THE UK SEMICONDUCTOR INDUSTRY:

CURRENT LANDSCAPE AND FUTURE OPPORTUNITIES

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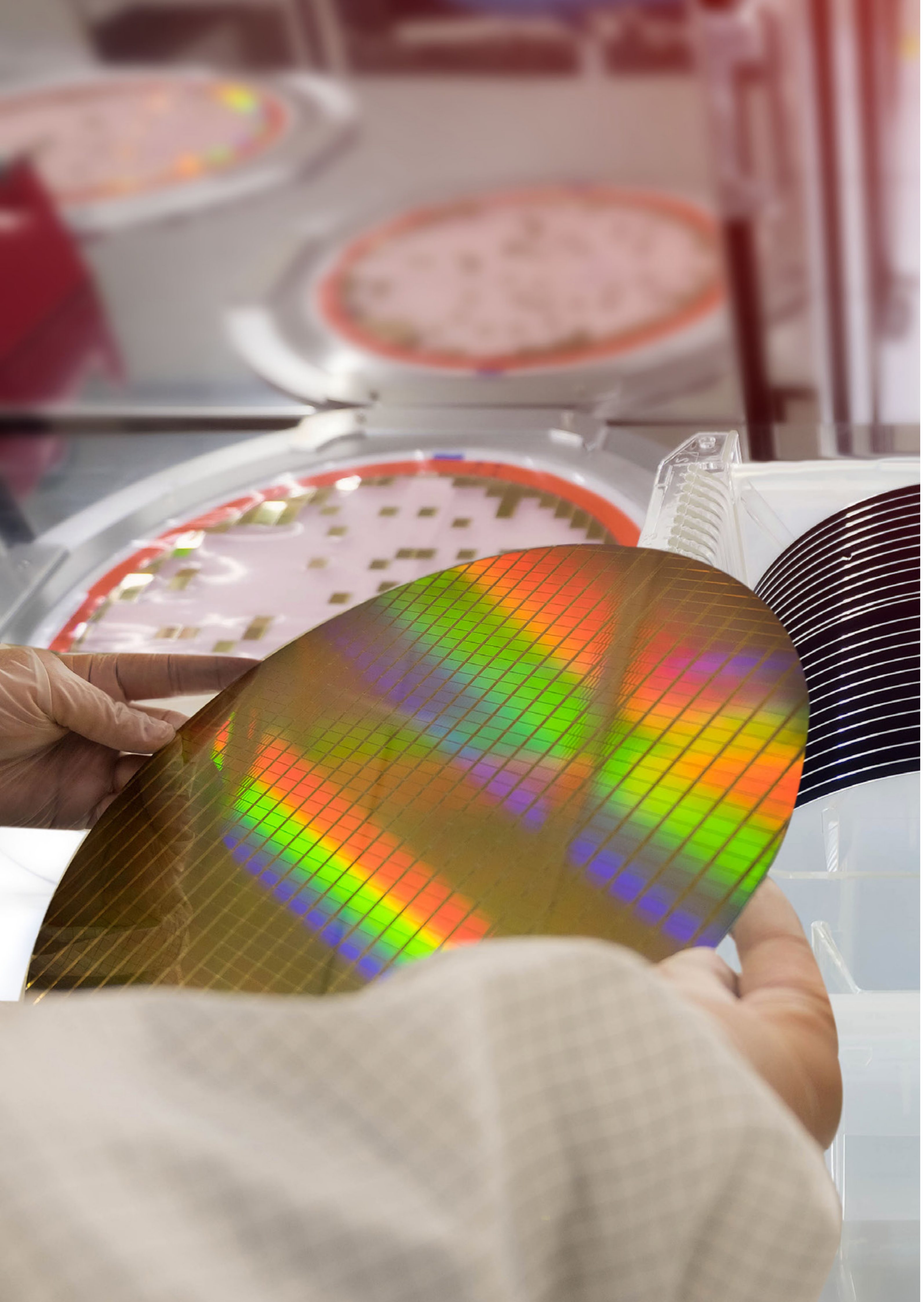

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EXECUTIVE SUMMARY

The reach of the semiconductor value chain is global and was responsible for $555.9 billion of revenue in 2021 [1]. Semiconductor devices underpin all modern technology, enabling the operation of, and advances in, communications, healthcare, transportation, energy systems, manufacturing, and many other sectors. The UK's involvement in the global value chain spans across all markets and uses both silicon and compound semiconductors (CS).

With the COVID-19 crisis disrupting supply chains and geopolitical tensions increasing, semiconductor companies have become increasingly focused on achieving end-to-end design and manufacturing capabilities. Many governments share an interest in this capability and are attempting to support their local semiconductor markets. The UK has political stability, a relatively low-cost workforce, and outstanding engineers supported by technical colleges and universities that specialise in the required leading-edge engineering fields, all of which make the UK an attractive country to invest in the manufacture and development of semiconductor products.

The objective of this paper is to highlight the importance of semiconductors in the modern world, explain the recent disruption seen within the international semiconductor value chain, and identify some of the key global companies and regions involved. It builds a comprehensive picture of the current UK semiconductor landscape and highlights future opportunities which the UK is capable of exploiting. It includes contributions from industry experts and provides several recommendations as to how the UK can build resilience in the future and grow the industry.

Some of the key points from this report are:

- The COVID-19 pandemic has disrupted the semiconductor value chain, highlighting the fragility and lack of resilience within it. This has sparked a review as to how the value chain operates, and how regions and companies can react and mitigate disruption in the future.
- There are two main themes for semiconductor devices: Moore's Law and More than Moore devices. Moore's Law devices focus on the drive for smaller, more powerful chips, mainly concerned with the processing of information, often seen within mobile devices and computers. More than Moore devices focus on the functional diversification of technologies, combining performance, integration and cost, often using new materials and novel packaging methods.
- Moore's Law technologies have become increasingly inaccessible due to ever-rising research and development costs, hugely capital-intensive facilities, and the vast expertise and knowledge required to produce these chips. There is an ever-increasing demand and opportunity in the research and manufacture of More than Moore technologies, brought about by developments in 5G connectivity, the Internet of Things (IoT), and new applications, ranging from autonomous driving to neural sensors.
- The UK has several long-standing semiconductor companies, as well as strong capabilities for More than Moore technologies, with 25 manufacturing sites in the UK and Ireland using a range of base materials with end markets in battery technology, magnetics, sensors, communications, photonics, and power applications. In addition to this, UK universities are conducting cutting-edge research in this area, with two clusters dedicated specifically to compound semiconductors and photonics.
- For the UK to remain a player within the worldwide value chain, it must look to adopt new More than Moore technologies early, to re-shore and contribute to more areas of the value chain, and progress with a coherent voice from academia, industry and government.

[1] The Semiconductor Industry Association, "Global Semiconductor Sales, Units Shipped Reach All-Time Highs in 2021 as Industry Ramps Up Production Amid Shortage," The Semiconductor Industry Association, Washington, 2021.

There are opportunities across several sectors, including digital technologies, healthcare, automotive and security, in groundbreaking areas such as compound semiconductors, power electronics, sensing, and artificial intelligence, as well as in simple silicon (larger node size) design and manufacture for discrete and analogue applications.

From the review of the current capabilities and future opportunities, several recommendations have been proposed, so that the UK can take advantage of the opportunities presented within the sector and build resilience to future disruption:

RECOMMENDATION 1:
UK senior industry leaders must come together to unite with one voice. This central point of contact should look to provide an agnostic outlook on the current state of play within the industry. It should take an objective look at the entire value chain, and openly and honestly assess the current risks and opportunities to the UK semiconductor industry.

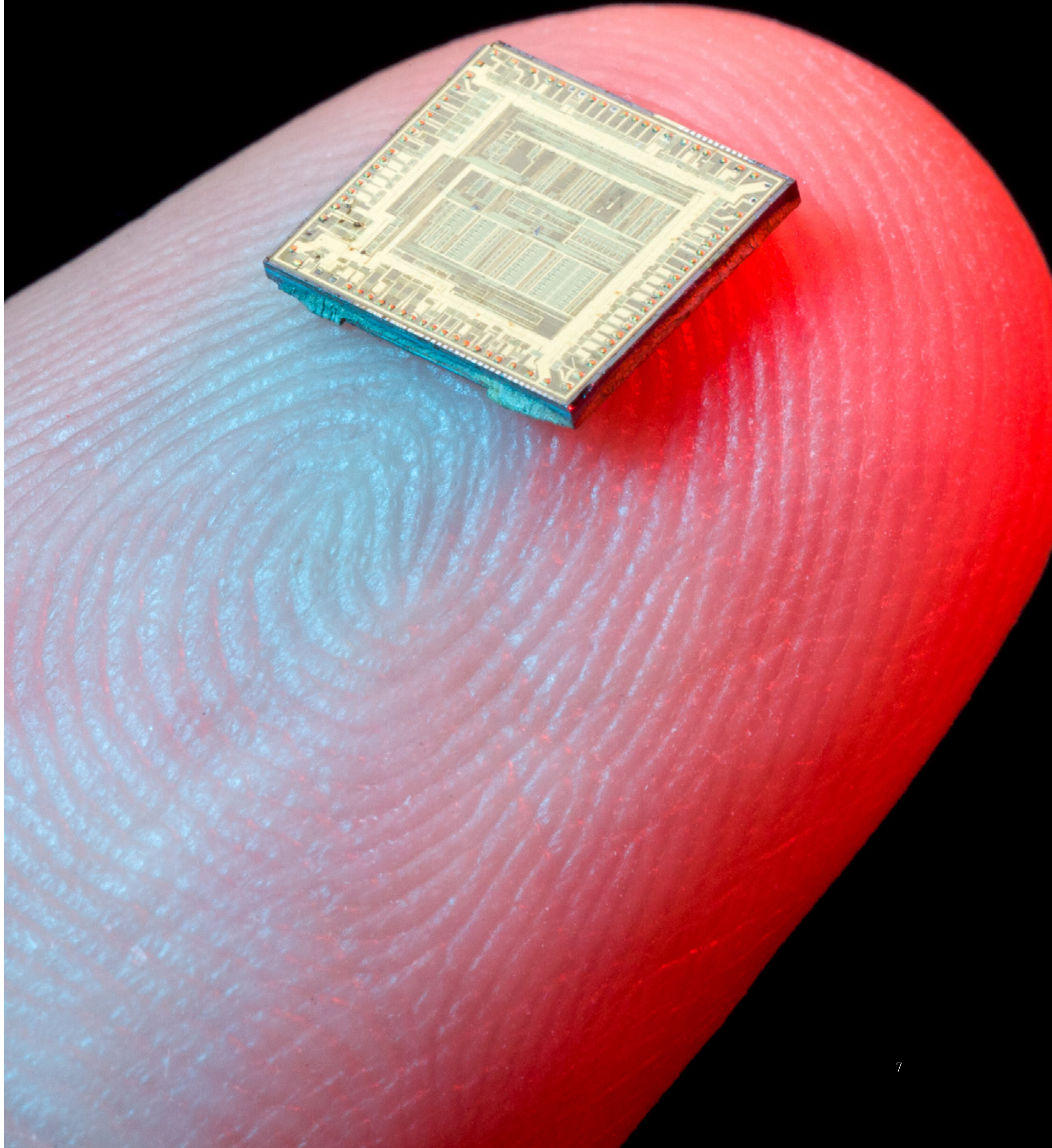
RECOMMENDATION 2:
Industry leaders should work more closely with government to create both short-term and long-term plans and strategies for the industry. These should provide actionable statements formed from value chain analysis, considering the risks and opportunities previously identified. Government should look to support these proposals both financially and operationally, to enable the industry to build competitive advantage.

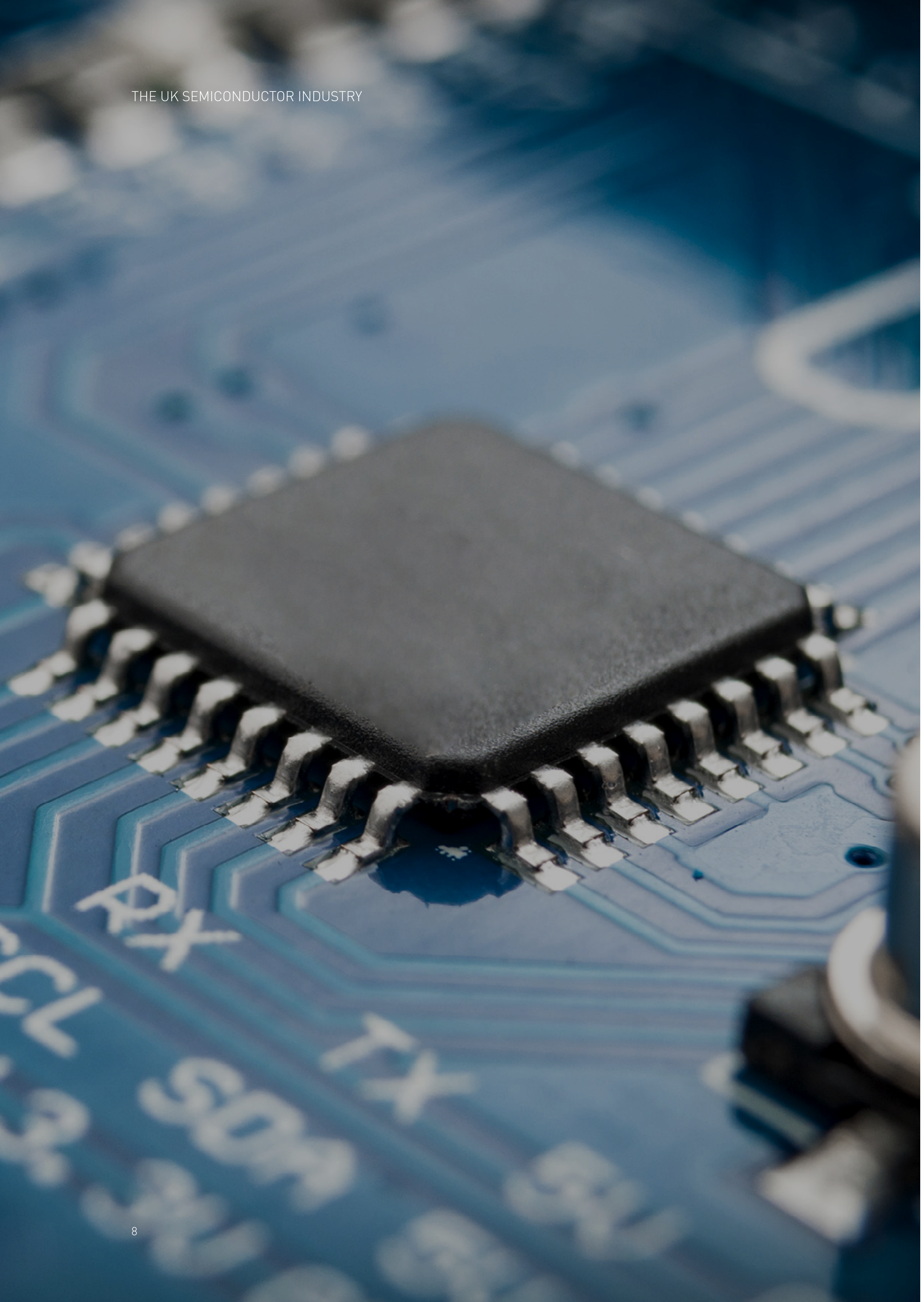
RECOMMENDATION 3:
The industry should capitalise on the research and innovation ecosystem that the UK possesses. Universities and academics are working at the forefront of several semiconductor research areas, the most notable being the development of compound semiconductor technologies. This is still an emerging area, and early adoption of the technology and the creation and support of a hub for knowledge and expertise within the UK would stimulate a thriving economic and innovation environment.

RECOMMENDATION 4:
Tap into the existing semiconductor expertise and talent pool that had already been established. The UK involvement in semiconductor technologies spans across all markets including rail, medical, consumer, automotive, aerospace and military, and uses both silicon and compound semiconductors. Although the UK does not possess the high volume, smallest node size manufacturing capabilities, there is still considerable scope to develop current More than Moore capabilities domestically, as well as support our simple silicon (larger node size) design and manufacturing facilities

RECOMMENDATION 5:
The UK must look to re-shore and compete in areas of the current global value chain. This is the only sure way that we can build resilience against future disruption. These areas include the development of wafer manufacturing capabilities, flexible chip manufacture, testing and packaging. This would also allow the nation to take more control in ensuring cyber resilience and quality control of products within the supply chain, reducing the reliance on other countries in areas of vulnerability, and building in supply chain security by design.

