Microelectronics in Finland

Microelectronics research, development and education strategy and roadmap – must win battle for ensuring Finland's competitive position in EUs sovereignty strategy

Towards 43 000 billion Euro global markets in 2030[1], of which EU region share target 20%, and Finland's accessible share over 200 billion Euro turnover (0.5% of global, 2.3% of EU)

[1] European Commission, Directorate-General for Communications Networks, Content and Technology, *Emerging technologies in electronic components and systems (ECS) : opportunities ahead : final report*, Publications Office, 2020, https://data.europa.eu/doi/10.2759/64162

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Everything in modern societies runs on microelectronics - Microelectronics comprises the study and manufacture of very small (micrometer-scale or smaller) electronic designs, often made of semiconductors. Microelectronics devices are tiny workhorses that hide inside consumer and capital goods. Out of sight they make normal life run smoothly, without them everything would crash down. We are now living in a time of great global upheaval; it is important to take care of our nationally and internationally important activities and expertise. Microelectronics and related technologies are part of critical technologies related to national security and defense.

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Tiivistelmä

Mikroelektroniikka on keskeinen menestystekijä Suomen taloudelle ja yritysten erottautumiselle EU:n omavaraisuustavoitteiden kautta maailmanlaajuisessa digitalisaatiokilpailussa. Kestävän kehityksen sekä hiilijalanjäljen pienentämisen suhteen mikroelektroniikka toimii monilla aloilla ratkaisevan tärkeänä mahdollistajana. Vahvuutemme perustuu korkeimman vaativuuden mikropiirien ja komponenttien suunnitteluosaamiseen; kyvykkyys, jota kokonaisuutena osataan vain muutamissa keskittymissä maailmassa. Suomalaisen teollisuuden kilpailukyky nojaa voimakkaasti mikroelektroniikan ja sen päälle rakentuneiden ohjelmistojen varaan lukuisilla liiketoiminnan alueilla.

- **Taloudellinen merkitys:** Suomessa teknologiateollisuuden n. 35Mrd€:n tilauskannasta (2022) mikroelektroniikan osuus on suuri, n. 9Mrd€, josta 90% menee vientiin (Lähde: Teknologiateollisuus, luku ei sisällä palveluita).
- **Laaja vaikuttavuus:** Suomessa painopistealueita ovat uudet materiaalit, komponentit, erikoispiirit ja -järjestelmät, joiden hyödyntäjäyritykset toimivat erittäin kilpailluilla globaaleilla toimialoilla aina energiateollisuudesta terveystuotteisiin ja telekommunikaatiosta autoteollisuuteen. Välillinen vaikuttavuus esimerkiksi vihreässä siirtymässä erittäin merkittävä.
- **Suomen vahvuudet:** Keskittyminen uusimpien teknologia-alueiden suunnitteluun ja innovaatioihin, kehittämällä räätälöityjä komponentteja, siruja ja erikoispiirejä eri liiketoiminta-alueille. Ilman pitkäjänteistä ja riittävävolyymista mikroelektroniikan koulutus-, tutkimus- ja kehitystoimintaa, meillä ei olisi nykyisenlaista kilpailukykyä kansainvälisillä markkinoilla.

Mikroelektroniikka on valittu EU:n prioriteettiteknologiaksi ja nähdään perustana tulevaisuuden yhteiskunnille. EU:n Chips Act-ohjelman tavoitteena on merkittävä elektroniikan suunnittelun ja tuotannon omavaraisuusasteen nostaminen. Suomalainen mikroelektroniikan toimiala on pohjoisen Euroopan suurin suunnittelun ja innovaatioiden TKI-keskittymä, ja vastaa Euroopan Unionin tavoitteeseen suunnittelun ja tuotannon omavaraisuudesta. EU tulee investoimaan alueen TKI-toimintaan ja tuotantoon voimakkaasti mm. EU Chips Act-ohjelmassa, joka jakautuu kolmeen pilariin:

1. **Chips for Europe -aloite** tukee teknologisen kapasiteetin rakentamista sekä siihen liittyvää tutkimusta ja innovaatiota. Osaamiskeskukset ja pilottilinjat ovat keskeisiä instrumentteja.
2. **Toimitusvarmuuden takaaminen.** Investoinnit tuotantokapasiteettiin vuoteen 2030 mennessä.
3. **Seuranta ja kriisivaste**: Oikeus pyytää yrityksiltä tietoja, pyytää yrityksiä hyväksymään ja priorisoimaan kriisille olennaisten tuotteiden tilauksia, ja tehdä yhteishankintoja.

Suomi on mikroelektroniikan TKIO:n osalta vielä kärkimaiden joukossa, mutta uhkana on, että jäämme jatkossa kehityksestä kansallisen rahoituksen niukkuuden ja sirpaleisuuden vuoksi. Jatkuvan menestyksen turvaamiseksi Suomen tulee panostaa koulutukseen, tutkimukseen, TKI-rahoitusohjelmiin, sekä pitkäjänteiseen yhteistyöhön EU- ja NATO-ohjelmissa.

1. **Teollisuuden osaajatarve painottuu tohtoritasoiseen osaajajoukkoon**, siksi on tärkeää tutkimuslaitosten ja yliopistojen oikea-aikainen ja pitkäjänteinen rahoituksen lisääminen, kansainvälisten opiskelijoiden houkutteleminen ja naisten osallistumisen edistäminen.
2. **Tutkimuksessa korostuu TKI-hankkeiden ja -investointien pitkäjänteinen tukeminen** sekä mikroelektroniikan sovellustoimialueiden yritysten kilpailukyvyn yhteistyö ja kehittäminen.
3. **Rahoituksen sirpaleisuus ja saatavuus on merkittävin ongelma Suomessa.** Ala on tutkimus- ja infrastruktuuri-intensiivinen. Viimeisin TKI-rahoitusohjelma on vuodelta 2001-4 Tekesin (nyk. Business Finland) EXSITE ja Akatemian Telectronics-ohjelmat.
4. **Globaalin aseman säilyttäminen yhtenä johtavista T&K-maista** tarkoittaa ajanmukaista tutkimusinfrastruktuuria, lahjakkaita ja intohimoisia tutkijoita sekä tutkimustoiminnan riittävää rahoitusta, jota on rakennettava oikea-aikaisesti ja pitkäjänteisesti.

Microelektroniikka Suomessa strategia on toteutettu alan tutkimuskeskittymien yhteistyönä. Esitämme useita toimenpiteitä ja investointeja, sekä tiekarttaa, jolla Suomalainen mikroelektroniikan toimiala pysyy kilpailukykyisenä, lunastaa paikkansa EU-tasoisessa strategiassa pohjoisena erityiskeskittymänä, sekä luo veto- ja pitovoimaa alan tutkimukseen ja liiketoimintaan: nämä ovat keskeisiä asiakokonaisuuksia Suomen kansantalouden kannalta. Tiekartan ja investointien osalta esitämme n. 110M€ vuotuista rahoituskokonaisuutta jakautuen koulutukseen, tutkimukseen ja yritysten menestystekijöiden (työpaikat, viennin arvo, kilpailukykyiset tuotteet ja palvelut) varmistamiseksi.

Executive summary

Microelectronics is the key enabler for core segments in EU and Finnish critical industries including telecom, forestry, retail, healthcare and logistics. Further, microelectronics is a critical enabler for running any applications using artificial intelligence.

One of the key cornerstones is the ability to design integrated circuits, i.e., 'chips' to this market and understand their technological opportunities and constraints when used in the devices, products and services. In 2021, out of the ten largest companies in the world by value, nine are investing in Microelectronics design.

To ensure Finland's competitiveness in microelectronics we propose the following actions:

1) **Education:** Dedicated funding for the excellence in microelectronics education: **20M€**/year, MEC
2) **Research:** Funding of 1) research, 2) infrastructure: **15M€**/year + **10M€** FIRI type call, AoF
3) **Innovation:** Funding of D&I-program: **120M€**/4-year BF
4) **EU Chips Act:** national part, including infrastructure: **15-25M€**/year MEAE and Program office for national activities and EU-influence: **2M€**/year
5) **Strategic roundtable:** established with a long-term roadmap with industry needs: MEAE
6) **Coordination:** Establish a joint program between BF and AoF (over 1)-5))
7) Maximizing **international impact** in microelectronics community

Total proposed actions for public funding: ca. 110M€/year (current annual funding ~57M€/2022 without education)

Microelectronics is characterized by highly intense R&D, with companies globally reinvesting more than 15% of revenues into research. Furthermore, research infrastructure costs (both capex and opex) are very high, while the infrastructure investments are critical to the long-term success of the microelectronics industry. Therefore, a significant R&D&I funding package for the field is needed and necessary infrastructure funding should be guaranteed in Finland while leveraging also EU Chips Act funding maximally.

> **The microelectronics industry is deeply dependent on access to skilled workers** for ensuring its innovation and competitiveness. The promotion of microelectronics-specialists in relevant fields, such as integrated circuit (IC) design, radio frequency (RF) and microelectromechanical components, photonics, quantum technology and semiconductor physics, through 1) the advancement of females in the field, 2) doctoral education with industry, 3) international student pools (BSc, MSc, DSc) and 4) growing expert migration to Finland are essential tools to prevent the lack of skilled workers from becoming the bottleneck for the industry's future. Developing top level experts take much longer time than the standard MSc takes, which is why companies also have higher role in the deeper education in the field. A significant increase of university funding for educational activities is needed: international BSc programs, industrial doctoral programs, and continuous education beyond MSc degree.

