020^:345

<Definition>通过加热（或辅以锤击、加压或加熔化的填充材料等方式）将金属材料连接起来的不可拆卸连接方法。

<Source>^zgbk.com, 玩洛百科全书^，https://www.zgbk.com/ecph/words?SiteID=1&ID=247276&Type=bkzyb&SubID=82855 （2024）

<Context>接装配好元器件后，开始进行原型机的信号完整性测试验证，同时与前一阶段的仿真分析形成闭环，用于指导下一代产品的设计和开发。

<Source>^王/赵/张 2024^:227

<Concept field>硬件

**

<Subject>Technology

<Subfield>Manufacture for specific uses

<en>To disassemble

<Morphosyntax>verb

<Source>^Soh/Ong/Nee 2014^:408

<Definition>To separate something into its different parts.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/disassemble?q=to+disassemble (2024)

<Context>Disassembly sequence planning aims at generating feasible disassembly sequences for a given assembly, where the feasibility of a disassembly sequence is checked by the existence of collision-free motions to disassemble each component or subassembly in the sequence.

<Source>^Soh/Ong/Nee 2014^:408

<Concept field>Hardware

<Equivalence en-zh>There is full conceptual identity between “To disassemble” and “拆卸” terms

<zh>拆卸

<Morphosyntax>verb

<Source>^魏/张 2008^:13

<Lexica>^赵 2020^:114

<Definition>拆卸，指把机器等拆开并卸下部件。

<Source>^baike.baidu.com, 网络百科全书^，https://baike.baidu.com/item/拆卸?fromModule=lemma_search-box （2024）

<Context>同时, 需要指出的是, 对于无法开机的手机机身信息提取运用本方法, 必须保证相关芯片完好性, 比如存储器、CPU 等没有被损坏。另外, 由于芯片封装工艺的不同, 芯片的拆卸和焊接也是难点。

<Source>^伟/张 2008^:13

<Concept field>硬件

**

<Subject>Computer science, information and general works

<Subfield>Systems

<en>To upgrade

<Morphosyntax>verb

<Source>^Zeng/Zeng/Xie/Lu/Xia/Chao/Li/Yang/Lin/Li 2012^:592

<Definition>To improve the quality or usefulness of something, or change it for something newer or of a better standard.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/upgrade?q=to+upgrade (2024)

<Context>The PCB mechanical recycling can be broadly divided into two major steps shown in Fig.2. The first step is the dismantling and/or separation of different components and materials, generally using mechanical or metallurgical processing to upgrade the desirable material content.

<Source>^Zeng/Zeng/Xie/Lu/Xia/Chao/Li/Yang/Lin/Li 2012^:592

<Concept field>Programs

<Equivalence en-zh>There is full conceptual identity between “To upgrade” and “更新” terms

<zh>更新

<Morphosyntax>verb

<Source>^宋/李/熊/叶/袁/赵/唐/冉 2023^:2

<Lexica>^赵 2020^:303

<Definition>本指除旧布新或改过自新，已引申为旧的去了，新的来到的意思，有着广阔的含义。

<Source>^baike.baidu.com, 网络百科全书 ^，https://baike.baidu.com/item/更新/33638 （2024）

<Context>同时，将元学习与微调策略相结合，元训练阶段更新整个模型参数，元测试阶段冻结部分参数，仅微调检测器头部，避免元知识迁过程中的分类混淆。

<Source>^宋/李/熊/叶/袁/赵/唐/冉 2023^:2

<Concept field>程序

**

<Subject>Technology

<Subfield>Manufacturing

<en>To weld

<Morphosyntax>verb

<Source>^Cabello/Aracil/Perdigones/Quero 2017^:2

<Definition>To join two pieces of metal together permanently by melding the parts that touch.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/weld?q=to+weld (2024)

<Context>The Printed Circuit Board (PCB) used in this module contents the NTC thermistor, EPCOS B572xxV5, and the microheater patterned in its copper layer. it also includes the pads to weld the components and the electrical connection where the electronic circuit and the Labview hardware are connected, so that some parameters, such as temperature or power, can be monitored.

