Semiconductor Technologies Roadmap 2026-2029

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Based on:

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ChipNL[1] proposal, December 2024, as offered to the minister of economic affairs on January 2025.

[1] ChipNL_Innovatieprogramma_DEF_01_2025.pdf

Public

Executive summary

Over the past six decades the prominence semiconductors have in our lives has grown significantly. In 2024 the chips market was $630B, largely fueled by the growth of AI and data centers its expected value by 2030 is well over $1000B. The Netherlands holds a globally unique position in the semiconductor value chain from design, manufacturing (fab, R&D lab and analytical equipment; wafer stepper/scanner, metrology, wafer processing, assembly), testing & reliability of components, to various high-tech systems and applications in which electronic components play a key role.
As Europe refines its semiconductor strategy, there is real value in explicitly recognizing that design sovereignty – the capability to architect chips that reflect European priorities and values – is just as important as manufacturing sovereignty. In that context, Dutch policy dialogue can help champion a balanced approach that supports the entire ecosystem: fabless design houses and IP providers, as well as equipment suppliers and fabrication facilities.
This roadmap covers the state-of-the-art, trends and challenges and identifies the following themes for further pursue in the period 2026-2029:

Human Capital:

- Talent: Address 10,800/year talent shortfall through STEM and cross-disciplinary training

Semiconductor manufacturing equipment:

- Complexity: Managing increasing equipment complexity through design simplification, automation, and digital twin technologies.
- Contamination: Controlling particle and molecular contamination critical for yield and equipment lifetime
- Sustainability: Developing circular supply chains, reuse methodologies, and sustainable equipment design.
- Equipment for Heterogeneous Integration: Advancing processes and equipment to support complex multi-die packages and new materials.

Electronics:

- Telecommunications and radar systems: Focus on ultra-low power, on high power RF amplifiers and integrated high-frequency circuits, more bandwidth and efficient spectrum management.
- Smart circuitry for Internet of Things, home- , building- and industrial automation: Facilitate the transition to surroundings that predict what is needed instead of react to what has already happened.
- Heterogeneous integration and packaging: Realize technology and design flows for heterogeneous integration that properly and efficiently include all relevant aspects (partitioning, layout, signal and power integrity, EMC, interference, thermal, etc.).
- Electronics for scientific instrumentation and harsh conditions: Explore solutions for extreme operating conditions, reliable operation at high temperature.
- Power electronics: Explore solution with high efficiency and affordable cost, under severe load cycles and harsh environments.

Implementation
This roadmap provides the input from industry in the Triple Helix process between government, knowledge institutes and industry in determining the action agenda for its implementation. Besides private investments into this roadmap, implementation through Public Private Partnership (PPP) projects will be an essential factor. A PPP typically consists of Large Enterprises, Small & Medium Enterprises (SMEs), Research Institutes and Universities. SMEs are involved both as suppliers to the Large Enterprises and as suppliers in the Equipment Markets.

It is recognized that frameworks should facilitate SME participation through proportionate administrative requirements. Example of funding instruments are: Chips JU, IPCEI, TKI-PPS or other calls.

Investment

Over the past years, investments in Public Private Partnerships have been in the order of €300M/year which is modest relative to €63B annual export. Increased public-private collaboration is needed, particularly in emerging technology areas where Dutch SMEs can establish differentiated positions.

The future

Semiconductor technology, in its broadest sense, will remain crucial for future welfare, economy, and safety[2]. These technologies are of key economic and strategic importance to the Netherlands. We have a unique position, and hence a unique opportunity, to continue its leading position in this domain. However, this requires focus and continuous innovation. This roadmap aims to facilitate this process by identifying areas for cooperation and growth and investment.

[2] Rapport Wennink - De route naar toekomstige welvaart

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1. Introduction

Over the past 6 decades, the prominence semiconductors have in our lives has grown significantly, enabling a multi-billion dollar business world-wide. The incredible flow of products from the Information, Communication and Consumer industries has changed our lives dramatically. At the basis of these innovations is a continuous drive for smaller, better, cheaper and more power efficient electronic components and circuits with increased functionalities.

Moreover, today, it is not only about the enablement of business and the increasing amount of electronic devices we daily use, but also about sovereignty, security and ability of nations to prosper and to have secure access to these technologies.

The scope of this roadmap is the semiconductor industry in the Netherlands which covers technologies for wafer processing, assembly & packaging and test-equipment, chips and electronics. It spreads from manufacturing equipment to chip technology, to integrated circuits to electronics based products and systems. It includes Design, Characterization, Production and Test methodologies.

This is the 1st version of the Semiconductor Technologies roadmap. The motivation for its creation comes for the National Technology Strategy in which Semiconductor Technologies has been identified as one of the ten priority technologies for the Netherlands. It is based on the combination of the former Semiconductor Manufacturing Equipment Roadmap and the Electronics roadmap. Its purpose is to cover the input from the Industry in the process of creation of action agenda's that are expected to result from the interaction between Industry, Knowledge Institutes and the Government, the Triple Helix.

This new roadmap covers applications and technologies, state of the art, trends and challenges. Its aims to highlight themes that need attention, and have industry's priority for implementation. It is our view that, next to other strategic documents, such as the National Technology Strategy (NTS), this combined roadmap has a strong purpose to align, connect and implement activities, through national action plans, within the semiconductor/electronics scope.

2. Economic and Societal relevance

The Netherlands has a significant role in the semiconductor industry due to several key factors:

- The Netherlands is home to leading suppliers of semiconductor equipment used in the R&D, ramp and production of semiconductor chips. With excellent relations with IDMs and foundries like Intel, Samsung, TSMC, NXP, Infineon, Bosch, ST, Global Foundries, etc and research institutes like IMEC, CEA-LETI, Fraunhofer and NY Creates, the country has significant influence on the global roadmap of some advanced semiconductor nodes.
- The Netherlands has a strong position in high-tech electronic systems, complementing the semiconductor equipment domain with the application side. Examples include leading system houses such as Philips Medical (MRI scanners), Thales Nederland (radar systems) and NXP (electronics components). Furthermore, there is a strong academic ecosystem in the area of analogue and digital electronics.
- The Netherlands has a well-developed high-tech ecosystem, including research institutions, universities, and a network of high-tech companies that collaborate closely. The Dutch government provides strong support for the high-tech sector, including favorable policies, funding for research, and initiatives to attract international talent and investment.
- The Netherlands' strategic location in Europe makes it an ideal hub for logistics and distribution. This is beneficial for the semiconductor industry, which relies on efficient supply chains.

- The country has a highly educated and skilled workforce, particularly in engineering and technology fields, which is essential for the semiconductor industry.

Specifically the triangle of manufacturing tools, metrology and workforce places the Netherlands in a unique position. (List based on for example: https://www.welcome-to-nl.nl/semiconductor-industry-netherlands)

2.1 Markets

Semiconductor Technologies enable many markets, ranging from semiconductor manufacturing equipment, to chips to electronics, with the impact and value of each building sequentially upon the former. *Figure 1*, provides an overview, based on the 2024 numbers from SEMI.org. Innovations in semiconductor technologies enables continued innovations in many, larger, markets.

Moreover, because Semiconductor Technologies are front runner in several key technologies, like mechatronics and optics, this industry is an enabler for other high-tech industries and markets, creating spillovers in industries such as equipment for bio-medical (including life sciences) instrumentation, health, food, mobility, displays and other non-semiconductor industry high tech materials and components (including batteries) or space & astronomy instrumentation.

With an expected compound annual growth rate for chips of approx. 8%, see Figure 1, it is expected that the chip market by 2030 will well exceed the $1T level see also report 3 by Mckinsey, and is expected to be largely fueled by the growth of AI and data centers.

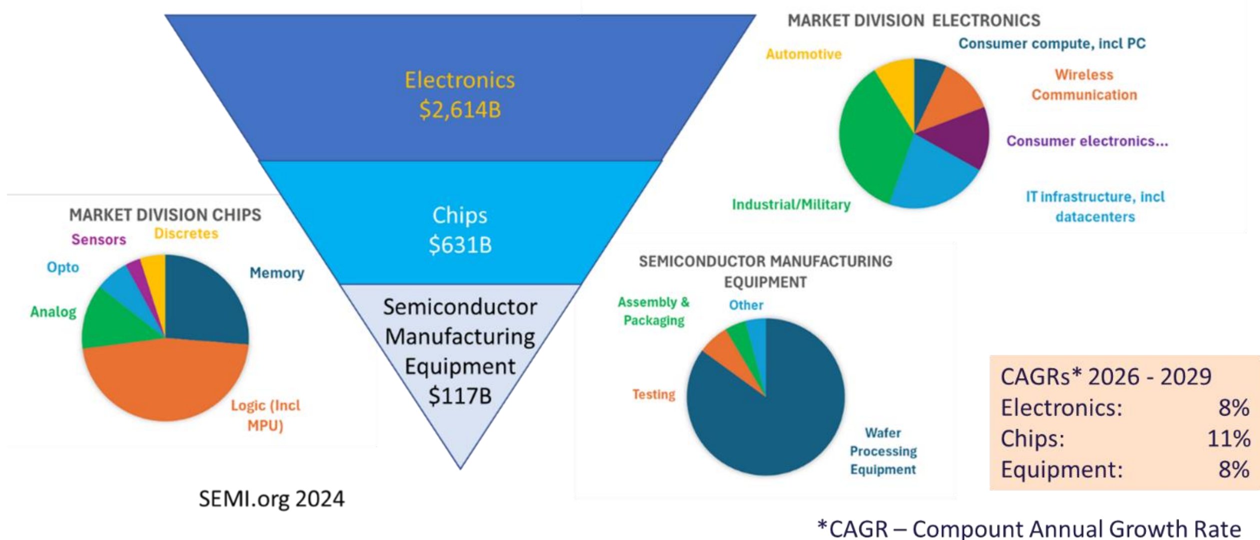

Figure 1: Markets enabled by Semiconductor Manufacturing Equipment, SEMI.org 2024. In Semiconductor manufacturing Equipment, "Other" represents Fab Facility equipment, Mask/Reticle Equipment and Wafer Manufacturing Equipment.

2.1.1 Market for Semiconductor Manufacturing Equipment

The Netherlands has a strong global position for Semiconductor Manufacturing Equipment. (Almost) the whole semiconductor value chain is represented in The Netherlands from design, manufacturing (fab, R&D lab and analytical equipment; wafer stepper/scanner, metrology, wafer processing, assembly), to testing & reliability. This thriving ecosystem forms the basis for innovation and development of leverage points in

[3] The underestimated size of the semiconductor Industry | McKinsey

emerging technologies, securing an even stronger position for the future. As a result of this strong global position, the Dutch ecosystem for Semiconductor Manufacturing Equipment Industry has an important contribution to the European sovereignty and to the earning power of the Netherlands.

In this roadmap the semiconductor manufacturing equipment market has been split into 4 domains, “Wafer Processing”, “Assembly & Packaging”, “Testing” and “Other” equipment. The latter covers *Fab Facility equipment, Mask/Reticle Equipment and Wafer Manufacturing Equipment.* Based on the SEMI.org 2024 numbers, the world market for Semiconductor Manufacturing Equipment is as indicated in *Table 1*. The maximum addressable market for Wafer Processing equipment in 2024 is by far the largest segment of the total market (in NL addressed by e.g., ASML, ASM, Thermo Fisher Scientific and Nearfield Instruments with their ecosystems), followed by Testing Equipment (without major Dutch players), and by Assembly Equipment in NL addressed by e.g., Besi, ITEC, Boschman and Sempro.

Semiconductor Manufacturing Equipment 2024: $117B			
Wafer Processing $99.6B	**Assembly & Packaging** $5.1B	**Testing** $7.5B	**Other** $4.9B

Table 1: World Markets for Semiconductor Manufacturing Equipment

2.1.1.1 Wafer Processing

From the SEMI.org 2024 report it follows that the wafer processing equipment worldwide market in 2024 was $99.6B.

Examples related to the Netherlands:

- ASML (with head office in Veldhoven) and its ecosystem of partners and suppliers, address the Lithographic Equipment and Process Diagnostic Equipment segments completing a Holistic Lithography workflow. Into the total Wafer processing Equipment market of $99.6B in 2024, ASML sold $28.3 billion which is more than1/4 of the addressable world market and includes a 100% market share for EUV (Extreme UV) Lithographic Scanners.[4]
- ASM (with head office in Almere) sold into the total Wafer Processing Equipment market €2.411 billion (~$2.6billion, so ~ 2.7% of the addressable world market share) in 2022.[5] ASM’s Atomic Layer Deposition (“ALD”) Product lines make the company a market leader in single wafer ALD, and enjoyed strong double-digit growth in 2022, with ALD continuing to represent more than half of the ASM equipment revenue. ASM’s other product lines also contributed strongly, led by the Epitaxy product line. In 2022, ASM expanded into the high-growth market of silicon-carbide epitaxy.
- Thermo Fisher Scientific (head office in USA) has its main R&D, manufacturing and European Semiconductor customer application support “Nanoport” site for high-end Transmission Electron Microscopes (“TEM”) in Eindhoven – established for over 50 years and the only high-end TEM R&D and manufacturing site outside north-east Asia. High-end TEM includes product lines specifically for the semiconductor market, in which Thermo Fisher Scientific is the market leader. It is worth noting that many high-end TEM innovations critical to the Semiconductor industry, result from initial R&D addressing needs in the Materials Science and Life Sciences TEM markets – this high-end TEM innovation also takes place at the Thermo Fisher Scientific site in Eindhoven. The high-end TEM business of Thermo Fisher Scientific is a significant part of the Analytical Instruments Group, reporting $7.4 Billion of the total Thermo Fisher Scientific 2024 revenue of $42.9 Billion [6].

[4] 2024 Annual Report based on US GAAP
[5] ASM International Annual Report 2022
[6] Thermo Fisher Scientific Inc. - Investors - Financials - Annual Reports

- The Dutch Semiconductor Manufacturing Equipment suppliers form vibrant ecosystems together with OEM module suppliers including VDL-ETG, NTS Group, Frencken, Demcon, Prodrive Technologies, Sioux and others. These OEM module suppliers also supply to other international Semiconductor Manufacturing Equipment companies. For example, system suppliers from the Dutch ecosystem support 7 out of the top-10 wafer processing equipment suppliers. The strong global position is also co-enabled by world-class know-how and knowledge, both in the companies and in Dutch Universities and RTOs, like ARCNL, VSL and TNO.
- On a smaller scale, Dutch mid-sized companies such as Tempress (Vaassen), Levitech BV, and Trymax (Nijmegen) provide annealing, oxidation, deposition and etching solutions to semiconductor R&D institutes, low-mid volume specialty fabs, and mature node fabs. These fabs are important suppliers of semiconductor chips required for the electrification (high power/automotive) and low-cost connectivity. Nearfield Instruments (with head office in Rotterdam) delivers metrology & inspection solutions (equipment and software) for in-line, non-destructive semiconductor manufacturing process control, based on high-throughput atomic force microscopy (AFM). First product QUADRA, on-surface metrology is deployed in world-wide high-volume manufacturing, while the second product, AUDIRA enables non-destructive subsurface metrology applications. NFI closely works with partners in the Dutch high-tech supply chain and is strongly embedded in the EU semiconductor ecosystem (a.o. as the only Dutch SME as Direct Partner in IPCEI ME/CT).
- Lam Research (Solmates) provides thin film Pulsed Laser Deposition (PLD) equipment. The diverse range of applications in Specialty Technologies requires the processing of novel materials. To address the challenging requirements of such materials, the very versatile PLD deposition technology is required to enable more advanced device design. In 2022 Solmates was acquired by Lam Research. Through this partnership the mass production of thin films for Specialty Technologies applications will be enabled.