Ability to 1) create original innovations by designing custom systems on semiconductor chips, and 2) manufacturing special designs has been the profitable strategic choice for Finland.[2]

> **Currently most of the successful and highly profitable semiconductor companies have been fabless.** Most of the high-profit R&D performed towards the products is being done that way. This means design of custom semiconductor chips for specific/different applications in a company that submits the design for the actual chip manufacturing at external foundry, like TSMC.

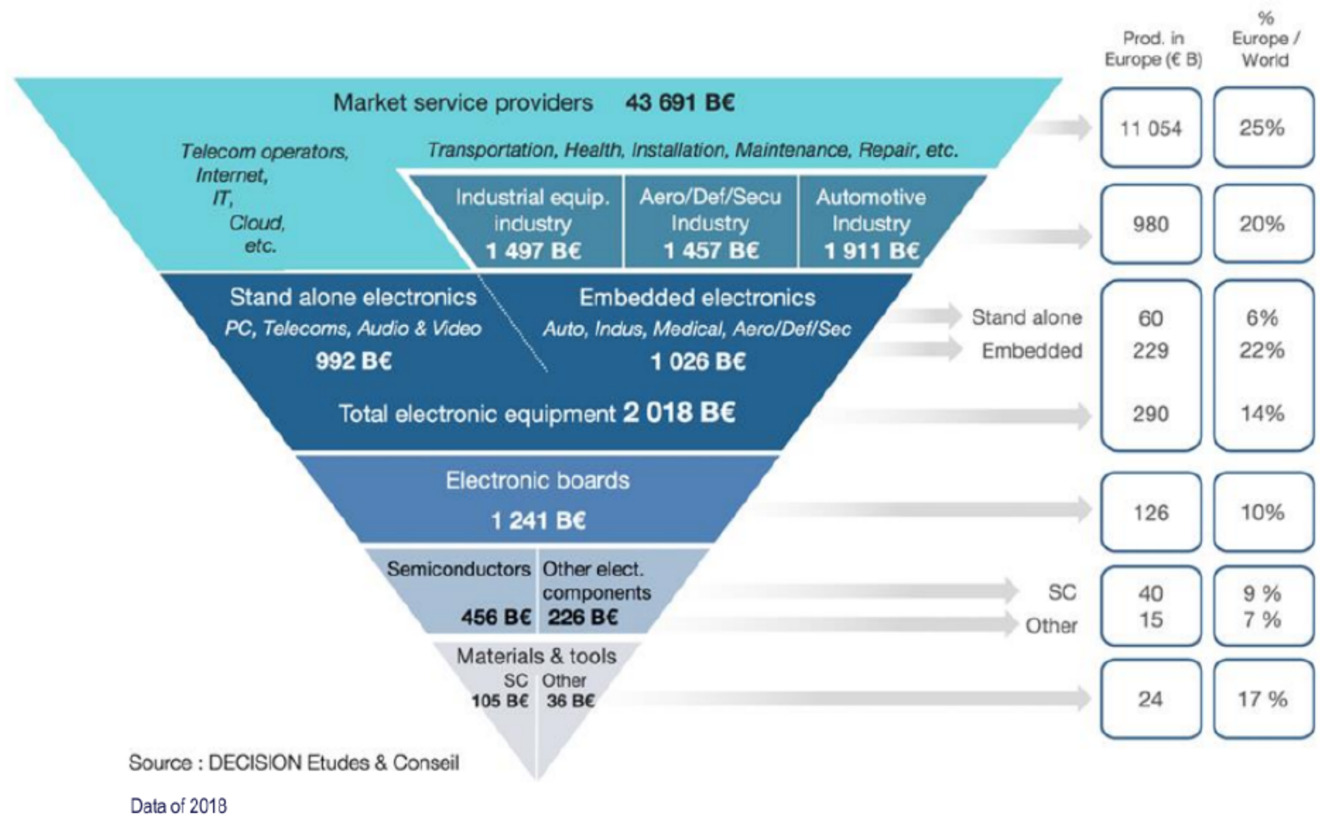
[2] Salainen aarre (Veijo Kontas) https://www.hs.fi/talous/art-2000008376168.html

Success will not continue without significant further investments for microelectronics areas, including 1) education, 2) research, 3) special R&D&I funding programs, and 4) entering continuous strategy and investment model. 5) These actions need to be implemented holistically at national and EU levels, in a way that they 6) enable maximal international impact. In addition, flexible and motivating legal and business conditions for attracting specialized microelectronics companies and manufacturing with dedicated R&D must be created.

Introduction

Microelectronics is globally a key enabler technology that supports the whole value chain of consumer electronics, automotive, aerospace, military and space applications. With a yearly market volume of about 500 billion €, for microelectronics only, it is about the same volume as the global forest industry. In total, microelectronics is working as the cutting-edge implementation platform for industrial market of 43 000 billion €.

Electronics market

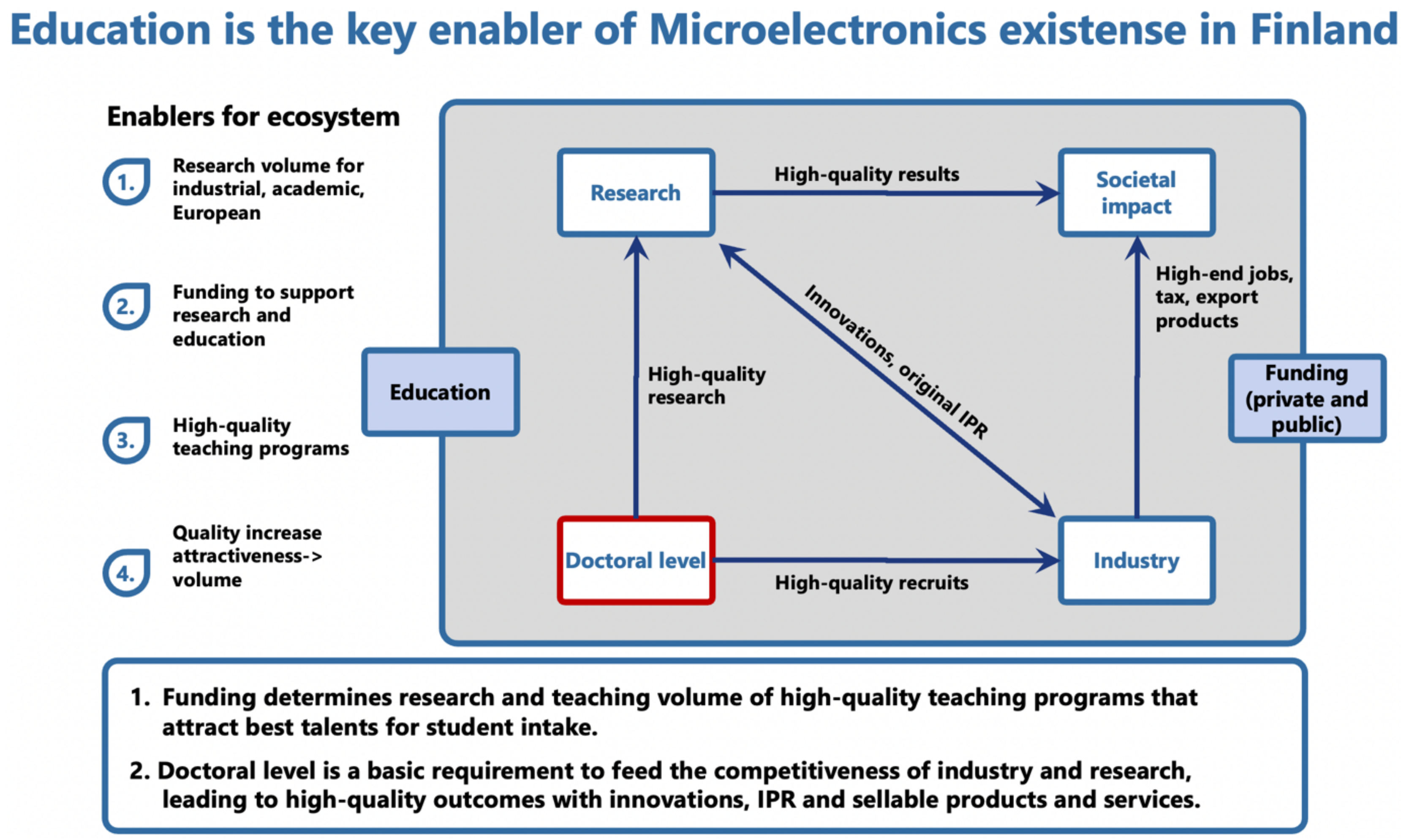


Emerging Technologies in Electronic Components and Systems (ECS) - Opportunities Ahead, final report, European Union, 2020.

- As reference: Global forest industry market is around $500 billion.