<Source>^Cabello/Aracil/Perdigones/Quero 2017^:2

<Concept field>Hardware

<Equivalence en-zh>There is full conceptual identity between “To weld” and “焊接” terms

<zh>焊接

<Morphosyntax>verb

<Source>^王/安/田/王 2016^:55

<Lexica>^赵 2020^:345

<Definition>通过加热（或辅以锤击、加压或加熔化的填充材料等方式）将金属材料连接起来的不可拆卸连接方法。

<Source>^zgbk.com, 网络百科全书^, https://www.zgbk.com/ecph/words?SiteID=1&ID=247276&Type=bkzyb&SubID=82855 （2024）

<Context>外引线焊接到印刷线路板上时通常采用锡基钎料软钎焊方法衰存在焊后必须清洗和高温强度低尧可靠性较差的问题。

<Source>^王/安/田/王 2016^:55

<Concept field>硬件

**

<Subject>Technology

<Subfield>Manufacturing

<en>Silicon wafer

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Kern 1990^:1887

<Definition>A very thin piece of silicon used in computers.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/it/dizionario/inglese/silicon-wafer (2024)

<Context>Impurities on silicon wafer surfaces occur in essentially three forms: (i) contaminant films, (ii) discrete particles, and (iii) adsorbed gases that are of little practical consequence in wafer processing. Surface contaminant films and particles can be classified as molecular compounds, ionic materials, and atomic species.

<Source>^Kern 1990^:1887

<Concept field>Hardware

<Equivalence en-zh>There is full conceptual identity between “Wafer” and “硅晶片” terms

<zh>硅晶片

<Morphosyntax>noun

<Source>^余/刘/贾/马/万/苏/王/汤/贺/龚 2024^:2

<Lexica>^mdbg.net, 词典^，https://www.mdbg.net/chinese/dictionary?page=worddict&wdrst=0&wdqb=硅晶片&email= （2024）

<Definition>硅晶片又称晶圆片，是由硅锭加工而成的，通过专门的工艺可以在硅晶片上刻蚀出数以百万计的晶体管，被广泛应用于集成电路的制造。

<Source>^baike.baidu.com, 网络百科全书^，https://baike.baidu.com/item/硅晶片?fromModule=lemma_search-box （2024）

<Context>随着IC集成度的提高，硅晶片表面的洁净度对于获得IC器件高性能和高成品率至关重要，决定着器件的最终性能。

<Source>^余/刘/贾/马/万/苏/王/汤/贺/龚 2024^:2

<Concept field>硬件

**

<Subject>Computer science, information and general works

<Subfield>Systems

<en>Electronic registration identification

<Morphosyntax>noun group, uncount.

<Usage label>main term

<Source>^Zheng/Xia/Chen/Sun 2020^:4363

<Definition>Electronic Registration Identification (ERI) is a concept where information currently found in motor vehicle registration certificates is stored on electronic devices, so called Electronic License Plates.

<Source>^Oyvind 2010^:3

<Variant of>ERI

<Context>In December 2017, China issued the national standard on ERI, which was formally implemented in July 2018. This indicates the broad application prospects of ERI in China. Chongqing, which is the earliest ERI pilot city in China and requires all vehicles equipped with RFID tags, has accumulated massive ERI data so far.