RECOMMENDATION 6:
Ensure more schoolchildren are aware of the importance and relevance of semiconductors, electronics and engineering. Industry and academia should collaborate and provide opportunities for young people to develop their interest in electronics and semiconductors through undergraduate courses and/or apprenticeships. This would help the next generation to pursue careers in semiconductors and be supported in their professional development. Relevant and focused postgraduate study should also be implemented to develop key areas of technical knowledge and understanding to contribute to innovation-led businesses and future semiconductor research and development. Graduates need to be able to join a community of semiconductor designers, manufacturers, and engineers to secure the future skills pipeline. There is a need to build relationships and provide a representative voice for the sector on skills.





INTRODUCTION

The third industrial revolution was responsible for shaping the highly computerised and processor-reliant world we live in today. Otherwise known as the digital revolution and beginning at the end of the last century, it was characterised by the introduction of electronic devices, telecommunications, and computing power.

The Altair, hailed as the first personal computer, was created in 1974 by a small firm named MITS and contained one of the very first semiconductor chips. Looking back now, it has arguably driven the largest advancement in human development since the discovery of electricity in the 19th century.

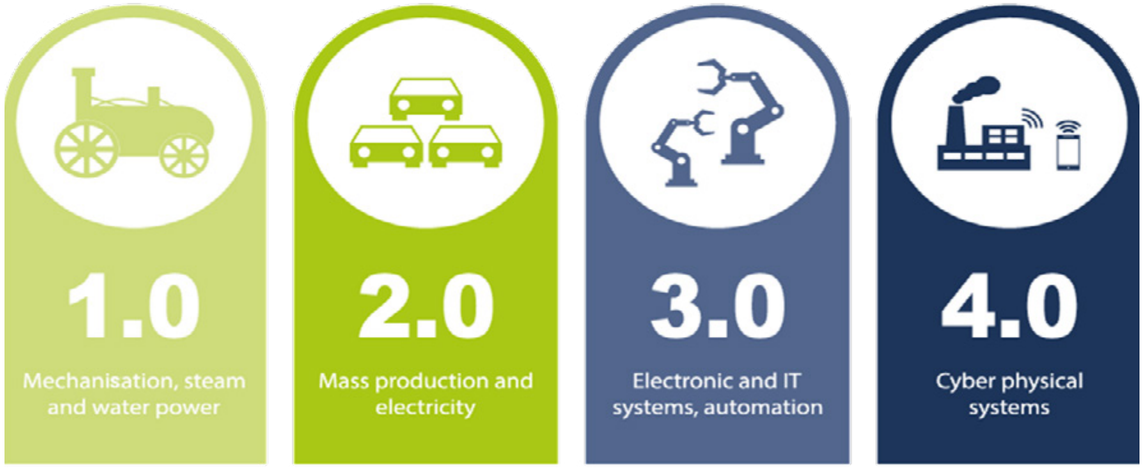


Figure 1: The Four Industrial Revolutions

This is primarily down to the development of the semiconductor chip, responsible for powering almost all electronic devices. Around the start of the digital revolution, Gordon Moore was one of the few who predicted the rise of computing. His prediction, later named Moore's Law, projected that the density of transistors that could fit onto a single microchip, and therefore the computing power of the device, would double every two years. In parallel, the cost of computing power would also be halved. Since then, we have seen the number of computations per second in microchips skyrocket from 10 to over 30 trillion. In today's world, we are currently experiencing a semiconductor shortage. Due to the recent pandemic, as well as the intricacies of the worldwide supply chain, delays have been forecast as far ahead as 2024, according to Marvell Technology CEO, Matt Murphy. [1]

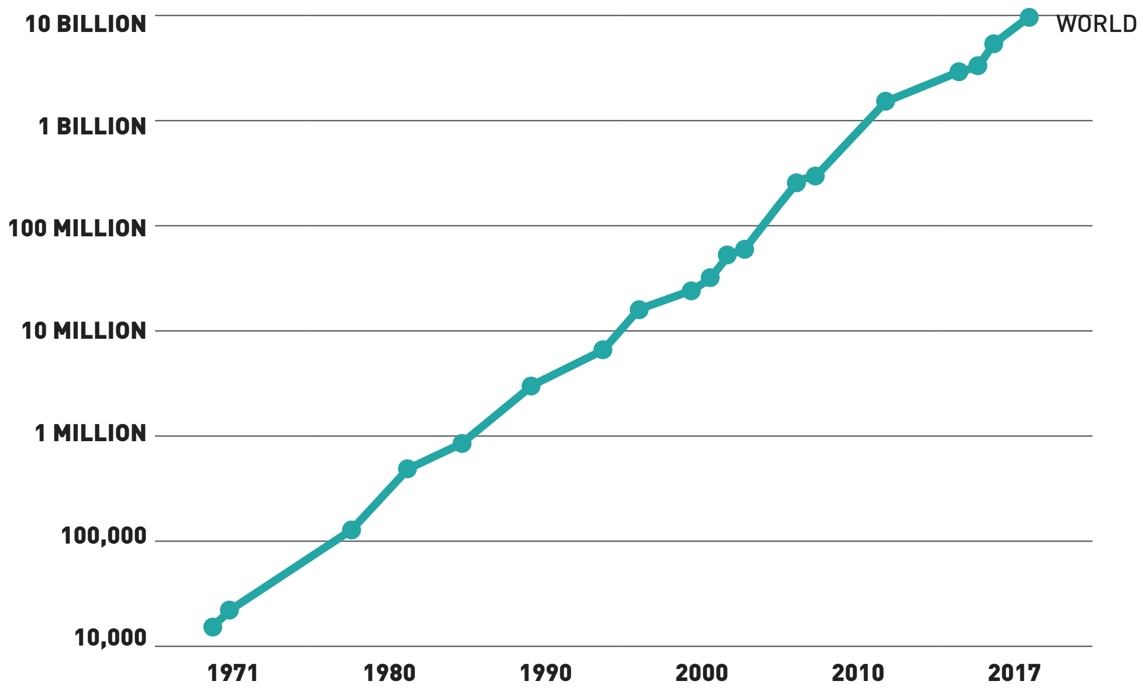
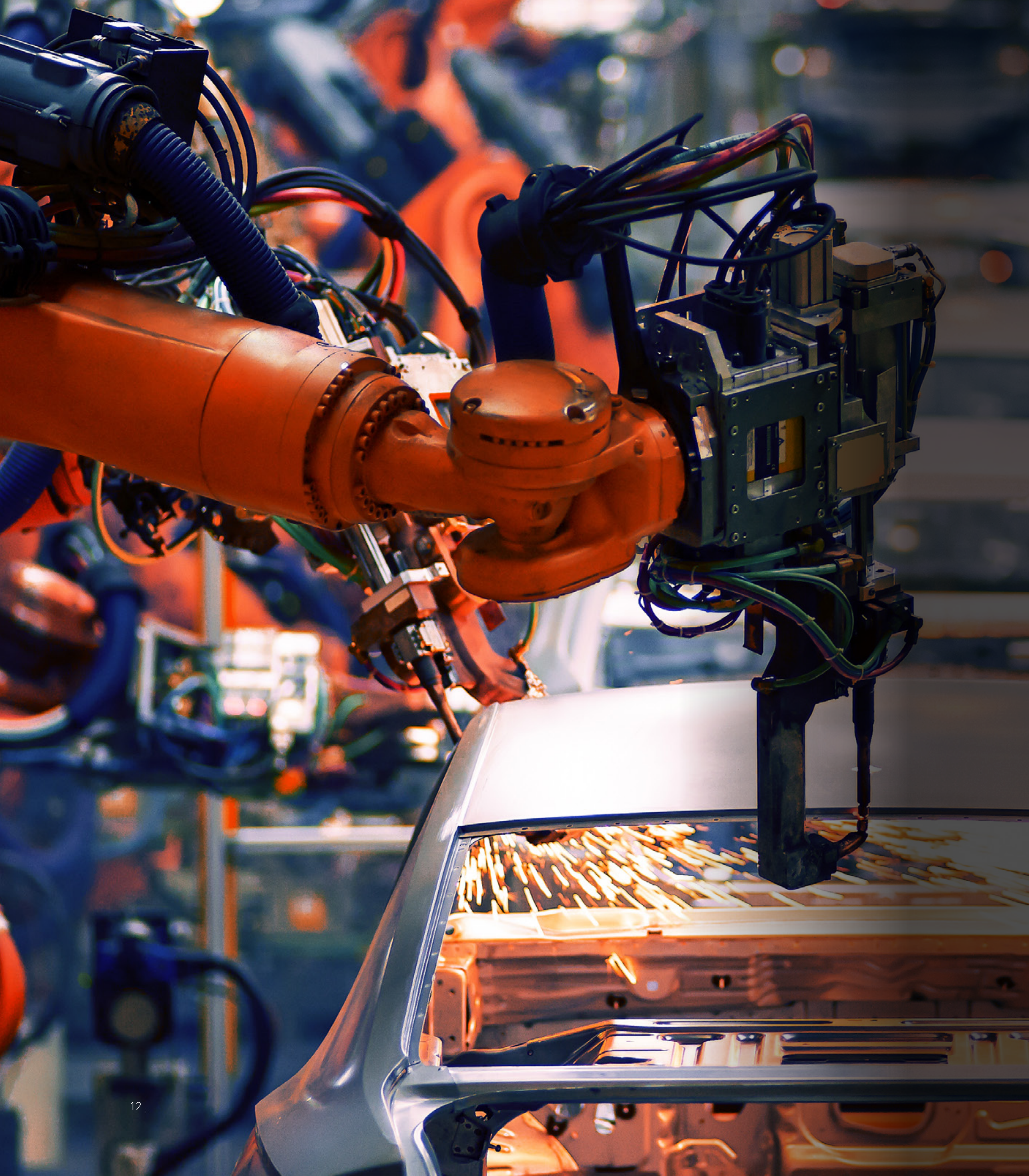


Figure 2: Number of Transistors Per Microchip, 1970-2017 [2]

[1] I. Thomas, "Semiconductor chip shortage could extend through 2022," CNBC, 3 October 2021. [Online]. Available: https://www.cnbc.com/2021/10/03/semiconductor-chip-shortage-could-extend-through-2022-marvell-ceo.html. [Accessed 08 November 2021].

[2] Max Roser and Hannah Ritchie (2013) - "Technological Change". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/technological-change'



THE WORLDWIDE SHORTAGE

The chip shortage is affecting businesses across the globe due to the worldwide value chain of semiconductor manufacture, and has been referred to as the 'perfect storm'. The pandemic forced millions of people to transition to working from home, or to hybrid working. This shift in work patterns made businesses reconsider their entire operation, with hundreds of businesses still working remotely even now. Because of this switch to homeworking, companies were required to supply workers with equipment that allowed them to perform their day-to-day tasks remotely. This included the purchase of new laptops, monitors, keyboards, and headsets, which all use semiconductor chips. In addition, companies had to upgrade their cloud facilities and servers to support all the remote connections and network traffic that would now occur, which also contributed to the increasing demand for chips. This spiral significantly impacted manufacturers of semiconductors, and according to the trade organisation, the Semiconductor Industry Association (SIA), sales in May 2021 were 26% higher than the same time the previous year [1].

In 2020, when countries across the world went into lockdown and the worst effects of the pandemic became apparent, the Society of Motor Manufacturers and Traders (SMMT) reported that just 1.63 million vehicles were registered on the road, the lowest number since 1992 [2]. As the demand for cars rapidly dropped, automotive manufacturers decided to halt orders, and cancel contracts with semiconductor manufacturers. During this time, due to the nature of semiconductor manufacture, production had to remain steady, and to shift the ongoing production, chip manufacturers took up new contracts with the desperate electronics markets to feed the unprecedented surge in demand. It was not until the beginning of 2021, when the effects of COVID-19 were easing, that car manufacturers began to accept orders again.

When approaching the semiconductor manufacturers to place new orders, automotive companies found that they were already at full capacity, with orders placed months in advance already dedicated to the electronics industry. Due to the extremely low flexibility within the semiconductor manufacturing facilities, this meant that auto manufacturers had no choice but to rethink their future production plans. They were forced to reduce product lines, concentrating on the most profitable and in-demand vehicles, and cutting production altogether of some of the least profitable models.

THE IMPACT ON JAGUAR LAND ROVER

In April 2021, Jaguar Land Rover (JLR), the largest UK automotive manufacturer, was forced to temporary shut down production at two of its main UK factories as a result of the semiconductor shortage. This included the Castle Bromwich site in the West Midlands, as well as the Halewood site in Liverpool. Although the manufacture was only halted for around a month, for a company selling 508,659 cars during 2019-2020, it has highlighted a huge supply chain issue, as well as a financial one. [3]

[1] M. Gooding, "Here's what we know about the global chip shortage," Tech Monitor, 2021.

[2] Society of Motor Manufacturers and Traders, "UK Automotive Trade Report 2021," Society of Motor Manufacturers and Traders, London, 2021.

[3] Jaguar Land Rover Automotive PLC, 2020

In addition, a fire within a Japanese chip plant responsible for producing large volumes of automotive microprocessors, and another in ASML's photolithography facility in Berlin, compounded pressure on the supply chain. Coupled with a massive power outage in Texas, where the government asked Samsung, one of the largest semiconductor manufacturers in the US, to shut down chip production, the worldwide shipping container shortage (impacted by the COVID-19 pandemic), and the US Government blacklisting several Chinese firms for political reasons, it is clear to see why it has been described as a perfect storm. [1]

Demand shows no sign of slowing down. With Industry 4.0 seeking to make a real impact on the manufacturing industry in the future, as well as continued enhancements of existing products, the inclusion of emerging technologies such as Artificial Intelligence (AI) in products and 5G networks, as well as rapid growth in automotive and industrial electronics, market projections from Precedence Research predict that by 2030, the global market for semiconductors will have almost doubled.

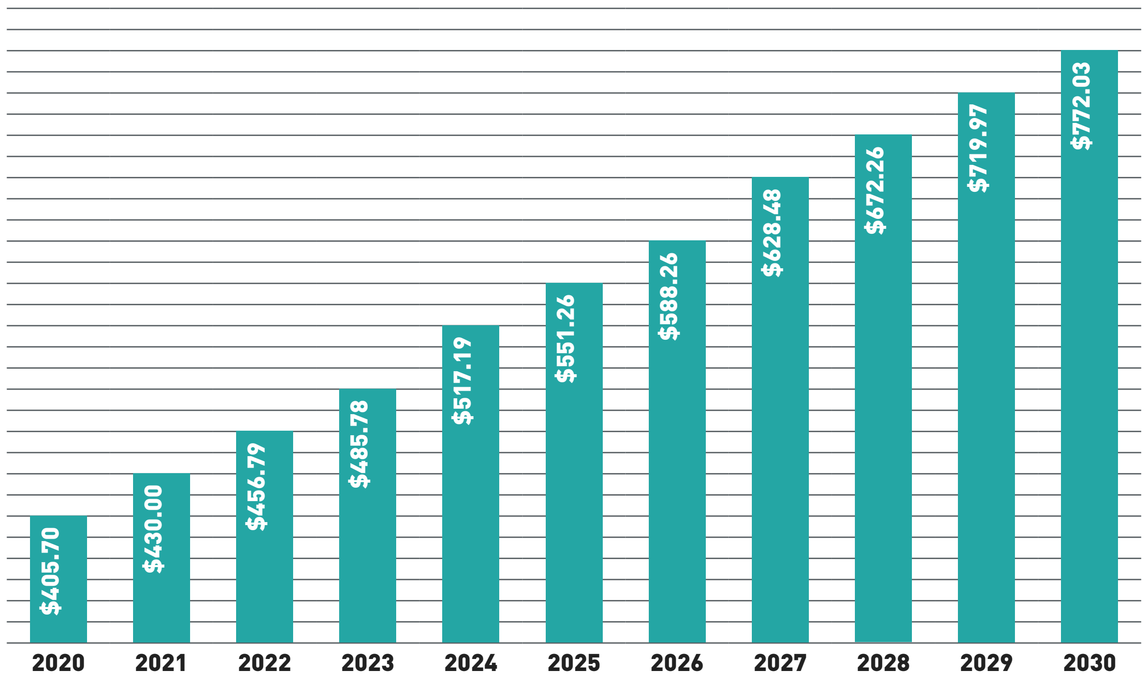


Figure 3: Semiconductor Market Size, 2020 to 2030 (USD Billion) [2]

The global semiconductor shortage has made one thing clear; the semiconductor industry does not have enough agility and flexibility within its value chain to respond to rapidly increasing demand.

To mitigate this, where the application of electronic devices and semiconductors shows no sign of reducing, countries need to look at how resilience can be built.