Microelectronics is the flagship of all electronics that builds on very high level on education (doctoral degree is presently considered as basic degree for microelectronics designer), and extremely expensive investments of semiconductor fabrication facilities with investment volumes of tens of billions per site. Finland is a nation which survival strategy relies on high education of highly competent workforce. Therefore, microelectronics design is an extremely suitable area of industry as the success story of Nokia shows. However, to be a credible player on microelectronics design field, there must be sufficient expertise and active participation for global development of the field. In Finland that expertise was built in the early 90s, but due to stalled resourcing it is gradually aging away.

The figure below describes the education ecosystem and its' dependencies in microelectronics.



It is a feedback system, where the success and positive visibility of industry, education, and research attracts more successful industry, more talented students and boosts performance in education and research that further boosts the success of industry. This positive circle is clearly visible for example in United States, where the best universities attract the best students that are educated to doctoral degrees with industrial and public (DARPA, NSF, etc.) funding to eventually be hired by the microelectronics industry in Silicon Valley and elsewhere in USA.

Globally microelectronics is a game of survival with a simple concept: if you are not in, as a credible player, you are out. Recently Europe has woken to the reality that the strategic competence on this field lies outside of Europe; in USA, Taiwan and China. In microelectronics, the mainstream applications flow from the Far East, but in many of its specialized fields, Finland is at the forefront of research, development, innovation, and education. As a cutting-edge technology, microelectronics does not have a single edge, so there are several battles for Finland to choose.

Europe's share in global chip manufacturing has dropped from 25% in 2000 to 8% today. In advanced semiconductor technology, Europe's market share has been falling from 19% in 2000 to basically zero today. Europe's dependence on Asian semiconductors has become critical effecting broader electronics sectors such as automotive and consumer electronics. For example, the current semiconductor supply shortages have significant influence for numerous European companies across all industries. Europe has now started the painful process of reinforcing the resilience and competitiveness of the semiconductor ecosystem in Europe. With the announcement of the Chips Act, Europe has taken a pivotal step in securing our supply chain resilience and the future competitiveness of the continent's microelectronics ecosystem.

From national perspective, the *manufacturing* of high-volume microelectronics products (CMOS or BiCMOS) currently is not within the scope of Finland's core competencies. Establishing the manufacturing facilities requires investments of several tens of billions and requires a highly educated workforce (Doctor of Science) counted in thousands per site. With these requirements Finland is simply not self-sufficient and attractive enough for that kind of volume of workforce. The assumption is that these sites in Europe continue to be located in Belgium, France, Italy, and Germany where the current production sites are located.

However, Finland has significant manufacturing capacity in specialized microelectronics, especially in MEMS sensors, e.g. Murata Electronics and Vaisala. In other specialized microelectronics fields, such as integrated photonics and quantum technology, Finland has significant expertise and growing companies (e.g. IQM). The creation of manufacturing base in these technologies is feasible in Finland, due to smaller and less costly typical fab size. In addition to this, Finland has many semiconductor fabrication equipment manufacturers, especially with a strong presence of Atomic Layer Deposition (ALD) tool makers (Applied Materials, ASM, Beneq).

In contrast to mass-production capability, strategic objective of Finland should be to increase the visibility of Finland's competence in *microelectronics design (so-called fabless design)* so that it would be an attractive country to establish design sites for the most prominent companies in the field: Intel, AMD, Nvidia, Samsung, Apple, Qualcomm, Analog Devices, Nokia, Ericsson, Infineon, Nordic Semiconductor, ST Microelectronics, Murata, LG Electronics, Mediatek and so forth. Many of these have design teams and sites in Finland and are planning to increase their recruiting. Continuous growth of demand is there for the highest talents in microelectronics design.

Global situation

The global semiconductor market is a highly competitive and rapidly growing and evolving industry, due to deepening digitalization. The fabrication of high-end chips is mostly done in Taiwan and South Korea, while the US dominates the design and design tools of semiconductors. Europe's strength is in semiconductor manufacturing tools where the Dutch company ASML is the one of market leaders and the Dutch company ASM together with Finnish Picosun and Beneq provide the leading ADL (Atomic Layer Deposition) tools for extremely thin film constructions. There is a concern in the US government as they see the dominance of non-US companies in fabrication as a strategic vulnerability, and in the European Union (EU) a risky dependency on other nation's production chains. This is not only for state-of-the-art devices but also for legacy products whose supply chain needs to be secured.

The EU is thus looking to increase its competitiveness in the global semiconductor market. The EU has announced the EU Chips Act, which aims to mobilize more than €43 billion euros of public and private investments to boost the EU semiconductor market competitiveness. However, the sum of EU governments' microelectronics incentives foreseen between 2020 and 2030 is quite small compared to what respectively e.g., China and the US are going to invest over the same time.

The global semiconductor market is driven by various trends and emerging technologies. Some of the key trends and drivers include RISC-V microprocessors, machine learning accelerators, self-driving cars, radio frequency (RF) electronics for communications and sensing in 5G and 6G, digital SoCs for 5G and 6G communications systems, sensors and sensor fusion for 5G/6G, automotive, health, robotics and automation, programmatic open-source integrated circuit design methodologies, defense applications, and microelectronics for health and wellbeing. Key areas are summarized below:

- RISC-V microprocessors, an open-source instruction set architecture, are becoming increasingly popular in the semiconductor industry. They offer an alternative to proprietary instruction set architectures and have the potential to reduce costs and increase innovation.
- Machine learning accelerators are also gaining momentum in the semiconductor market, as they are critical for enabling the deployment of artificial intelligence (AI) and machine learning (ML) applications. These accelerators are designed to accelerate the processing of large amounts of data, making them essential for a wide range of applications including autonomous vehicles, medical imaging, and industrial automation.
- Automotive industry is another area where semiconductors are playing a critical role. Semiconductors are used in digitalization of cars for various applications such as sensor fusion, image processing, and control systems. Also, the increasing trend towards self-driving cars is expected to drive the growth of the semiconductor market.
- RF electronics for communications and sensing in 5G and 6G are also important drivers of the semiconductor market. 5G and 6G networks require advanced RF electronics to support faster data rates, lower latency, and improved reliability. These RF electronics are critical for the deployment of 5G and 6G networks and are expected to drive the growth of the semiconductor market.
- Digital SoCs for 5G and 6G communications systems are also important drivers of the semiconductor market. These SoCs are designed to handle the high data rates and low latency requirements of 5G and 6G networks. They integrate various functions such as digital signal processing, memory, and power management into a single chip, making them more efficient and cost-effective.
- Sensors, including RF, optical and MEMS devices and systems and sensor fusion for 5G/6G, automotive, health, robotics, and automation are the key drivers of the semiconductor market. These are used to collect data from the environment and fuse it together to provide a more accurate and reliable representation of the environment. They are used in a wide range of applications such

as autonomous vehicles, health monitoring, and industrial automation.

- Programmatic open-source integrated circuit design methodologies are also gaining popularity in the semiconductor market. These methodologies allow for the creation of open-source integrated circuits, which can reduce costs and increase innovation.
- Defense applications are another area where semiconductors are playing a critical role. Semiconductors are used in defense applications for various purposes such as radar systems, communication systems, and electronic warfare systems.
- Microelectronics for health and wellbeing is another area where semiconductors are playing a critical role. Microelectronics is used in applications such as medical imaging, health monitoring, and diagnostic systems.
- Quantum technology and quantum computing for applications from materials science and quantum chemistry, to finance industrial optimization.

The global semiconductor market is driven by various trends, emerging technologies and movements in competition between countries and regions. The increasing demand driven by large scale digitalization of societies and businesses is expected to drive the continues double digits growth of the global market in the coming years.

EU and Europe

The EU considers the semiconductor industry a strategic asset and economic driver. In response, the EU announced the EU Chips Act, a comprehensive effort to boost EU semiconductor market competitiveness. The EU Chips Act seeks €43 billion in public and private funding to promote the semiconductor industry. The Chips for Europe Initiative will directly fund technology leadership in research, design, and manufacturing capacities up to 2030 with €11 billion, focusing on new semiconductors technologies in e.g., 5G, AI, and IoT. A key target is to boost and ensure improved semiconductor self-sufficiency in the future and reduce dependence on vulnerable non-EU suppliers. For R&D&I-purposes, especially the soon-to-be-selected Pilot Lines and Competence Centers will be of high value. Also, the international trade situation (USA-China-EU) and recent shock in the European continent (such as Ukraine war) has escalated the need for better managed R&D, sourcing, logistics and overall improvement of self-sufficiency in microelectronics and semiconductor markets.

Europe’s strengths are in special semiconductors used mainly in cars and in power electronics. E.g. Murata electronics in Finland is a major supplier of inertial MEMS sensors to automotive industry. The EU has also launched many programs and microelectronics initiatives to encourage semiconductor sector development, including the Chips for Europe Initiative and European High Performance Computing Joint Undertaking (EuroHPC JU). For example, the EuroHPC JU seeks to create a large-scale European high-performance computing program to enhance AI and quantum computing.

Research and innovation investments reflect the EU's renewed semiconductor focus. The EU's Horizon 2020 initiative has funded microelectronics research, including €1 billion for breakthrough semiconductor technology. Horizon Europe, a new EU research and innovation program, will prioritize enabling technologies like microelectronics.