<Source>^Zheng/Xia/Chen/Sun 2020^:4363

<Concept field>Internet of things

<Equivalence en-zh>There is full conceptual identity between “Electronic registration identification” and “汽车电子标识” terms

<zh>汽车电子标识

<Morphosyntax>noun

<Source>^吴/金/李/王 2020^:34

<Lexica>^baike.baidu.com, 网络百科全书^，https://www.autohome.com.cn/ask/510281.html#:~:text=汽车电子标识是一,标签真正的标记作用%E3%80%82 （2024）

<Definition>汽车电子标识是一种基于物联网无源射频识别（RFID）技术的高科技系统，用于全国车辆真实身份识别。它在汽车上安装一个芯片，能够实现高速运动状态下对车辆身份的识别、动态的监测，附带实现流量监测。汽车电子标识具有防伪、防借用、防拆卸等功能，能够确保电子标签与被识别车辆形成一一对应的关系，起到电子标签真正的标记作用。

<Source>^autohome.com.cn^, https://www.autohome.com.cn/ask/510281.html#:~:text=汽车电子标识是一,标签真正的标记作用%E3%80%82 (2024)

<Context>汽车电子标识是公安部交通管理局统一标准、统一推行、统一管理,与汽车车辆号牌并存,并且具有与车辆号牌同等法律效力的汽车身份识别系统,是嵌有超高频无线射频识别芯片并存储汽车身份数据的电子信息识别载体。

<Source>^吴/金/李/王 2020^:34

<Concept field>物联网

**

<Subject>Technology

<Subfield>Manufacturing

<en>Technology node

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Zhang/Zhang/Luo/Yin 2024^:2

<Definition>The technology node (also process node, process technology or simply node) refers to a specific semiconductor manufacturing process and its design rules. Different nodes often imply different circuit generation and architectures.

<Source>^en.wikichip.org, encyclopedia^, https://en.wikichip.org/wiki/technology_node#:~:text=The%20technology%20node%20(also%20process,different%20circuit%20generations%20and%20architectures , (2024)

<Variant of>Process node, process technology, node

<Context>As ICs continued to be developed beyond the 22-nm node, further scaling of the transistor L_G using singular and planar gate structures was no longer sufficient to maintain the electric field strength and switch off the transistor effectively.

<Source>^Zhang/Zhang/Luo/Yin 2024^:2

<Concept field>Hardware

<Equivalence en-zh>There is full conceptual identity between “Technology node” and “工艺技术” terms

<zh>工艺技术

<Morphosyntax>noun

<Source>main term

<Source>^彭/刘/程/张 2022^:206

<Definition>工艺技术是指工业产品的加工制造方法，包括从原料投入到产品包装全过程的原料配方、工艺路线、工艺流程、工艺流程图、工艺步骤、工艺指标、操作要点、工艺控制等。

<Source>^baike.baidu.com, 网络百科全书^, https://baike.baidu.com/item/工艺技术?fromModule=lemma_search-box （2024）

<Context>基于微组装工艺的微波开关则选用裸芯片PIN 二极管、芯片电容等器件，通过基板烧结/粘接、芯片共晶/粘接、金丝键合等微组装工艺来实现的。微组装关键工艺技术主要是粘接/烧结工艺技术和微型焊接工艺技术，它是微组装工艺技术中的重要和基础技术。微型焊接工艺技术包括芯片的粘接/共晶工艺技术，金丝楔/球键合工艺技术。

<Source>^彭/刘/程/张 2022^:206

<Concept field>硬件

**

<Subject>Technology

<Subfield>Manufacturing

<en>Nanometer

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Alvarez-Puebla/Liz-Marzan/Garcia de Abajo 2024^:2428

<Definition>0.000,000,001 of a meter

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/nanometer (2024)

<Variant of>nm

<Context>Several ingenious methods have been devised to break that limit and push spatial resolution of optical techniques down to truly nanometer scales.