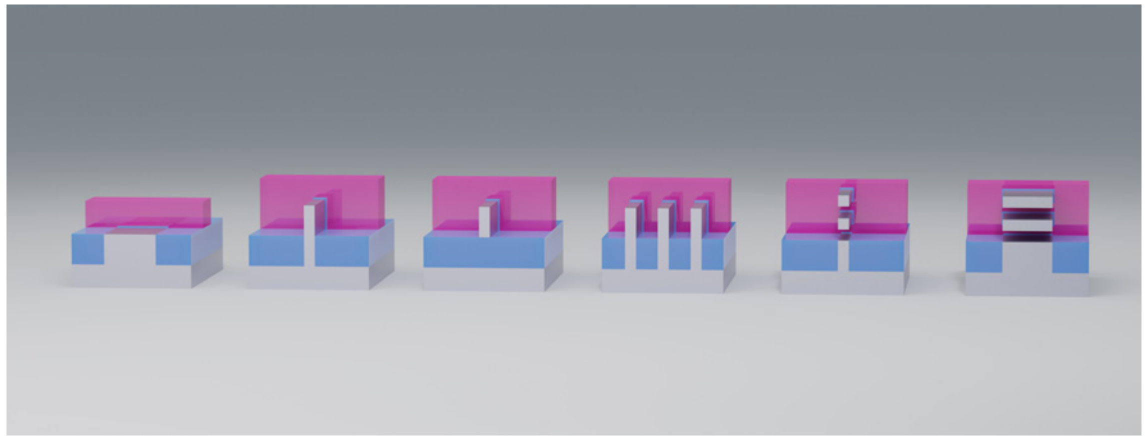
[1] B. Vakil and T. Linton, "Why We're in the Midst of a Global Semiconductor Shortage," Harvard Business Review, Boston, 2021.

[2] Precedence research, "Semiconductor Market - Global Industry Analysis, Size, Share, Growth, Trends, Regional Outlook, and Forecast 2021 - 2030," Precedence research, Ontario, 2021.

SEMICONDUCTOR MANUFACTURE

The manufacture of semiconductor chips takes place in what is known across the industry as fabs, or foundries. When looking at semiconductor manufacture, the main driver for the past few decades has been size: to reduce chip size and integrate an increasing number of smaller, faster transistors on each chip at the next manufacturing node, known as Moore's Law technologies. Chip companies often use the term 'node size' when describing the size of the new components they are manufacturing, measured in nanometers. But what does node size mean?

Historically, gate length was used to determine the node size, which is simply the distance between the drain and source electrodes on the transistor, or how far the electrons have to travel. As the design of chips has developed, it has become increasingly difficult to measure node size, and in our current age, node size is used simply as a measure of the power of the chip, rather than an actual measure of dimensions. Different manufacturers have different specifications for how they define the node size for their components, but the overarching theme is that the smaller the node size, the more developed the technology within the chip is.



PLANAR	FINFET	FINFET SOI	TRIGATE FINFET	NANOWIRE	NANOSHEET
1960	1998	1998	2001	2012	2022

Figure 4: Transistor Design Development

In 1994 the node size of semiconductor chips was around 350 nanometres (nm). Looking at the most recently manufactured chips, used mainly in high-end mobile phones and PCs, we are seeing the production and use of 5nm chips. In a recent forecast, made by the Institute of Electrical and Electronics Engineers (IEEE), the 1nm size will be reached by 2028, which could potentially bring about a huge change in semiconductor manufacture, when lithography reaches its limits. Lithography is an essential step in the semiconductor process, whereby lasers are used to project the circuit pattern onto a chip in a highly specialised and energy-dependent process.

In an article by the Institute of Electrical and Electronics Engineers, its chairman, Paolo Gargini, wrote: "Around 2029, we reach the limit of what we can do with photolithography. After that, the way forward is to stack... That's the only way to increase density that we have."

Currently, chips are made using single layers of transistors, connected further by dozens of layers of metal interconnects. Research and development is currently underway by leading manufacturers to build two layers of transistors instead of one, nearly doubling the density of transistors within the chip.

This is a key indicator of how beneficial the early adoption of technology could be. If the UK can predict trends within the industry, it can provide several opportunities in selling Intellectual Property (IP) and in creating its own manufacturing processes.

Producing the smallest node size chips has become an increasingly more capital intensive and specialised process, meaning that only industry giants, such as the Taiwan Semiconductor Manufacturing Company (TSMC) and Intel can achieve such tasks. This has driven a trend known as More than Moore, whereby focus is shifting away from the obsession with smaller node sizes, to a new, functional diversification of technologies, combining performance, integration, and cost, not limited to standard silicon chip scaling [1].

Advanced node sizes are no longer bringing the desired cost benefit that they once did, and we are seeing R&D investment in new photolithography solutions and devices below 10nm node size rising significantly. To satisfy market demand, the industry is looking for technological solutions that add functionality through integration, whilst still improving the cost and performance of the chip. More than Moore devices now represent a new functional diversification of technologies, where digital electronics meets the analogue world. These applications are poised to expand dramatically with the advent of 5G connectivity, the Internet of Things, and new applications ranging from autonomous driving to neural sensors. Although reduced size and increased speed will still be in demand, there will be emerging opportunities for companies to produce less capital intensive, larger node size chips, allowing for more accessibility. Almost all of the UK manufacturing capability is within this More than Moore area, and the development of these capabilities is a vital component to the industry going forward.

[1] A. Pizzagalli and E. Jolivet, "More than Moore Devices: The Wind of Change," Semi, Milpitas, 2018.

WAFER FABRICATIION

The crucial foundation of semiconductor chips has historically been silicon. As well as being very stable, silicon has a key property that makes it the ideal material for chip manufacture; the ability to control electrical properties based on the addition of specific dopants. These dopants can be in the form of boron, phosphorus, arsenic, or antimony, and differ depending on the type of chip required. To create the wafers that act as the base for the chips, silicon is most commonly extracted from quartz and quartzite sands, which are subjected to a number of purification processes in order to obtain the near 100% pure silicon required. Once this has been achieved, the pure silicon is melted and pulled into single crystal ingots. The ingots are then sliced and finished to create semiconductor grade wafers.

Although the majority of high-grade raw materials for semiconductor wafers are mined in the United States, a large amount of the unprocessed material is shipped to China, which has a 64% production share for silicon, the most widely used material in semiconductor manufacture. Notwithstanding this, the United States and its allies do have large reserves of the material, as well as extraction capabilities. [1]

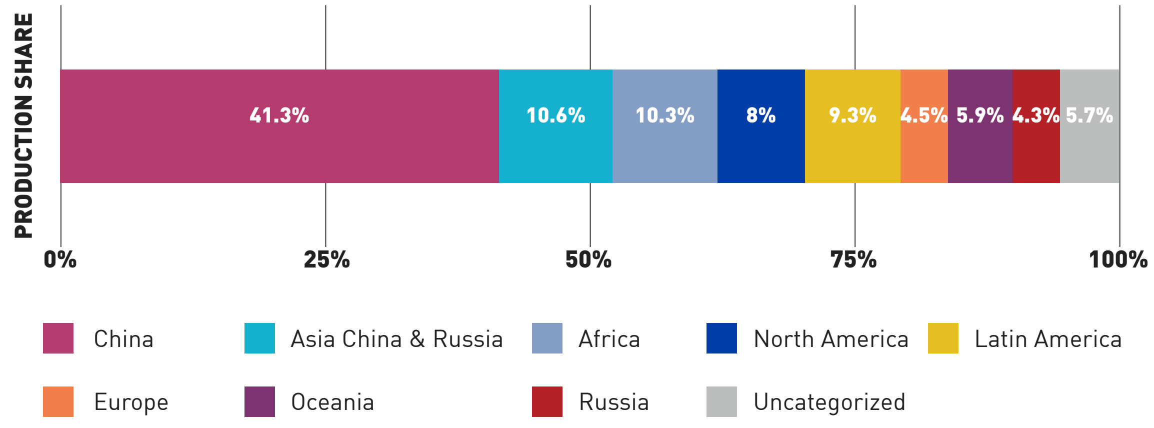


Figure 5: 2019 Total Material Production Share by Country [2]

This has been the standard procedure for creating silicon semiconductor wafers, which has been relatively constant for the past few decades. Something that is becoming ever more important and crucial within the semiconductor industry though, is the shift from Moore's Law to More than Moore technologies. This involves the use of compound materials such as silicon carbide and gallium nitride, which allows the manufacture of chips with higher speeds, greater efficiency, and optical properties by altering the base properties of the wafer. When creating chips of larger node size and for different applications, the process for semiconductor wafer manufacture will slightly differ. This is also true for the process for chip manufacture, and often, for larger node sizes, the process can be simplified, although many of the core processes remain.

[1] D. Ernst, "China's bold strategy for semiconductors - Zero-sum game or catalyst for cooperation?," East-West Center, Honalulu, 2016.

[2] S. M. K. e. al, "The Semiconductor Supply Chain: Assessing National Competitiveness," CSET, Washington DC, 2021.

CHIP MANUFACTURE PROCESS

Chip manufacture is a mature process, where variations are commonly seen through repetition or alteration of existing elements of that process, rather than adding new or different stages. On the next page is the typical process flow for the creation of semiconductor chips, which involves creating thousands of transistor gates on silicon chips and linking them together in multiple layers. It is important to note that this is the typical process for mainstream silicon semiconductor processing, and there will be slight differences to the process depending on the base material and application of the chip.

SILICON WAFERS

In almost all cases, silicon wafer manufacture will be outsourced by the fabs, with only a cleaning and inspection stage needed before use.

OXIDATION

Once the wafers have been thoroughly cleaned and inspected, the first step in the process is the application of a thin layer, usually aluminium oxide, acting as an insulation layer on the wafer.

IC DESIGN

This is the fundamental design stage of the chip, whereby the company will create a virtual circuit diagram, using a variety of transistor patterns and interconnects, to perform the intended function.

MASK SHOP

The design will then be transferred into a number of photomask sheets, which are used within the photolithography stage as a template for the light to pass through, projecting the circuit pattern onto the wafer.

PHOTOLITHOGRAPHY

PHOTORESIST

A thin layer of photoresist is then applied over the oxide layer. This is applied via centrifugal force to ensure an even coating across the wafer. This layer is crucial as it is later developed in the process to expose the oxide layer. [1]

EXPOSURE

This is one of the most important steps in the process, whereby a photomask is loaded into the stepper/scanner machine with the circuit design printed onto it. The stepper is then responsible for beaming light through the mask, projecting the design onto the photoresist layer on the wafer, where only the areas exposed to the light undergo a structural change.

DEVELOPMENT

A development solution is then sprayed onto the wafer, which dissolves all areas exposed to light, which reveals the oxide layer from under the photoresist material.

ETCHING

There are two main types of etching, wet and dry. Both have the same purpose; to remove the oxide layer that has now become exposed by the development process. Wet etching uses chemical solutions to remove the layer of oxide that has been exposed but does come with disadvantages. Because it uses liquid, the layer of oxide will be removed in all directions, both downwards and outwards, meaning that the oxide layer and photosensitive film above will not be completely aligned, making it only suitable for less fine circuit diagrams. It does mean that the process is much faster and cheaper than the alternative. Dry etching uses plasma to remove the oxide layer, which is a much slower and more expensive process but can offer far greater accuracy, meaning much finer and more complex circuits can be produced. [1]

IMPLANTATION

Specific dopants are then implanted into the silicon to alter the conducting properties. This happens by bombarding the surface with ions and, depending on the conductivity required, will commonly use boron or phosphorous. N-type dopants are electron donors, giving a positive overall charge, and P-type are electron acceptors, giving a negative charge of the semiconductor.

FILM DEPOSITION

Depending on the type of semiconductor chip being produced, additional layers of conductive or isolating material are applied in extremely thin layers to the surface of the chip.

REPETITION

After the remaining photoresist is cleaned from the wafer, the above process can be repeated up to hundreds of times to build up a complicated multi-layer chip. Contact holes are etched between the oxide coatings of each layer for connections to be made between each conductive pathway.

TESTING AND INSPECTION

Each wafer and chip are subjected to a series of inspections and tests, for both defects and performance.

FINISHING

Each wafer can contain hundreds, if not thousands of individual chips, which are seperated via a sawing process called dicing. The chips are then attached to a protective base, given external connections, and housed within a moulding to protect them from temperature and humidity. Each chip is then subject to further testing before it is packaged for sale.

[1] Apogeeweb Semiconductor Electronic, "Semiconductor Manufacturing Steps with Flow Charts," Apogeeweb, London, 2021.

[1] Screen Semiconductor Solutions Co, "Semiconductor manufacturing processes," Screen Semiconductor Solutions Co, Kyoto, Japan, 2021.

Semiconductor fabs operate under stringent conditions to ensure that the complex manufacturing process is not impeded. They must also be running for 24 hours a day, as the process cannot simply be halted and restarted. This includes having extremely strict heating, ventilation, and air conditioning (HVAC) systems, to monitor and maintain the air temperature and humidity, as well as additional particle measuring systems (PMS) to assess the air purity. When assessing the overall air quality, excessive humidity/moisture can lead to corrosion of 'circuit points'. This moisture leads to condensation on the surface of the chip, and the photoresist layer to not properly adhere to the oxide surface, ultimately causing failure of the manufacturing process [1]. Semiconductor cleanrooms also require staff to be specially dressed with full-body overalls, boots, hairnets, masks, gloves, and goggles, as well as pass through an air shower upon entry to the shop floor. At the cutting edge of chip manufacture, each wafer is housed within its own individual carrier which is moved about the factory on a series of tracks hanging from the roof, while for most UK manufacturers, batches of product are hand-carried through the facility. The entire photolithography departments are lit by yellow lighting, as white light can unintentionally trigger the exposure process, and after the hundreds (and sometimes thousands) of processes have been applied to the raw wafers to turn them into functioning chips, each has to be thoroughly tested and packaged.

The cost of building a semiconductor fab depends on the node size that is being produced, as well as the type of chip. In a recent report by the Financial Times [2] it was said that Intel has planned to invest over $20 billion to create a facility housing two fabs in Ohio, putting the cost per factory at over $10 billion. The larger node size chips that are produced within Europe and the UK have much lower capital expenditure required, but this still stretches into the tens of millions. This does illustrate the huge barrier to entry that exists within the industry, which is the colossal amount of capital required to begin producing some of the smallest node sizes available. In addition, the time from initial investment to wafer production can take up to four years. Therefore, it is important to consider the entire value chain when assessing UK opportunities, and not limit the opportunities to just Moore's Law technologies.

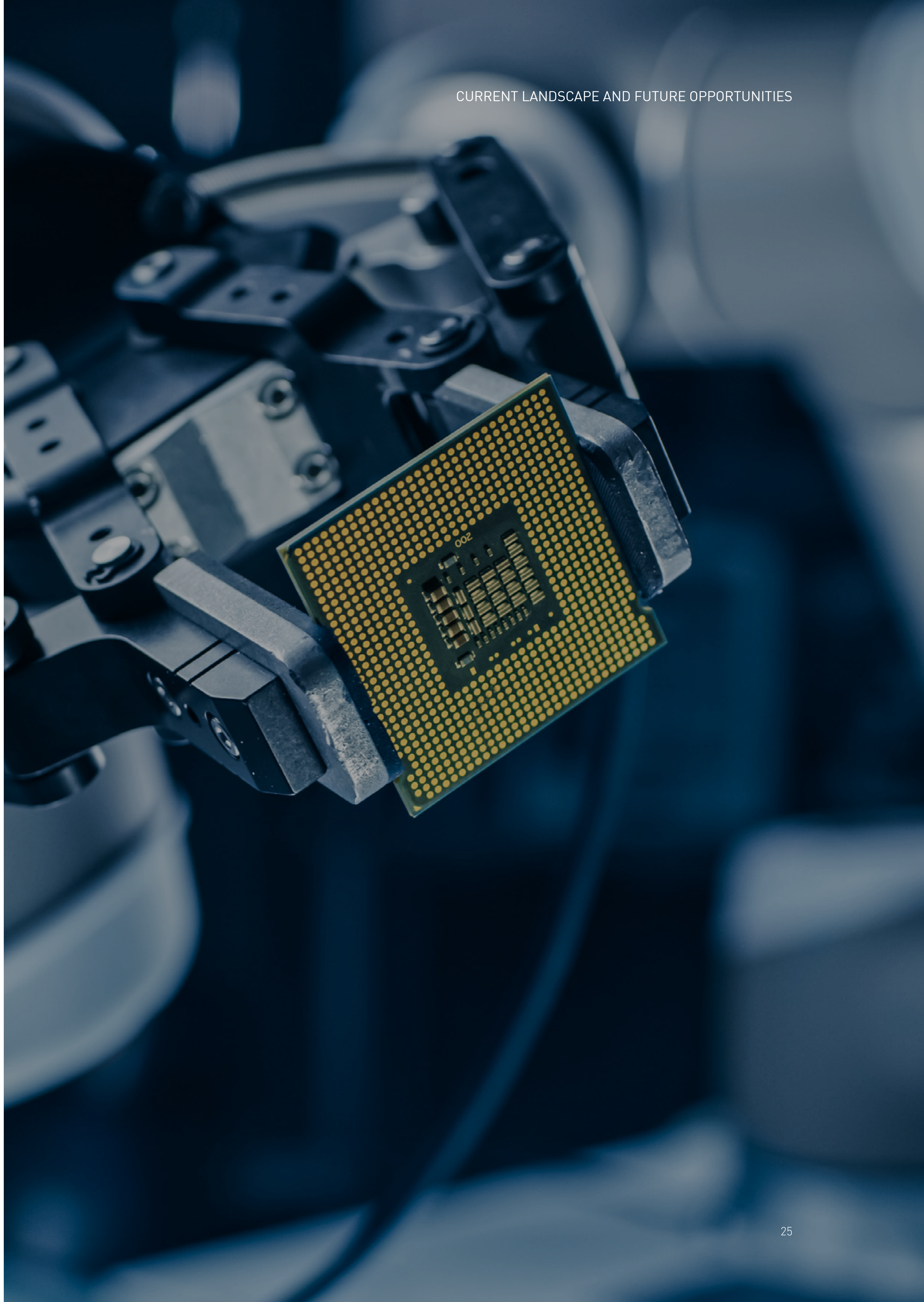
[1] Munters Ltd, "Semiconductor Manufacture," Munters Ltd, [Online]. Available: https://www.munters.com/en/industries/electronics/semiconductor-manufacture/. [Accessed 15 December 2021].