EU semiconductor strategy is ambitious and well-funded. The EU's concentration on technical leadership, self-sufficiency, and investment in special areas e.g., 5G, AI, IoT, and HPC shows the ambition to lead (or at least provide more secured, self-sustained status of) selected semiconductor sectors. Moving forward, the EU must overcome some obstacles to become a key player in semiconductor R&D and manufacturing. Asia and North America combined produce the majority of semiconductors globally. The

EU lacks international semiconductor manufacturing companies that can compete with large companies like Intel, Samsung, and TSMC. The EU's high labor expenses and environmental laws may make it hard to compete on cost and efficiency, also the lack of “semiconductor mega-factories” in EU is a weakness, lately discussed heavily. The EU may build new semiconductor technologies and companies by investing (FDI) in advanced technologies, research, innovation and allying with e.g., Taiwanese companies. The EU may also foster semiconductor technology innovation by financing spearhead projects and investing in manufacturing plants in selected critical industry sectors, such as automotive.

USA

The United States has a long history of innovation and leadership in the semiconductor industry. The US semiconductor sector is one of the largest in the world, with a market size of around (LE) $64.3 billion in 2023. According to a report by the Semiconductor Industry Association (SIA), the US semiconductor industry is the largest and most technologically advanced in the world, accounting for nearly 40% of global semiconductor sales. The US semiconductor industry also employs around 250,000 people and is a major contributor to the US economy. The US semiconductor market is projected to grow at a CAGR of 5.5% from 2021 to 2028. The US government has recognized the strategic importance of the semiconductor industry and has implemented various policies and initiatives to support its growth and development. One of the key initiatives in the US is the National Semiconductor Technology Roadmap (NSTC), which is a collaborative effort between the government, industry, and academia to support the development of advanced semiconductor technologies. The NSTC focuses on long-term research and development in areas such as advanced manufacturing, nanoelectronics, and quantum computing.

The US government has also invested heavily in research and development in the semiconductor sector through various federal agencies such as the National Science Foundation (NSF), the National Institutes of Standards and Technology (NIST), Defense Advanced Research Projects Agency (DARPA), and the Department of Energy (DOE). These agencies provide funding for research in areas such as advanced manufacturing, quantum computing, and energy-efficient semiconductors.

The US has a very strong private sector presence in the semiconductor industry. Many of the largest semiconductor companies in the world, such as Intel, Qualcomm, and Texas Instruments, are based in the US. These companies have invested heavily in R&D and played a key role in driving innovation in the semiconductor industry. The US also has a well-established ecosystem for the growth of startups and small and medium-sized enterprises (SMEs) in the semiconductor sector. The US government provides various tax incentives and funding opportunities for startups and SMEs to encourage innovation and entrepreneurship in the semiconductor industry. Additionally, there are many venture capital firms and angel investors in the US that provide funding for startups in the semiconductor sector.

One of the key strengths of the US semiconductor industry is its advanced manufacturing capabilities. The US has a well-established infrastructure for the production of semiconductors, with many of the world's most advanced fabrication facilities. This infrastructure has allowed US companies to stay at the forefront of the industry and maintain a competitive advantage.

However, the US also faces new challenges in the semiconductor sector. One of the major challenges is the increasing competition from other regions, particularly Asia. Many Asian countries, such as China, have been investing heavily in the semiconductor industry and are rapidly catching up to the US in terms of technology and manufacturing capabilities. Another challenge is the lack of a clear long-term strategy for the semiconductor sector, lately being a focus in a new government. Furthermore, the US is lagging behind Taiwan (TSMC) and Korea (Samsung) in the most cutting-edge fabrication (below 2 nm technology).

Asia and China

In recent years, the semiconductor and microelectronics industries in Asia, notably Japan, Taiwan and China, have experienced substantial growth and expansion. TSMC (Taiwan Semiconductor Manufacturing Company) and UMC (United Microelectronics Corporation) are two of the largest foundries in the world. Taiwan is a prominent player in the global semiconductor industry. The manufacture of semiconductors for the consumer electronics, communications, and computer sectors relies heavily on the advanced manufacturing techniques and technologies of these businesses.

By the end of the year 2021, the semiconductor industry in Taiwan was composed of a total of 250 IC fabless design houses, 13 fabrication businesses, and 37 packaging and testing houses. Tables below depict the largest 1) fabless design companies and 2) fabrication (manufacturing) companies in Taiwan.

NT$B

2021 Ranking	2020 Ranking	Company	2020 Revenue	2021 Revenue	Growth (%)
1	1	Mediatek	322.1	493.4	53.2%
2	2	Novatek	80.0	135.4	69.3%
3	3	Realtek	77.8	105.5	35.7%
4	4	PHISON	48.5	62.6	29.0%
5	5	Himax	26.2	43.3	64.9%
6	6	Silicon Motion	15.9	25.8	61.7%
7	9	Raydium	14.4	24.8	72.2%
8	7	ESMT	15.3	23.8	56.2%
9	13	Fitipower	10.9	22.9	110.1%
10	10	Sitronix	13.8	22.3	61.2%

Note: 1. Based on companies' combined revenue.
2. Data discrepancy may occur due to rounding.
Source：Company Statement; TSIA, ISTI-ITRI (May 2022)

NT$B

2021 Ranking	2020 Ranking	Company	2020 Revenue	2021 Revenue	Growth (%)
1	1	TSMC	1,339.3	1,587.4	18.5%
2	2	UMC	176.8	213.0	20.5%
3	4	Winbond	60.7	99.6	64.1%
4	3	Nanya	61.0	85.6	40.3%
5	5	PSMC	45.7	65.6	43.5%
6	6	MXIC	39.8	50.6	27.1%
7	7	Vanguard	33.1	44.0	32.9%
8	9	Nuvoton	20.7	41.5	100.5%
9	8	Win Semiconductors	25.4	26.0	2.4%
10	11	Episil	5.7	7.3	28.1%

Note: 1. Based on companies' combined revenue.
2. Data discrepancy may occur due to rounding.
Source：Company Statement; TSIA, ISTI-ITRI (May 2022)

Japan has a strong focus on research and development (R&D) for semiconductors, with various government programs in place to support this industry. The EU Delegation recently assessed Japan's R&D programs for semiconductors and found that there are around 12 programs in total. These programs are primarily managed by the Ministry of Economy, Trade and Industry (METI) through the New Energy and Industrial Technology Development Organization (NEDO), followed by the Ministry of Internal Affairs and Communications (MIC) and the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

In terms of funding, the initial budget for these programs was estimated to be around €8 billion. However, a second supplementary budget in December added an additional €9 billion, bringing the total budget for FY2022 to around €17.5 billion.

Of this funding, 95% is allocated to three main projects. The first project is the Advanced Semiconductor Production Facilities, which received €4.4 billion in funding. The second project is the Post-5G Information and Communication Systems Infrastructures, which received €2.2 billion in funding. The third project is the Green Innovation Fund projects, which received €1 billion in funding.

Overall, Japan's R&D and support programs for semiconductors demonstrate a strong commitment to the growth and development of this industry. The large budget allocation and focus on specific projects such as advanced production facilities and post-5G technology show that Japan is positioning itself to be a leader in the semiconductor industry. The Green Innovation Fund projects also indicates that Japan is keen on promoting sustainable development of the semiconductor industry.

China's semiconductor sector has also been expanding significantly, with the government investing considerably in the local semiconductor industry. SMIC (Semiconductor Manufacturing International Corporation) and Tsinghua Unigroup have made considerable achievements in the sector and are becoming more competitive with their worldwide competitors. The Chinese government has been investing heavily in the development of the domestic semiconductor industry, with a goal to achieve self-sufficiency in the production of semiconductors by 2025.

By the end of the year 2021, the semiconductor industry in China is composed of a growing number of companies. According to industry reports, there were around 150 IC fabless design houses operating in China, along with over 20 fabrication businesses and around 30 packaging and testing houses. These companies are primarily located in regions such as Beijing, Shanghai, and Shenzhen, which have become major hubs for the semiconductor industry in China.

The rising need for semiconductors in consumer electronics, especially smartphones, is one of the primary growth factors in Japan, Taiwan and China. With the growth of 5G networks, beyond 5G technologies (e.g., emerging 6G requirements) and the next generations of Internet of Things (IoT), it is anticipated that the need for semiconductors will increase dramatically in future years. In addition, the high growth of special electronics needed by artificial intelligence (AI) and machine learning (ML) is anticipated to fuel semiconductor demand.

Despite the expansion and development of the semiconductor sector especially in Taiwan and China, there remain major obstacles that must be overcome. The dependence on foreign technology and intellectual property is one of the most significant obstacles in China, investing considerably in R&D to catch up to the world's technological leaders.

Continuing trade tensions between the United States and China provide a further difficulty for the Asian semiconductor sector. The United States has put taxes on Chinese imports and established limitations on the sale of sophisticated technology to China, including key value chain from components, design, manufacturing equipment and services, which has had an effect on the development of the Chinese semiconductor sector. In addition, US administration officials and the U.S. export controls issued on October 2022 a statement, designed to “freeze” China’s technological capabilities in supercomputing, artificial intelligence (AI), cutting-edge fabrication and manufacturing equipment.

Finland's targets in microelectronics

In Finland the microelectronics ecosystem has been built to support national and international telecommunications and specialized electronics industry. The capabilities of designing RF, analog, mixed-mode and digital functions and to combine those in complex Systems-on-Chips (SOC) has been seen as key enabler of the past success of Finnish industry and this has put Finland on forefront with continuing company investments.