<Source>^Alvarez-Puebla/Liz-Marzan/Garcia de Abajo 2024^:2428

<Concept field>Units of measurement

<Equivalence en-zh>There is full conceptual identity between “Nanometer” and “納米” terms

<zh>納米

<Morphosyntax>noun

<Source>^刘/郝 2002^:1

<Lexica>^赵 2020^:586

<Definition>纳米，又称奈米，为微米的千分之一倍（符号 nm，英式英语：nanometer、美式英语 nanometer，字首 nano 在希腊文中的原意是“侏儒”的意思），是一个长度单位，指1米的十亿分之一（10^{-9}m）。

<Source>^zh.wikipedia.org, 网络百科全书^，https://zh.wikipedia.org/zh-hans/纳米#:~:text=纳米，又称奈米，，为10%2D10m%E3%80%82，（2024）

<Context> 在纳米量级内，物质颗粒的尺寸已经接近原子，这时量子效应已开始影响到物质的结构和性能。

<Source>^刘/郝 2002^:1

<Concept field>度量单位

**

<Subject>Technology

<Subfield>Manufacturing

<en>Panel

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Rajagopal/Rajarao/Cholake/Sahajwalla 2016^:471

<Definition>A flat section in shape of a rectangle that is part of or fits into something larger.

<Source>^dictionary.cambridge.org, dictionary^, https://dictionary.cambridge.org/dictionary/english/panel (2024)

<Context>In this study, the use of non-metallic PCB waste andWAP in the fabrication of sustainable composite panels is demonstrated. Using a hot press, composite panels with different ratios of non-metallic PCBs toWAP are produced. The panels are then subjected to various physical and mechanical studies. The results clearly show the addition of non-metallic PCBs to WAP increases the density, flexural, tensile and compressive properties of the panels.

<Source>^Rajagopal/Rajarao/Cholake/Sahajwalla 2016^:471

<Concept field>Metalworking and primary metal products

<Equivalence en-zh>There is full conceptual identity between “Panel” and “面板” terms

<zh>面板

<Morphosyntax>noun

<Source>^张 2023^:68

<Lexica>^赵 2020^:567

<Definition>钢板在粗下料时，所切形状为矩形时（形同面板），便称之为面板。

<Source>^baike.baidu.com, 网络百科全书^，https://baike.baidu.com/item/面板?fromModule=lemma_search-box （2024）

<Context>单面和双面板一般用于低中密度的线路布局情况，相关人员在进行线路布局设计的过程中，要从成本发展的角度出发考虑成本的因素，同时要将单面板和双面板应用于民用设备的设计。

<Source>^张 2023^:68

<Concept field>金属加工和初级金属产品

**

<Subject>Technology

<Subfield>Electricity and electronics

<en>Oscillator

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Vittoz 1988^:776

<Definition>Oscillator, any of various electronic devices that produce alternating electric current, commonly employing tuned circuits and amplifying components such as thermionic vacuum tubes.

<Source>^britannica.com, encyclopedia^, https://www.britannica.com/technology/oscillator-electronics (2024)

<Context>Excellent oscillators can be implemented by using essentially a single transconductance device, such as a bipolar or a MOS transistor.

<Source>^Vittoz/Degrauwe/Bitz 1988^:776

<Concept field>Device

<Equivalence en-zh>There is full conceptual identity between “Oscillator” and “振荡器” terms

<zh>振荡器

<Morphosyntax>noun

<Source>^梁/吴 2009^:30

<Lexica>^mdbg.net, 词典^，https://www.mdbg.net/chinese/dictionary?page=worddict&wdrst=0&wdqb=振荡器&email= （2024）

<Definition>产生周期性的量的有源器件。该量的基频取决于器件的特性。

<Source>^zgbk.com, 网络百科全书^，https://www.zgbk.com/ecph/words?SiteID=1&ID=124191&Type=bkzyb&SubID=99044 （2024）

<Context>功耗增加时，环形振荡器对节点寄生电容充放电电 流增加，转换速率提高，从而改善相位噪声性能。

<Source>^梁/吴 2009^:30

<Concept field>器件

**

<Subject>Compute science, information and general works

<Subfield>Computer programming, programs and data

<en>Debugger

<Morphosyntax>noun, count.