[2] Financial Times, "Intel to invest $20bn in new Ohio chipmaking complex," Financial Times, Chicago, 2021.

Semiconductor chips have key functions, which are vital to the understanding of why some regions or companies tend to focus on the production of certain types of chips, rather than producing a range. One of the most common chips are logic chips. These are the chips found in laptops and home computers and fall within the Moore's Law category of technology. Moore's Law-type chips require far more capital to produce as they are at the forefront of technology, with years of expertise and experience required. Among logic chips are Central Processing Units (CPUs), the 'original' chips first designed in the 1960s [1], and Graphical Processing Units (GPUs), specifically designed to process visual displays.

Another common type is memory chips. These are responsible for storing information and therefore have different architecture and designs. There are two key types of memory chips: Dynamic Random Access Memory (DRAM), which are the 'working memory' chips that only save data while the device's power is turned on, and NAND Flash, which saves data even after the device is turned off. Looking at More than Moore technologies, we see chips designed for discrete, analogue and other (DAO) applications, which are often specifically designed for optical devices, microwave devices, sensors and discrete devices (such as diodes), across markets such as aerospace and defence, automotive, medicine, wireless communications and data centres.

[1] McKinsey & Company, "Semiconductor design and manufacturing: Achieving leading-edge capabilities," McKinsey & Company, 20 August 2020. [Online]. Available: https://www.mckinsey.com/industries/advanced-electronics/our-insights/semiconductor-design-and-manufacturing-achieving-leading-edge-capabilities. [Accessed 22 December 2021].



THE GLOBAL VALUE CHAIN

Many areas contribute to the value chain for semiconductor chips, whether it be the intellectual property ownership of the chip or process design, the wafer production, the tools that go into the fabrication plants (fabs), or the fabs themselves. The global semiconductor market has experienced turbulence due to the pandemic. However, the overall production of semiconductors, as well as total sales, reached record highs in 2021. According to the Semiconductor Industry Association (SIA), over 1.15 trillion semiconductors were manufactured in 2021, with the total sales amounting to $440.4 billion. Figure 6 shows the percentage value added to the market for each activity and region. This is the value of the companies within each activity based on headquarters location, with the sum of all company values giving the total market size.

	SEGMENT VALUE ADD	MARKET SHARES						
		U.S.	S. KOREA	JAPAN	TAIWAN	EUROPE	CHINA	OTHER
EDA	1.5%	96%	<1%	3%	0%	0%	<1%	0%
CORE IP	0.9%	52%	0%	0%	1%	43%	2%	2%
WAFERS	2.5%	0%	10%	56%	16%	14%	4%	0%
FAB TOOLS	14.9%	44%	2%	29%	<1%	23%	1%	1%
ATP TOOLS	2.4%	23%	9%	44%	3%	6%	9%	7%
DESIGN	29.8%	47%	19%	10%	6%	10%	5%	3%
FAB	38.4%	33%	22%	10%	19%	8%	7%	1%
ATP	9.6%	28%	13%	7%	29%	5%	14%	4%
TOTAL VALUE ADD		39%	16%	14%	12%	11%	6%	2%

Figure 6: Semiconductor Value Add and Market Shares by Segment and Firm Headquarters [1]

The US adds the highest value to the market, contributing 39% of the total. Based on the breakdown of activities, this is primarily because it has a market majority in the highest value-adding activity, which, unsurprisingly, is the manufacture of semiconductor chips. The US also adds the majority of the value to fab tools (the equipment and machinery found within the factories), as well as being the main designer of chips. A key disadvantage that the US has is its reliance on other regions for the assembly, testing and packaging of chips, as well as negligible wafer production capabilities. This leaves the country especially vulnerable to both logistical and political issues within the supply chain.

The second-largest contributor is South Korea, adding 16% of the total value to the market. The standout activity that South Korea involves itself in is the manufacture of data storage or memory chips, giving it a 22% market share for total chip fabrication. This is a result of Samsung's presence within the region. South Korea also contributes heavily to the processing of materials for wafers, as well as the production of wafers for the semiconductor industry.

A further key region to highlight is Taiwan. Although it contributes only 19% to the production of semiconductor chips, it owns almost all the production of the most advanced logic chips. Within Taiwan is the company TSMC, which acts as a pure-play foundry, meaning it exclusively produces chips for other companies. It dominates the production of the smallest node size chips (under 10nm) and produces chips for Apple, Intel, Qualcomm, AMD and Nvidia.

When assessing Europe's contribution to the market, it has engagement across almost the entire value chain. The strongest contribution lies within Core IP. This is chiefly driven by the UK's ownership of Arm Ltd., as well as ownership of IP relating to manufacturing processes and machine design, with Holland's ASML being the world's largest producer of photolithography machines.

[1] The Semiconductor Industry Association, "Global Semiconductor Sales, Units Shipped Reach All-Time Highs in 2021 as Industry Ramps Up Production Amid Shortage," The Semiconductor Industry Association, Washington, 2021.

SPOTLIGHT

ASML

ASML is a Netherlands based company, specialising in lithography technologies for the semiconductor industry. It was founded in 1984 and has grown to become the top supplier of photolithography machinery and services, with over 28,000 employees spread across 16 countries. It was initially setup as a joint venture between Philips and Advanced Semiconductor Materials International (ASMI) to support the production of microchips, at a time where the massive future opportunities within the industry were only just being realised. It was not a smooth journey though; with difficulties arising in the 90s amongst fierce competition from the Asian market, ASML required more investment, and but for the backing and persuasion from Philips' board member Henk Bodt, the company could have folded. Research and development was always amongst the key offerings of ASML, and was instrumental in ensuring that it stayed competitive at the time, shown by the release of the PAS 5500, a modular lithography machine, enabling the production of multiple generations of advanced chips using one device. Since this breakthrough the company has not looked back, keeping R&D at the heart of the company ethos, spending over €2.2 billion on this in 2020 alone.

In order to produce some of the newest and most cutting-edge chips, often used in high powered personal computers, the photolithography machines required to print the smallest node sizes on the wafers are exclusively produced by ASML. In addition to this, the company has also developed the software alongside the hardware, in order to control the machines, as well as provide diagnosis and drive continuous improvement within the process.

In the latest Annual Report published by ASML, the net sales of the company for the year of 2021 were around €14 billion, and with the huge demand for more semiconductor fabs to be built over the next 5 to 10 years, it is difficult to see a scenario where ASML will not continue to prosper [1]. This is a crucial example of how early adoption of a technology, as well as continued R&D expenditure, has enabled long term success and resilience. [2]

[1] ASML, "Annual Report 2020," ASML, Eindhoven, 2020.

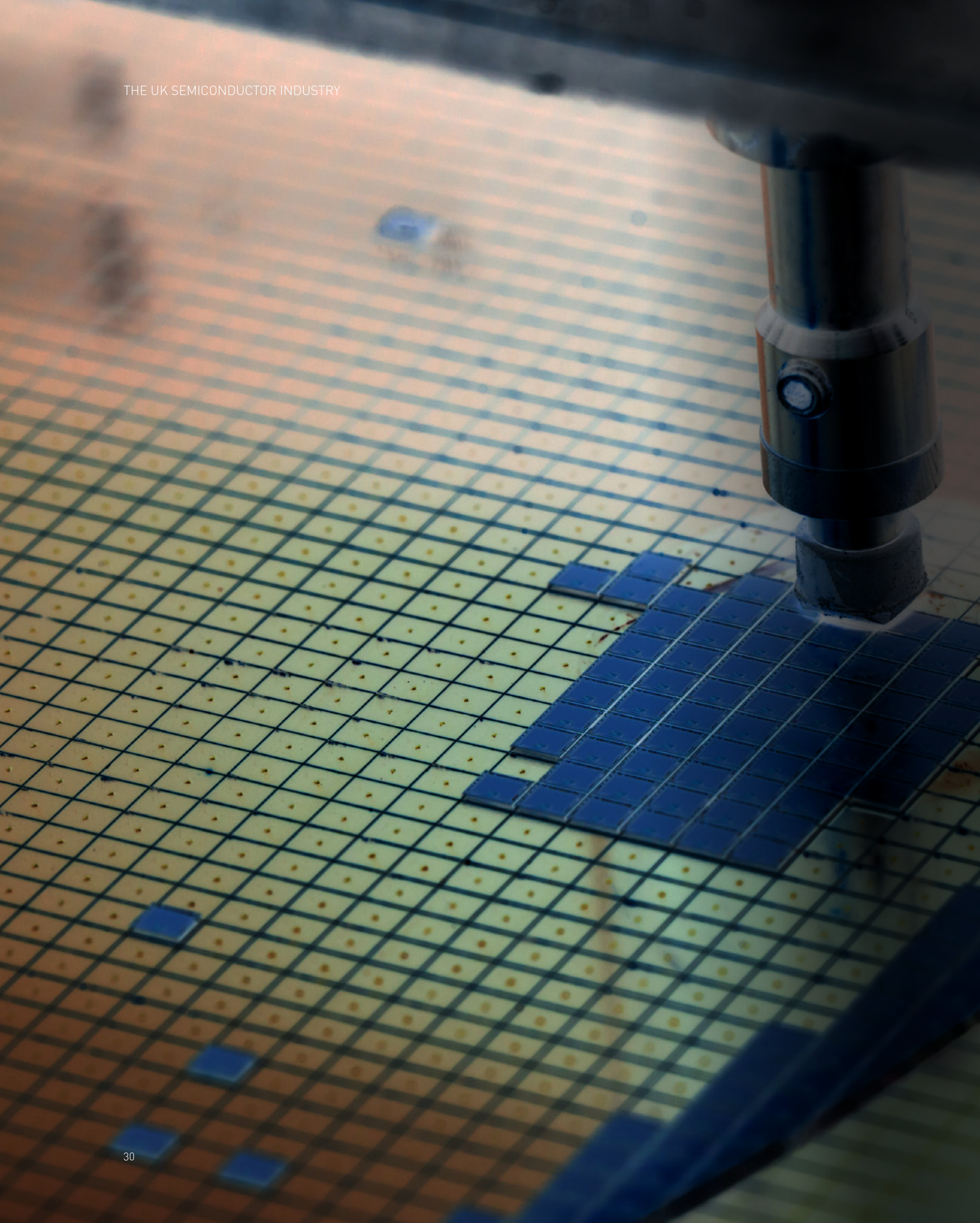
[2] https://www.asml.com/en

It is important to note that while much media attention is drawn towards the mass manufacture of high-end chips which fall into the Moore's Law category, there is a strong market for the less cutting-edge chips. By widening the lens to the whole ecosystem, taking into consideration More than Moore, we see that half of Europe's capacity is for chips with structure or node size measuring 180nm or more, which are generations behind the technologies dominated by TSMC and Samsung. By comparison, these transistors come in at a few nanometres and are most useful for consumer devices, the bulk of which are assembled in Asia. The larger European nodes are sufficient for the continent's many industrial firms that require specialised silicon for products such as cars, machine tools and sensors. "European chipmakers focus on their customer base," explains Jan-Peter Kleinhans of SNV, a German think tank. [1]

Specific UK data is difficult to retrieve as most of the information was collected whilst the UK was part of the European Union (EU). As Europe's contribution to the market is less than 25% across all areas, separating the UK from this data set, when compared to the rest of the world, is far too granular. As the UK has left the EU, the data on the UK's contribution to the global and European value chains will become clearer and give a stronger numerical indication of its position.

As the UK is not a world leader in the high-end chip sector, nor does it have large scale fabrication capabilities, the focus on niche high-value manufacturing is a key strategy for the long-term development of the UK semiconductor industry. Companies such as PragmatIC Semiconductor Limited have already taken the initiative. In a statement from the company's Chief Operating Officer Ken Williamson, the following points were made: "As the world focuses on the current global semiconductor shortage and blue-chip companies redirect billions of dollars to Moore's Law capacity expansion, there is a need for the world, and the UK, to re-think how we approach semiconductor applications. Not every device needs to be capable of running ultra-high-speed (GHz) applications – often what we need is something that ticks along in the background or is occasional use electronics. Although this circuitry does not need to be built on the latest generation (deep sub-micron) technology nodes, this is where the mainstream electronics world has been focused and where it continues to expand capacity. This "performance-at-any-cost" approach adds needless complexity and cost to what should be a simple circuit, along with an unnecessarily high carbon footprint."

[1] The Economist, "In the global chips arms race, Europe makes it's move," The Economist, London, 2022.



THE UK LANDSCAPE

The UK's involvement in the global value chain spans across all markets and uses both silicon and compound semiconductors (CS). Although silicon chips have their limitations in terms of speed, efficiency, and power, they are unlikely to be replaced completely anytime soon by compound semiconductors. The end markets that UK companies supply into include rail, medical, consumer, automotive, aerospace, military, energy, industrial, maritime including subsea, and space and defence including satellite. With the COVID-19 crisis disrupting supply chains and geopolitical tensions increasing, semiconductor companies have become more interested in achieving end-to-end design and manufacturing capabilities for their technology. Many governments share this interest and are attempting to support their local semiconductor markets. The UK has political stability, a relatively low-cost workforce, and outstanding engineers supported by technical colleges and universities specialising in the leading-edge engineering fields, all of which makes the UK an attractive country to invest in, whether manufacturing or developing semiconductor products. In the 70s, many large global semiconductor companies invested in the UK as an ideal location. Their selection was based on a combination of factors that included political stability, an environment that was free from natural disasters such as tsunamis, earthquakes, and arid environments, yet with an abundance of high purity water, resilient energy supply, a skilled workforce and creative and innovative engineers trained by world class universities and colleges. However, due to reduced shipping costs and a low-cost labour force, many customers relocated to Asia. Today, the UK still has the same benefits and resources, whilst the labour costs in Asia are beginning to rise, the lack of skilled workers is increasing, and the issues with human rights and political stability worsen. This once again makes the UK a strong country of choice. With a united and effective message to central government, the UK can build resilience, especially within the new emerging technologies and carbon neutral materials markets.

In July 2021, the government released 'The UK Innovation Strategy: leading the future by creating it'. Within this document, it states the following: "The UK is a leader in power electronics that allows us to connect and construct systems. Without it, we could not connect renewable energy systems to our existing grid or shift between electric and petrol sources in our hybrid vehicles. Microelectronic chips are used in every digital device. The UK is already a leader in the design of semiconductors, and with sufficient support, it has the potential to become a leading designer and manufacturer of compound semiconductor chips and technologies. This would allow the UK to capitalise on increased global demand for semiconductor chips and support domestic production in critical sectors like health, telecoms and automotive. By the mid-2030s UK companies – including those based at established clusters in Wales, Bristol and Cambridge – could play an increasingly central role in a supply chain of acute geopolitical importance."

At present, there is no definitive UK consensus or strategy for semiconductors. This is where the UK senior industry leaders must come together to unite with one voice. This should be a central point of contact between industry and government and replicate the success shown by the Society of Motor Manufacturers and Traders (SMMT), whose purpose is to support and promote the interests of the UK automotive industry at home and abroad. Their main focus is to work closely with member companies, and act as the voice of the motor industry, promoting its position to government, stakeholders, and the media.