The microelectronics industry can be broadly understood as containing the whole ecosystem starting from chemistry and materials to large variety of electronics products including consumer, business-to-business and military devices. Fabless design of integrated circuits and selected specialized manufacturing technologies have been the key drivers for semiconductor industry in Finland.

Fabless design industry, as the most profitable part of the ecosystem with long history in Finland, has suffered in recent years from lack of funding and new generation of designers to continue the excellence in the field. That is partially due to strong reformation of the industry starting around 2007. Despite of that the fabless design and competences available in Finland are forming a vital ecosystem that can be enhanced with world-class research and education. The target in this field is to enable future growth to support actions proposed in EU Chip Act by educating a new generation of talented researcher for industry and research in the field that require both to flourish. Microelectronics is the core competence that can support many industries from communications to sensors and other devices that are part of modern society. Competences in fabless design of integrated circuits are considered globally as a scarce resource and will give competitive edge both for existing and new industrial segments.

On the other hand, during the past two decades Finland has emerged as a leading R&D and industrial hub for fabrication of III-V compound semiconductor wafers used in optoelectronics, giving rise to a dynamic industrial ecosystem including several world leading photonics chips suppliers (e.g., Modulight Oy for laser diode chips or Elfys Oy for optical detectors).

Besides design skills, Finland has significant manufacturing capacity in certain specialized microelectronics, especially in MEMS sensors, e.g. Murata Electronics and Vaisala. The wafer manufacturer Okmetic has specialized in sensors and other high-value special Silicon wafers e.g. for RF. Further Finland has specialized materials companies, such as PIBond developing and supplying surface passivation and coating materials for semiconductor industry.

In other specialized microelectronics fields, such as integrated photonics and quantum technology, Finland has significant expertise and growing companies (e.g. IQM). The creation of manufacturing base in these technologies is feasible in Finland, due to smaller and less costly typical fab size.

In addition to this, Finland has many semiconductor fabrication equipment manufacturers, especially with a strong presence of Atomic Layer Deposition (ALD) tool makers (Applied Materials, ASM, Beneq).

On the packaging and integration aspects, printable electronics infrastructure has been also recognized as a major area of expertise, supported by e.g., Printocent ecosystem.

The table below summarizes the current status of major areas of design expertise, infrastructure for chip fabrication and characterization, pointing also areas of recognized strengths and improvement needs.

Summary of leading areas of expertise in Finland 2023

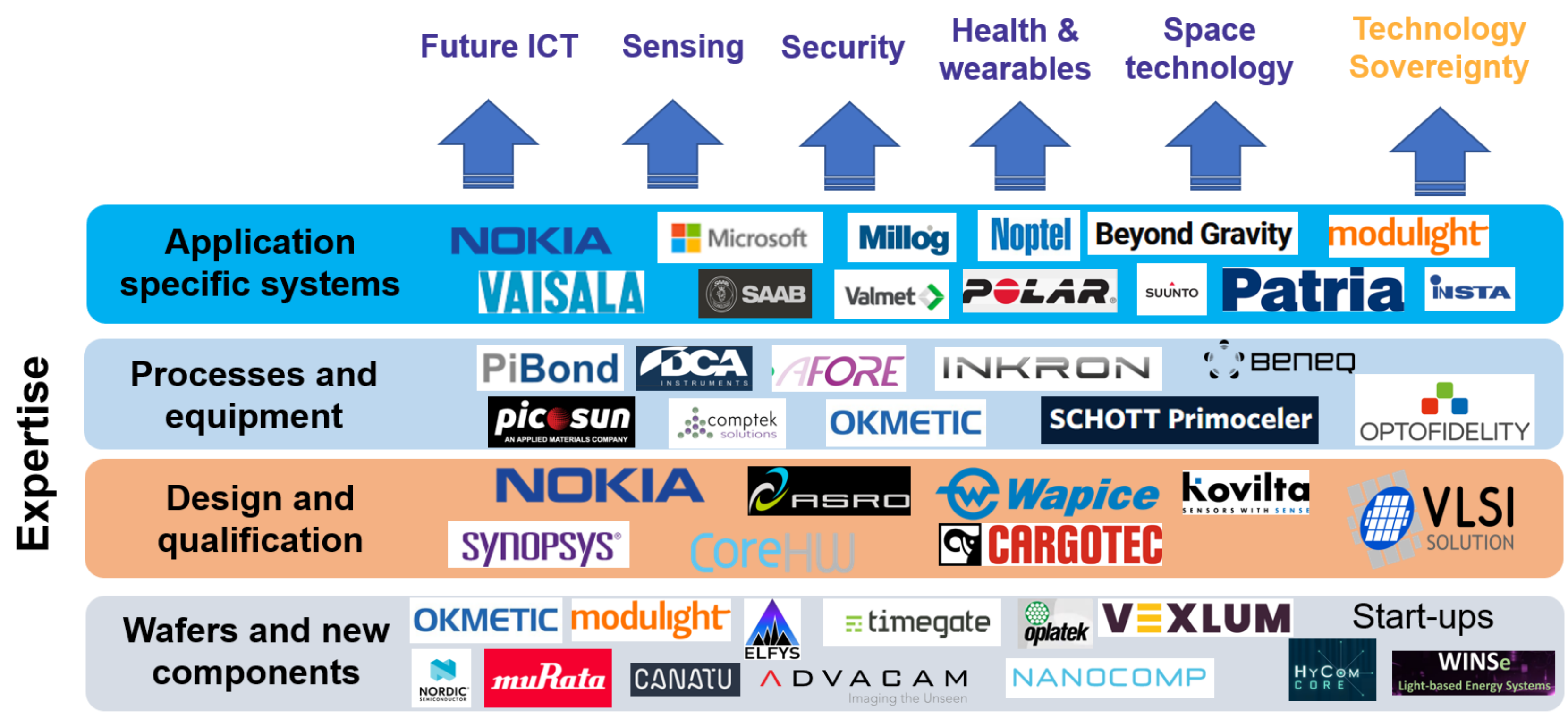
Institution	Design	Infrastructure	Strength	Weakness
Aalto University	• System level integration (SoC) • Mixed signal system (SoC) design • Digital and AI accelerators • Wireless communications SoC's • In-house microprocessor design • Programmatic design methodologies • One of the leading European institutions in programmatic analog design methodology • Materials, semiconductor and photonics	• Aalto ICT laboratory facility for measurements of complex IC's from digital to teraherz • State of-the-art computing cluster for design and verification of mixed-mode systems • Micronova cleanroom and optics	• Long tradition in mixed mode communications IC's • Several CMOS, BiCMOS and GaAs design environments installed. • Fully programmatic mixed-mode-design flows established • Strong collaboration and funding with national and international companies. • Semiconductor sensors • Photonics and 2D materilas	• Taping out large IC's requires significant funding or donated silicon. • Design of complex systems requires a lot of engineering work valid from industrial perspective, but not recognized by academic research criteria. • Human resources
University of Oulu	• Wireless communication RFIC • Wireless system design from pre-standardized concepts to HW architectures and IC prototyping (6G flagship etc.) • Single-photon optic circuits e.g. for laser range finding and sensoring • In-house contribution analysis of nonlinear distortion • Material, sensor/component and package designing • Thermal management and modelling	• RF measuring and material characterization facilities and competences up to 330 GHz • OTA testing of wireless transceivers from sub-blocks to complete systems • Printed and multilayer electronics fabrication facilities • FIB facility for repairing IC routing • Equipment and processes for packaging • Destructive/NDT testing and reliability analysis of microelectronics	• Long tradition in mixed mode communications IC's • Strong, world-class competence in wireless communications research • Cross-disciplinary collaboration from systems to IC (6G flagship, EU Hexa-X, etc.) • Expertise from material synthesis, through fabrication processes to components and systems • Industrial collaboration • Reliability modelling and management	• Funding of expensive equipment and IC fabrications • Human resources • Packaging methods of modern ICs • Volume of IC design

Tampere University	• Leading-edge very large scale System-on-Chip design and IP integration • Agile HW design flow development • RISC-V multicore and on-chip network designs • openasip.org customized DSP HW/SW design environment • IP-XACT based IP modeling, integration and exchange methodology with open-source toolset Kactus2 • Rust based code generators for RISC-V firmware, BSPs and SDKs • High-speed SerDes IP design • Wireless communication • Photonic chip design	• Extensive server and FPGA emulation capacity for SoC verification • Cleanroom and lab facilities for chip packing and testing • III-Vs wafers fabrication • Photonic chips micro- and nano-fabrication • Flexible and printed electronics fabrication lines	• New depth of company-university collaboration model on co-developing System-on-Chips • sochub.fi multiparty framework for legal, technology and EDA tools • Participation in major RISC-V focused EU projects • Strong industrial ecosystems • FiRi roadmaps • "Silicon2Action" Profi7 SoC+wireless+robotics) • Photonics Flagship	• Human resources • Outdated infra for III-Vs fabrication • Photonics-microelectronics system level integration at early phase • More attention to mission specific chips
Åbo Akademi University	• Electronic Materials • Additive manufacturing • Software integration, optimization and testing	• Functional Printing laboratory (for electronics and materials) • Extensive materials characterization	• Strong competence in materials chemistry and physics	• Gap between materials research and systems development • No traditional micro-electronics research or education
University of Turku	• Si, Ge, III-V and organic semiconductors, surface passivation • Detectors for space applications • Memristors, neuromorphic chips, spin valves • Optoelectronic applications, microcavities for printed optoelectronics	• Microelectronics Clean Room lab • Surface science lab • Bottom-up fabrication of soft microelectronics • Research at international synchrotron and free-electron laser centers	• Long tradition in research of materials and research-based education • Successful transfer of innovations to industry • Strong in computational research • Extensive equipment for surface characterization	• High throughput film deposition facility lacking • Traditional microelectronics is fading • Human resources
VTT	• MEMS for RF and sensors • Antennas and front-end modules for	• Micronova cleanroom • MilliLab (ESA's external laboratory) • Quantum and cryogenic	• Focus on innovation and enabling commercial	• Lower academic track record than for universities • Infrastructures