2.1.1.2 Assembly & Packaging

According to SEMI.org, the world market for Assembly Equipment amounted in 2022 to $5.1B and consists of assembly inspection equipment, dicing, bonding, packaging and integrated assembly systems.

Examples related to the Netherlands:

- Besi (with head office in Duiven) sold €607 million[7].
- Other companies, like Boschman, Kulicke & Soffa (with headquarters in Singapore with part of its R&D in the Netherlands), ASMPT and ITEC.
- ITEC (an independent subsidiary of Nexperia) develops pick & place equipment to manufacture high volume, high precision, high quality, low cost and small dies (with spill-over to RFID, mini/micro-LED and wearable health diagnostics markets). ITEC aims to grow its sales in Assembly and Test equipment to 150M€ in the next five years.

2.1.1.3 Testing

The world market for Test Equipment was in 2022 $7.5B and consists of Test and Measurement systems, handlers, and probers to optimize production of ICs for Memory, Logic, System-on-Chip, Micro Processors, Graphics Processors; Wireless Communications, etc.

Example related to the Netherlands:

This market is dominated by large players like Advantest (Headquarters in Japan, with subsidiary Salland Engineering in NL) and Teradyne (Headquarters in the USA). VLSI research (listing threshold > ~ 0.1M$) does not list Test Equipment companies in the Netherlands with revenue from sales of Test Equipment. Though there are companies that aid in development of new Test Equipment and provide Test Services, such as Advantest's Salland Engineering (Zwolle). Some Dutch companies also are intending to develop Test and Metrology tools for Photonic Integrated Circuits, like IMS (and partners).

[7] Annual report 2024, www.besi.com

2.1.2 Market for Chips

The Chips market exceeds the semiconductor manufacturing equipment market by about 6 times, coming in at $631B in 2024. It is divided into Logic (Including MPU), Memory, Analog, Opto, Discretes and Sensors, see *Table 2.*

Chips 2024: $631B					
Logic (Incl. MPU) $294B	**Memory** $166B	**Analog** $80B	**Opto** $41B	**Discretes** $31B	**Sensors** $19B

Table 2: Chips market division

In the first half of 2025 it reached 346 billion dollars, an 18.9 percent increase year-over-year. Growth was driven primarily by strong gains in Logic (up 37 percent) and Memory (up 20 percent), supported by demand for data center infrastructure and the emergence of initial AI edge applications. Sensors also performed well, rising 16 percent. Analog and Micro categories saw moderate growth of 4 percent each, respectively. In contrast, Discretes (-4%) and Optoelectronics (-0.5%) posted single-digit declines.

Figure 2 : Chips market revenues (source WSTS 2025)

The 2025 WSTS forecast, *Figure 2,* has been largely confirmed by the results from the first half of the year. Incorporating the latest data, the full-year 2025 forecast has been revised upward to 728 billion dollars, reflecting an annual growth of 15.4 percent, an increase of 4 percentage points. The outlook for 2026 changed slightly upwards, with projected growth of 9.9 percent to 800 billion dollars for the year.

For 2025, all product segments show upward revisions. The key growth drivers, Logic and Memory, are now expected to grow by 29 percent and 17 percent (both up 5 percentage points), respectively, reflecting stronger-than-expected performance in the first half of the year.

Regionally, all major markets are expected to expand, with the Americas and Asia Pacific continuing to lead the growth, while Europe is expected to strengthen and Japan to decline slightly.

Application trends

McKinsey projects the global semiconductor market will grow at a 6-8% annual rate until 2030, reaching over $1 trillion in value. This growth will be primarily driven by the automotive, computation and data storage, and industrial market.

Automotive Semiconductors

Expected to be the fastest-growing sector, driven by the shift to electric vehicles and the adoption of advanced driver-assistance systems (ADAS) and autonomous driving features. The automotive AI chipset market is projected to reach USD 14.68 billion by 2034 (20% CAGR)[8]. Chiplet-based architectures are becoming essential due to the 'Compute Trilemma'—balancing performance, power efficiency, and functional safety in constrained thermal envelopes. European AI chip designers developing modular, safety-certifiable inference engines, can address OEM requirements for ASIL-D compliant AI processing—a capability gap identified at AD Europe 2025 where integration expertise was highlighted as critical.

- Edge AI is transforming vehicles: AI models are increasingly executed directly in vehicles (edge AI), reducing latency and improving privacy. This shift is driving demand for neural processing units (NPUs) and modular system-on-chip (SoC) architectures. [mckinsey.com]
- Digital features are a key differentiator: In premium markets like Germany, 38% of car owners would switch brands for better digital experiences, highlighting the strategic importance of AI-driven features. [mckinsey.com]
- Autonomous driving is reshaping chip demand: OEMs are investing heavily in advanced driver-assistance systems (ADAS) and autonomous vehicle (AV) technologies, prompting a surge in demand for specialty silicon and in-house chip design. [mckinsey.com]

Computation and data storage

Continued growth in data centers and the demand for high-performance computing will fuel this sector. Physicality Compute and Physical AI is a big new market and very heavy compute & robust intensive. That is going to demand for Heterogenous compute architecture and new packaging . The mkt size currently is 5,41 bn USD to grow to 61,19 bn USD by 2034. Some even predicting to be 1Trn USD in near future.[9] Where:

- AI is a major growth engine: Generative AI and machine learning are driving explosive demand for high-performance chips, especially among top-tier companies like Nvidia and AMD. [mckinsey.com]
- Value creation is uneven: In 2024, the top 5% of semiconductor firms captured all economic profit, while the rest faced squeezed margins and slower recovery. [mckinsey.com]
- AI inference in vehicles: Automakers must decide whether to run AI models in the cloud, on the vehicle, or both. This decision affects hardware selection, latency, and cost. [mckinsey.com]

A key growth market relevant for the Netherlands is AI Chips in regard to Design and application. The global AI accelerator market reached $140B in 2024 and is projected to reach $440B by 2030 ((CAGR 25%), with edge AI accelerators specifically growing at 30.83% CAGR[10]. European companies developing energy-

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[8] *Mordor Intelligence automotive AI; Edge AI Vision Alliance, Oct 2025*

[9] https://finance.yahoo.com/news/physical-ai-market-size-expand-150000542.html?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAIGNRgrNP__O7yNSJLcVDWIMNQT8fxq8e6xPAMEmW1QTy2eCpb1qHZCBotg5W3vzDm9WnFpdvHlMHttMj6N5SmFwTiEXlt8M

[10] Mordor Intelligence AI Accelerators Market, Aug 2025; Precedence Research Edge AI Accelerator Market, Mar 2025

efficient inference architectures—including digital in-memory computing (DIMC) and RISC-V-based solutions—are positioned to challenge GPU-centric incumbents in this high-growth segment. To consider are:

- Axelera AI and AI chip design ecosystem: Netherlands' flagship AI chip company.
- Memory dependencies: HBM3E/HBM4 supply relationships and adoption of memory wafer stacking by hybrid bonding are critical for AI chip sovereignty but remain unaddressed.
- Advanced packaging for AI: hybrid bonding technique required to produced chiplet packages for CoWoS and co-packaged optics opportunities

Chip Design Capabilities

- EDA tools: The 85% US EDA dependency (Synopsys/Cadence/Siemens) creates strategic vulnerability worth acknowledging
- EU Chips Design Platform: The €15.8B initiative (April 2025, TU/e partner) could be integrated with national strategy
- RISC-V and open-source hardware: Given EU DARE project (€61.6M, includes Axelera) and ChipNL focus, consider explicit RISC-V positioning

Ecosystem Connections

- Semiconductor-AI partnerships: ASML-Mistral (€1.3B), Nvidia Netherlands deal (€204.5M), NXP-Kinara (€307M)
- EU Chips Act alignment: Netherlands' AI Factory selection and Competence Centre role could strengthen sovereignty framing

Thermal Management for AI
Current equipment energy efficiency focus (kWh/wafer) could be complemented with AI chip thermal challenges (1,200W+ chips, liquid cooling requirements) as market opportunity for Dutch companies.

In-memory computing architectures represent a paradigm shift for AI inference, moving computation directly to where data resides and dramatically reducing the energy costs of data movement—the dominant factor in conventional von Neumann architectures. Digital in-memory computing (DIMC) approaches offer particular advantages for edge AI applications where power efficiency (measured in TOPS/Watt) is the defining competitive metric. European companies pioneering these architectures address both the sustainability imperative and technical requirements of the rapidly growing edge AI market.

Industrial market
Industrial sectors are also benefiting from semiconductor innovation:

- Edge computing and IoT are enabling smarter factories and infrastructure.
- Advanced packaging and regionalization are helping industrial players reduce supply chain risks and improve performance. [mckinsey.com]

2.1.3 Market for Electronics

In its turn, the Electronics market exceeds the chips market about 4 times with $2,614 in 2024. It is divided in Industry/Defense , IT Infrastructure including Datacenters, Consumer electronics incl smartphones, Wireless communication, Automotive and Consumer compute including PCs, see *Table 3*. It should be noted that the Semiconductor Equipment industry is also a consumer of chips, electronics modules and

sub-systems, in the Industrial/Defense segment, based either on standard processes and products, or specialized processes and products required for some of the unique requirements of semiconductor equipment.

Electronics[11] 2024: $2,614B					
Industrial/Defense $932B	**IT infrastructure Incl Datacenters** $584B	**Consumer electronics incl smartphones** $364B	**Wireless communication** $318B	**Automotive** $232B	**Consumer compute, incl PC** $184B

Table 3: Electronics market division

2.2 Societal, economic & geopolitical relevance

Semiconductor technologies and their role in the creation of electronic components and systems is an essential enabler for solving the major societal challenges, like the climate- and energy crisis, digitalization and circularity in all sectors. Moreover, fueled by geopolitical tension, there is also the challenge of deglobalization to consider, calling for greater strategic autonomy and securing of supply chains. As such it is of prime strategic importance to defend and strengthen the Dutch position in the semiconductor value chain. It is a necessity to further strengthen the traditionally strong position in semiconductor manufacturing equipment and grown through diversification by enabling innovation and leveraging Dutch core competences. This will safeguard the future security of supply and strengthen a flourishing economic sector for the Netherlands.

The central role of semiconductors in solving societal challenges

The semiconductor equipment sector drives significant innovations for Electronic Components and Systems with more/other functionality and more embedded electronic computing power. The sector does this in two main ways.

First, it drives the need for more computing power and higher energy efficiency by continuously pushing Moore's law: more transistors – computing power- on the same chip area. This enables high-end computing needs like massive data centers with High Performance Computers for Cloud Computing, mobile devices with a high degree of functionality and internet-of-things devices. Furthermore, the sector drives innovations in the More than Moore area: combining different chiplets, platforms and functionality in one device.

Second, these innovations are at the heart of the digital transition, driving the possibilities of AI and connectivity. The transitions to a circular economy and an economy based on renewable energy will critically depend on Electronic components and systems and digitalization. Mobility will be powered by smart vehicles with integrated sensors and computing power, the energy grid needs smart adaptations and for a circular economy a high degree of digital tracking will be indispensable.

Economic opportunities in an ever changing global context

This changing context creates opportunities for the Dutch semiconductor equipment sector. Reshoring manufacturing, packaging and testing to Europe and North America increases the total market size for equipment in a significant way. Moreover, reshoring also drives demand for more cost-effective, i.e. less labor intensive, far-reaching automation and digitalization. Moreover, geopolitical fragmentation, tech sovereignty, and export controls are actively reshaping the semiconductor landscape — particularly around the U.S., China, and Europe.

[11] In these numbers Medical is covered in Industrial/Defense

Security of supply and open[12] strategic autonomy

Semiconductor value chains are known for their complexity. The high pace of innovation, capital- and knowledge intensity and diversity in requirements for individual steps have over the past decades led to a highly economically efficient and global industry. Moreover, the pace of innovation and the efficiency improvement have enabled the far-reaching societal benefits of affordable digitalization.

Some of the individual steps within the value chain are so capital- and/or knowledge intensive that only a single company, like for example ASML, for lithography, ASM for Atomic Layer Deposition, KLA-Tencor for inspection and Tokyo Electron for tracks, can provide the highest level of technology. The unique knowledge positions of these companies lead to strong interdependencies, between companies and states. These interdependencies pose risks on the security of supply to downstream industries and consumers. A changing geopolitical context further compounds these risks. Dependency on third countries for essential chip technology leads to the societal demand for increased security of supply.

For a small country such as the Netherlands, and even for Europe, full autonomy is not obtainable, or even practical. Therefore, strategic autonomy and an increased security of supply should be addressed in the light of the complexity of value chains and interdependencies. A strategy of maximizing the quantity and quality of unique knowledge positions, if not control points, within in the value chain is viable. This strategy should include the preservation of existing control points, and the development of novel control points in emerging technologies and capabilities. Herein, technological leadership is key.

Further priority is derived from the societal transitions. The equipment sectors drive innovations for Electronic Components and Systems with more/other functionality and more embedded electronic computing power and thereby enable solutions for almost all sectors involved in energy, digitalization and circular economy.

2.3 Development in future markets

The market pull in the past years came primarily from high demands for conventional consumer devices (in particular Smartphones), related communication network devices (4G, 5G) and data centers (and associated high data rate and switching capacity optical communications technologies requiring semiconductor devices). Today there are AI and High-Performance Computing (HPC):

- The biggest growth driver today is AI infrastructure — training and inference for large language models, edge AI, and specialized accelerators (GPUs, TPUs, NPUs).
- This has created enormous demand for advanced logic chips, HBM (High Bandwidth Memory), and advanced packaging — all of which require cutting-edge lithography, deposition, and testing equipment.
- The surge in AI datacenters is also stimulating growth in power electronics and high-speed optical interconnects.

Advanced Packaging and Heterogeneous Integration:

- As Moore's Law slows, performance gains are coming from chiplet-based architectures and advanced packaging (e.g., 2.5D/3D integration).
- Another area is wafer level packaging. The global advanced packaging market is expected to achieve 10-12% CAGR through 2030, with chiplet-based architectures specifically growing at over 30% CAGR (Gartner). Automotive applications are driving adoption due to the 'Compute Trilemma'—balancing performance, power efficiency, and functional safety in constrained thermal envelopes. European AI chip designers developing modular, safety-certifiable inference engines address OEM requirements for ASIL-D compliant processing.13

[12] "Open strategic autonomy" is the policy choice of NL (and Europe): https://open.overheid.nl/documenten/ronl-5b134a1ba15379fdfc6ecb0b6dcc431843087193/pdf .