Senior semiconductor industry leaders are currently in the initial stages of coming together with a united voice, to highlight the UK's strengths and capabilities across horizontal markets to the government. This is an initiative being driven by NMI and has support from CSA Catapult, Bessemer Society, industry analysts, academia, and manufacturing site leaders, with the results of this sure to have huge implications on the future of the UK semiconductor industry.

Jillian Hughes
NMI (National Microelectronics Institute)

THE CURRENT CAPABILITIES – MORE THAN MOORE

The UK semiconductor landscape covers different substrates including silicon, compound semiconductors and other emerging materials (film and diamond structures etc.). There are currently 25 manufacturing sites in the UK and Ireland that use a range of base materials with end markets in battery technology, magnetics, sensors, communications, photonics, and power applications. These sites range from a few hundred wafer starts per month (how many wafers can be processed per unit time by the facility) to several thousand, employing from 50 to 1000 staff. In addition to this, the nation has wafer manufacturers Shin-Etsu and IQE providing the raw materials used to process the device/chip. There is strength in larger node size silicon semiconductor manufacture, with over 50 years of experience in the UK in this area from both a manufacturing and design perspective. The processing of all silicon chips is built on fundamental processing technologies, largely common to all product types. Based on this common processing technology, there is a potential opportunity for migration of existing silicon semiconductor manufacturers to compound semiconductors (wide-bandgap technology) should the market and business roadmaps determine this, aligned with government priorities and focus. The UK also has strong compound semiconductor know-how in the development of products for end markets such as sensors and communications.

It is also key to include the many other manufacturing facilities which do not directly produce chips, but which lie within the supply chain, as these will be vital to the future of the UK semiconductor industry. This includes material and chemical suppliers and manufacturers, as well as equipment manufacturers and packaging companies.

As has been made evident through the conflict in Ukraine, the reliance on other countries for key resources and services has had worldwide impacts. One of the main effects has been the increase in gas prices, as Russia supplies around 41% of Europe's natural gas. This is in addition to the energy crisis already being experienced across Europe. There are also direct impacts on the semiconductor supply chain in the form of neon shortages. Neon is vital within the photolithography process, and over 90% of the world's neon supply originates from Russia [1]. The full effects of the conflict have yet to be realised, but with the increased sanctions against Russia being put in place by numerous countries, supply chain issues will have an impact for potentially years to come. As mentioned earlier in the report, the only sure way to build true resilience within supply chains is to have capabilities in each sector, reshoring and competing as much as possible.

[1] E. Segal, "Ukraine Crisis Creates New Strains on Global Supply Chain," Forbes, Ney York, 2022.

MATERIAL	UK DESIGN CAPABILITY	UK FABRICATION CAPABILITY	MOORE'S LAW	MORE THAN MOORE
SILICON (SIMPLE) – LARGER NODE SIZE, GREATER THAN 180NM	HIGH	HIGH: SOME FABS CAPABLE OF 1 BILLION DEVICES PER YEAR		YES
SILICON (COMPLEX) – SMALLER NODE SIZE, LESS THAN 180NM	HIGH: WORLD-LEADING MICROCONTROLLER UNIT (MCU) DESIGN	NONE	YES	
COMPOUND SEMICONDUCTORS – MADE FROM TWO OR MORE ELEMENTS	HIGH: START-UPS, SMES AND LARGER COMPANIES	HIGH: MIX OF SMALL BOUTIQUE AND LARGE-SCALE PRODUCTION		YES
OTHER – THIN FILM – USED WITHIN PHOTOVOLTAIC CELLS AND OPTICS	HIGH: SUPPORTED BY ARM	HIGH: WORLD-LEADING THIN FILM FABRICATION		YES
OTHER – 2D – NATURAL SEMICONDUCTORS WITH SINGLE ATOM THICKNESS	HIGH	HIGH: EARLY-STAGE COMPANIES		YES

Figure 7: UK Semiconductor Capabilities

CLUSTERS

Clusters are fast becoming one of the most critical contributors to economic growth and recovery in the UK. For the country to sustainably recover from both the effects of COVID-19, as well as the uncertainties that Brexit has brought about, high performing firms in all sectors across the country are needed more than ever, whether these are co-located in a cluster or distributed more widely. Some of the key statistical reasons for the adoption of clusters include the major contributions to growth. In 2014, there were 31 economically significant clusters across all sectors operating in the UK, around 8% of the UK's businesses came directly from these, generating 20% of UK output (gross value added) [1]. In addition to this, clusters provide a pool of high-value, well-paid jobs within the economy.

The United Kingdom's top 31 clusters together employ four million out of the 30 million employed individuals, with the average salary typically higher than those in the surrounding region. Finally, clusters bring advantages to businesses that are not easily measured or replicated in other environments. Clusters are ecosystems buzzing with soft knowledge across a myriad of networks and connections that not only promote a better understanding of what customers want, but also support emerging innovations.

This also drives huge attraction to the area from investment firms and businesses, as well as from talent both nationally and internationally. This virtuous circle is difficult to create by design – accordingly, such clusters can represent a defensible competitive advantage for the UK. The mixing of cleverly placed and strategically important clusters with the UK's levelling up agenda is a potential strategy to create thriving economic and innovation environments in areas that desperately require investment and attention.

The UK has expert knowledge and skills within the semiconductor manufacturing technology area, gained over many years. With the rise of new technology and applications, there are many new opportunities and capabilities across the compound semiconductor market, with leading academic institutions including the universities of Swansea, Cardiff, UCL, Sheffield, Manchester, Bangor, Cambridge, Strathclyde, Glasgow, Nottingham, Bath and Warwick. Talent retention and cultivation is an important focus for the UK, and with numerous world class clusters distributed across the UK and Ireland, there are only two which focus on semiconductors, located in Scotland and South Wales/Bristol, with additional electronics and technology research being undertaken in the Cambridge Tech Cluster.

[1] McKinsey & Company, "Industrial Revolutions: Capturing the Growth Potential," McKinsey & Company, London, 2014.

SPOTLIGHT

CSCONNECTED

CSconnected is helping to create the world's first compound semiconductor (CS) cluster. The cluster is found in the South Wales and Bristol region, and brings together leading university researchers, high-tech companies and future-focused businesses, linking to diverse sectors including healthcare, digital communications and energy. To date, the cluster contributes a GVA of £172 million per annum to the regional economy, which creates a turnover of half a billion pounds, and supports around 2,100 full time equivalent jobs.

Compound semiconductors are much more complex than long established silicon technology. At the moment, around 80% of the semiconductor chips produced in the world are of pure silicon. The remaining 20% use compound semiconductors, which combine two or more elements to form a compound. For example, silicon (Si) and carbon (C) form silicon carbide (SiC). Although compound semiconductors are more complex to manufacture than silicon, they possess three properties that outperform silicon:

- Power (power electronics for electric vehicles)
- Speed (radio frequency for 5G and RADAR)
- Light (photonics for optical fibre communications)

This is why CSA Catapult has three matching technical divisions, supported by Advanced Packaging. Those are Power Electronics, Photonics and RF & Microwave. There are many ways of combining two or more elements from the periodic table, which creates a wide variety of semiconductor materials, each with unique properties. Some of the more common compound semiconductors include: gallium arsenide (GaAs), gallium nitride (GaN), silicon carbide (SiC), indium phosphide (InP) and even aluminium gallium indium phosphide (AlGaInP). Their unique properties mean that compound semiconductors are finding increasingly diverse applications, and could be vital in allowing future technologies such as AI, 5G and electric vehicles to become commonplace across the world. [2]

A range of organisations have helped unlock industry innovation by bridging the gap between academia and industry, and by addressing skills and training needs create a national pipeline of individuals with qualifications and knowledge to meet current and future demand. The success of this groundbreaking cluster has been built through sustained, long term investment and partnership between the Engineering and the Physical Sciences Research Council (EPSRC) and UK Research and Innovation (UKRI), the Compound Semiconductor Applications Catapult, the Welsh Government, the Higher Education Funding Council for Wales and the Cardiff City Regional Deal. [1]

One of the up-and-coming technology areas being investigated by the Advanced Propulsion Centre, part of the CSconnected cluster, is the research of gallium oxide. This is an ultra-wide-bandwidth (UWB) material, which could provide a step change in performance relative to silicon carbide (SiC) and gallium nitride (GaN), and is still very much at a low technology-readiness level. This technology shows great promise in the high-power electronics sector, allowing the processing of high voltages and currents to deliver power, supporting needs such as regulating voltage levels, controlling power flow to electric motors and enabling a plug-in vehicle to charge from the electricity grid. [3] [4]

[1] J. O'Neill, "What Role Will Semi Play in the Future of Industry 4.0?," DesignNews, California, 2020.
[2] Compound Semiconductor Applications Catapult, "What are Compound Semiconductors," Compound Semiconductor Applications Catapult, Newport, 2021.
[3] Advanced Propulsion Centre UK, "Power Electronics Roadmap 2020," Advanced Propulsion Centre UK, Warwick, 2021.
[4] https://csconnected.com/

CASE STUDY

SCOTLAND'S PHOTONICS CLUSTER

INTRODUCTION TO PHOTONICS

Photonics is the critical enabling technology of the 21st century. It underpins modern innovations that are fundamental across many aspects of modern life including optical fibre internet connections and liquid crystal display (LCD) screens. Photonics enables efficiency improvements and step-changes in product performance across a diverse range of sectors from healthcare and transport, to agriculture and communications. In addition, the quantum technologies of tomorrow, including quantum computing and quantum imaging, will require further new advanced photonics technologies, with some estimates suggesting that around 60-80% of all quantum technology is dependent on lasers and advanced optics. Given the ubiquitous nature of photonics technologies, it is perhaps unsurprising that it represents a significant opportunity with the global photonics market estimated to be worth £575 billion and predicted to reach £800 billion by 2025. [1]

PHOTONICS IN SCOTLAND

Scotland has a long and distinguished history in the field of photonics, and has been punching above its weight in a globally competitive market for over a century. The photonics sector in Scotland is a £1.2 billion industry [2] supporting more than 6,400 high value jobs, with a GVA per employee at three times the national average. It is also a hugely internationalised sector, with 97% of output exported outside Scotland, 79% beyond the rest of the UK [3]. In many ways the photonics sector in Scotland meets the blueprint for a formal cluster. Around 60 companies make up its industrial core, with a number of large, multinational anchor organisations sitting alongside high growth potential SMEs. They are supported by an internationally recognised academic base and an enviable array of translational assets providing research capability, access to funding and a focal point for collaborative opportunities. It is also a sector that remains remarkably resilient to the twin challenges of COVID-19 and Brexit and this resilience has positioned the sector to play a critical role in Scotland's post-pandemic recovery. Indeed, the sector was recognised as a key opportunity area for Scotland within the Scottish Government's recently published National Strategy for Economic Transformation. Scottish photonics products and services are applied to a diverse range of application areas with aerospace and defence, healthcare and industrial manufacturing leading the way as traditional areas of strength for the sector in Scotland. Scientific research and the photonics supply chain are also key global markets for the sector. In addition there is increasing activity in areas such as energy, communications and transport, and more recently space and quantum. Particular areas of expertise in Scotland include laser system manufacture, optical communications, supply chain, imaging and advanced sensors.

PHOTONICS SCOTLAND

Photonics Scotland, originally founded as the Scottish Optoelectronics Association in 1994, is one of the oldest national photonics organisations in the world and remains one of the largest technology communities in Scotland. It is a community for all photonics and photonics-enabled organisations in Scotland, being the focal point for the sector and a trusted partner to a number of members allowing the representation of their views to a number of key stakeholders. Photonics Scotland also facilitates a cohesive sector, providing a range of events, working groups and networking opportunities that help to drive collaboration between industrial and academic partners. Ultimately, the goals are simple: to raise the profile of the sector, help grow this thriving cluster, and drive innovation in photonics in Scotland. In 2019, this included the publication of a vision paper – 'Photonics in Scotland: A Vision for 2030'. Central to this paper, which was developed with input from across the industry, is a vision to treble the size of the sector by 2030. [4]

Dr Alison Mcleod
Technology Scotland

[1] Photonics 21, "Market Data and Industry Report 2020," Photonics 21, Paris, 2020.
[2] Photonics Leadership Group, "Youtube," Photonics Leadership Group, 1 July 2021. [Online]. Available: https://www.youtube.com/watch?v=QoyMsRkB1tA. [Accessed 8 March 2022].
[3] Photonics Scotland, "Photonics in Scotland 2021 Report," Technology Scotland, Glasgow, 2021.
[4] https://technologyscotland.scot/wp-content/uploads/2019/04/scottishphotonics-paper-final.pdf

DIGITAL MANUFACTURING

Automation and robotics are heavily linked to digitalisation and Industry 4.0 principles, which all provide massive opportunities within the semiconductor sector. Industry 4.0 is the latest stage of the industrial revolution, and there is a lot of hype and myth surrounding what Industry 4.0 and a Smart Factory is. A number of definitions have been used within the last decade to try and better explain what it really means, including:

- A fully integrated and collaborative manufacturing system that responds in real-time to meet changing demands and conditions.
- It is the integration of smart digital technology and manufacturing, which emphasises automation, machine learning and real-time data.
- A highly digitised shop floor that continuously collects and shares data through connected machines, devices, and production systems.

Additional technologies, data analytics, cloud computing, Internet of Things (IoT), artificial intelligence, augmented reality (AR), Total Productive Maintenance (TPM) and digital twins all form part of Industry 4.0 and Smart Factory. To simplify, Industry 4.0 is about using data to improve processes. Design, production, quality, purchasing, sales, and stores all generate data, and can all use that data to help deliver improvements. The key is understanding what needs to be measured or improved, what data needs to be collected, how it can be linked and how it should be presented.

For semiconductors, measurement of the product can be linked to the manufacturing process to refine wafer production and increase yield per wafer. As the density of semiconductors increases, the effect on product performance can quickly be analysed, and the quality of the product is improved. The ability to collect and analyse large quantities of data and quickly compare results after product or process modification reduces development time and cost, allowing a high-quality product to be released to market much faster.

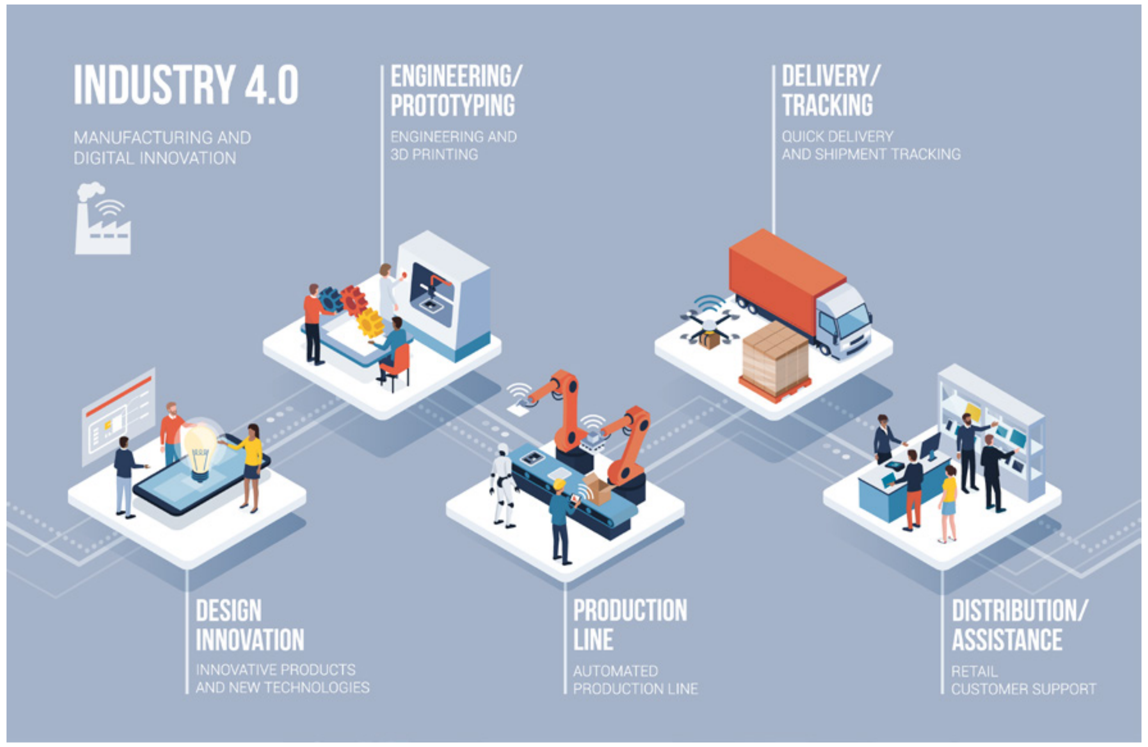


Figure 8: Industry 4.0 Applications

The systems and components required for real-time data sharing, data acquisition and storage rely on semiconductors. There is huge scope for the development of chips to support these applications and, more specifically, chips for AI.