	5G/6G communication. • Silicon photonics integrated circuits and modules for communication and sensing. • Radiation detectors. • Hyperspectral technologies and imaging sensors for space, earth, environmental and consumer (e.g. health) applications. • Wafer-level and LTCC Packaging. • Post CMOS integration of biosensors (e.g. graphene based) and AI computing. • ASIC and electronic system design. • Quantum tech HW & SW, e.g. sensors (SQUIDs), single photon detectors, travelling wave parametric amplifiers (TWPAs), fabrication know-how, quantum algorithms	characterization lab including a 5-qubit quantum computer and soon 20-qubit quantum computer. • Optics and photonics characterization lab. Sensor lab.	exploitation. • Strong links to industry • Spin-off company creation. International activities in forms of public projects, contract research and stake-holder groups.	limited and recruitments challenging for growth areas.

Based on the strong research foundation and especially telecommunications industry in Finland, our companies have been very successful in utilizing the design knowledge, i.e., fabless design and specialized manufacturing. Thus, Finland's microelectronics ecosystem actors have been able to form a competitive industry, build new start-ups for various high-demand sectors and advance to new promising areas such as quantum computing and printed intelligence in the last decades. The investments to education, research and industrialization make currently a significant portion of our export-driven ICT business revenues in multiple product verticals.

The major building blocks of the industrial microelectronics ecosystem in Finland is depicted by the schematic picture below. This reflects the need to cover education across the full value chain from design, materials and process developments, component manufacturing, fabrication equipment, to system integration. It also reveals the major application areas that are impacted by the industry.



Mircea Guina, TAU

Our target is to continue investments in most-demanding and internationally high-demand areas in Microelectronics in the future. While Finnish Microelectronics R&D is at the forefront of international demand, we excel especially in Fabless areas, i.e. in design part of the business. Microelectronics is promoted in the EU as a "critical technology areas, impacting all key areas in societies" with the target to gain better standing in own design and manufacturing in EU area. This is being executed through various high-profile policies and programs, such as EU's Chips Act, where this strategy and Finland's microelectronics needs to be integral part. Thus, our target setting includes not only continuing the national-level agenda, but also needs to merge to EU's agenda, including taking a leadership in selected area(s). Since microelectronics is one of the most demanding areas in terms of education, specialization and craftmanship, our target has to be set to cover the "full spectrum" of actions from education, research, collaboration (ecosystem development), product design and creation, and international joint activities. All these areas need to succeed in order to stay competitive in R&D and claim the "original microelectronic designs from Finland"-status. Thus, all these efforts come together in highest value integrations in our companies' products and systems utilizing everything from ICT materials science to special components, systems on chip and entire microelectronics-enabled system products. Thus, Finland's focus in the future is set on fabless design capabilities complemented by tailored electronics manufacturing, pilot lines and advanced creations for specialized customers. With this strategy we aim to base our growth in value and profitability in specialization, knowledge and focus on high-demand – low-competition areas, i.e. the most advanced area in electronics, discussed further in the next sections.

Ultimately microelectronics designs cover entire R&D processes from development of new materials, components, technologies, systems and products merge in "Systems-on-Chips" (SoC), which combine all the functions of a device to the same chip. They are a key element in technological development and can increase a company's competitiveness significantly.

SoCs have become a critical enabler in vehicles, machines, monitoring of different processes, consumer electronics and IoT devices in order to implement edge computing and fast communications, but also in data centers to significantly reduce energy consumption especially in AI computing. Thus, microelectronics designs and manufacturing (Fabless and Manufacturing) demand is driven by practically all verticals. There is an ever-growing demand for high expertise in the domain of SoC creation. Finland's target in this domain is to be the SoC-design-country of Europe, where all companies will have their eye on. We need to educate enough experts for the needs of industry and to have necessary support functions in place.

SoC's are inherently mixed mode products, and especially in communications they contain vast amount of specialized building blocks related to wireless communications. One of the identified strengths in Finnish microelectronics ecosystem is the widespread globally recognized expertise in the design of wireless integrated circuits. Several Finnish based companies and academic institutes have expertise that is built on the designing IC for 2G/3G/4G/5G/WLAN/BT systems. Currently, several telecommunication device manufacturers are building more capabilities to design their own ICs and provide new functions and enablers on-chip to maintain their competitive edge. With the development of arrays, millimeter wave and sub-THz circuits and including functions like sensing it has become evident that we need to invest more on the IC design capabilities even to maintain our current design capabilities. The complex mixed mode design in the future will require for example deep co-design with hardware aware algorithms including AI, optimized and codesign antenna/data interfaces, and design methodology development, which supports large scale designs. In this domain, during the last decade it has become clear that there is a large demand for DSc level experts in the industry.

1. **Digital SoC**

Semiconductor chips for digital signal processing are core elements and seen as critical success factors for major telecommunication and other high-tech companies. The complex architectures for those SoCs of such entities are more and more designed by system houses, like Nokia, and not by purely fabless players. The strategy related to this relies on the fact that cost and power efficient implementation relies strongly on the system level know-how on the particular protocols and algorithms (communications, machine learning/artificial intelligence etc.) and can be optimized only by understanding the system (like telecom product) and its future requirements. Therefore, many companies in Finland have invested heavily in recent years in this area and requested also further educational activities from the universities.

2. **Radio Frequency (RF) circuits and systems**

RF and analog electronics are the gateway from antennas to digital signal processing in radio communications and sensing requiring highly dedicated and specialized skillset. From an industrial perspective competence at different levels is similarly essential, but different, compared to digital SoC. The main trends towards 6G which require further attention compared to current industrial state-of-the-art include adaptation to higher frequencies, larger antenna systems impacting also strongly on electronics side and many other details that require co-design with other skillsets from radio protocols to antenna integration and packaging. For those both educational and research efforts are needed to support future industrial needs. The other major trend is to model highly complex and dedicated RF technologies in system level with sufficient abstraction and accuracy. National activities have been initiated here for example in Business Finland funded RF Sampo project under Nokia Veturi and in European context towards 6G in EU funded Hexa-x and Hexa-x II projects. The industrial demand is obvious to both improve R&D efficiency of products and make correct decisions with solid technology background for future system planning like 6G to validate the more theoretical communications systems research at an early phase. The RF Semiconductor Market is projected to grow from USD 17.4 billion in 2020 to USD 26.2 billion in 2025, at a CAGR of 8.5% between 2020-2025.[3] In addition, 5G Chipset Market is expected to grow from USD 36.3 billion in 2023 to USD 81.0 billion by 2028, at a CAGR of 17.4% from 2023 to 2028[4]. This number includes both SoC and RFIC's that are inseparable. The number is on the top of the dedicated RF semiconductor market. The global radio frequency components market size was valued at USD 30.68 billion in 2022 and is expected to expand at a compound annual growth rate (CAGR) of 14.2 % from 2023 to 2030.[5]

[3] https://www.marketsandmarkets.com/Market-Reports/rf-power-semiconductor-market-79671536.html
[4] https://www.marketsandmarkets.com/Market-Reports/5g-chipset-market-150390562.html
[5] https://www.grandviewresearch.com/industry-analysis/radio-frequency-rf-components-market

3. **Sensors**

The market for intelligent and interconnected sensory devices, globally referred to as the Internet of Things (IoT), is expected to significantly grow in the next decade. Currently valued around $480 billion in 2022, it is projected to be $2465.26 billion by 2029. The IoT market includes both applications for individuals (e.g., wearables, smartphones) and industry (e.g., automotive, space). The Finnish ecosystem hosts several major players in sensor design, including sensor fabrication such as Microelectromechanical Systems (MEMS), and sensor interface design as integrated circuits or SoCs. The current trend in IoT is to move towards more intelligent devices relying on embedded Artificial Intelligence (AI), also referred to as edge AI. Currently in Finland, there is a gap in between the “software” AI ecosystem, with various companies, start-ups and world leading research centers (Finnish Center for Artificial Intelligence) and the “hardware” side of AI, including the design of computing infrastructures, hardware/software co-design the development of processors and AI accelerators. Investments in that area will clearly benefit the sector of sensors in Finland, create major opportunities for both academia and industry. Closing this gap would enable Finland to have all necessary components of the next generation of smart sensor interfaces.