<Usage label>main term

<Source>^Handigol/Heller/Jeykumar/Mazieres/McKeown 2012^:55

<Definition>A debugger is a software program used to test and find bugs (errors) in other programs. A debugger is also known as a debugging tool.

<Source>^technopeda.com, technology encyclopedia^, https://www.techopedia.com/definition/597/debugger (2024)

<Context>In this new world, we can start to debug networks like we debug software: write and execute control programs, use a debugger to view context around exceptions (errant packets), and trace sequences of events leading to exceptions to find their root causes.

<Source>^Handigol/Heller/Jeykumar/Mazieres/McKeown 2012^:55

<Concept field>Software

<Equivalence en-zh>There is full conceptual identity between “Debugger” and “调试器” terms

<zh>调试器

<Morphosyntax>noun

<Source>^杨 2024^:40

<Lexica>^youdao.com, 词典^, https://www.youdao.com/result?word=debugger&lang=en （2024）

<Definition>一种用于检测和调试目标程序正确性的计算机程序。又称调试工具。

<Source>^zgbk.com, 网络百科全书^，https://www.zgbk.com/ecph/words?SiteID=1&ID=171805&Type=bkzyb&SubID=81635 （2024）

<Context>自动化调试系统的总体架构主要包括调试器、被调试器和上位机三个部分，其中调试器用于对被调试器进行调试，而被调试器则是被调试的机械设备，上位机则是对整个调试过程进行监控和操作。

<Source>^杨 2024^:40

<Concept field>软件

**

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ENGLISH - CHINESE GLOSSARY

英/汉词典

<en> 英文	<zh> 中文	Pinyin 拼音
Adapter	适配器	Shìpèiqì
Artificial intelligence (AI)	人工智能	Réngōngzhìnéng
Asymmetric cryptography	非对称加密	Fēiduìchēng jiāmì
Augmented reality	增强现实	Zēngqiáng xiànshí
Automotive advanced driver assistance system (ADAS)	驾驶辅助系统	Jiàshǐ fǔzhù xìtǒng
Binary code	二进制编码	Èrjìnzhìbiānmǎ
Bit error rate (BER)	比特误码率	Bǐtè wù mǎlù
Chipset	芯片组	Xīnpiànzǔ
Cloud computing	云计算	Yúnjìsuàn
Connector	连接器	Liánjiēqì
Controller	控制器	Kòngzhìqì
Debugger	调试器	Tiàoshìqì
Dedicated short-range communication (DSRC)	交通专用短程通信	Jiāotōng zhuānyòng duǎnchéng tōngxìn
Device driver	驱动器	Qūdòngqì

Electronic manufacturing services (EMS)	电子制造服务	Diànzǐ zhìzào fúwù
Embedded system	嵌入式系统	Qiànrù shì xìtǒng
Emulator	仿真器	Fǎngzhēnqì
Electronic non-parking toll collection system (ETC)	电子不停车收费系统	Diànzǐ bùtíng chē shōufèi xìtǒng
Electronic registration identification	汽车电子标识	Qìchē diànzǐ biāoshí
Error correcting code (ECC)	纠错码	Jiūcuò mǎ
EPROM	可擦写可编程只读存储器	Kěcāxiěkěbiānchéngzhīdúcúnchǔ qì
Firmware	固件	Gùjiàn
Flash memory	快闪存储器	Kuàishǎncúnchǔqì
Ground-loop	接地回路	Jiēdì huílù
Guide rail	导轨	Dǎoguǐ
Screw	丝杠	Sīgàng
Haker	黑客	Hēikè
Hardware	硬件	Yìngjiàn
In-system programming (ISP)	在线烧录	Zàixiàn shāolù
In-vehicle infotainment (IVI)	车载信息娱乐系统	Chēzài xìnxī yúlè xìtǒng
Integrated Circuit (IC)	集成电路	Jíchéng diànlù
Intellectual property (IP)	知识产权	Zhīshí chǎnquán
Internet of Things (IoT)	物联网	Wùliánwǎng
Manual toll collection system (MTC)	人工收费系统	Réngōng shōufèi xìtǒng
Microchip	微芯片	Wēi xīnpiàn