AI chips provide one of the biggest opportunities within semiconductor manufacture moving forward, as they are still in the early stages of design and development. Applications of AI are becoming more and more apparent, from big data analytics and military equipment to facial recognition software and self-driving cars. The semiconductor industry is key to responding to both the opportunities and challenges associated with this technology. AI describes a machine or software application's ability to reason, learn, and act like human cognition. In essence, AI is attempting to make it possible for machines to do what we as humans consider as thinking. Semiconductor architectural improvements are needed to address data use in AI-integrated circuits. Improvements in semiconductor design for the specific application of AI will be less focused on the raw performance and size of semiconductor chips, as seen historically when developing chips for high-end computers and mobile phones. The focus is likely to shift far more to the speed of movement of data in and out of memory, and more efficient memory systems, something which will require new advances in packaging, materials and design, rather than cramming more and more transistors onto a chip. [1]

[1] Institute of Electrical and Electronics Engineers, "International Roadmap for Devices and Systems," Institute of Electrical and Electronics Engineers, Piscataway, 2020.

Artificial intelligence cannot become successful simply by using AI chips alone. Memory is also an important component in the development and realisation of AI technology, where high throughput parallel processing places multiple strains on the data bandwidth in memory systems. The demand for AI system memory will create opportunities for companies that can produce the necessary memory components. In addition, as AI systems scale up, the performance of the architecture linking subsystems and devices will become a bottleneck. As a result of this, opportunities also exist for companies within the semiconductor sphere to create high speed interconnects to meet the demand of high-volume data flowing between systems. Additionally, AI chips today can contain multiple processors to achieve maximum parallelism, resulting in very large node sizes. This presents a significant challenge for thermal and high voltage power management in which custom cooling solutions may be required. This creates opportunities for packaging vendors to come up with products that have a thinner form factor and less thermal dissipation for a more cost effective solution. [1]

Analysts are projecting there will be more than 75 billion installed IoT devices worldwide by 2025.

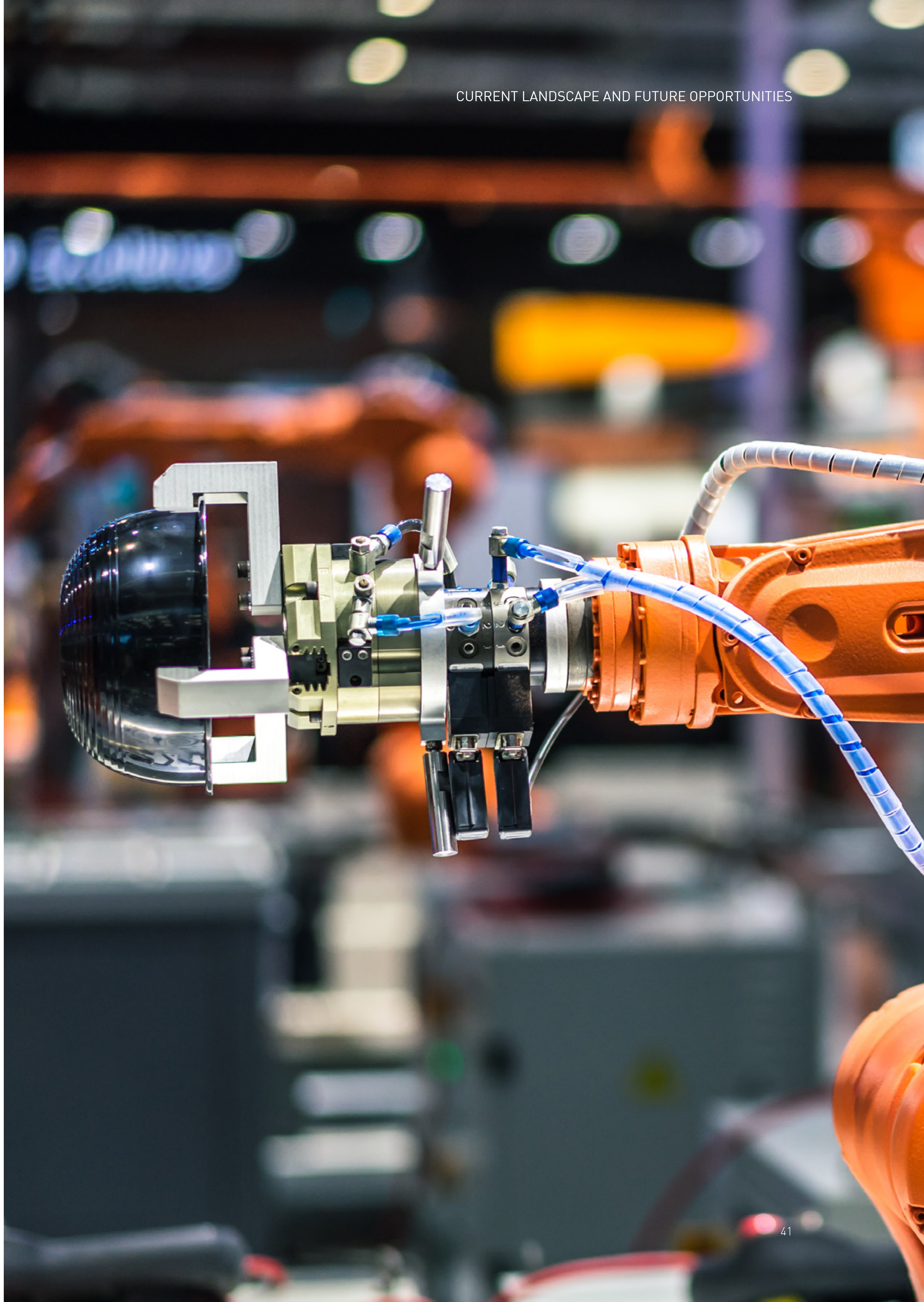
- An autonomous car will generate 4,000 GB of data each day.
- The volume of global data is expected to increase ten-fold to 163 zettabytes from 2016 to 2025.
- By 2023, 5G technology is forecasted to reach 1.3 billion subscriptions worldwide.
- Emerging technologies such as electric vehicles, drones, smartphones and tablets, flexible displays, ultra-high-speed internet, and more, are forecasted to reach $6.9 trillion by 2030.

Something clear from these predictions is the reliance on computing power to handle the large amounts of data at speeds that haven't been reached before. Not only is this new digital era an opportunity for manufacturers, suppliers, transporters, and consumers, but it also has major implications for the semiconductor industry. The industry provides a much wider spectrum of components than previously, beyond the classic computer and phone processing chips. Developments in leading-edge logic and memory chips to support applications like AI, cryptocurrency, big data, AR/VR, and more, will be of vital importance to enable the adoption of Industry 4.0 and growing the UK semiconductor industry. [2]

David Roddis
MTC Digital Transformation Team

GLOBAL SEMICONDUCTOR DEMAND BY END-USE					
COMPUTER	**COMMUNICATIONS**	**CONSUMER**	**INDUSTRIAL**	**AUTOMOTIVE**	**GOVERNMENT**
32.3%	31.2%	12.0%	12.0%	11.4%	1.0%

Figure 9: Global Semiconductor Demand by End-Use [3]



[1] Deloitte, "Semiconductors – the Next Wave," Deloitte, London, 2019.
[2] J. O'Neill, "What Role Will Semi Play in the Future of Industry 4.0?," DesignNews, California, 2020.
[3] Semiconductor Industry Association, "2021 State of the U.S. Semiconductor Industry," Semiconductor Industry Association, Washington, 2021.

RESEARCH AND INNOVATION

CASE STUDY

COVENTRY UNIVERSITY: GALLIUM NITRIDE (GAN) SMART POWER INTEGRATED CIRCUITS

Researchers at Coventry University are currently involved in world leading research of Hall-effect magnetic sensors and GaN power integrated circuit technology development. They have patented a next generation of GaN Hall-effect magnetic sensors operating at wide bandwidth and in harsh environments. These sensors enable higher efficiency, greater precision and extended use for applications in automotive, non-destructive testing, non-vertical wells, automation, space, etc. The GaN magnetic sensors are fully compatible with the 600V GaN Power HEMT technology implicating that they can be easily integrated to form a smart power technology platform and future GaN power ICs. Bearing in mind evolution of silicon technology from discrete power devices to power ICs, GaN based power transistors need to follow the same path if there is to be a widespread adaptation of the technology in high volume applications such as propulsion systems. The widespread adaptation of wide bandgap technologies such as GaN helps support the UK Government's net zero target.

Coventry University is leading a UK based consortium working on transforming a high performing GaN discrete device into a smart power electronic solutions by monolithically integrating 600V power HEMTs, temperature sensors, senseHEMTs and Hall-effect sensors to galvanically monitor overload, open-load and for load current analogue feedback. This integration will increase functionality, enable a reduction of system volume, reduce cost of assembly and as chip temperature can be actively compensated, improve reliability and efficiency of the power device. These are fundamental requirements for complex power electronics systems, when installed in limited volume, hostile (high temperature/vibration) environments (electric vehicles for example).

Gallium Nitride (GaN) High Electron Mobility Transistors (HEMTs) offer fundamental advantages over silicon-based devices. The higher critical electric field with lower dynamic on-state resistance and smaller capacitances compared to silicon Metal Oxide Field Effect Transistors (MOSFETs) make GaN suitable for high-speed switching applications. Therefore, GaN HEMTs operate with reduced dead-times resulting in higher efficiency and enabling passive cooling. High switching speed brings smaller passive components and improve overall power density.

Magnetic current sensing in power electronic systems enable system control, protection and diagnostic features. Although there are many current sensing methods, only three are commonplace in volume applications, namely resistive, current transformer and Hall-effect techniques.

Resistive sensing is widely used and low-cost. However, the shortcomings are insertion loss, lack of galvanic isolation and series inductance constraining its operating frequency range.

Current transformers representing the next tier of commonplace solutions are bulky, costly, filter direct currents (DC), and are mostly designed for narrow frequency ranges. They offer electrical isolation and don't require external power.

The Hall-effect sensors offer greatest linearity over a wide range of magnetic fields from nano-Tesla to several tens of Tesla, provide galvanic isolation, sense direct currents and alternating currents and are customisable and fully compatible with emerging wide bandgap technologies.

Soroush Faramehr and Petar Igic
Coventry University

IP OWNERSHIP

SPOTLIGHT

ARM LIMITED

Arm started out as a small UK company in 1983 called Acorn Computers, based in Cambridge. During the 80s the company was developing its very own computer, and a small team within Acorn was tasked with sourcing a processing chip. Not being able to find a chip that fit the specifications at the time, they decided to design their own. The purpose of the computer being designed was part of a government initiative to have a computer within every classroom in Britain, so the chip powering this should be useful, but simple by design. The design of the chip was based on something called 'Reduced Instruction Set Computing', which is the way that instructions are given and processed within the chip. After the launch of the classroom computer, the BBC micro, the company decided to create its own spin off company, specifically for chip design, and with this Advanced Risk Machine LTD (Arm Limited) was born.

When Arm Ltd was officially launched in 1990, it was a joint venture between what is now Apple Inc. and VLSI Technology. The deal between the companies was that Apple could provide the initial cash injection, VLSI could provide the tools and machinery to produce the chips, and Acorn provided the engineers. One of the breakthroughs for Arm was in 1993, when Nokia was in search of a chip to power its new mobile phone. Arm created a custom chip for Nokia, and the design was officially licensed by Texas Instruments, and sold to Nokia. The Nokia 6110 was a huge success, and the Arm7 chip inside it became the flagship for mobile phones, with over 10 billion chips sold.

By 2008 the demand for smartphones was huge, and increasing the performance of mobile phones whilst extending the battery life was an ever more important specification. This led to the introduction of the multi core chip, named the Cortex-A9 MPCore, which was able to address the huge dynamic range in processing to accommodate for a smartphones vastly different user needs, from gaming to texting. [1]

The Arm business model is different from most others; it maintains independent relations with hundreds of customers around the world, many of which are rivals. Unlike some other firms in the industry such as Intel, Arm does not manufacture, sell and ship its own products, preferring instead to license its intellectual property in return for a fee. This allows the British company to work with any chip manufacturer. Using this business model, Arm Limited has not only become the largest tech company in the UK, but has managed to grow into a £31 billion business with more than 6000 employees. [2]

THE FUTURE OF ARM

The Company was initially purchased in 2016 by a Japanese investment group, SoftBank, with the sole motive of ownership. In 2020 though, a bid worth around $40 billion was put in from US tech giant Nvidia, who is a direct competitor to Arm with its own design capabilities, to take over the company. As well as this, there were rumours of plans to move the heart of the company abroad. The British Government have been fighting to block the deal, as under the Enterprise Act 2002, ministers can block any deals that could potentially pose a threat to the nation's security, media plurality and financial stability. In addition to this, there was a great deal of industry opposition, as well as the Federal Trade Commission moving to block the move, as it would give Nvidia too much market share. More recently, reports have suggested that the deal may fall through as regulatory hurdles and industry opposition mounts, making it almost certain that the two-year time frame the companies aimed to complete the deal in will expire. Stories such as this highlight the need for the UK to invest in and protect our semiconductor industry, and gain resilience. It also provides an excellent opportunity, in which companies can have huge impacts on the industry without having the manufacturing capabilities themselves, something which could be vital for the UK, who are lacking in any high-volume semiconductor manufacture. [3]

[1] B. Walshe, "A Brief History of Arm," Arm Community, Cambridge, 2015.
[2] R. Davies, "Arm Holdings: what is it and does its sale to Nvidia matter?," The Guardian, London, 2020.
[3] https://www.arm.com/

ENVIRONMENTAL IMPACT

The environmental impact of semiconductor manufacture is becoming an ever more pressing issue. As the complexity of chips increases and the size continues to decrease, the operational requirements to power the machines and facilities are growing exponentially. The fabs rely heavily on huge amounts of electricity and water to function properly. Processes such as photolithography and ionization take up a vast amount of energy, and the constant running of the almost entirely automated factories has led to the average fab taking up more energy than most automotive plants. Another issue is water usage. To keep the wafers stable between ion implantation, they are heated to over 1000 degrees, and subjected to thorough wet cleanses between each heating cycle, of which there can be over 25 of these, using roughly 20,000 tonnes of water per day, which is equivalent to around 58,000 homes. [1]

When assessing the emissions a company produces, a scope system has been created as an international accounting tool, named the Greenhouse Gas (GHG) Protocol. To fully understand the impact that chip manufacturers have, it is important to consider not just scope 1 emissions, but to also look deeper into scope 2 and 3. Scope 1 emissions are defined as 'direct emissions from company-owned and controlled resources', which includes fuel combustion, company vehicles and fugitive emissions. Scope 2 is defined as 'indirect emissions from the generation of purchased electricity, steam, heating and cooling consumed by the reporting company'. This is a particularly important consideration for semiconductor fabs, due to the large amount of electricity used. Both scope 1 and 2 emissions are easy for companies to track as they are direct results of the operations and processes which they carry out, but scope 3 emissions are more complicated. Scope 3 emissions are 'all other indirect emissions that occur in a company's value chain' [2]. As the semiconductor value chain is global and a lot of the areas of the value chain are region-specific, such as almost all testing and packaging facilities being in Taiwan and China, the logistical emissions and impact are significant, and where the majority of the company's emissions will come from. In the push for net zero, the rules and regulations around emissions and energy use are only going to get stricter, and there will be an ever-increasing responsibility on companies to not only be mindful to reduce their emissions, but to also look upwards and downwards within supply chains.

This gives a strong case for countries to begin reshoring various parts of the value chain and to develop their capabilities, giving more stability within their value chain, as well as reducing emissions. Companies such as PragmatIC within the UK have already begun to develop capabilities to cover the entire process of semiconductor manufacture, albeit on a small scale [3]. Managing the entire supply chain, including producing wafers, manufacturing the chips, as well as testing and packaging them, allows PragmatIC to operate with far more agility than traditional fabs can, meaning they are able to suit the demands of the market and switch product lines in days rather than months. Focusing on customer needs and changing the current ideology of the industry is also key. Producing chips that meet customer requirements, not adding unnecessary power and complexity to the product, ensures that the process can be far less energy intensive.