4. **Integration of electronics and photonics in a system in a package (SiP)**

Photonics is one of the research areas where Finland is strong and where ecosystem is starting to flourish. This is also an area where Finland has comprehensive expertise and infrastructure for the entire value chain starting with wafer production all the way to hybrid systems incorporating photonics and electronics chips. The combination of photonics-enabled semiconductor chips with advanced microelectronics functionality means a revolution in the way photonics technologies are accessible to mainstream applications and penetration outside specialized niche applications. Finland’s target is to offer customization and agile production from chip to board level for industries. This target requires lots of research and innovation and especially having a (European wide) pilot line providing facilities to design, implement, prototype, and support production of photonics and semiconductor chips based on emerging technologies.

In addition, advanced packaging technologies and/or heterogenous integration of sensors, antenna, memories, ICs and other components (referred also as More-than-Moore technology) plays also existential role in microelectronics not only in performance and miniaturization but also cost, reliability and lifetime, thus giving competitive edge in global competition. As an example, traditionally packaging of e.g., MEMS devices has cost more than the operating component itself. Similarly, in the area of photonics integrated circuits (PICs) the packaging cost is the major component in the total production chain, and this often doesn’t include the co-packaging of control electronics chips. As the complexity of systems increase, more demanding the designing and integration becomes requiring in-depth but also multi-disciplinary understanding about physical and technological constrains and their influence on whole system techno-economic assessment. The ability to co-design hybrid photonics-microelectronics SiPs is thus an area with strong differentiation potential yet it requires sustained actions on education and building new infrastructures (or better synergy of existing infrastructure).

5. **Power management**

Microelectronics by nature is green, as there always is trend to reduce the power consumption – the reasons may be system or packaging constraints, or limits of power supply due to e.g., battery lifetime control or energy harvesting. Energy management ICs of bigger systems usually contain high-efficiency switched-mode regulators and low-noise linear regulators, as well as many supplementary blocks that may need a process with higher supply voltage. Power management circuits use multitude of dedicated techniques from charge pumps, bootstrapping, and efficient switched-mode supplies, and they generally need a well-tuned feedback controller, that may have very strict transient load response requirements, for example. Developing a mixture of discrete-time/continuous-time switched-mode regulators typically requires separate simulation tools, too.

Increasing demands for energy harvesting add up to the complexity: the design of energy harvester requires good understanding of the physics of energy generation and transfer, and how much the energy source can be loaded for maximum power harvesting.

6. **Quantum technology**

Finland has strong excellence and research background in quantum technologies, from research in universities to infrastructures and applied research in RTOs to successful growth companies. Quantum components and systems rely on microelectronics manufacturing methods but use them to create components that take advantage of quantum behavior of particles and structures, even on individual level. The most well-known application is quantum computers, where Finland is in the global forefront in developing superconducting quantum computers. But quantum sensors, such as optically pumped or superconducting magnetometers, are being developed. In communications, quantum key distribution (QKD), either self-standing or in combination with post-quantum cryptographic algorithms, is being developed, and the first experimental networks are being implemented. Quantum sensors and QKD are entering the markets already today. Quantum technology is identified as a critical technology globally and in Europe many initiatives have been built up for its development: The European quantum flagship, European quantum communications initiative EuroQCI, implementation of quantum computers as part of high-performance computing is supported in EuroHPC, and finally, Chips Act includes a significant focus in quantum chips. Finnish infrastructure, expertise and ecosystem is lucrative place for new companies and start-ups to develop their products and services. Quantum computing market size is estimated to be 500 M€, with CAGR of over 30 %[6].

7. **Infrastructures**

EU Chips Act Pilot Lines and Competence Centers

An important part of funding in EU Chips Act will be used in the establishment of advanced Pilot Line facilities, to enable a path from laboratory breakthrough to fab production, and in a network of Competence Centers, to build up capacity for semiconductor design. Access to the pilot lines should be open, non-discriminatory, and cost-efficient even to SMEs.

RF Parks

With the new radio connectivity generations, we will face the situation when radio connectivity is in key roles to enable totally new set of applications and activities. To be able to turn world class research and results of related research projects into business, we will face the need of close co-operation between the industry, SME ecosystem and public sector. The mission of the RadioPark concept is to provide a frame for (i) the cluster type co-creation operational model for the solutions and devices creation, (ii) world class facilities for testing, (iii) strong linkage with the research organizations and the company base and (iv) provide shared support for marketing and sales of the solutions. The concept is currently in set up phase, the needed structures and teams are building up. RadioPark concept is planned for companies that work in different industry verticals. RadioPark will drive the innovations and solution creation in health, automotive, energy and IoT sectors. Along with 6G, the role of the sensing technologies and SoC solutions in various industry sectors will grow significantly that leads to the growing need for the enabling testing and productization environments. RadioPark concept will be developed based on the needs from the research and companies, that is why it can play an important role in supporting the development of microelectronics in coming years.

Printed Intelligence Infrastructure

[6] https://www.fortunebusinessinsights.com/quantum-computing-market-104855

Printed intelligence infrastructure (PII) is established to provide word-class research and development environment to researchers and technology developers in academy and industry. It offers easy access to a modern research and pilot-manufacturing infrastructure covering the whole research/development path from (i) materials via (ii) functional printing, (iii) components and devices to (iv) circuits and systems. It is joint research infrastructure of University of Oulu, Tampere University, Åbo Akademi and VTT Technical Research Centre of Finland. Printed Intelligence Infrastructure is also on Finland's roadmap for research infrastructures 2021-2024. PII speeds up and establishes technology transfer, scientific work, and education at all levels on this particular area utilizing microelectronics and being one part of its development branches. Today, more than 300 experts are actively utilizing the PII infrastructure, and it has been an enabler for projects with a total volume of 93 M€ (2015-2019) funded by Academy of Finland, EU, Business Finland (formerly Tekes), and industrial partners.

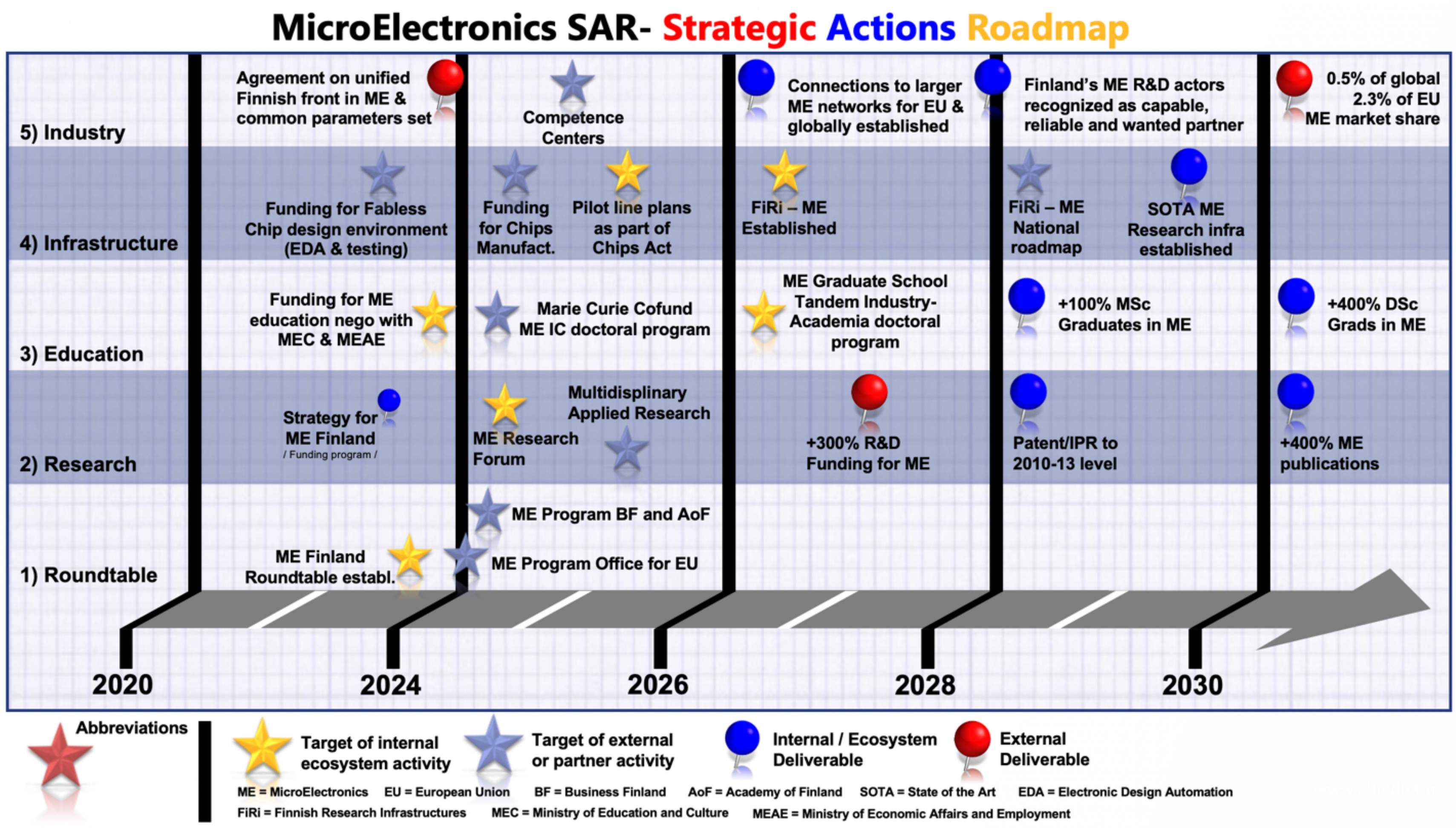
Emerging Technology Pilot Line Kvanttinova

Kvanttinova supports specialized microrelectronics technologies in RF, MEMS sensors, integrated photonics, new materials and devices on CMOS backend as well as quantum technology. The goal is to a) build a new pilot line for increased support from SME and growth companies, b) increase the availability of emerging technologies, c) enable new innovation though new materials and capability, and d) support in small volume manufacturing as well as e) development of manufacturing scale-up.