Microcontroller	微控制器	Wēi kòngzhìqì
Microprocessor	微处理器	Wēi chǔlǐqì
Motherboard	主板	Zhǔbǎn
Multi-chip package (MCP)	多芯片封装	Duō xīnpiàn fēngzhuāng
Nanometer	纳米	Nàmǐ
Network protocol	网络协议	Wǎngluòxiéyì
Optical isolator	光隔离器	Guānggélíqì
Original equipment manufacturer (OEM)	代工生产	Dàigōngshēngchǎn
Oscillator	振荡器	Zhèndàngqì
Panel	面板	Miànbǎn
Port	端口	Duānkǒu
Power dissipation	功耗	Gōnghào
Printed circuit board (PCB)	印制电路板	Yìnzhìdiànlùbǎn
Printed circuit board assembly (PCBA)	印制电路板装配件	Yìnzhìdiànlùbǎn zhuāngpèijiàn
Programmer	编程器	Biānchéngqì
Property right	产权	Chǎnquán
QR code	二维码	Èrwéimǎ
Robotic	机器人技术	Jīqìrén jìshù
Rugged computer	强固计算机	Qiánggù jìsuànjī
Secret Key	密钥	Mìyuè
Serial port	串行端口	Chuànxíng duānkǒu

Silicon carbide (SiC)	碳化硅	Tànhuàguī
Silicon manufacturers	硅制造商	Guī zhìzàoshāng
Silicon wafer	硅晶片	Guī jīngpiàn
Stepper	光刻机	Guāngkèjī
Symmetric encryption	对称加密	Duìchēng jiāmì
System on module	模块系统	Mókuài xìtǒng
Time server	时间服务器	Shíjiān fúwùqì
Servo	伺服电机	Sìfú diànjī
Software	软件	Ruǎnjiàn
Technology node	工艺技术	Gōngyì jìshù
Test fixture	测试夹具	Cèshì jiājù
Test machine	测试机	Cèshìjī
Test point	测试点	Cèshì diǎn
To debug	调试	Tiáoshì
To decrypt	解密	Jiěmì
To encrypt	加密	Jiāmì
To install	安装	ānzhuāng
To leak	外泄	Wàixiè
To solder	贴	Tiē
To disassemble	拆卸	Chāixiè
To upgrade	更新	Gēngxīn
To weld	焊接	Hànjiē

Virtual reality	虚拟现实	Xūnǐxiànshí
Wire rod	线材	Xiàncái

CHINESE - ENGLISH GLOSSARY

汉/英词典

Pinyin 拼音	<zh> 中文	<en> 英文
ānzhuāng	安装	To install
Biānchéngqì	编程器	Programmer
Bǐtè wù mǎlù	比特误码率	Bit error rate (BER)
Cèshì diǎn	测试点	Test point
Cèshì jiājù	测试夹具	Test fixture
Cèshìjī	测试机	Test machine
Chāixiè	拆卸	To disassemble
Chǎnquán	产权	Property right
Chēzài xìnxī yúlè xìtǒng	车载信息娱乐系统	In-vehicle infotainment (IVI)
Chuànxíng duānkǒu	串行端口	Serial port
Dàigōngshēngchǎn	代工生产	Original equipment manufacturer (OEM)
Dǎoguǐ	导轨	Guide rail
Diànzǐ bùtíng chē shōufèi xìtǒng	电子不停车收费系统	Electronic non-parking toll collection system (ETC)
Diànzǐ zhìzào fúwù	电子制造服务	Electronic manufacturing services (EMS)