As well as this, semiconductors are vital to enabling technologies that will ensure the UK meets its net zero strategy, intending to decarbonise all sectors of the UK economy and reach net zero emissions by 2050. Dr Wyn Meredith, Director of the Cardiff-based Compound Semiconductor Centre, commented that: "Reducing the energy consumption of future electronic systems cannot be achieved by optimisation of existing ICT hardware solutions alone. The UK needs to harness its extensive, world class semiconductor materials research base to focus on developing solutions which take a holistic approach from novel materials to electronic devices and components." [1]

Semiconductor material development will be key to enabling countries to reach their net zero targets, and research being completed by the Henry Royce Institute, a partnership of nine institutions within the UK, is looking to prove this. The institute has created a key framework containing five technology roadmaps, each looking to develop materials for applications in sectors that will be imperative to reducing emissions:

- Materials for photovoltaic systems to increase the amount of power generated by solar panels.
- Materials for low-carbon methods for the generation of hydrogen and chemical feedstock.
- Thermoelectric energy conversion materials. These are found in heating, refrigeration, and air conditioning systems.
- Caloric energy conversion materials, to eliminate the use of carbon in heating and refrigeration systems.
- Materials for low-loss electronics, resulting in more power-efficient electronics and computing.

Baroness Brown of Cambridge, Julia King, the chair of the Henry Royce Institute, commented that: "Making the transition to cleaner, greener energy that meets the growing needs of multiple UK sectors from transportation to utilities, and the individuals they serve, while at the same time reducing our waste streams, will require continued industry innovation and government support and intervention." Specific funding channels for semiconductor manufacturing and material development will be instrumental to meeting the UK's net zero targets.

Companies such as Clas-SiC Wafer Fab have already begun to make huge strides in this area, opening the world's first dedicated open foundry to manufacture silicon carbide semiconductors for the power sector. Silicon carbide (SiC) wafer and compound semiconductor technology are fast emerging as the key enabler in smaller, lighter and more energy efficient power systems of the future. One of the key applications for this area is in reducing the energy usage of power systems, enabling huge reductions in emissions to contribute to a carbon neutral economy.

1 E. Barrett, "Taiwan's drought is exposing just how much water chipmakers like TSMC use (and reuse)," Fortune, New York, 2021.

2 World Business Council for Sustainable Development, "The Greenhouse Gas Protocol," World Resources Institute, Washington DC, 2015.

3 The Manufacturer, "Goodbye Mr (expensive and wasteful) Chips".

1 L. Shipton, "Welsh Semiconductor Cluster and Henry Royce Insititute call for a UK initiative to address the net-zero future of electronic systems," Henry Royce Institute, Manchester, 2020.

THE AUTOMOTIVE INDUSTRY

The need for cars to be more fuel efficient, and the impetus of government regulation to lower emissions, are driving up semiconductor demand for both traditional vehicles and electric/hybrid electric vehicles (EV/HEVs). As this happens, the number of electronic components, and therefore semiconductors within them, will grow.

ELECTRONIC SYSTEMS AS % OF TOTAL CAR COST

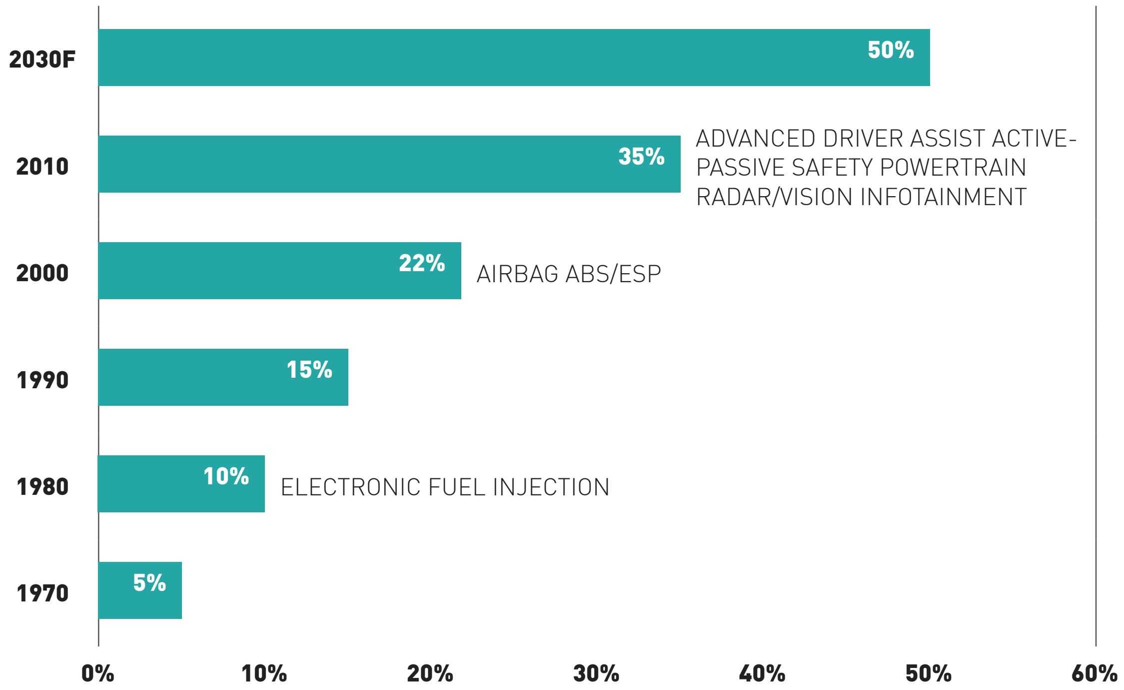


Figure 10: Electronic Systems as a Percentage of Total Car Cost [1]

The UK government has announced a two-phase plan for the transition to electric vehicles. Phase one will see the sale of petrol and diesel cars prohibited after 2030. This means that cars without the capability to run purely on electricity or have the capability to drive a significant distance with zero emissions, for example, hybrids, will be banned after this date. Phase two will begin in 2035, whereby after this date, all vehicles will be required to be fully zero emissions, meaning that fully electric cars will dominate the market. This includes providing grants for homeowners, businesses, and local authorities to install charge points, and supports the deployment of rapid charge points in locations such as service stations. The government has also pledged £583 million in grants to the public, for the purchase of zero or ultra-low emission vehicles. A study conducted by the Advanced Propulsion Centre showed that for an automotive electronics power converter, up to 40% of the total bill of materials cost is from the semiconductor chip, highlighting just how key they are to this area.

[1] Deloitte, "Semiconductors – the Next Wave," Deloitte, London, 2019.

The transport Secretary Grant Shapps MP stated: "Bringing forward the phase-out date (from 2050 to 2030) could create 40,000 extra jobs by 2030, particularly in our manufacturing heartlands of the North East and across the Midlands, and will see emissions reductions equivalent to taking more than four million cars off the road" [1]. This roadmap from the government is a bold one, with the automotive sector having to rapidly adapt to the new upcoming plan. This change though is all underpinned by the electronics industry having to provide the subsystems to support both the new vehicles being produced, but also the infrastructure changes and charging points. Even now, the average new car on the road holds over 1000 semiconductor chips, controlling everything from the airbags to the satnav.

Several opportunities will become available through the growing electrified automotive sector, and some are particularly important to the UK. One of these is the unique requirements of the automotive electronics sector compared to consumer electronics. Consumer electronic chips, like those found in smartphones and PCs, are completely driven by size and processing capability. This means that the node sizes are ever decreasing in this sector, and only the giants of the industry such as TSMC and Intel can produce these chips. Looking to the automotive sector, we see a difference in priorities whereby the size of the chips is less important, and the reliability and resilience to environmental conditions become vital. Reliability in a car compared to a mobile phone is much more important, as the safety implications of failure are far greater than in consumer electronics, as are the ranges of temperature, vibration, and humidity. This opens doors for countries such as the UK, which may not be able to create chips at the bleeding edge of technology down at the 5nm node sizes, to develop and manufacture semiconductor chips for very different applications to what has been seen traditionally.

[1] Department For Transport, "Government takes historic step towards net-zero with end of sale of new petrol and diesel cars by 2030," Department For Transport, London, 2020.

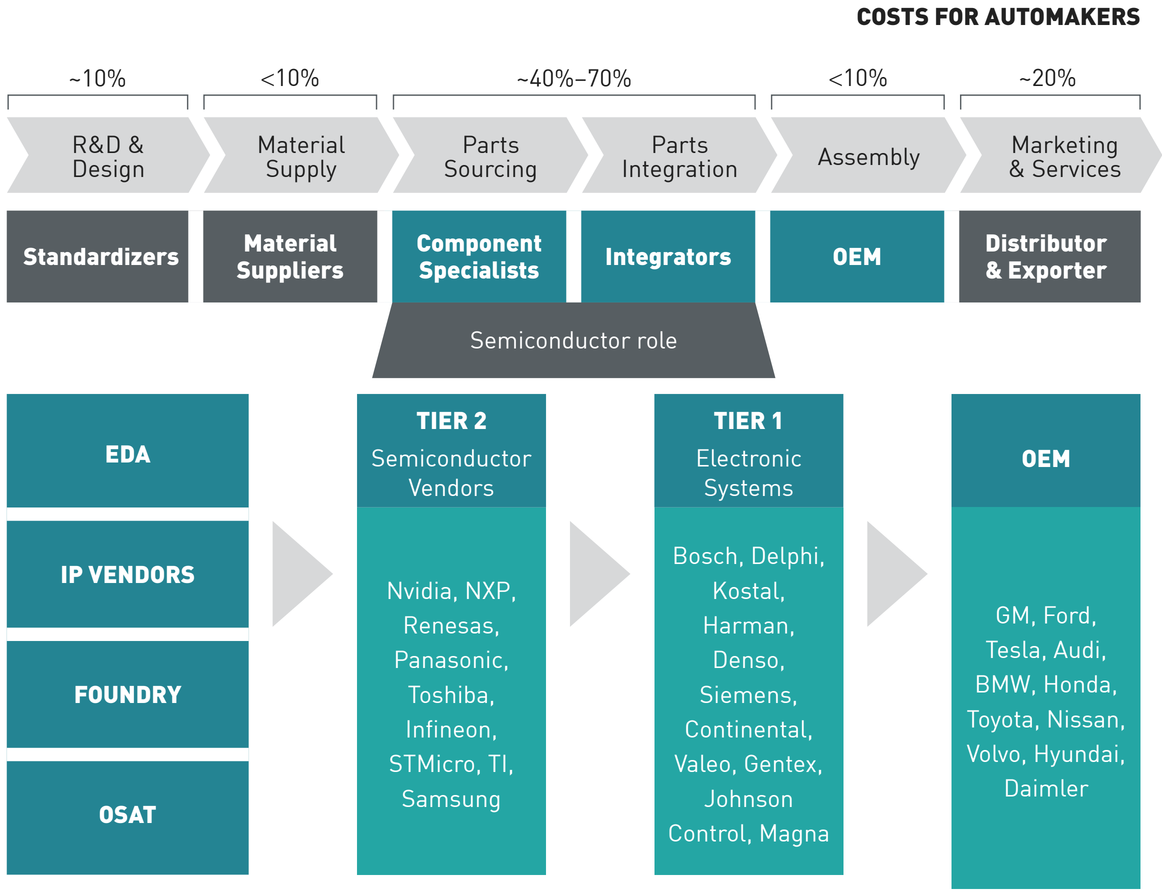


Figure 11: Role of Semiconductors in the Automotive Ecosystem [1]

In addition to this, the supply chain model for the automotive sector has begun to change in recent years. Previously the supply chain model has been relatively linear, whereby Tier 2 semiconductor vendors provide components to Tier 1 electronic systems companies, who integrate these into their products and sell to OEMs. Companies such as Tesla have been disrupting this model, developing their own integrated circuitry (IC), software and operating systems to have more control over their supply chain and product. This is also chiefly because with cars becoming more and more electronic, they are also becoming more connected. As the evolution of driverless technology and digital connectivity in cars increases, whereby the internal workings of the car are connected to each other and the outside environment, it becomes more crucial for the systems to be able to communicate efficiently. This has led to the need for the supply chain to work much closer together, to develop systems that are highly connected and collaborative. A key example of this is Nvidia, who are currently collaborating directly with Audi to build an artificial intelligence platform with deep learning technology for autonomous driving. [2]

[1] Deloitte, "Semiconductors – the Next Wave," Deloitte, London, 2019.

[2] www.nvidia.com/en-gb/self-driving-cars/partners/audi/

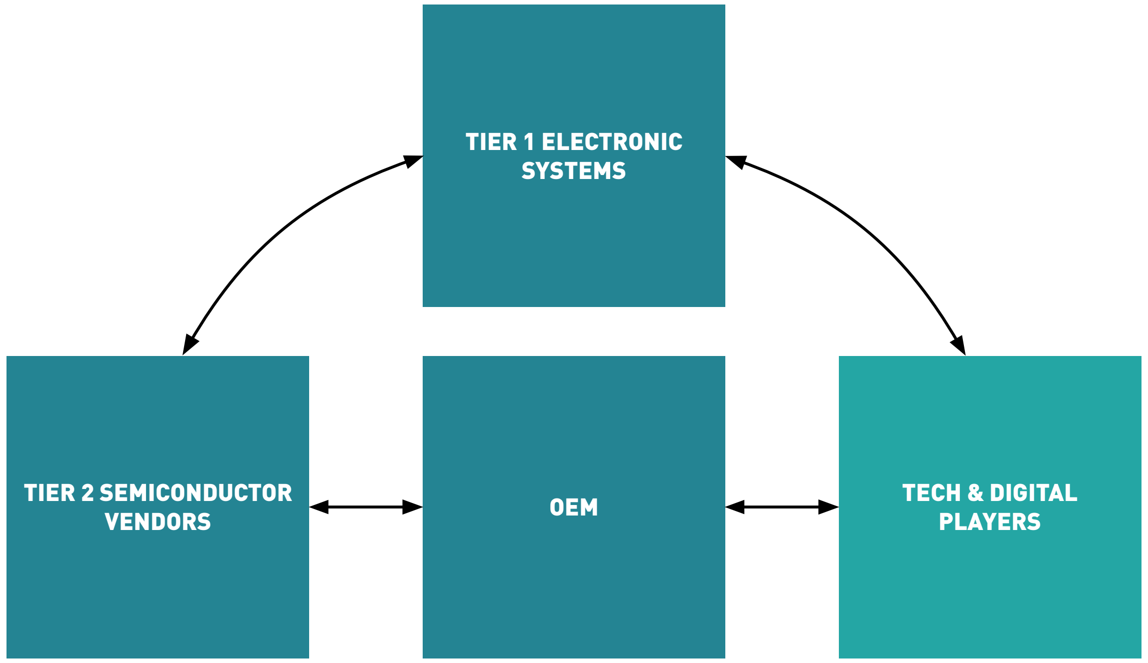


Figure 12: New Automotive Supply Chain Ecosystem [1]

If we couple this with the already well established and world-renowned automotive industry that exists within the UK, there is huge potential to grow and revitalise the industry. The UK automotive industry is a vital part of the UK economy, worth more than £78.9 billion in turnover adding £15.3 billion to the UK economy. With some 180,000 people employed directly in manufacturing and an excess of 864,000 across the wider automotive industry, it accounts for 13% of total UK export of goods, worth £44 billion, and invests £3 billion each year in automotive R&D. [2]

[1] Deloitte, "Semiconductors – the Next Wave," Deloitte, London, 2019.

[2] Society of Motor Manufacturers and Traders, "SMMT Motor Industry Facts," Society of Motor Manufacturers and Traders, London, 2020.

SECURITY

National defence and security are on every government's list of priorities, and cyber security is an essential goal for any leading technology nation to develop resilience against increasing risk of attack.

The globalisation of the semiconductor industry means that the supply chain of integrated circuits (ICs) is now separated and distributed worldwide. To reduce production costs and shorten the time-to-market, more and more third party entities are involved in the supply chain to provide outsourcing of design services, foundry services and off-the-shelf intellectual property (IP). However, several untrusted entities may be involved, which increases the security risk from cyberattacks across the supply chain. To ensure the resilience of the supply chain, engineering design practices need to ensure that they include the ability to identify code or IP that has not been part of the original design specification, such as the insertion of hardware Trojans (malicious modifications to the IC which can enable unconsented data sharing, denial of service and even device shut down).

In the last couple of decades, various advanced computing systems, embedded systems and electronic devices have been developed and widely deployed. There have been multiple examples of security attacks within this time, with key examples being 'Meltdown' and 'Spectre', two separate hardware attacks which exploit critical vulnerabilities in modern processors. As well as this, both Amazon and Apple reported in 2015 that surveillance chips had been discovered within their server hardware. The ubiquity of the Internet of Things (IoT) also revolutionises lives through remote healthcare, autonomous vehicles, and smart homes. However, the large number of connected devices opens new cyberattack vectors.

In the semiconductor industry, the patent-related technical information of a product is the most valuable for the company that designs, manufactures, and owns the product. However, an adversary can deconstruct an IC to reveal the layout, netlist, and architecture or extract knowledge from a hardware circuit. This process is commonly referred to as reverse engineering.