[13] *Gartner/Yole advanced packaging projections; Edge AI Vision Alliance AD Europe 2025 report*

In addition, there are the societal challenges associated with the 3 transitions in Energy & climate, Digitalization and Circular Economy which are expected to result in *additional* fast-growing markets for Electronic Components and Systems.

Digitalization

For example, the 5G IoT market in 2021 is $2.6B and is expected to grow to $40B in 2026. A CAGR of 73%. Or the healthcare Micro-technology market with 11.6B in 2020 which is expected to grow to $21.3B in 2025, a CAGR of 11%, driven by an increased use of remote diagnostics health care (lab-on-a-chip) and connectivity to cope with an aging population. This requires lowering the device production costs either through increased test throughput or more complex (e.g., parallel) test methods. Eliminating production waste via better process monitoring can also improve circularity in the production chain. Both goals can be achieved by innovations in test technology for the R&D, wafer or final test phases of the production cycle.
In general, there is mutuality across solutions like the use of AI in our systems and usage of Semiconductors as the enabler of digitalization.

- Post-pandemic supply disruptions and labor shortages have accelerated demand for smart factories, AI-driven process control, and robotics in semiconductor manufacturing.
- Equipment vendors are expected to provide more automated, data-driven solutions, which increases their value per fab.

Energy & Climate

Semiconductors are enabling electrification, with a $1.4B market in 2020 which is expected to grow to $4.5B in 2026, a CAGR of 25.9%.
According to external studies, 1 kWh spent in production in a new manufacturing line helps conserve 4 kWh of energy globally. In addition, smaller and novel transistor and memory structures consume less energy while boosting computing performance. However, this does not mean that semiconductor manufacturing equipment makers are “off the hook”. The industry itself grows and its consumption is expected to go up by 4x by 2040, hence there is a lot of pressure for the industry to limit energy usage, for which further innovations are required. Next to that, new technologies may be required to manufacture parts (in the supply chain) in a more sustainable way, possibly using new/alternative materials.
The promise of energy-efficient computing for data-intensive applications like artificial intelligence, cloud computing, and autonomous electric vehicles increasingly relies upon advances in material research and the ability to construct 3D nanostructures. To make this possible extensive novel materials research and equipment development is required.
In order to enhance energy efficiency of invertors used in renewable energy and electric mobility wide bandgap semiconductors like SiC, GaN and some lower TRL level wide bandgap materials are essential. The enhanced efficiencies will result in lower levelized cost of energy and extend the range of electric mobility solutions to allow further adaptation. Also, assembly will play an important role. All in all:

- The move toward electric vehicles (EVs), renewable energy, and smart grids is driving demand for power semiconductors (SiC, GaN).
- These applications require new production lines and specialized equipment, expanding the equipment market beyond traditional logic and memory.

Circular Economy

Equipment for a lifetime, through refurbishment & re-use of parts and upgradability. For example 95%, of ASML machines ever built are still in use. ASML and Thermo Fisher Scientific have re-use programs in place aiming at maximizing re-use (= repair/remanufacture) of returned parts to create new modules or parts.
In the recent past, ASM refurbished all of the available legacy vertical furnace systems. For its novel SiC epitaxy systems, a constant component refurbishment flow drives up-time of the system, while reducing waste.

Another example would be deployment of ultra low-cost ID tags (Solutions on Silicon) to packaging in order to enable tracking and better recycling.
At ASML there is a packaging program that optimizes machine and module packaging for footprint and waste reduction.

3. Applications & Technologies

3.1 More Moore vs More than Moore

Figure 3 below, depicts the two essential technology developments that underpin the Semiconductor Technologies roadmap: Miniaturization through More Moore and Diversification through More than Moore.

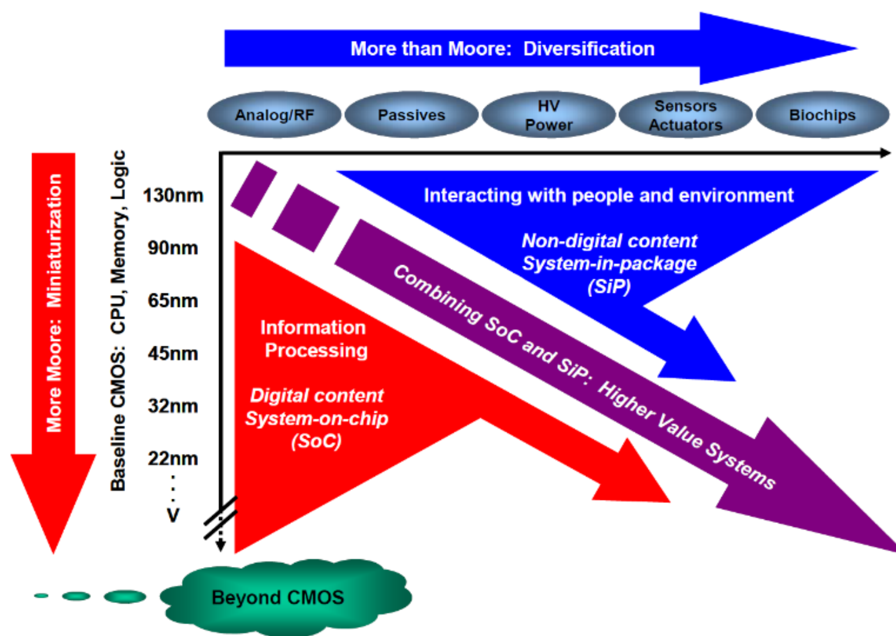

Figure 3: The combined need for digital and non-digital functionalities in an integrated system is translated as a dual trend in the International Technology Roadmap for Semiconductors: miniaturization of the digital functions ("More Moore") and functional diversification ("More-than-Moore").

The main line of technology development under Moore's law is focused on digital CMOS scaling.

New hardware/software building blocks for advanced signal processing functions target mobile, IoT, Artificial Intelligence (AI) and automotive applications. The challenge is to deal with design complexity, product configurability and performance aspects (including power). This requires innovative hardware/software (multi-core) architectures in conjunction with new hardware/software verification technologies to master design complexity under stringent performance, energy and reliability constraints.

Advancements in technology push for growing integration of functions on a single die. Digital functions are extended with memories, input-output drivers, analog-to-digital interfaces, wireless interfaces and power management. Further functional integration will lead to system solutions with a minimum number of external components, thereby reducing the system cost and the energy consumption.

Extremely small dimensions and new materials (metal-gate, graphene, etc.) require design and model adaptations for every process node: new phenomena appear and old worries vanish. Slow degradation over life time, radiation hardness, reliability of components and the inherent variability require more attention.

Future RF, analog and also digital design methodology will need to adapt to these new phenomena. Topics in the Dutch context: modeling of advanced devices and structures, incorporation in EDA tools, testing, advanced libraries and DSP architectures.

Downscaling and reliability demand circuit operation at (very) low voltages and power levels. New insights in circuit design, new technology options and the possibility to design intelligent analog and digital calibration mechanisms demand new system partitioning. Analog and RF components designed in scaled technologies can benefit from digitally-assisted and digitally-dominant design methodologies. Dutch industry and academic research has an excellent reputation improving the performance of communication, radar, automotive and signal-processing circuits. As the technological progress of advanced CMOS still continues, more advances in the neighboring "More-than-Moore" areas can be expected. Many "More-than-Moore" technologies exist because they enrich the circuits to a diversification available in CMOS technology.

3.2 State-of-the-art, Trends & Challenges

3.2.1 Semiconductor Manufacturing Equipment

Continuous innovation over the past 6 decades, has enabled major innovations in the industry using/applying ever improving electronic component and systems, co-enabled by important Dutch inventions. This is underpinned by:

- ASML's introduction of Extreme Ultra Violet Lithography for leading edge logic and memory technology for sub 5nm IC-nodes and its extension to high NA EUV;
- ASM's realization of several high-productivity systems to deposit enabling new materials by (Plasma-Enhanced) Atomic Layer Deposition, epitaxy and chemical vapor deposition;
- BESI's creation of Advanced Packaging Equipment for Exposed Die Molding Wafer Level Packaging (WLP) and Saw singulation stepcut processing;
- Thermo Fisher Scientific's Transmission Electron Microscopy (TEM) platform to measure and qualify materials and transistor structures at sub-atomic scale, leveraging advanced capabilities such as aberration-correction, in-situ/operando experimentation, 4D-scanning, and correlative multi-modal analysis to deliver enhanced structural, chemical and dynamic insight.
- Nearfield Instruments' high-throughput atomic force microscopy enabling non-destructive, in-line, atom-scale 3D on-surface and subsurface metrology.
- Salland Engineering's (Advantest) specific MEMS test IP, developed together with Saxion, Maser, University of Twente, made it possible to test this kind of semiconductors without the physical stimulation.
- Deployment of expertise in other area's such as in the "Einstein Telescope", knowledge on contamination control for EUVL is applied in space instrumentation, and systems engineering and nanofabrication expertise is now applied to quantum technologies.

3.2.1.1 Wafer processing

The *forefront* of Wafer processing Equipment is currently applied to *Logic* and *High-Performance Memory* which is used mainly in portable devices as well as advanced cloud computing (incl. AI) and data storage platforms. Currently, double, triple and quadruple patterning are used with immersion (DUV) lithography in combination with advanced materials deposition (led by ASML and ASM respectively), single patterning EUV lithography (ASML as single supplier) is used to realize line widths of less than ~ 14 nm for IC nodes of 5nm and lower, and 3D NAND Memory with 128 layers and more. Creating a leading-edge IC nowadays is a process consisting of several hundreds of individual steps.

A state-of-the-art IC-Fab typically applies EUV for the critical patterning layers, and iDUV (immersion Deep UV) for the less critical layers, with a mix-and-match of EUV and iDUV equipment to secure correct relative placement (Overlay) of each layer with an accuracy of 2.5 nm.
High resolution, accurate, reliable and automated analysis of the results of lithography and deposition steps is required, with TEM solutions provided by Thermo Fisher Scientific being a critical technique used by in fabs, often with multiple systems, during R&D of the processes and production ramp-up to ensure the correct selection of process parameter windows and high yield operation of the wafer fab. With the growing complexity and wafer throughput of EUV based manufacturing, demand for "near-line" TEM analysis of production wafers "sampled" from in-line processes is becoming increasingly routine in modern fabs.
From 2024 onwards, enabled by current Deposition, Lithography, Etch, Processing, Analytical and Metrology tools – a significant part of it provided by Dutch vendors - and their performance, the 2nm technology node is to be ramped-up by market leaders Intel, TSMC and Samsung, and solutions for 1.4nm and beyond are being explored.

Major trends in the wafer processing equipment industry are:

- Continuous scaling of dimensions, illustrated by imec's device development roadmap, depicting progress from the N2 (2nm) node in 2024 to the A7 (7 Angstrom) node in 2030, continuing Moore's law, see *Figure 4.*
- Dimensional scaling will still progress, albeit, not with the 0.7x per node the industry has been used to. The metal pitch is expected to shrink from 21nm in 2024 to 16-14nm by 2030.
- Further functional scaling will be achieved by device and material innovation enabling the industry to migrate towards 3D transistor & memory devices, such as moving from the present FinFET to Gate All Around and 3D CFET devices.
- Lastly there will be a trend to introduce scaling boosters like back side power distribution, Super Vias and Through Silicon Vias (TSVs) to enable stacked die/wafer solutions
- In the power semiconductor market, wide band-gap materials such as SiC, GaN will have to be further developed and new device architectures with materials such as high-k dielectrics, and other wide band-gap materials such as AlN and GaO will be developed

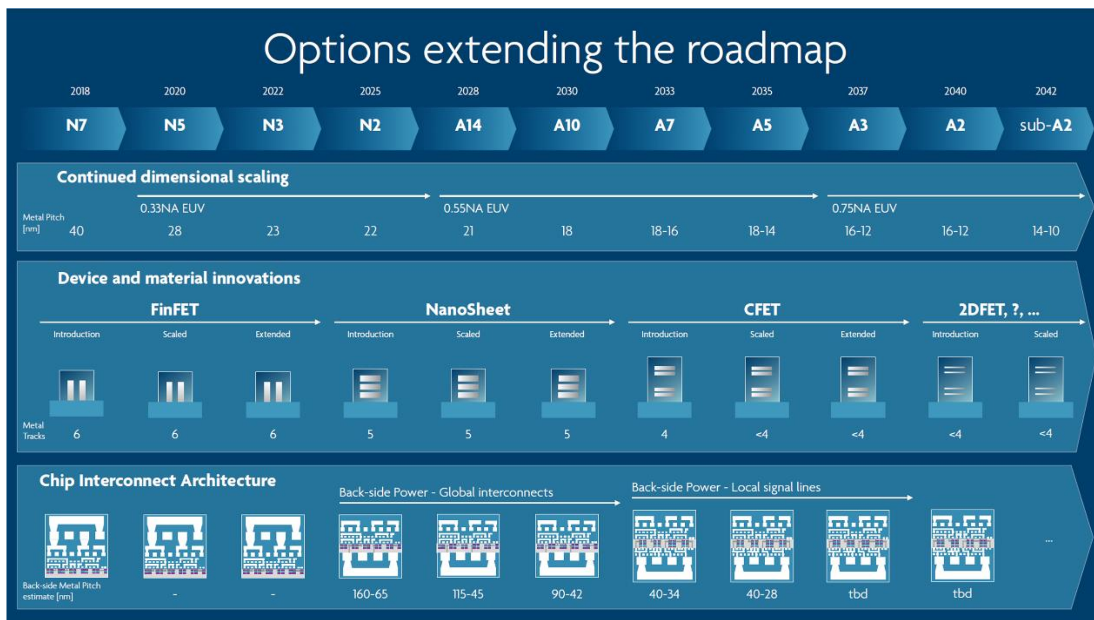

Figure 4: Potential roadmap extension of high-performance CMOS logic, imec

For the next technology nodes, new materials are required, *either* to optimize electrical properties, in which case the materials stay in the structure, *or* to enable the creation of challenging 3-dimensional geometries, in which case the materials might sometimes be sacrificial. Deposition of materials has to be more and more

selective in the areas to deposit on, the layer thickness, the deposition on horizontal and/or vertical surfaces. Equipment with such capabilities includes the ALD tools by ASM, which are more selective than (Chemical Vapor Deposition (CVD) and other processing tools. The increasingly strict low-thermal, low-voltage, and low-leakage budget requirements for state-of-the-art process flows increase these challenges considerably.
Productivity improvement and energy reduction remain a constant drive in the industry. To reduce cost, the number of wafers that are processed per hour is constantly pushed upwards by Wafer-Fabs at an equal or lower power consumption. This can be achieved by *either* throughput improvements of semiconductor manufacturing equipment and workflow *or* process simplifications. (Although throughput differs strongly per manufacturing equipment segment, like in lithography throughput levels in DUV currently are around 295 wafers per hour and 170 in EUV, whereas, throughput in deposition might take up to a few minutes of single wafer deposition processes, with mini-batch taking up to ten minutes per wafer, and for full batch up to a few hours in a vertical furnace, depending upon the chemical process and desired film thickness.) For all equipment this means a push for higher throughput and higher yield, as well as better process control to limit additional process steps or rejected wafers. More advanced equipment both in patterning, processing and metrology is the result. The kWh/wafer is a key KPI to drive innovations for sustainability.