Duānkǒu	端口	Port
Duìchēng jiāmì	对称加密	Symmetric encryption
Duō xīnpiàn fēngzhuāng	多芯片封装	Multi-chip package (MCP)
Èrjìnzhìbiānmǎ	二进制编码	Binary code
Èrwéimǎ	二维码	QR code
Fǎngzhēnqì	仿真器	Emulator
Fēiduìchēng jiāmì	非对称加密	Asymmetric cryptography
Gēngxīn	更新	To upgrade
Gōnghào	功耗	Power dissipation
Gōngyì jìshù	工艺技术	Technology node
Guānggélíqì	光隔离器	Optical isolator
Guāngkèjī	光刻机	Stepper
Guī jīngpiàn	硅晶片	Silicon wafer
Guī zhìzàoshāng	硅制造商	Silicon manufacturers
Gùjiàn	固件	Firmware
Hànjiē	焊接	To weld
Hēikè	黑客	Haker
Jiāmì	加密	To encrypt
Jiāotōng zhuānyòng duǎnchéng tōngxìn	交通专用短程通信	Dedicated short-range communication (DSRC)
Jiàshǐ fǔzhù xìtǒng	驾驶辅助系统	Automotive advanced driver assistance system (ADAS)
Jíchéng diànlù	集成电路	Integrated circuit (IC)
Jiēdì huílù	接地回路	Ground-loop

Jiěmì	解密	To decrypt
Jīqìrén jìshù	机器人技术	Robotic
Jiūcuò mǎ	纠错码	Error correcting code (ECC)
Kěcāxiěkěbiānchéngzhīdúcúnchǔ qì	可擦写可编程只读存储器	EPROM
Kòngzhìqì	控制器	Controller
Kuàishǎncúnchǔqì	快闪存储器	Flash memory
Liánjiēqì	连接器	Connector
Miànbǎn	面板	Panel
Mìyuè	密钥	Secret key
Mókuài xìtǒng	模块系统	System on module
Nàmǐ	纳米	Nanometer
Qiánggù jìsuànjī	强固计算机	Rugged computer
Qiànrù shì xìtǒng	嵌入式系统	Embedded system
Qìchē diànzǐ biāoshí	汽车电子标识	Electronic registration identification
Qūdòngqì	驱动器	Device driver
Réngōng shōufèi xìtǒng	人工收费系统	Manual toll collection system (MTC)
Réngōngzhìnéng	人工智能	Artificial intelligence (AI)
Ruǎnjiàn	软件	Software
Shíjiān fúwùqì	时间服务器	Time server
Shìpèiqì	适配器	Adapter
Sìfú diànjī	伺服电机	Servo

Sīgàng	丝杠	Screw
Tànhuàguī	碳化硅	Silicon carbide (SiC)
Tiáoshì	调试	To debug
Tiàoshìqì	调试器	Debugger
Tiē	贴	To solder
Wàixiè	外泄	To leak
Wǎngluòxiéyì	网络协议	Network protocol
Wēi chǔlǐqì	微处理器	Microprocessor
Wēi kòngzhìqì	微控制器	Microcontroller
Wēi xīnpiàn	微芯片	Microchip
Wùliánwǎng	物联网	Internet of Things (IoT)
Xiàncái	线材	Wire rod
Xīnpiànzǔ	芯片组	Chipset
Xūnǐxiànshí	虚拟现实	Virtual reality
Yìngjiàn	硬件	Hardware
Yìnzhìdiànlùbǎn	印制电路板	Printed circuit board (PCB)
Yìnzhìdiànlùbǎn zhuāngpèijiàn	印制电路板装配件	Printed circuit board assembly (PCBA)
Yúnjìsuàn	云计算	Cloud computing
Zàixiàn shāolù	在线烧录	In-system programming (ISP)
Zēngqiáng xiànshí	增强现实	Augmented realty
Zhèndàngqì	振荡器	Oscillator
Zhīshí chǎnquán	知识产权	Property right

Zhǔbǎn	主板	Motherboard

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