Strengthening and scaling up the UK semiconductor industry to help us design and manufacture products within the UK would allow us to take more control in ensuring the quality and cyber resilience of the supply chain and manufacturing process, reducing the reliance on other countries to provide support in areas of critical vulnerability, and reduce the effectiveness of reverse engineering being successful in building in security by design into the supply chain.

Jillian Hughes
NMI (National Microelectronics Institute)

HEALTHCARE

The COVID-19 pandemic has highlighted just how important healthcare systems and the NHS are for the United Kingdom. The healthcare system is underpinned by a range of technologies that provide displays, processing and storage of information, power management and connectivity, which are all powered by semiconductor technologies. Many medical devices rely on semiconductors to function such as electronic beds, ventilators, x-ray and ultrasound equipment, patient monitors and drug delivery devices.

Modern medicine is becoming more and more reliant on new technologies to advance patient care and provide more accurate and early diagnoses. Such technology is enabling surgeons to remotely operate robotics, giving far greater accuracy and precision to the surgeons, as well as enabling the surgery to be less invasive for the patient. Neuromorphic chip technology, which can mimic the human brain, can be used in applications such as retinal implants, helping people who have lost their sight to regain partial vision. Predictions for the coming years forecast a shift in medicine, with remote care of patients becoming more and more prevalent. This includes the use of web-integrated wireless devices, used to connect doctors to patients from their own homes, and allow examinations to become remote. Wearable technology is also becoming far more widespread, allowing users to monitor things such as sleep, blood sugar levels and ECG information, giving them a better idea of their health [1].

The adoption of new technologies within healthcare presents numerous More than Moore opportunities, whereby the need for small node size, high processing power chips, is limited. This allows countries such as the UK to play a prominent role in this sector, and companies such as Ilika have begun to take advantage of this development. Ilika is a UK-based pioneer in solid-state battery technology, leveraging the advantages of semiconductor materials to create ultra-low-power micro-batteries. These are used to power remote or implantable medical devices, allowing applications such as health monitoring, vagus nerve stimulation devices and smart contact lenses.

[1] A. Samet, "The top medical monitoring and healthcare wearable device trends of 2022," Insider Intelligence, New York, 2022.

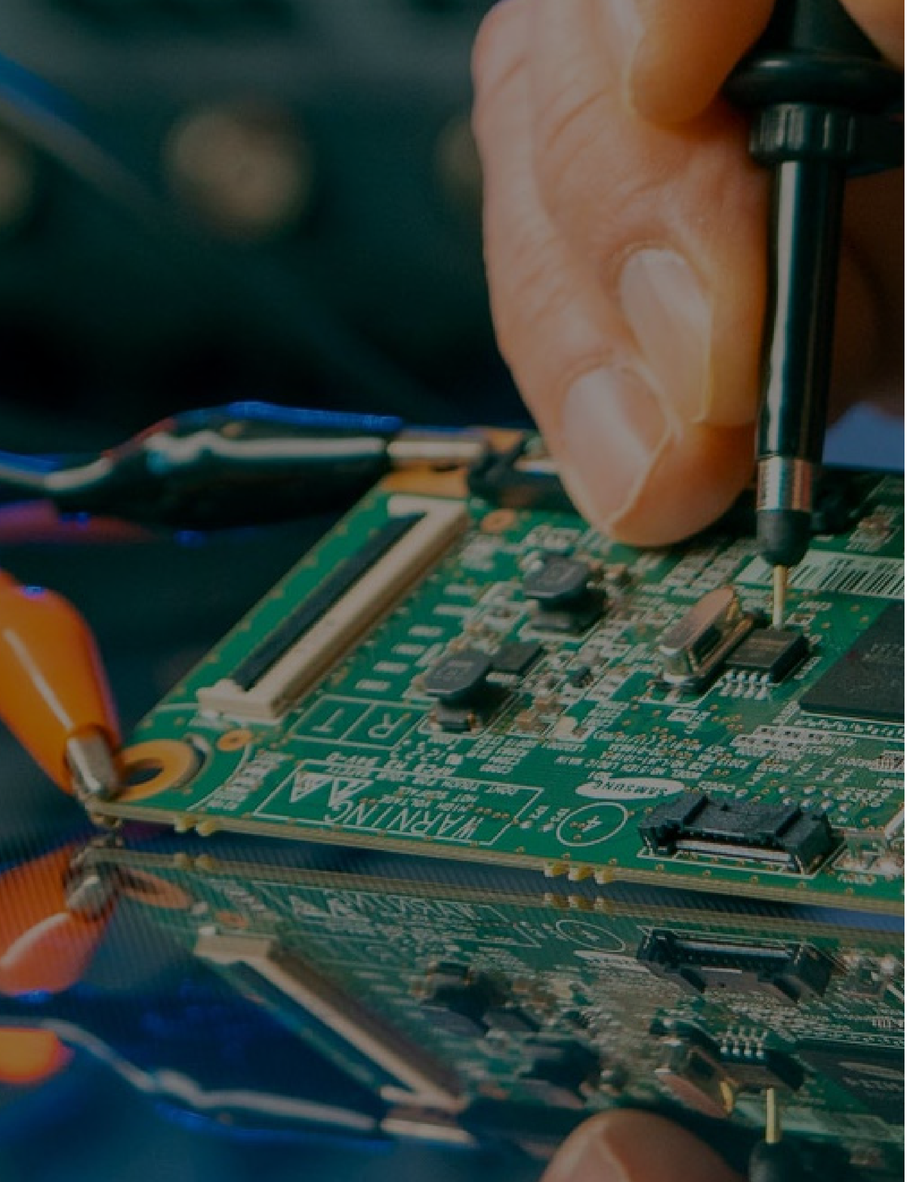
UK OUTLOOK ON SKILLS

There is a fundamental problem for the UK. Our participation in and leadership of technological advances is being limited by a chronic skills shortage in semiconductors and electronic engineering.

Over many years, too few students have been studying electrical & electronic engineering and this means that there are insufficient graduate engineers to drive forward innovation and progress. This shortage is particularly acute in the sphere of semiconductor manufacturing and embedded systems design.

The semiconductor and electronics sector is extremely important to the economy of the UK; it contributes £8.4 billion GVA and £19.4 billion turnover, which represents 4.7% of manufacturing and 12% of R&D spend in the UK [31]. However, the demand for employable graduates is currently outstripping supply. According to UCAS, in 2021 only 3,245 UK students enrolled on degrees in electronic and electrical engineering, and of these only 335 were women. This is less than half the number of students starting mechanical engineering degrees (7,050) [1].

We know that 22% of employers in this sector have reported problems in recruiting engineering graduates and the IET has reported that there are only 11% females in the electronics workforce in the UK. Therefore, without intervention, the problems of gender imbalance and the overall shortage of graduates will only get worse for the electronics sector. This situation, of increased demand and insufficient supply, is evidenced by the salaries being currently offered. As shown in Figure 13, graduate starting salaries in IC processing are averaging £32,000.



[1] UCAS, "UCAS End of Cycle Analysis 2021," UCAS, Cheltenham, 2021.

EXPERIENCE		GRADUATE	3 YEARS	5 YEARS	10 YEARS	12+ YEARS
DIGITAL IC DESIGN	Perm (p.a)	£34,000	£42,000	£52,000	£52,000	£75,000+
	Cont (p.h)	-	£42	£48	£50	£52+
DIGITAL IC VERIFICATION		£34,000	£42,000	£55,000	£65,000	£80,000+
		-	£42	£48	£52	£55+
PHYSICAL DESIGN		£34,000	£42,000	£52,000	£65,000	£75,000+
		-	£40	£46	£50	£52+
FPGA DESIGN		£31,000	£40,000	£47,000	£60,000	£70,000+
		-	£40	£48	£50	£52+
ANALOG/MIXED SIGNAL IC DESIGN		£34,000	£42,000	£52,000	£65,000	£75,000+
		-	£42	£48	£52	£55+
RF IC DESIGN		£37,000	£45,000	£57,000	£70,000	£85,000+
		-	£42	£48	£52	£55+
ANALOG/RF LAYOUT		£30,000	£38,000	£41,000	£52,000	£60,000+
		-	£40	£45	£50	£50+
IC TEST		£32,000	£38,000	£40,000	£45,000	£60,000+
		-	£45	£50	£55	£60+

Figure 13: Semiconductor Industry Salary Distribution [1]

[1] Intellectual Capital Resources, "2021 end of year Salary Review - Software, Semiconductors, Electronics, Sales & Marketing, Supply Chain," Intellectual Capital Resources, Reading, 2021.

To tackle the skills challenge, we must develop a coherent, national, strategy. This should be underpinned by strategic initiatives to build a skills base in semiconductors in the UK. There are five problems that need to be tackled:

1. Lack of engagement in schools with little visibility about semiconductors for young people.
2. A shortage of graduate engineers coming into the semiconductors and electronics workforce.
3. A lack of knowledge among educators about the opportunities and routes into the semiconductors sector.
4. A lack of specific undergraduate course content to support the future semiconductor workforce.
5. A lack of industry-academic engagement to produce the high-level post-graduate skills in sufficient numbers.

Initiatives should be developed to:

- Ensure more schoolchildren are aware of semiconductors, electronics, and engineering and demonstrate to these children, their parents, and teachers that there are exciting and worthwhile careers available as designers and engineers in the semiconductor sector.
- Collaborate and provide opportunities to allow young people to develop their interest in electronics and semiconductors, through university study and/or apprenticeships.
- At university, ensure that undergraduates are encouraged to pursue careers in semiconductors, and they are supported in their professional development so when they graduate, they are equipped with work-ready skills and experience.
- Provide relevant and focused post-graduate study to develop key areas of technical knowledge and understanding to contribute to innovation-led businesses and future semiconductors research and development.
- After graduation, there is a need for a community of semiconductor designers, manufacturers, and engineers to secure the future pipeline, and further need to build relationships and provide a representative voice for the sector on skills.

Stewart Edmondson
UK Electronics Skills Foundation

CONCLUSION AND RECOMMENDATIONS

The recent disruption within the semiconductor industry has highlighted a need for more resilience, and for companies and regions to re-evaluate their position within the value chain. As Moore's Law technologies have become so inaccessible due to the huge capital investment needed, as well as how complex and detailed the manufacturing process has become, the UK must look to take advantage of the growing demand for More than Moore.

As discussed within this report, there are opportunities across several sectors such as digital technology, healthcare, automotive, and security, in groundbreaking areas such as compound semiconductors, power electronics, sensing, and artificial intelligence, as well as in simple silicon design and manufacture for discrete and analogue applications.

The recommendations that follow apply to all relevant stakeholders within the industry including government, technology providers, research and educational establishments, the finance community and, not least, manufacturers, and are intended to guide relevant policy and future initiatives.

RECOMMENDATION 1:
UK senior industry leaders must come together to unite with one voice. This central point of contact should look to provide an agnostic outlook on the current state of play within the industry. It should take an objective look at the entire value chain, and openly and honestly assess the current risks and opportunities to the UK semiconductor industry.

RECOMMENDATION 2:
Industry leaders should work more closely with government to create both short-term and long-term plans and strategies for the industry. These should provide actionable statements formed from value chain analysis, considering the risks and opportunities previously identified. Government should look to support these proposals both financially and operationally, to enable the industry to build competitive advantage.

RECOMMENDATION 3:
The industry should capitalise on the research and innovation ecosystem that the UK possesses. Universities and academics are working at the forefront of several semiconductor research areas, the most notable being the development of compound semiconductor technologies. This is still an emerging area, and early adoption of the technology and the creation and support of a hub for knowledge and expertise within the UK would stimulate a thriving economic and innovation environment.

RECOMMENDATION 4:
Tap into the existing semiconductor expertise and talent pool that had already been established. The UK involvement in semiconductor technologies spans across all markets including rail, medical, consumer, automotive, aerospace and military, and uses both silicon and compound semiconductors. Although the nation does not possess the high volume, smallest node size manufacturing capabilities, there is still considerable scope to develop current More than Moore capabilities domestically, as well as support our simple silicon (larger node size) design and manufacturing facilities.

RECOMMENDATION 5:
The UK must look to re-shore and compete in areas of the current global value chain. This is the only sure way that we can build resilience against future disruption. These areas include the development of wafer manufacturing capabilities, flexible chip manufacture, testing and packaging. This would also allow the nation to take more control in ensuring cyber resilience and quality control of products within the supply chain, reducing the reliance on other countries in areas of vulnerability,
and building in supply chain security by design.

RECOMMENDATION 6:
Ensure more schoolchildren are aware of the importance and relevance of semiconductors, electronics and engineering. Industry and academia should collaborate and provide opportunities for young people to develop their interest in electronics and semiconductors through undergraduate courses and/or apprenticeships. This would help the next generation to pursue careers in semiconductors and be supported in their professional development. Relevant and focused postgraduate study should also be implemented to develop key areas of technical knowledge and understanding to contribute to innovation-led businesses and future semiconductor research and development. Graduates need to be able to join a community of semiconductor designers, manufacturers, and engineers to secure the future skills pipeline. There is a need to build relationships and provide a representative voice for the sector on skills.

DEFINITIONS

SEMICONDUCTOR

Semiconductors possess specific electrical properties. A substance that conducts electricity is called a conductor, and a substance that does not conduct electricity is called an insulator. Semiconductors are substances with properties somewhere between the two. Integrated circuits (ICs) and electronic discrete components such as diodes and transistors are made of semiconductors. [1]

FAB

A semiconductor fab is a manufacturing plant in which raw silicon wafers are turned into integrated circuits. Several semiconductor companies are known as foundries, meaning they are only involved with the manufacture of chips, and often take up contracts with other companies to manufacture semiconductor chips using their own facilities. [2]

SEMICONDUCTOR CHIP

Used interchangeably with a chip, microprocessor or Integrated circuit (IC), a semiconductor chip is an electric circuit with many components such as transistors and wiring formed on a semiconductor wafer. [3]

COMPOUND SEMICONDUCTOR (CS)

These are semiconductor materials made from two or more elements, for example, silicon and carbon to create silicon carbide.

NODE SIZE

This is the industry-standard measure of the size and development of chip technologies, whereby the smaller the node size, the more developed the technology within the chip is.

TRANSISTOR

A transistor is a semiconductor device used to amplify or switch electrical signals and power. These are the basic building blocks of integrated circuits.

INDUSTRY 4.0

Industry 4.0 describes the growing trend towards automation and data exchange in technology and processes within the manufacturing industry. Industry 4.0 is about using data to improve processes. Design, production, quality, purchasing, sales, and stores all generate data, and can all use that data to help make improvements. [4]

INTERNET OF THINGS (IOT)

The Internet of Things describes real-life items that are integrated with sensors, processing ability, software, and other technologies. This is all connected to other devices and systems via the internet or other networks.

MOORE'S LAW TEC HNOLOGIES

Moore's Law focuses on reducing node size as much as possible, integrating more, smaller, and faster transistors onto a chip, following the general trend that, every two years, the density of transistors will double. This involves the use of silicon and produces mainly logic chips, used for the processing of information within computers and mobile phones.

[1] https://www.hitachi-hightech.com/global/products/device/semiconductor/about.html

[2] https://www.techtarget.com/searchstorage/definition/semiconductor-fab

[3] https://www.hitachi-hightech.com/global/products/device/semiconductor/process.html#:~:text=A%20semiconductor%20chip%20is%20an,integrated%20circuit%20(IC)%E2%80%9D

[4] https://www.twi-global.com/what-we-do/research-and-technology/technologies/industry-4-0

MORE THAN MOORE TECHNOLOGIES

More than Moore is a new, functional diversification of technologies, combining performance, integration, and cost, not limited to standard silicon chip scaling. This can involve the use of compound materials allowing the manufacture of chips with higher speeds, greater efficiency, and optical properties, for applications such as 5G connectivity, the Internet of Things, and new applications, ranging from autonomous driving to neural sensors. It also includes the manufacture of larger node size chips for discrete and analogue uses.

AUGMENTED REALITY (AR)

An enhanced version of the real physical world that is achieved using digital visual elements, sound, or other sensory stimuli delivered via technology.

TOTAL PRODUCTIVE MAINTENANCE (TPM)

Using machine run and downtime data to determine maintenance schedules and reduce unplanned stoppages.

DIGITAL TWIN

Simulation models of real production facilities that allow the analysis of various production scenarios to optimise factory performance.

CALORIC ENERGY CONVERSION MATERIALS

Caloric materials undergo significant temperature changes when an external field – a magnetic field, electric field, stress, pressure – is applied to them (or withdrawn from them). Thus, caloric materials show reversible thermal changes, i.e. caloric effects that are due to changes in applied driving fields. [1]

[1] https://www.royce.ac.uk/content/uploads/2021/10/M4ET-Caloric-Energy-Conversion-Materials-roadmap.pdf

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