Another trend (more generic) is the need for more efficient methods for equipment design and realization to mitigate the growing technical complexity and increased labor demand. The ever-increasing technical complexity necessitates significant increase in labor to enable the design and realization of future semiconductor manufacturing equipment solutions, be it in lithography, etch, deposition, metrology or analytical characterization. Without efficiency improvements, the local labor marked would not be able to supply enough highly skilled personnel resulting in slower innovation than technically possible. Eventually this will have an impact on profit margins, as the increase in technical complexity is slowly outpacing the achieved throughput improvements.
In the area of manufacture there is the trend of further automation, e.g., Industry 4.0 and 5.0, needing more exchange of data, requiring secure access to design data into manufacture and manufacturing information from equipment in the production environment. This links to the Smart Industry roadmap.
In the area of deposition and advanced materials there is a trend of applying “Computation Chemistry” in which feedback from real-world metrology is indispensable. In addition there is the trend of applying in-situ measurements for real-life optimization of processes and process window. And increase use of “pre-clean” / etch techniques in support of deposition processes.
Lastly there are the environmental aspects, where there is the elimination of harmful & polluting materials, like to phase out PFAS containing materials in equipment and processes and High Voltage insulating gas, SF6, on one hand, and to reduce energy and material consumption on the other. Most of the stock-listed equipment companies operations in NL, have committed themselves to ambitious NetZero strategies. To achieve these, they drive to make equipment more efficient on energy, water and material consumption, and address recycling opportunities for components utilities such as gases (notably hydrogen and carbon dioxide) and processed materials. This goes both ways: in our own production facilities and in our equipment. Most often, such efforts involve close collaboration with equipment component and material suppliers. Refurbishment and re-use of components, sub-systems and systems is also a long term activity gaining momentum.
All-in-all, this represents a major challenge to the international semiconductor industry in the areas of lithography, material innovation, processing, assembly, process control, analysis and testing, as well as an opportunity to the well-positioned Dutch equipment vendors and their network of suppliers.

For Lithography equipment, beyond-state-of-the art knowledge and technology is generated by many R&D specialists at ASML and its *industrial/private* partners and suppliers. In the case of Analytical and Metrology Equipment, beyond-state-of-the art knowledge and technology is generated by hundreds of Thermo Fisher Scientific R&D specialists and its ecosystem for, e.g., new electron microscopes solutions (using e.g., TEM/STEM/EELS/EDX [14], automated workflows and metrology. AI, etc.) for fast, sub nanometric 3D imaging

[14] (S)TEM = (Scanning) Transmission Electron Microscope, EELS = Electron Energy Loss Spectroscopy, EDX = Energy Dispersive X-ray

and chemical analysis, and other measurement equipment to enable the development and near line process ramp and production monitoring for leading IC nodes.

Nearfield Instruments, together with development partners in the high-tech ecosystem, continuously generate new technologies and know-how to realize non-destructive, high-throughput on- and subsurface atom-scale metrology.
In ASM, which has a globally decentralized network, many new materials and deposition technologies are being developed, connecting the Netherlands to a vast materials innovation network.

In addition to this private/industrial R&D:

- ARCNL develops, in a PPP - Public Private Partnership, beyond state-of-the-art knowledge and technology for Computational Imaging, Contact Dynamics, EUV Generation & Imaging, EUV Photoresists, EUV Plasma Processes, High-Harmonic generation and EUV science, Light-Matter Interaction, Materials & Surface Science for EUV Lithography, Nanolayers, Nano-photochemistry, Nanoscale Imaging and Metrology [15].
- TNO develops, in PPP's, business contracts or by spin-off creation, beyond state-of-the-art knowledge and technology for Molecular Contamination Control and enhanced lifetime for EUV optics, particle contamination control for EUV lithography and assembly equipment, optical column conditioning for immersion and dry DUV lithography systems, opto-mechatronics for new lithography concepts, new metrology solutions for beyond 7nm nodes and for heterogeneous integration based on combined optics, acoustic, scanning probe, and quantum technologies, Thermal & Flow plus vacuum & plasma solutions for iDUV, new sensors and actuators for enhanced machine control, unique equipment for research, and material and concept qualification, alternatives for PFAS and other harmful materials, new methods for optical design, AI based digital twinning techniques for equipment R&D and assembly, AI for preventive maintenance, architectures for embedded software.
- Universities and other institutes such as the Technical University of Eindhoven (TU/e), the University of Twente (UT), TUD, VSL and DIFFER, develop with involvement of private/industrial companies beyond-state-of-the-art knowledge and technology as well as provide new talent on various topics, like:
  - Mechatronic and related power electronics solutions for wafer stages operating at beyond 30G accelerations in combination with (sub) nanometer level accuracy and precision;
  - Advanced measurement, control, and optimization techniques (including AI and Machine learning) to operate mechatronic systems at their maximally capable accuracy and throughput;
  - Advanced construction design techniques, (meta-) materials, and manufacturing techniques for extreme-precision and stability of mechanical structures;
  - EUV (deformable) optics, optical surfaces and pellicle technology;
  - Flow and temperature solutions for cooling concepts in near vacuum conditions;
  - Tribology research for e.g., improved understanding of wafer deformations during movements;
  - New mechanisms and technologies for clean substrate transfer;
  - Models for prediction of particle generation and transport to achieve high levels of cleanliness;
  - Plasma technologies to manage nano contamination in equipment;
  - New metrology and sensor concepts, including realization of test and qualification equipment;
  - Advanced materials, plasma physics and chemistry related to contamination control and behavior of systems in extreme conditions;
  - Machine learning and digital twinning for predictive maintenance to achieve increased availability of equipment;
  - Artificial intelligence, machine learning and other computing methodologies to handle the large big-data volumes produced in Holistic/Computational lithography and metrology.
  - Design automation to optimize equipment performance, lower cost, reduce over-dimensioning, improve labor productivity, and improve resilience through platforms and standards;
  - New materials and deposition technologies for future devices, both in More-Moore and More-than-Moore areas;
  - Model Based System Engineering, MBSE

[15] https://arcnl.nl/research

- Knowledge of Design for Sustainability

3.2.1.2 Assembly & packaging

Since 2000 packaging technology of semiconductors has evolved considerably, see *Figure 5.* The *forefront* trends in Assembly equipment development are:

- To maximize the benefits from ICs made for IC-nodes of 7 nm and less, going *from* simple wire bond *to* Ball Grid Array/Flip Chip, *to* (Fan-Out) Wafer Level Packaging without substrate interposer, *to* complex 3D structures with Through Silicon Vertical Interconnect Accesses (“TSVIA”), micro-bumps and thin dies, and *to* wafer-to-wafer bonding to speed up production of 3D ICs;
- Functional diversification of technologies, where digital electronics meet the analog world, using advanced assembly/packaging of heterogeneous pieces of chips (“chiplets”) and of chips, sensors and/or smart antenna components. (Obviously, these trends are closely related to the trends formulated for (front-end) wafer processing equipment, amongst others creation of silicon vias and backside power distribution networks.)
- An ongoing focus on enhancing functionalities of heterogenous systems by combining “traditional” semiconductors with integrated photonics components or chiplets. Trend that is also being largely spurred on by large investments from for instance “national growth fund projects” (Quantum Delta NL, PhotonDelta and NXTGEN Hightech) and other (public private) projects and partnerships.
- Addressing high speed component transfer by the assembly industry, with ambitious goals of developing transfer capability up to 1 million components per hour (without contact) by 2028.

Besides this technological frontier, trends for Assembly equipment are:

- Factory automation to increase product reliability with multi-facetted device inspections, sorting and advanced tracking and tracing as well as data storage through full production lines;
- Product developments for highly specialized applications such as medical applications, organ on chip devices;
- Application for laser satellite communication and agrifood;
- Power modules/discrete devices for electric cars, power grids and industrial equipment and Integration of optical inputs/outputs in electronic IC’s.
- Integration of optical inputs/outputs in electronic ICs[16]: Co-packaged optics (CPO) is becoming essential for AI datacenter infrastructure, enabling the bandwidth required for multi-GPU/multi-accelerator communication at sustainable power levels. The integration of photonic ICs with electronic ASICs requires advanced packaging capabilities where Dutch equipment manufacturers (Besi, ITEC) and photonics expertise (PhotonDelta ecosystem) can contribute. AI accelerator designers incorporating optical I/O can differentiate on system-level bandwidth and power efficiency metrics increasingly important for hyperscale deployment.
- Development and application of 3D printing technology in heterogeneous integration, covering materials, process and equipment.
- TEM is a *very powerful* tool for understanding materials, defects and structures at the nanoscale. TEM will also become an indispensable tool for advanced packaging following innovations in sample preparation and accessibility, material heterogeneity and sensitivity, increasing throughput and minimizing sampling bias. This will meet increasing demands for 3D and correlative analyses, alignment with real-world reliability conditions, and tool/instrumentation gaps for the packaging use-case.

[16] *Industry CPO analysis; PhotonDelta strategic documentation*

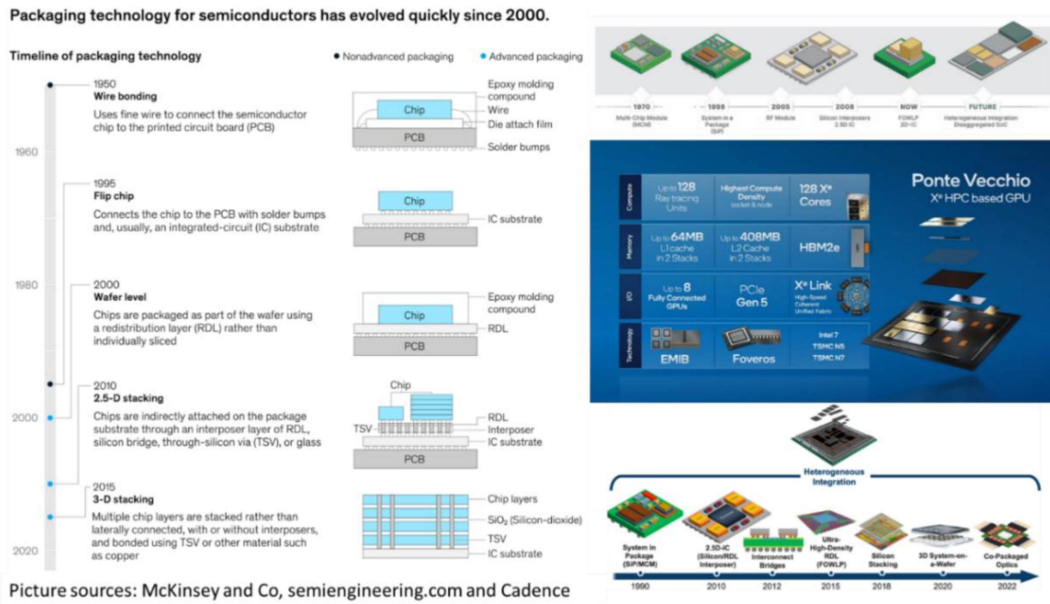

Figure 5: Evolvement of semiconductor packaging technology since 2000.

For the advanced Packaging Equipment, beyond-state-of-the art, knowledge and technology is generated by R&D specialists at Besi and its *private/industrial* partners and suppliers to meet the technical challenges as described above. Besi is the market leader in nano-scale wafer level assembly using high precision die to wafer assembly, and Besi is investigating advancements in the precision and productivity to enable 3D IC integration roadmaps. This could give synergy with ASML and European Foundries for specialty ICs. As of today, PPP projects are done only in European projects that also include universities and RTOs in the Netherlands. But PPP projects are also done by national growth fund (like NXTGEN Hightech, PhotonDelta and Quantum Delta). In these projects companies intensively work together to develop relevant cutting-edge solutions that make semicon assembly equipment tools faster and more accurate. But also the lack of specialized tools for integrated photonic chips is being addressed in these PPP's. Companies in the Dutch ecosystem are also dedicated to continuously develop and expand on their technological knowhow. Companies like Nexperia/ITEC, Kulicke & Soffa, Sempro, Besi, Etteplan, IMS, etc. are continuously developing their OEM offerings and are increasing speed, precision and sustainability of their machines, in order to make semiconductor assembly more efficient and future proof.
Advanced packaging knowledge and technology is also developed at the CITC in Nijmegen which explicitly focused on: packaging of chiplets (system in package), advanced photonic packaging, power electronics, design and material characterization for RF devices and additive packaging manufacturing.
Beyond state-of-the-art knowledge and technology also needs to be developed for assembly equipment for new package formats that support the energy transition. Examples are die attach equipment for Ag- and Cu-sintering and high-volume compound power modules with single or double exposed area's to increase power density.

3.2.1.3 Testing

The forefront development of Test Equipment is taking place in Japan and the USA. In the Netherlands there are a few companies contributing to this Test Equipment market, like:

- NTS Optel as SME in automated Optical Test Equipment in the application areas of Cell Phone, VR, AR and MR. Common products in these applications are DOE and MLA.
- BE Precision Technology that designs and manufactures probe-cards which are crucial parts of a wafer test set-up, and which are the mechanical interface between a test system and the bond-pads on the wafer under test;
- IMS BV that develops new metrology and test equipment for integrated photonic chips. The first machines are due to reach the market by 2024.

- Salland Engineering (Advantest) that designs and manufactures high performance or high channel density instruments for automatic test equipment (ATE), including automation software and data analysis, as well as custom test solutions throughout the production cycle of Silicon-Based Devices.[17]
- ITEC (Nexperia) develops automated test equipment solutions for discrete analog small signal and power semiconductors (wafer test and final test) and automated optical inspection (lead frame, post clip bond, 3D inspection).

On testing there is the drive from AI[18], with the need test solutions for AI accelerators and heterogeneous chiplet packages: AI chips present novel test challenges—verification of neural network operation across billions of parameters, testing of die-to-die interconnects at UCIe speeds (up to 64 GT/s), and characterization of in-memory computing elements. Dutch test equipment developers and test services providers have opportunities to develop specialized solutions for these emerging requirements, building on existing expertise in high-density IC testing and more-than-Moore device characterization.

Opportunities for new business development and related R&D in test equipment:

- Need for cost-effective test solutions production for 3D ICs using advanced packaging (e.g., using chiplets);
- Need for test solutions for special ICs, like IC-packages with integrated photonics or “lab-on-a-chip”.
- Need for better and faster analysis tooling to do faster product characterization.