Microelectronics is an investment-heavy industry. The cost of required infrastructure, from design software to fabrication facility and development laboratories creates a barrier for new companies to enter the market, as well as a bottle neck to the growth of especially SME companies. Centralized Infrastructure to support companies in developing their new products without extensive up-front investment is thus needed. The Micronova cleanroom supports sensor, RF, photonics, post-CMOs integration and quantum technology chip development and fabrication. For the development of above-mentioned technologies, namely, RF, sensors, co-packaging of electronics and photonics and quantum technologies, an emerging technology pilot line Kvanttinova is planned as an extension of Micronova in Espoo. This would improve research opportunities by new materials and capabilities, as well as support company growth by adding capacity for scale-up development.

Implementation & Microelectronics roadmap

The following strategic actions are proposed in a jointly agreed roadmap, based on Microelectronics R&D strategy discussed. The implementation plan is targeting to 1) safeguard Finland's competitive position, 2) increase investment critical microelectronics areas, including education, and 3) maximize our domestic and international impact with e.g., global microelectronics players, EU Chips Act, and maintaining ownership of selected next generation original designs and innovations:



From the microelectronics Strategic Action Roadmap, the following short-to-midterm (2023-2025) items are defined below in more detail, depicting the actions and targets planned for the key areas.

1. **Roundtable: Establish national-level body driving joint microelectronics interests**

   a. Roundtable: Establish a national roundtable and later a program office for microelectronics-activities and EU-influence. Joint program office operating in three selected cities as a one team. Joint funding from BF and large hubs. **Key collaboration: Roundtable member's home organization, Ministry of Economic Affairs and Employment**

   b. Strategy work: Develop a continuous strategy, model and framework for planning, agreeing and evaluating the impact of research and development in microelectronics that considers evolving trends and modifies investment needs and priorities accordingly. This model should adapt to evolving frontiers and conditions, and meet long-term R&D objectives.
   Key collaboration: Roundtable members, including invited international experts.

   c. International collaboration: Promote international cooperation and partnerships to capitalize on global microelectronics-network, funding, students and resources: Identify key institutes and similar bodies from other countries, then establish relations and strategic collaboration on national level(s). This will improve the quantity and quality of education, research and hasten the creation of new technologies. **Key collaboration: Ministry of Economic Affairs and Employment, Ministry of Education and Culture, Ministry of Foreign Affairs, Business Finland, Academy of Finland**

d. Comptetitiveness: Create analysis and initiatives to ensure Finland's competitiveness for next generation microelectronics with proposals for specific funding programmes in collaborative dialogue with Academy of Finland and Business Finland. **Key collaboration: Universities, Academy of Finland, Business Finland, Technology Industries of Finland**

2. Research: "National, EU and global research"

a. Funding: Strategy and actions for special funding programmes in Microelectronics:

i. Strategy: Develop strategy for collaborative R&D initiatives with universities, research institutes, and industry partners in order to promote new investments to research, education, knowledge sharing, technology transfer, and commercialization.
Key collaboration: Roundtable members and invited industry

ii. Basic Research: Establish a proposal for new funding program for microelectronics basic research to enable cutting-edge technologies including ICT material technology, RF technology, SOC technologies, advanced electronics components, and future communication networks. **Key collaboration: Academy of Finland**

iii. Applied and co-creation research: Focused microelectronics program from Business Finland. Establish a proposal for Microelectronics R&D with a high risk-to-reward ratio supported by specialized funding scheme for applied solutions. This will inspire our R&D ecosystem and companies to pursue novel ideas that could result in significant advancements and potential market value. **Key collaboration: Business Finland, EU Chips Act**

b. Microelectronics Research Forum: Encourage the commercialization of Microelectronics technologies through supporting small and medium-sized businesses and start-ups by co-creation funding schemes. This will assist in closing the gap between research and commercialization and enhance the effect of microelectronics innovations. **Key collaboration: Business Finland, EU Chips Act**

3. **Education: Secure the talent and quality of education**

a. National program for education: Develop and implement a comprehensive **"Excellence in Microelectronics Education" program** that encompasses all facets of Microelectronics, from the foundations to advanced topics. This action should be created to recruit and educate the next generation of scientists and R&D engineers.

Key collaboration: Ministry of Education and Culture

b. Talent pools: Develop a talent recruitment program that will attract and retain elite Microelectronics talent, I.e., doctoral level skill-pool. This program should be intended to encourage the formation of inclusive and diverse teams.

Key collaboration: Ministry of Economic Affairs and Employment, all actors

c. Continuous learning: Develop specific training programs for industry experts to strengthen their microelectronics skills and understanding. **Key collaboration: Ministry of Economic Affairs and Employment**

4. **Infrastructure: Ensure Finland has tools to execute on microelectronics R&D**

    a. Infrastructure: Create a joint forces plan to continuously invest in sophisticated national infrastructure, joint sourcing, where feasible, for fabless, laboratory and fabrication capabilities to ensure our competitive frontier status in national spearhead areas in microelectronics.
    Key collaboration: Roundtable, Academy of Finland, Business Finland, EU, companies

5. **Industry: Ensure Finland microelectronics R&D ecosystem in competitive and renewing**

    a. Networking: Develop research-to-business and industry collaboration to a level, where Finland's microelectronics strategy is a) differentiating, b) proposed highest-value yield to our companies, and c) focuses the efforts to most promising areas in microelectronics, including EU scope and special actions. The actions should be managed in e.g., specialized competence centers and programs.
    Key collaboration: Roundtable, industry, regional competence hubs/ecosystems, Technology Industries of Finland, key companies

    b. New business models: Encourage the creation of new business models and collaborations that better capitalize on future Microelectronics technologies to generate new value and opportunities.
    Key collaboration: Roundtable members, Ministry of Economic Affairs and Employment, Business Finland, EU Chips Act and programs

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2. https://vm.fi/digitalisaatio1
3. https://rf-sampo.com (National Business Finland funded RF technology project related strongly also to microelectronics, part of Nokia Veturi program)
4. https://hexa-x.eu/ (European flagship towards 6G, RF and radio modelling including microelectronic technology capabilities)
5. https://www.corenect.eu/ (European roadmapping activity related to ChipAct)
6. https://www.hs.fi/talous/art-2000008376168.html Salainen aarre (Veijo Kontas

Abbreviations

AI	Artificial Intelligence
ALD	Atomic Layer Deposition
AoF	Academy of Finland
BF	Business Finland
BiCMOS	Bipolar Complementary Metal-Oxide Semiconductor
BSc	Bachelor of Science
BT	Bluetooth
CAGR	Compound Annual Growth Rate
CMOS	Complementary Metal-Oxide Semiconductor
D&I	Diversity and Inclusion
DARPA	Defense Advanced Research Projects Agency
DOE	the Department of Energy
DSc	Doctor of Science
EU	European Union
EuroHPC JU	European High Performance Computing Joint Undertaking
EuroQCI	European Quantum Communication Infrastructure
FDI	Direct Foreign Investment
FIB	Focused Ion Beam
FY	Fiscal Year
HPC	High Performance Computing
HW	Hardware
IC	Integrated Circuit
ICT	Information and Communication Technology
IoT	Internet of Things
MEAE	Ministry of Economic Affairs and Employment
MEC	Ministry of Education and Culture
MEMS	Microelectromechanical systems
METI	Ministry of Economy, Trade and Industry (Japan)
MEXT	Ministry of Education, Culture, Sports, Science and Technology (Japan)
MFA	Ministry of Foreign Affairs

MIC	Ministry of Internal Affairs and Communications (Japan)
ML	Machine Learning
MSc	Master of Science
NEDO	New Energy and Industrial Technology Development Organization (Japan)
NIST	the National Institutes of Standards and Technology
NSF	National Science Foundation
NSTC	National Science and Technology Council
PIC	Photonics Integrated Circuits
PII	Printed Intelligence Infrastructure
QKD	Quantum Key Distribution
R&D	Research and Development
R&D&I	Research, Development and Innovation
RF	Radio Frequency
RFIC	Radio-Frequency Integrated Circuit
RTO	Research and Technology Organisation
SIA	the Semiconductor Industry Association
SiP	System in Package
SME	Small and Medium-sized Enterprise
SMIC	Semiconductor Manufacturing International Corporation
SoC	System on Chip
TSMC	Taiwan Semiconductor Manufacturing Company
UMC	United Microelectronics Corporation
USA	The United States of America
USD	United States Dollar
WLAN	Wireless Local Area Network