Several private companies in the Netherlands develop knowledge and technology in the field of test equipment. In addition, beyond state-of-the-art knowledge and technology is being developed at universities, for instance at TU Delft on testability of emerging computing paradigms using novel devices, which may become important for novel Test Equipment[19]. Saxion, as a University of Applied Science, works with industry on optimalisation of new wafer-test processes and data handling for more-than-Moore devices such as MEMS and photonics. In addition, the PITC (Eindhoven and Enschede) and CITC (Nijmegen) are codeveloping new integrated photonic test knowledge and technologies in collaboration with several industrial partners, to bring these new techniques to market.

3.2.2 Electronics

Design is covered in the following technology domains

3.2.2.1 Analogue and RF / High Frequency and Mixed Signal Technologies

From the onset of the semiconductor industry, analog performance improvement has been at the top of the agenda. This is because overall electronic system performance depends crucially on the performance of the analog parts. Especially nowadays, given for example the increasing demands on bandwidth under severe power constraints, improving the analog (RF and mixed signal) performance remains a top priority. Where in the early days advances in performance were primarily connected to technology improvements (e.g. for low noise or high power), nowadays researchers also use a highly creative toolbox and increasingly complex architectures to achieve the requirements set for future systems. Fueled by digital technologies, electronic systems have become extremely complex, in which analog, RF and mixed signal functionality is the main differentiator. The Netherlands is world leading in this field. The presence of the complete chain, from research to end-user, in the form of academia, institutes, design houses, manufacturing SME’s and system integrators consistently leads to analog innovations with a worldwide impact. In the past Philips led the global TV market with their “one chip TV”. Bluetooth and Wifi are Dutch inventions and these chips were and still are being developed in the Netherlands, making them better, faster and cheaper. Today we find Dutch analog/RF innovations in almost every electronic product: noise cancelling amplifiers and filters in

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[17] Several Dutch companies offer test services to the Semiconductor Manufacturing Industry (like Maser Engineering) without manufacturing and sales of test equipment.

[18] *Semiconductor test equipment market analysis; AI chip requirements*

[19] https://www.tudelft.nl/ewi/over-de-faculteit/afdelingen/quantum-computer-engineering/computer-engineering/staff/said-hamdioui/

smartphones, extreme low power wireless chips for communications including IoT and 5G , (defense) radar systems, but also precision sensor and actuator (audio) interfaces, circuits for power conversion, RF power generation and drivers. This has led to strong ecosystems of analog design companies clustering in the Eindhoven, Twente and Delft regions. Moreover, the demand from industry for analog and RF talent from universities in still undiminished. Global players even move design centers to the Netherlands because of the high quality and talent present in our ecosystems. All large companies, design houses and SME's recognize that despite the big words about digitization in today's society, analog/RF design innovations are, and will remain, crucial. The Netherlands is and will remain the global hotspot in analog/RF design..

3.2.2.2 Sensors and actuators

Sensors and Micro-Electro-mechanical systems (MEMs) can be seen as the eyes, nose and ears of mobile systems, such as mobile phones, cars, and robots. Similarly, actuators, such as motors, loudspeakers and valves can be seen as their hands and feet. Together, sensors and actuators are used in a vast range of applications, ranging from motor vehicles, water quality, chemical detection, personal security, condition-based sensing to medical diagnosis. In the near future, sensors will be embedded everywhere, in our clothes or even on and in our bodies. Together with local artificial intelligence, they will make everything "smarter". Smart sensors will be interconnected via the internet (the Internet of Things), respond in real-time to dynamic and complex situations, while maintaining control, system safety and reliability. In turn, they will enable smart systems that are self-adaptive, robust, safe, and intuitive. The leading position of Dutch academia, institutions and industry in this field is based on an excellent educational system, the presence of several top experts, and a strong focus on applications. In the short term, sensors based on standard IC/MEMS technology such as temperature sensors, force sensors and Coriolis flow sensors will soon be on the market. Medium term topics are gas sensors (Micro-Gas Chromatographs for food monitoring or for health applications), various (3D) imaging technologies, and advanced patient monitoring systems. Micro-actuators are still relatively unexplored, and have a large long-term potential. Also on the horizon are radical new solutions, which will gradually make their way to the market. Some promising examples are lab-on-a-chip systems and nuclear magnetic resonance (NMR) systems for low-cost chemical analysis, THz imagers for non-destructive material analysis, implantable actuators and sensors, and the integration of photonic functions on CMOS. New material such as graphene and silicon carbide will open the way to sensors that can function in harsh environments, while sensors based on quantum principles, e.g. kinetic inductance detectors (KIDs) will achieve fundamental detection limits.

3.2.2.3 High Voltage and Energy

High power electronics is required for conversion of electrical energy for transport, storage or usage of electrical energy. With the strong trend towards a more electrical society, the need for high performance power electronic systems increases. Especially for industrial and energy applications this requires high reliability, long life time high efficiency and low cost of ownership. Latest wide bandgap devices (such as SiC and GaN) promise huge improvement on component level with respect to high working voltage and efficiency. But new packages, topologies and design rules are required to make full use of these promises. With lower switching losses the switching speeds can be significantly increased, which results in converters with smaller magnetics, higher power density and, in the end, lower cost. The high switching frequency can also help in those applications which require both high power and high accuracy, for example in positioning, imaging, or plasma processing. A big challenge with the increased switching frequencies is to comply with the latest EMI requirements, especially if power electronic converters are used close to residential users. For very high power applications (for example, energy storage or electrolysis), stacking of topologies is required both in voltage as in current levels to reach the demanded power levels. This ads more complexity in control, but also the possibility to make the system redundant for component failures. With the foreseen large penetration of electronic converters, the interaction between the converters can become critical. This requires new 'resilient' control and communication approaches, which are only possible with advanced digital control, including AI.

3.2.2.4 Large area and Flexible Electronics

Flexible electronics will lead to ultra-thin, flexible electronic products such as curved photodetectors, foldable displays and skin patches that measure vital signs. New printing technologies allow for a relatively easy realization of distributed electronic functionalities on large surfaces. There has been already for a number of years strong industrial interest to print arrays of sensors on such large surfaces. Examples are photodetectors for imaging and sensing applications, pressure sensors (shoe inlays, smart bedding) and also temperature sensors (thermal mapping). The capability of the printed sensors will be further increased in the coming years by materials and technology innovation, in a close interaction between academia, research institutes and industry.

The use of flexible substrates in combination with novel deposition technologies also enables new production methods of solid-state batteries that will play a critical role in the energy transition, for transport (electric vehicles) and energy storage (smart grid), as well as IoT and consumer and health applications.

3.2.2.5 Terahertz

Terahertz sensor technology has been identified as an important tool in the areas of safety, security, non-destructive inspection of materials, for instance in process control and medical diagnostics applications. The THz frequency band ranging from 100 GHz to 3000 GHz is also of high relevance for future 6G high-speed short-distance communication applications. Research and development in this area will lead to communications systems with much higher data rates, better radar and localization systems, high-resolution imaging and better ways of identifying dangerous substances and control production processes. 5G and future 6G high data rate communication systems and high frequency car-radar systems will grow continuously over the coming 10 years with large industrial players. Strategic new terahertz applications in sensing and imaging are currently in the developing phase often in niche markets, opening opportunities for SMEs. Some concrete examples, relevant for the Dutch industrial ecosystem, include measurements on plants in greenhouses to reduce the use of pesticides, high resolution terahertz microscopy for e.g. cancer margin detection and security control cameras at harbors, airports and sports stadia. Many challenges need to be overcome to build systems in this region of the spectrum. Specifically, signal generation, conditioning and detection in Silicon as well as III-V technologies or in hybrid electronic-photonic modules should be addressed to improve the performance in the lower THz range and enable systems in the frequency range above 1 THz. Next to this, for successful system integration, antenna/antenna array technology, novel beam steering systems as well as fast AD/DA converters and advanced signal analysis needs to be researched and developed for the different application areas. The research effort should be focused on two areas: 1. Affordable high performance systems for imaging, spectroscopy, localization and communication and 2. Study of new applications in the THz frequency range, including the required signal processing and the use of artificial intelligence techniques. On the medium to long term, the use of terahertz technology by non-specialists outside the laboratory walls can lead to a multiplier effect that can grow the market volume in the future.

3.2.2.6 From packaging to system integration

The integrated circuit is today synonymous with the concept of technological progress. Integrated circuit (IC) chips are now much faster and smaller and the packaging is more efficient, reliable, and cost effective. Historically, the leading industry trend was or still is in Moore's Law, elaborated in roadmaps such as the NTRS, ITRS and IDRS [20, 21]. However, as downscaling becomes more costly, fewer companies are capable to

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follow Moore's law[22, 23, 24]. Although novel 3D device architectures are proposed to keep Moore's law in its scaling path[25], packaging is increasingly recognized as a means of driving the performance growth of microelectronics. [26, 27, 28] and is further elaborated in the heterogeneous integration roadmap (HIR) [29,30]. As evolved from the NTRS and ITRS, the IDRS is focusing on front end semiconductor/computing domains, while the HIR has the focus on the integration of separately manufactured components from very different domains into a higher-level assembly (System in Package SiP) that provides enhanced functionality and improved operating characteristics [28]. An example of such an higher level assembly is given in note[31]. Multi domain/heterogeneous or 3D integration examples can be found in notes [32,33] (liquid cooling for computing and power respectively) and notes [34,35] (RF and 5G applications). Furthermore, integration of more components in a SiP enables health monitoring[36] for advance life cycle management. Aside from the integration to enhance the SiP functionality, the conventional method of building increasingly larger systems on chips (SOC) has become less and less appealing, both technically and financially. Hence, major semiconductor companies are designing products that break the larger designs into smaller pieces ("chiplets") and combine them [28, 37, 38]. This not only enables the integration of known good dies (KGD), but it also enables the re-use of IP blocks in other or future SiP products. Currently, chiplet technology is applied in the computing domain, however as this technology matures, applications in other HIR domains will follow, a trend that will put packaging in the center of system integration. Not only the requirements of enhanced functionality drives the packaging R&D, emerging wide bandgap semiconductors (WBS) with their higher operating temperatures, requires novel packaging materials and processes such as nano metallic die attach and sintering processes [39, 40, 41] and ceramic encapsulation[42]. Also trends such as a cost reduction requirement

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in ultra-small discrete device packaging or micro led displays requires solutions for high volume pick & place, die attach and encapsulation. In the broad field of micro technologies, packaging is the final manufacturing process transforming semiconductor or micro devices into functional products for the end user. Therefore, the packaging industry has developed specific encapsulations for a broad range of devices from different domains such as microelectromechanical systems (MEMS), bio-MEMS, and nanoelectronics, bioelectronics, RF and power electronics and organic light-emitting diodes (OLEDs), photovoltaics, and optoelectronics etc.. Obviously, in device packaging, the materials and processes are optimized to match with the device characteristics. However, as conventional packaging will evolve towards system integration enabling multi device package or system in package (SiP) processes and materials must meet more boundary conditions compared to packaging a single device. There is no single packaging technology that can serve this multi scale multi domain needs, hence it is clear that either monolithic homogeneous or heterogeneous integration at the die level or heterogeneous integration at the package level requires novel packaging solutions to optimize system performance and minimize cost.

Global trends in micro system technologies will put packaging in the center of system integration, not only for the high end SiP's, where packaging is the enabler for system integrations, also for applications such as discrete and power packages, where the right materials and processes enables the system to operate reliable at low cost. Furthermore, heterogeneous integration (HI) will broaden the spectrum of applications for which packaging solutions are required, hence the increasing volumes are spread over multiple applications with shorter time to market and closer to the regional markets.

3.2.2.7 Micro system platforms

Dutch companies have developed a strong presence in the fields of design, fabrication and applications of novel microsystems. The already available know-how in microelectronic IC technology enabled this development to cover areas such as photonic communication & sensing technologies and more currently bio- and nano-enabled devices like fluidics and biosensing. Companies such as Micronit, Neways, Xiver, Smart Photonics, Lionix, Bronkhorst, SmartTip, Mimetas, etc. lead the transformation of established microelectronic technologies into wide-use microsystem platforms where applications meet solutions through design, knowledge and adaptability. Fluidic devices with integrated electronic as well as biological functions, when miniaturized and applied on the large scale, are set to address the challenges of Health & Care via improved diagnostics in home situations and in infectious disease prevention. MEMS sensing & control devices with integrated electronic and fluidic aspects find their way to portable desalination machines and in other purification apparatus with large impact towards solving the challenges of Water, Food and Agriculture. Others use integration of sensitive IC electronics and chemical nano-coatings to sense ppm or even ppb concentrations of gaseous volatiles in air. Nevertheless, the inherent complexity of these combined-aspect devices requires knowledge of the various interactions across the functional domains: electric-chemical-optical-fluidic-biological. In order to address the modern societal challenges in the Energy, Healthcare, Food and Security areas, efforts will need to focus on several areas: a) knowledge, methods and tools in the areas of predicting device reliability, b) improving designability via smart EDA tools suited for multi-physics design flows, c) improving production & test technologies as well as d) continue transferring knowledge between the functional domains.

3.2.3 Overview of Knowledge and competence

In the tables below an overview is provided of the knowledge and competence in the Dutch Semiconductor Equipment and Electronics ecosystems.

In *Table 4 and Table 5* below an overview is given of parties and the knowledge & technology domains they are active in.

Name	AAE	ASM	ASML	ASMPT	Besi	Demcon	Eurofins	ITEC	itility	IMS	KMWE	Levitech	Motion Imager	MI-partners	Nearfield	Nedinsco	Neways	NTS Group	NXP	Prodrive Technologies	Reden	Salland	Saxion	SolMates	SoS	Technolution	TegralC	Tempress	ThermoFisher	Trymax	VDL-ETG	ARCNL	TNO	TUDelft	TU/e	UTwente	VSL
Optics			X	X		X							x		X	X		X		X									X		X	X	X	X	X	X	X
Photonics			X			X							x				x		x	X			X														X
Metrology			X	X		X		X	X	X			x	X	X		x	X		X		X	X			X			X		X	X	X	X	X	X	X
Thin films		X	X			X	X					X			X					X				X	X			X	X	X		X	X	X	X	X	X
Material Science		X	X	X			X					X	x		X					X				X				X	X	X	X	X	X	X	X	X	X
System engineering		X	X	X	X	X		X		X		X	x	X	X	X	x	X	x	X		X		X	X	X		X	X	X	X		X	X	X	X	X
Mechatronics		X	X	X	X	X		X		X	X	X		X	X	X		X		X			X	X	X			X	X	X	X		X	X	X	X	X
Etch & Deposition technology		X	X			X						X								X				X	X			X	X	X		X	X	X	X	X	
AI & Machine learning		X	X	X		X		X	X			X	x		X		x		x	X		X		X		X			X	X	X	X	X	X	X	X	X
Software & Control		X	X	X	X	X		X	X			X	x	X	X	X	x	X	x	X		X		X	X	X	X	X	X	X	X				X	X	X
Cleaning		X	X	X			X				X	X		X	X		x	X		X		X						X	X	X	X		X	X	X		X
Design Automation		X	X	X				X	X			X					x	X	x	X								X	X	X	X			X	X		
Design for Sustainability		X	X		X			X	X							X	x		x	X								X	X				X	X	X		
Production technology		X	X	X	X		X	X	X		X		x			X	x		x	X		X	X					X	X		X		X	X		X	
Model based System engineering			X	X		X		X	X			X							x	X	X								X		X		X		X	X	X

Table 4: Division of Knowledge & Technology domains across parties

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	Topic	AltumRF	ASMPT	Levitech	Motion Imager	Neways	NXP	Prodrive Technologies	TegralC	Thalis Nederland
RF technologies	Mixed signal technology	x			x		x	x	X	x
	RF power amplifiers	x	X				x	x	X	x
	Analog-to-digital conversion				x	x	x	x	X	x
	Digital-to-analog conversion				x	x	x	x	X	x
	Mixers	x					x	x	X	x
	Low noise amplifiers	x					x	x	X	x
	Filters						x	x	X	x
	mm wave amplifiers	x					x		X	
	THz devices						x			
High power	DC power electronics		X			x	x	x		
	High voltage devices						x	x		
	Power conversion		X			x	x	x		x
Photonics	Photonic circuits				x		x	x	X	
	Photonic circuit packaging		X		x	x	x			
Electronics for harsh conditions	Rad hard devices								X	
	High temperature devices								X	
Modelling	Signal integrity					x	x	x		x
	Thermal modelling		X	x		x	x	x		x
	EM modelling	x				x	x	x	X	x
	Device modelling	x				x	x	x		
Device technology	III-V technologies	x		x	x		x	x	X	
	Si/SiGe technologies	x	X	x	x		x		X	
	SiC Technology		X			x	x			
Packaging	Overmoulded packaging	x				x	x			x
	Advanced packaging technologies	x	X			x	x	x		x
	Heterogeneous integration	x	X		x		x	x		x
	Interconnection technologies		X			x	x	x		x
	Integrated cooling technologies		X		x		x	x		x
System level	System engineering		X		x	x	x	x		x
	Sensors (e.g., acceleration, temp)		X		x	x	x	x		
	Edge processing		X	x	x	x		x		
Design	Analogue						x			
	Logic						x			
	FPGA/ASIC						x			

Table 5: : Division of Knowledge & Technology domains across parties for the Electronics topics. At publication available information has been taken along. Paties who would like to be mentioned, please, provide the detail information to frans.list@asml.com

4. Subjects and Themes

Based on the above mentioned trends, the following subject and themes have been identified for pursuit in collaborative activities.

4.1 Subjects

4.1.1 Wafer processing

- Lithography systems for advanced Systems-in-Chip. in particular (D) UV (Deep Ultra Violet) and EUV (Extreme Ultra Violet) technology, with associated light sources, optics, sensors, electro-mechanics, vacuum technology (for EUV), temperature stabilization, embedded software, multi e-beam inspection technology and advanced computational lithography software.
- Equipment for manufacturing new materials for nano-structuring technologies, such as for substrate, resist, chemical gases, shielding membranes.
- Equipment for manufacturing thin films, via deposition, epitaxy, diffusion, temperature treatments, etching with the associated factory infrastructure.
- Equipment for wafer processing (cutting, etching, polishing, cleaning, epitaxial deposition, thinning and making alignment marks with a laser.
- Equipment for Minimalfab for "More-than-Moore" ICs using 12.5 mm wafers in sealed cassettes without the need for a clean room.[43]
- Equipment for manufacturing of existing and new technologies for diversified ICs, such as ICs with integrated photonics[44], and "lab-on-a-chip" typically using special microelectromechanical systems (MEMS) devices.[45] [46]
- Equipment for analysis, characterization, dimensional metrology and inspection, including sample preparation, at micro scale to sub-atomic scales with scanning probe, electron beam, X-ray, EUV and acoustic methods for determining geometric, thermal, electrical and chemical properties (multidimensional and multidomain).
- Multidimensional analysis and metrology equipment suitable for 3D extensions of devices.
- Photonic Integrated Circuits metrology equipment.
- Sustainable equipment design

4.1.2 Assembly & Packaging

- Equipment for heterogeneous integration enabling System-in-Package.
- Equipment for wafer level packaging of Exposed die Molded UnderFill (MUF).
- Equipment to manufacture three dimensional functional packages in which the package geometry has additional functions/requirements, next to protecting the electronic device.
- Equipment for assembly of integrated photonics and of other emerging new technologies, like arrays of capacitive micromachined ultrasonic transducers.
- Equipment to increase the reliability of processed devices by inspection, sorting and providing detailed process data on the device level (track & trace), as well as machine level (big data).
- Equipment for biomedical production, upscaling device manufacturing.
- Equipment to manufacture future LED-displays, which require ultrafast, accurate and low-cost pick & place solutions. According to market trend forecasts, this spillover market for pick & place equipment will outgrow the semiconductor assembly market by an order of magnitude.

[43] https://bits-chips.nl/artikel/dutch-semicon-ecosystem-is-introduced-to-minimal-fab/
[44] https://www.tue.nl/en/research/research-areas/integrated-photonics/
[45] https://www.utwente.nl/en/education/master/programmes/electrical-engineering/specialisation/lab-on-a-chip-systems/
[46] https://en.wikipedia.org/wiki/Lab-on-a-chip

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4.1.3 Testing

- Equipment for testing (on wafer- or module level) emerging and more-than-Moore devices such as photonics, MEMS, LoC and quantum in the future
- Equipment for System level test while testing at wafer or package testing is not sufficient anymore to guarantee the end product quality.
- Equipment and tooling to do faster and easier in Silicon production ramp-up, and which is closer related to high volume test equipment to avoid long correlation exercises.
- Automatic test equipment with smart functions that interpret and provide data across the production cycle, from EDA to final packaging.

4.1.4 Complex system design

- Complex system, be it a highly integrated chip or a complete lithography machine or complex sensor requires engineering solutions that can handle the high level of interaction between the various disciplines that are involved. This requires both a comprehensive system engineering approach, but also accelerated use of advanced design methods, making use of, for example, AI.

4.3 Themes

4.3.1 Semiconductor Manufacturing Equipment

Theme 1: Talent

Availability of talent has been raised as a major issue by the parties involved in this roadmap.

According to the ECSA Skills Strategy 2025 (published November 19, 2025)[47], Europe faces a structural talent crisis: nearly 30% of the current semiconductor workforce will retire by 2030, while graduate inflow in relevant fields grows by less than 1% annually. This will result in an annual shortfall of approximately 10,800 skilled workers across the value chain. Beyond traditional manufacturing roles, the industry increasingly requires specialists in system architecture, AI-enabled hardware development, verification, and cybersecurity—skills central to emerging chip design houses.

In regard to talent further follow-up is covered through the Beethoven[48] project.

Theme 2: Complexity

As transistors are getting smaller and smaller, the equipment needed for production is getting bigger and more complex. This represents a huge challenge for both equipment manufacturers and the supply chain to manage. Individually, for OEMs, this means identifying use cases/modules within their equipment that, together with the supply chain, can be simplified or automated. At a collective level, companies need to delve into design methodologies, such as Model-Based Systems Engineering and developing/purchasing EDA-like tools for equipment to simplify tools and processes. Associated themes arrived at are: *Connecting tools together, Digital Twin, Automation of design flow and Life Cycle Management (Legacy), see the ChipNL [49]proposal section 3.3 for further detail.*

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[47] *ECSA Skills Strategy Report 2025, SEMI Europe, Nov 2025*

[48] Project Beethoven 2024: strengthening the microchip industry and quality of life

[49] ChipNL_Innovatieprogramma_DEF_01_2025.pdf

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Partners: ASM, ASML, Besi, Demcon, ITEC, Neways, Nearfield, Prodrive Technologies, Thermo Fisher Scientific, TNO, TUe, VDL-ETG, Itility

Theme 3: Contamination

This theme Is about controlling contamination during chip production which is an important competence. In front-end equipment, contaminants can reduce the yield of production processes and it is therefore essential to control them for system productivity. In addition, contamination can shorten the lifetime of equipment systems. Because of its relevance to (especially EUV) lithography and other FEOL equipment, the Netherlands has built up a unique knowledge position.

With increasing technological complexity and smaller sizes of mid- and back-end equipment, contamination control is becoming increasingly important for companies focusing on such processes. Back-end equipment is also moving to cleanroom environments, bringing new and stringent requirements. The ecosystem's excellent knowledge position will be leveraged to develop specific knowledge for back-end production. New demands also arise for the front-end. Further expansion of our knowledge position is needed here. Associated themes arrived at are: Cleanliness standards harmonization and Understanding particle and molecular contamination physics and chemistry, *see the ChipNL [49]proposal section 3.3 for further detail*.
Partners: ASM, ASML, Besi, Demcon, ITEC, Nearfield, Neways, Prodrive Technologies,, Thermo Fisher Scientific, TNO, VDL-ETG, Meilink, FastMicro, D&M Vacuum Systems and Microcentrum

Theme 4: Sustainability

Driven by availability issues and sustainability goals, reuse of critical (raw) materials is gaining more and more traction. This is also true for the semiconductor industry, but the transition to circular practices requires time and effort. Because of the extremely high cost of (unpredictable) downtime, reliability of circular systems is of the utmost importance. Hence, methodologies for circular solutions will only be accepted by the industry if they can be tested and qualified reliably. The creation of these new methodologies requires research, and solutions will have to meet the high-quality standards of the industry.

In this theme, partners collaborate on development of shared methodologies for re-use of components and materials in semiconductor manufacturing equipment, in a way that the industry is still able to meet the high-quality standards. Associated themes that have been arrived at are: *Design and implementation of a circular supply chain, Data management system for circularity, Circular business models and Design for sustainability, see the ChipNL proposal section 3.3 for further detail.*

Partners: ASM, ASML, Besi, Demcon, ITEC, Nearfield, Thermo Fisher Scientific, TNO, VDL-RTG, KMWE, Prodrive Technologies, Neways, Meilink, BoM, ImpactX, Fontys, TUe

Theme 5: Equipment for heterogeneous integration and advanced packaging

Heterogeneous integration is an important development to increase the capabilities of semiconductors and chip systems. Integrating more functionality in a smaller space requires a Lego-like approach to integrate separately fabricated components (dies) into a higher-level assembly (System-in-Package, multi-chip modules, and so on) New assembly equipment is needed, providing processes for these increasingly complex and changing build and integration approaches. The demand for these process capabilities will increase in the future and go far beyond current capabilities. This demand requires a fundamental leap forward. This leap poses

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a challenge for equipment development, as conceptual changes pose risks and the processes are not yet fully understood.

The aim of this theme is to make the aforementioned leap in process and machine development through process and machine technology research for future heterogeneous integration processes. In addition, seizing and strengthening the future position of Dutch OEMs in equipment for heterogeneous integration. Associated themes that have been arrived at are:

- *Process identification and development*

New levels of complexity arise in the production of heterogeneously integrated devices: co-design of enclosures, interfaces between dies, thermal management, testing, reliability and failure analysis. This expands the process capabilities far beyond those currently available. This task links OEMs to RTOs to identify new and foreseeable process needs and develop these processes.

Activities include identifying - for specific use cases - process challenges and needs, and exploring approaches and methods to achieve significant improvements: > 10x.

- *Equipment creation*

To enable a technological leap forward and develop new identified processes, concepts need to be translated into equipment. This poses a challenge for equipment development, as conceptual changes carry risks and processes are not yet understood. Therefore, test equipment is needed, as well as analytical equipment for future generation chips and advanced packaging, among others. For this, OEMs will use their expertise to make equipment. This can take the form of test rigs, (cyber)physical or digital design models or adaptation of existing equipment.

- *Process and equipment Integration*

The goal here is to integrate the developed process into prototype equipment. Bridging the gap from conceptual and provisionally tested concepts to real prototype machines is a path with many challenges. Combining efforts and learning from previous tasks, OEMs focus on prototyping equipment in this task.

Partners: Nexperia, Besi, Ampleon, Neways, Thales, Signify, ITEC, DoMicro, FononTech, Keiron, TNO, Tempress (wafer to wafer) , CITC, TU Delft, TUe, UTwente, Fontys, Saxion, Han.

4.3.2 Electronics

The ambitions on Electronics have been captured in five themes that cover both the industrial research ambitions in this roadmap as well as the directions in which the academic education and research will develop. The themes are driven by the many needs of the applications that depend on the developments in Electronics. These requirements and applications have been described in the previous chapters. The topics that are executed within the program on Electronics can be grouped in the following five themes.

Theme 1: Telecommunications and radar

Communication systems connect the world. This application field will remain for decades one of the dominant system drivers for electronic components and circuits. Ranging from relatively low-performance but ultra-low energy sensor communication to high-performance radar systems, many

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novel applications and implementations are expected. With cheaper components in smart packages, Ultra Low Power Networks (LAN, PAN, BAN, zero net power) equipped with sensors will enable the monitoring of parameters, going from body centric to large and complex infrastructures "Internet of Things". An optimum integration in the network is required. The ultimate goal is to strive for net-zero power devices, where nodes in a network harvest their energy from the environment. Electronics for IoT is described in detail in Theme 3. A system-level power optimization approach by applying the broader concept of RF/analog/digital co-design will enable a mixed-signal design and/or heterogeneous design containing More-than-Moore components. Co-operative networks and cognitive radios use the available bandwidth and are carrier-frequency adaptive. Especially in the lower frequency bands (< 5 GHz) traffic congestion can be avoided. On electronics level this requires broadband radio circuits. The traditional radio paradigm, from antenna, architecture and circuit design must be reinvented. The push towards higher bandwidths, accuracies and higher energy efficiencies in RF circuits, conversion topologies, drivers, power-amplifiers etc. is essential to enable this development.
The need for more bandwidth on one hand and the issues related to efficient spectrum management on the other hand will require very demanding specifications on analogue and mixed-signal circuits with respect to pulse shaping/modulation, robustness, resilience, re-configurability, frequency selectivity and linearity. Technology breakthroughs in these areas are necessary. Future 5G systems will open a mass market for millimeter-wave circuits and advanced beamforming architectures. More and more high-frequency electronics are needed for the ever-increasing data throughput on a ubiquitous wireless infrastructure. 60GHz wireless systems have been developed, car radar electronics will be centered around 77 GHz, and Terahertz frequencies will be introduced. The THz frequency band has unique properties as spectroscopy of materials, imaging capabilities and an extremely high bandwidth for future communication systems. These unprecedented high frequency and high bandwidth systems are an enormous challenge for electronics and require new insights in working principles of new electronic devices working far beyond today's frequency limits. Applications range from astrophysical research to security. Sensors developed in the THz domain for professional applications (e.g. space) will penetrate in other application areas (security, health). Active digitized arrays will steadily replace single receivers and transmitters. Individual users will receive their information through tailored, user-centered beams. Depending on the optimal partitioning of the system digitization will be performed on either the element level or on array level.

Partners: Ampleon, Ansem, Antenna Company, ASTRON, Boschman, Bruco, CTIT, CWTe, Dialog, DIMES, Holst Centre (TNO & IMEC), ItoM, Keysight, MESA+, NXP, Salland Engineering, Neways, Qorvo, Qualcomm, SRON, Teledyne DALSA, Thales Nederland, TNO, 4TU

Theme 2: Smart circuitry for Internet of Things, home- , building- and industrial automation

The last decade has seen great advances in the realization of the Internet of Things (IoT). Not only through the introduction of new enabling technologies such as Narrowband-IoT and 5G connectivity, but also with the penetration of a wide range of applications in multiple domains. This has a considerable impact on the way we live and work. Combining a combination of several functions is essential to come to self-managed, cost-effective and durable solutions:

- Sensors are the essential eyes and ears of the Internet of Things. From basic physical parameters (acceleration, temperature, pressure, ...) via monitoring activity (presence, motion, ...) and vital signs (ECG, breathing rate, ...) to awareness of our surroundings (air quality, light conditions, proximity, ...). Specific solutions often require today a More-than-

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Moore implementation, but a relentless drive will continue to push sensor systems to CMOS implementation for cost reasons and mass adoption.

- Low power radios of multiple standards are employed in parallel or combined, and new standards will emerge over time to facilitate solutions that build on information from multiple domains.
- The implementation of smart algorithms enhances sensor readings. Combining data from multiple sensor modalities with advanced algorithmic approaches will allow for feature extraction in the sensor unit itself. Artificial Intelligence is rapidly becoming a key ingredient, not only in the cloud, but also in distributed (extreme) edge nodes with severe power and size constraints.
- A connected world with distributed data analysis needs a high level of security that is built into the solutions from the very beginning. Security and user authentication are essential ingredients to create trust in safety critical applications.

Today, these developments provide the means to make the next step in automation of homes, buildings, and industrial sites. Multimodal interconnected sensor nodes embedded in our environment facilitate the transition to surroundings that predict what is needed instead of react to what has already happened. This step from 'one size fits all' to truly personalized solutions will open a realm of new possibilities that build on the Internet of Things.

Partners: Ansem, Bruco, Dialog, Eindhoven Energy Institute, Holst Centre (TNO & IMEC), Keysight, NXP, Technolution, Neways, Systematic, Teledyne DALSA, TNO, 4TU, CTIT, CWTe

Theme 3: Heterogeneous integration and packaging

Heterogeneous Integration refers to the assembly and packaging of multiple separately manufactured components onto a single chip in order to improve functionality and enhance operating characteristics.
Since the start, integration of more than one transistor we followed Moore's law to decrease the technology and on the other hand to increase functionality per area. *Figure 6* shows the functional density over the years and *Figure 7* shows the performance increase over the years. The growth rate of the functional density as well as the performance per area is slowing done even more efforts has been spent. The only way to get a suitable growth rate is to use the right chip technology (Si, GaN, SiC, GaAs) for the right functionality and to integrate these different technologies into one package. This means a totally different thinking of circuit design as the package and assembly technology need to be considered from the start of the development.

Application driven
The upcoming markets like IoT or 5G require high bandwidth networks to cope with all the generated data. Artificial Intelligence (AI), crypto currencies and data security require huge calculation power. So high bandwidth and high computing power are the main driving factors for a higher integration level.

Challenges
The main challenge is on the one hand the energy required to run the application driven demands and on the other hand to get rid of the generated heat by the applications. The higher the computing power or the frequency of high bandwidth connections the shorter the interconnects between different electronics devices should be, as longer lines/interconnects mean transmission loss or unexpected radiated transmissions or cross-talk which all degrade the entire system

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performance. Higher bandwidth or more computing power requires also increasing amounts of interconnections like e.g. 2.500 connects within an area of 5x5 mm.

A lot of these challenges can be addressed by heterogenous integration and packaging.
Partners: Holst Centre (TNO & IMEC), NXP, CITC and Neways

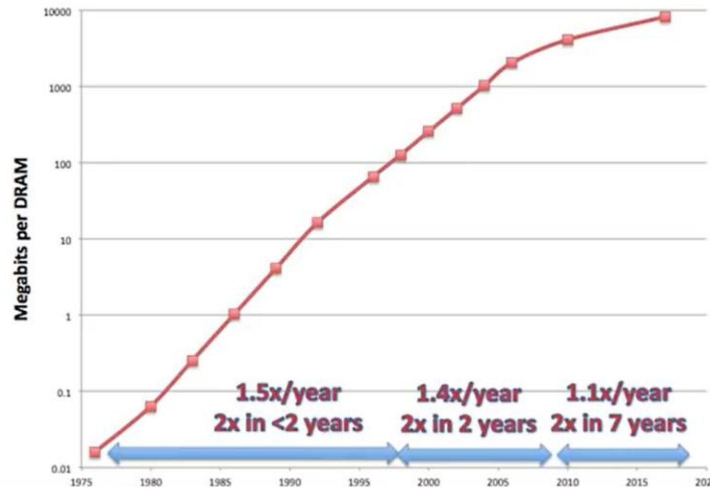

Figure 6: Increase of functional density over time, John Hennessy at DARPA ERI Conference July 2018.[50]

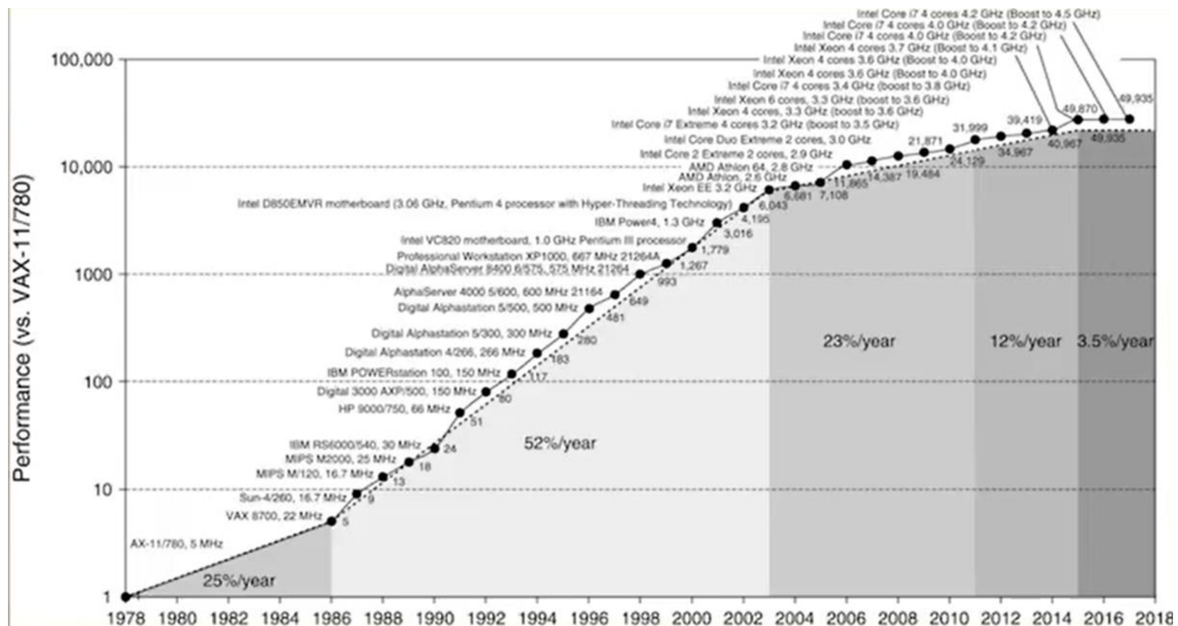

Figure 7: Performance increase over time, John Hennessy at DARPA ERI Conference July 2018[49].

Heterogeneous integration will be essential for future of integrated circuits. It will deliver development and production cost savings and faster time to market by enabling re-use of existing IPs and architectures.

Design flow to properly and efficiently include all relevant aspects (partitioning, layout, signal and power integrity, EMC, interference, thermal, etc.) to support design of heterogeneously integrated

[50] DARPA ERI Summit 2018: The End of Moore's Law & Faster General Purpose Computing, & a New Golden Age - YouTube

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mixed-signal products is currently not available and needs to be developed and validated. This will be done in close cooperation with EDA vendors, IC design teams and packaging team.

Theme 4: Electronics for scientific instrumentation and harsh conditions

Advanced components and circuits with extreme performance levels allow building instruments that enable breakthroughs in many scientific areas. The Netherlands has a strong position in several of these domains (material analysis, medical, robotics, microscopy, lithography, photonics, and detectors for particle physics and space exploration). This field produces vehicles to explore extreme operating conditions and is of significant value for industrial and scientific instruments. The instrumentation and space challenges lie in the field of very low power and low noise circuitry, increased intelligence per pixel (per square micron), radiation hard electronics, and high speed (wireless) data transceivers. Another challenge is the low-cost and efficient integration of electronic circuitry with photonics for various applications, from new sensors with interferometric readout to very high-speed data communication links. Further research is required on 3D integration & packaging, temperature stability, and cooling for optimal integration of components in a final instrument.

For automotive (under the hood) and industrial applications, high temperature reliable operation is an important area of study. The harsh environment where these circuits operate requires improved reliability, packaging, and increased lifetime.

Partners: Adimec. ASTRON, Bright Photonics Bruco, Nikhef, NXP, Panalytical, Neways, SMART Photonics, SRON, Systematic, Technolution, Teledyne DALSA

Theme 5: Power electronics

Significant advances in the electrification of mobility and industry is needed to reach the goals of the energy transition. Power electronics will play an important role in the transformation of energy, with high efficiency in the right shape for usage, storage or transport. Generated (renewable) energy has to be connected to the grid or converted in and industrial process to gas or liquid for storage. Energy will be transported as electricity were smart grid technology will help to steer and stabilize the power flow. Industrial users will have to convert the electrical energy to the right shape that fit with their industrial processes or transportation. Power electronics can only become successful if it matches the high expectations of the industry. Conversion should be done with high efficiency and affordable cost. Reliability and lifetime should be high, under severe load cycles and harsh environments. The inherent controllability of power electronic converters will help to increase the acceptation and implementation. But new solutions are required to guarantee stability and safe usage of large scale distributed control. Security of digital electronic systems which will run for decades will also here become a relevant topic.

New wide bandgap components have the promise to increase efficiency and reduce the overall cost. The accompanying new semiconductor materials, system architectures and use-case scenarios can potentially introduce new and unknown failure modes and safety risks. The high switching frequency will help to increase the power density, but special precautions may be require to comply with EMC regulation. New design methodologies are required to make use of the these possibilities in electronic circuits and systems. High power applications will required scalable concepts with advanced control, redundant operation or health monitoring.

Partners: AME, Boschman, Differ, Heliox, Nexperia, NXP, PRE, Prodrive Technologies, Neways, TUe, TUdelft, UT

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4.3.3 Main Semiconductor Manufacturing Equipment Milestones in 2030

- Milestones to follow imec roadmap for semiconductor technology
- ASML (2030): Holistic and High NA Lithography enabling IC nodes at 14 Angstrom and beyond with advanced patterning solutions, competitive wafer throughput, overlay performance, uptime and cost.
- ASM (2030): The world's lead player supplier for ALD and Epitaxy Equipment with leading technology to create ultra-thin films of exceptional material quality, uniformity and conformality for small geometries (to below 2nm IC node) for more complex device structures like Gate-All-Around transistors and advanced DRAM. This includes driving the adoption of ALD with the application of Selective ALD, the introduction of new materials like molybdenum as a replacement of CVD Tungsten/PVD Copper, and improving plasma sources for VHAR gap-fill. Epi gains market share in the transition to GAA and 3D DRAM, whereas the SiC Epitaxy adoption results in market leadership. The newly developed SONORA furnace continues the good momentum, and selective inroads are made with technically differentiated nice offerings. Finally, new opportunities in advanced packaging and heterogenous integration in areas of ASM core strengths are pursued. This all while achieving our NetZero ambition on all scopes.[51]
- Besi (2030): Assembly equipment for advanced heterogeneous integration of systems in three dimensional functional packages and seamless integration of the assembly equipment in the automated factory.
- Thermo Fisher Scientific (2030): higher throughput near-line/industrialized TEM workflow solutions for atomic resolution structural and chemical analysis, metrology and failure analysis for materials a structures, including 3D, used in sub nanometer IC-node CMOS logic, leading edge memory, and More than Moore devices.
- Nearfield Instruments (2030): high-throughput, non-destructive, in-line probe-based metrology & inspection solutions for 2 nm and beyond process control for the entire semiconductor value chain (advanced wafer processing, specialty nodes and advanced packaging).
- Salland Engineering: development of test IP building blocks to address future test challenges and applicable in high volume, validation equipment and System Level test.
- Smaller Dutch Semiconductor Manufacturing Equipment Companies, Contract Development Companies and Contract Manufacturing Companies work towards increased market shares.
- Some of several new (metrology) machine concepts and technologies by TNO, VSL, universities, and PPP consortia have been introduced in the market by Dutch companies.

4.3.4 Collaboration in, and leverage with, European and multi-national policies and programs

The R&D done in the context of this roadmap:

- Leverages the EU Chips-act and associated initiatives for pilot line and competence center development
- Leverages the PPP-Clusters: Chips JU, Xecs, ITEA4, EUREKA, Dutch Programs for PPS/TKI and TTW (Applied Technical Research) for HTSM, in which there is cooperation with Dutch companies, RTOs and universities in National and Horizon Europe collaboration projects;
- Leverages the Strategic Research and Innovation Agenda for electronic component and systems with a full chapter devoted to Semiconductor Manufacturing Equipment;[52]
- Will be done in collaboration with Dutch companies, RTOs and universities in the context of the new Horizon Europe Program.

[51] ASML Investor Day 2023
[52] About | ECS SRIA

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Moreover, the September 2025 Semicon Coalition declaration[53]—signed by Austria, Belgium, Finland, France, Germany, Italy, Poland, Spain, and the Netherlands—calls for a revised EU Chips Act emphasizing ecosystem development, coordinated public/private funding including IPCEIs, and expanded workforce development. The Commission's 2026 Work Programme confirms a legislative proposal for Chips Act 2.0 in Q1 2026. This roadmap aligns with the Coalition's emphasis on supporting the entire semiconductor value chain, including fabless design houses, SMEs, and startups as critical innovation drivers.

5. Partners and processes

5.1 About this roadmap

This initial version of the roadmap is based on the Electronics, the Semiconductor Manufacturing Equipment roadmaps and the ChipNL program proposal. Both roadmaps and program proposal represent an active network of academia, institutes and industry and were created in an environment where partners met in dedicated workshops, sharing the latest insights identifying themes for developing programs and project proposals.

It is intended that this joint roadmap serves the purpose of providing input from Industry in the discussion between Industry, Public Authority and Knowledge domains, the "Triple Helix".

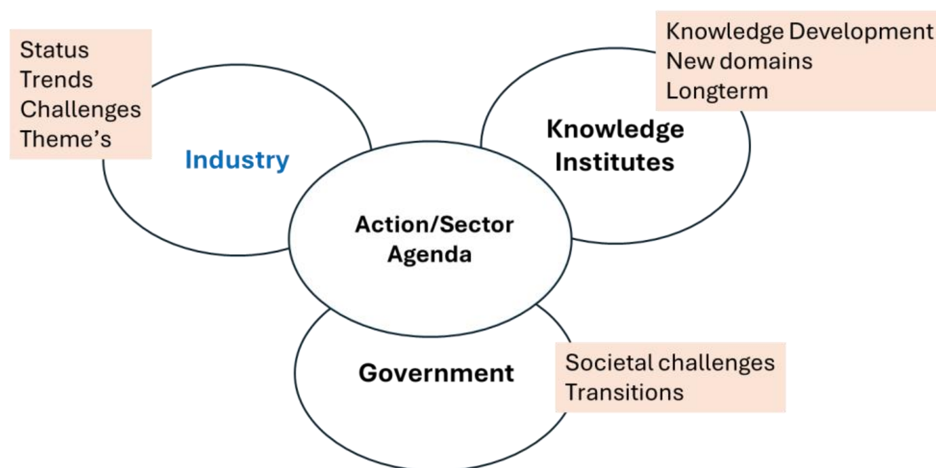

Figure 8: Triple Helix, Industry, Knowledge Institutes and Government driving into Action/Sector Agenda development.

The aim is to review and make regular updates of this document as needed on the basis of dynamicsin Industry, Knowledge domain and societal challenges over time. To this purpose it is envisaged to have twice a year roadmap events.

In regard to partners there have been:

[53] *Semicon Coalition Declaration, Sep 29, 2025; EC Work Programme 2026*

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- Industry: Ademic, AME, Ansem, ASM, ASML, ASMPT, ASTRON, Besi, Boschman, Bright Photonics, Bronkhorst High-Tech, Bruco, Demcon, Dialog, Domicro, Eurofins, Frencken, Heinmade, Heliox, IBS Precision Engineering, ITEC, Itility, KMWE, Kulicke & Soffa Liteq, Malvern Panalytical, MI-Partners, Nearfield Instruments, Nedinsco, Nexperia, Nikhef, NXP, PRE, Omron, Panalytical, Prodrive Technologies, Reden, Neways, SMART Photonics, SIOUX, Solmates (LAM), Solutions on Silicon, Technolution, SRON, Systematic, Etteplan, Thales Nederland, Tempress, Levitech BV, Teledyne DALSA, Thermo Fisher Scientific, Trymax, VDL-ETG, Salland Engineering and NTS group and XIVER
- Science and RTOs: ARCNL, TNO (in particular in Delft and Eindhoven), Holst Centre (TNO & IMEC), VSL, TUD, TU/e, UT, DIFFER, CITC, RUG, KU Leuven, RWTH Aachen, Saxion, Eindhoven Energy Institute.

5.2 National Technology Strategy

The National Technology Strategy aims to strengthen technological leadership of the Netherlands by prioritizing key enabling technologies that are local core competences in science and industry. Of the "short list of technologies", a direct link to the semiconductor equipment roadmap can be identified for "Mechatronics and Opto-mechatronics", "Micro-electronics", "Imaging Technologies", "Artificial intelligence and data science", "Optical systems and Integrated photonics" and "Quantum technologies". This is either based on impact of this roadmap on innovation and progress in these technology areas, or the dependence of this roadmap on these technology areas and thereby them being an opportunity for technology deployment in products realizing economic impact. These technologies enable the rapid innovation pace of the Dutch Semiconductor Equipment ecosystem. Moreover, the Semiconductor Equipment ecosystem has been, and will be, one of the most important drivers for technological leadership in these technologies.

In regard to the other technologies on the short list; "Biomolecular and cell technologies", "(Bio) Process technology, including process intensification" and "Energy materials", there is a connection with Electronic Components and Systems being the common denominator enabling their innovation. Moreover, in these cases, there is a direct connection in electron microscopy, via two-way innovation flow with e.g. life sciences and materials areas.

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However, for the Semiconductor manufacturing Equipment roadmap there are more critical technologies that should not be ignored. As is illustrated in *Table 4*, besides the 6 mentioned above there are another 11 enabling technologies, of which Material Science (or Advanced Materials) and System Engineering are most prominent. With Advanced Material not only being relevant in Semiconductor manufacturing equipment but also forms the basis to solutions in the other technology domains key to the 3 transitions, like in carbon capture (ALD-driven), perovskite solar materials, solid state batteries and electrification of industry & mobility.

5.3 Implementation of this roadmap in public-private partnerships and ecosystems

Besides private investments into this roadmap, implementation through Public Private Partnership (PPP) projects will be an essential factor. A PPP typically consists of Large Enterprises, Small & Medium Enterprises (SMEs), Research Institutes and Universities. SMEs are involved both as suppliers to the Large Enterprises and as suppliers in the Equipment Markets.
It is recognized that frameworks should facilitate SME participation through proportionate administrative requirements. Innovative SMEs often possess differentiated IP that larger players seek to integrate into platform solutions.

- Main Questions (but not limited to):

1. How to benefit from Public-Private Partnerships (with RVO co-funding[54]) and support of Applied Technology Projects at universities/RTOs (with NWO funding[55]) to keep on pushing the limits of key enabling technologies, resulting in semiconductor manufacturing equipment with a good business case for manufacturers of electronic component and systems, in order to respond to the large market pull for innovation?
2. How to ensure that promising ideas, that benefit from public R&D in the Netherlands, are *not* routinely manufactured in the Far East (at lower cost due to state-aid and/or lower taxes), by simple by-passing the Make Industry in the Netherlands and the EU[56]?
3. How to boost involvement of SMEs/start-ups in PPS/TKI-allowance projects in the Netherlands:
    - Make it less expensive to outsource R&D to universities/RTOs?
    - Somewhat less academic research with long-term objective/deliverables, and more industrial research with long-term objectives but *also* with short-term deliverables?
    - RVO/NWO to address the disproportionally large legal overhead to get PPP projects started, e.g. by introduction of standardized templates for IP agreements?
4. How to approach the need for an Industrial policy, for choices, partnerships, strategic alliances?
5. How to avoid fragmentation of measures of support and funding instruments?
6. How to ensure that roadmap implementation satisfies long term societal needs and adheres to industry strategy?
7. How to cope with the impact of geographical shifts in the industry – “Re-shoring”?
8. Optimize contributions by RTO, talent development and partner innovation
9. Building and stimulating ECO systems and communication between eco-systems
10. How to organize the innovation ecosystem to smoothly transition from low to high TRL?
11. How to enhance knowledge sharing and labor productivity through standards and common design methods and tools?
12. How to reduce the environmental impact of the industry (without hampering progress)?
13. How to bridge the period between R&D and ramping real business. There are a lot of R&D programs but not much after this period where scaling of business and pre-investments are made?

[54] https://www.rvo.nl/subsidie-en-financieringswijzer/pps-toeslag-onderzoek-en-innovatie
[55] https://www.nwo.nl/onderzoek-en-resultaten/programmas/htsm
[56] https://www.vdlgroep.com/nl/nieuws/opinieverhaal-chinese-bussen-kosten-banen-in-nederland

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14. How can we secure to be not only an ''Engineering country'' but as well being involved in equipment manufacturing and keep as well semiconductor related production, like Assembly and testing in the Netherlands/Europe to create a more autonomous supply chain?
15. How to cover the part from TRL9 to actual product manufacture?

- What the Dutch government can do to support the semiconductor manufacturing equipment and electronics industries:

The Dutch government could help the semiconductor manufacturing equipment and electronics industries to grow and prosper by guaranteeing certain conditions are met. This concerns certain policy areas:

- Talent and education:
  - The Dutch government should invest in the availability and quality of STEM educated talent. This applies to all levels (primary, secondary, vocational, and higher education) and STEM studies. STEM education should be a part of the curriculum from an earlier age.
  - There should be no limits on the number of students in STEM studies (no numerus fixus).
  - The Dutch government should invest in being an attractive place for talent to come to the Netherlands (e.g., keeping the 30% ruling).
  - The Dutch government should facilitate and invest more in collaboration within the European Union between RTO's, universities, and companies.
- Infrastructure, mobility, housing and grid congestion:
  - The semiconductor manufacturing equipment and electronics industries will grow in the coming decade. This growth should be enabled and facilitated by the Dutch government.
  - The Dutch government should invest in infrastructure and mobility to enable the development of the industry, not only for the industry, but also for the people that work in it.
  - The Dutch government should invest in more affordable housing by building more houses. Talent will not come and stay in the Netherlands without proper housing.
  - Companies are not able to grow if grid congestion is not properly addressed. The Dutch government should prioritize helping companies in the semiconductor manufacturing equipment and electronics industries.
- Innovation and industrial policy:
  - The Dutch government should identify current and potential strengths within the semiconductor manufacturing equipment and electronics industries and invest.
  - SME and start-ups should be supported by reducing wage taxes to enable lower wage costs.
  - Start-ups and scale-ups should be supported by creating an investment climate for growth (also in view of retaining earlier investments).
  - In regard to financing for companies, "red tape" should be reduced.
  - The Dutch government should create centers of excellence for semiconductor equipment and electronics focusing on certain areas (such as optics).
- The Dutch government should continue actively promoting the diversity and excellence of semiconductor equipment manufacturing and electronics activities in the Netherlands, also abroad during economic missions.
- Tendering & payment conditions more favorable towards SME's. Payment structures should avoid SME's having to prefinance equipment in European Universities & institutions
- Promote dutch / EU equipment suppliers in tendering procedures for Dutch / EU projects

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6 Investments

In regard to Semiconductor Manufacturing equipment, the graphs in *Figure 9* illustrate the investments and benefits in the sector in terms of; yearly R&D investment, Revenues, patent applications and jobs in the Netherlands. The numbers are based on input from ASM, ASML, Besi, Nearfield, Prodrive Technologies and TNO over the past 10 years showing very substantial increase over time underpinning the economic significance of the sector and its potential for growth.

Figure 9: Investments and benefits in the sector in terms of yearly R&D investment, Revenues, patent applications and jobs in the Netherlands. The numbers are based on input from ASM, ASML, Besi, Nearfield, Prodrive Technologies and TNO over the past 10 years

In regard to investment in this roadmap through Public Private Partnership projects, over the past years this was estimated to be in the order of 330M€/year of which approx. 178M€ is private and 153M€ is public investment which is divided over:

- RTO 28MEuro/year
- Universities 21MEuro/year
- NWO D + I 7MEuro/year
- NGF 29MEuro/year
- IPCEI EZK Co-funding 18MEuro/year
- EZK co-funding EU + NL projects 28MEuro/year
- European Commission Co-financing 22MEuro/year

Although substantial, the volume of PPP initiatives of 330M/year is rather low when compared to the approximately 63 B€/year[57] industry (export) for the Netherlands and the associated total private R&D investments of 3.5B€ Euro in 2022, *Figure 9.* The relevance of the PPP projects to the industry is very clear from both the content and the realized volume, but at the same time there is ample opportunity for significant extra growth and impact.

[57] Netherlands Exports By Category

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7. Conclusions

Semiconductor technologies and its applications are of key economic and strategic importance to the Netherlands.

In all areas of this roadmap, parties are experiencing an unprecedented pace of innovation. This is driven by the increasing complexity and interdependencies of technologies that need to be mastered at each new technology node. Additionally, the continuous drive for more functionality necessitates greater integration, whether at the design, package, or system level. This demand for enhanced system functionality is pushing for heterogeneous integration at the chip level, to the point where assembly technology may be incorporated into front-end chip manufacturing. Furthermore, innovation in test equipment is driven by the need to keep up with performance improvements achieved in More Moore, as well as to develop process control solutions for 3D monolithic devices and heterogeneous integration in More than Moore.

Based on these new technologies, system houses and application developers experience the same fast pace of innovation. The interaction between these domains and technology push/application pull creates a unique ecosystem to foster new developments. This interplay between semiconductor equipment and manufacturing on one hand, and applications on the other, will get more crucial in the coming years because this dependence keeps increasing in importance.

These developments make the Dutch semiconductor manufacturing equipment industry, as well as the application developers that depend on these new technologies, thrive. The Netherlands is internationally recognized to excel in complexity and high paced innovation. However, we cannot afford to get too comfortable. The (public) boundary conditions are not keeping pace with the needs of the successful and growing sector: talent is in short supply, the infrastructure at TO2 institutes is out of balance with similar resources in other European countries and the volume of this sector, the upscaling capital for scale-ups is falling short to keep and build position for equipment in renewing and new innovative supply chains. All in all, to not fall behind this needs addressed with a sense of urgency

Moreover, the financial overview demonstrates a volume of about 330M€/year for Dutch Public Private Partnerships. We consider this as too modest for a ~63 B€/year[58] industry (export) of NL made electrical and electronic equipment in 2024. It is unlikely that this incredible ROI can be maintained at the long run, especially in view of all the government involvements in other countries.

In order to keep ahead and stay competitive the industry needs increased effort in:

- Talent development: capacity, education and retainment of talent. For this sector this means efforts in STEM subjects in general and specifically in physics, electronics, mechatronics, opto-mechatronics, optical design and systems engineering.
- Infrastructure: keeping pace with investments in other (EU) countries. The Netherlands should position itself as the equipment supplier of Europe and the world, including the infrastructure and access. For talent development, lab development, education environments are needed.
- Nurture/support of new businesses, especially in the scale-up phase.

With the recent geopolitical changes and the renewed ambition of reshoring some of the chip production in Europe, it is crucial to keep supporting and stimulating local equipment production as well. Major efforts need to be put on the continuous stimulation of the R&D and production of this

[58] Netherlands Exports By Category

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equipment in the Netherlands. Additionally, it is required to consider the complete value chain, from design to application, in order to realize a sustainable industry.

This all can be done with ongoing availability of PPP's. Companies depend on these partnerships in order to be able to develop products and technologies that span further than their direct roadmap allows them to do. These partnerships also allow the companies to further expand their collaborations with knowledge institutions and RTO's. Together they play a crucial role in maintaining existing positions and to expanding in emerging technologies and capabilities. It is only with continuous support of the semiconductor equipment manufacturers and developers that we can tackle the societal and strategic challenges as defined in this document.

The EU Chips Act mobilizes large investments from both private and public sources. Public national funding and strategy is required, however, to make part of these budgets work for the Netherlands. Without that, most of the funding and resources will flow to other regions within the EU, which would be detrimental to the position of the Dutch ecosystem.The EU Chips Act rightly places strong emphasis on manufacturing, but the Netherlands also has a distinctive role to play across the broader semiconductor value chain. Besides Dutch companies having good positions in equipment and various application areas, there is also promising momentum in nascent areas, such as advanced chip design – from AI accelerators to specialized application-specific solutions. As Europe refines its semiconductor strategy, there is real value in explicitly recognizing that design sovereignty – the capability to architect chips that reflect European priorities and values – is just as important as manufacturing sovereignty. In that context, Dutch policy dialogue can help champion a balanced approach that supports the entire ecosystem: fabless design houses and IP providers, as well as equipment suppliers and fabrication facilities.

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