Semiconductors: A test for the new Government

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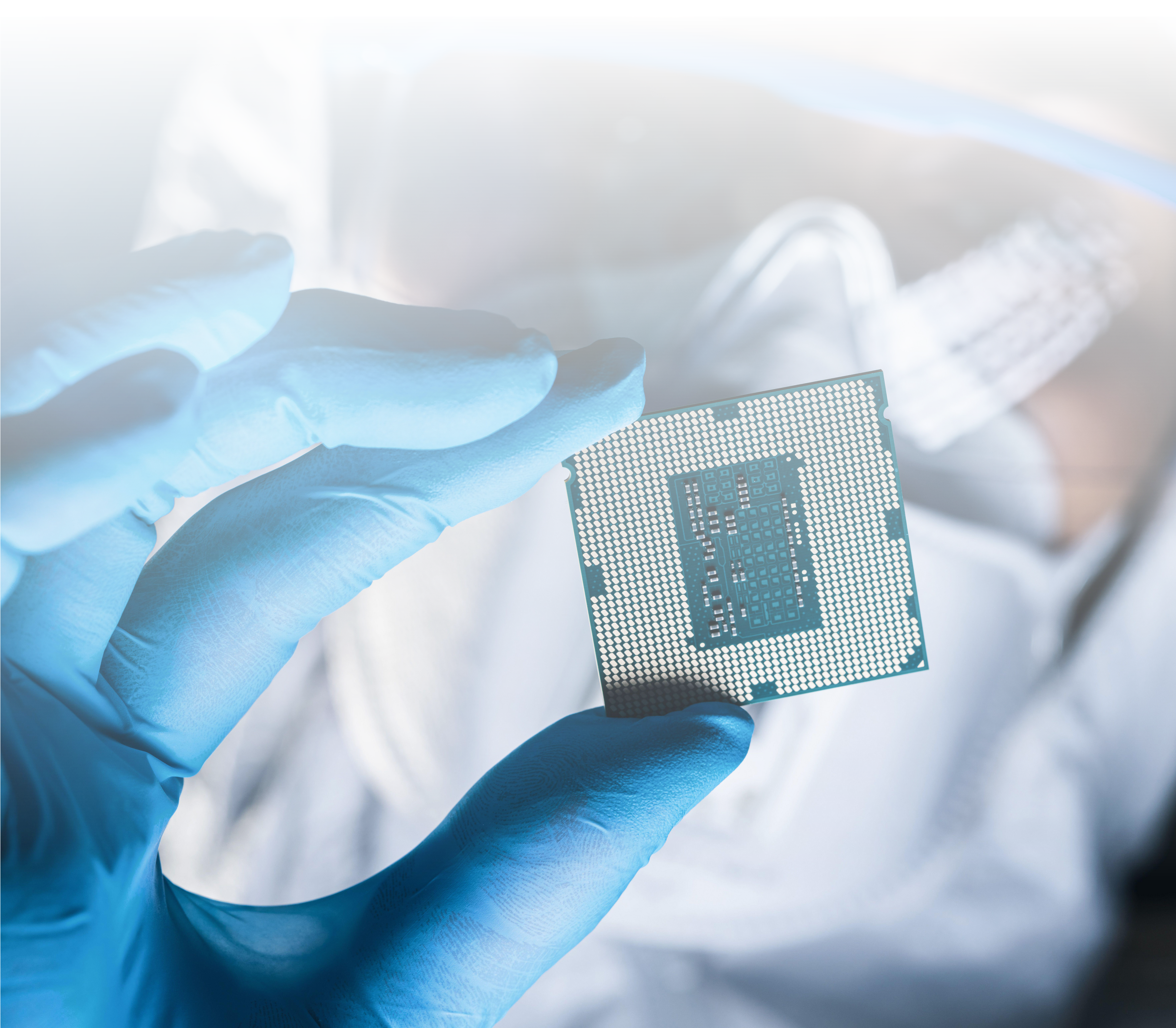
Foreword by Ruth Jones MP



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About the Author

Since joining the Financial Times in 1958, the author has been a close observer of industrial policy. He worked as the FT's industrial correspondent and industrial editor, and as US correspondent in New York. He left the FT between 1969 and 1972 to work for the Industrial Reorganisation Corporation and then for British Leyland. After returning to the FT he served as deputy editor (1973- 1980) and editor (1980-1990). After retiring from the FT he worked as a lecturer at the London School of Economics. In 2019 he was appointed head of industrial policy at Policy Exchange.

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Foreword

Ruth Jones MP

The Government has identified economic growth as its top priority. It has rightly recognised that a strong and consistent industrial strategy will be fundamental part of delivering that growth, alongside the clarity and consistency that gives industry the confidence to invest.

As Chair of the All-Party Parliamentary Group for Semiconductors, I have long championed the way that semiconductors play a pivotal role not only in our economic ambitions, but in underpinning our national security. Semiconductor companies, such as the semiconductor cluster in my constituency, are tremendous forces of innovation, generating valuable exports and supporting skilled local jobs.

Unfortunately, over the decades, previous Governments of all stripes have not always provided the industry with the support it deserves. Without further action, we risk falling further behind the EU, United States and other nations who are providing the investment and policy framework needed strengthen and grow the industry. We must do more to support the semiconductor design and manufacturing industries in this country, and to ensure that UK domestic capacity is embedding within reliable and secure global supply chains.

Policy Exchange's excellent report provides a forensic analysis of the history of semiconductor design and manufacturing in the UK. The creation of an open access foundry for compound semiconductors, as Policy Exchange recommends, would be transformative for the future of the industry, and is something I hope that Government will consider adopting as part of its industrial strategy.

The semiconductor industry needs to know the government is on their side and has a serious, considered plan to enable growth. That means embedding it within its industrial strategy – and treating it with the same seriousness as we do other priority sectors. Our semiconductor industry is not only a beacon of scientific progress, but can unlock developments and investment in fields such as healthcare, defence and AI.

As a country, we must identify our semiconductor strengths and build out from them. Policy Exchange's report provides us with the necessary foundations to do this, and I hope it will be read carefully by all who are making policy in this area.

Ruth Jones MP is Chair of the All-Party Parliamentary Group for Semiconductors

Executive Summary

As the new government works out its priorities for what it promises to be an active industrial policy the semiconductor industry is likely to be high on the agenda. This is an industry which has been central to the revival of industrial policy in other countries, and one to which the previous government devoted a good deal of attention.

The semiconductor strategy which the Conservatives published in 2023 was widely criticised as an inadequate response to the changes that have been taking place in the world semiconductor industry - the US-China trade war, the moves by the US and the EU to reduce their dependence on imports, and the increasing economic and strategic importance of semiconductors, not least for national security.[1]

The new government will have to decide whether to stick with that strategy or do something different. This paper suggests a way forward, based not on what other countries are doing but on building a distinctive position in a sector of the market - compound semiconductors - where the U.K. already has considerable strengths.

The government's options are constrained, as they were for its predecessor, by the fact that UK-based companies have largely withdrawn from the high-volume production of silicon chips. There is no large, broad-based semiconductor manufacturer comparable to the three leading European companies: Infineon in Germany, NXP in the Netherlands, and the Franco-Italian group, STMicroelectronics. All three of these companies are building new European fabrication plants, helped by government subsidies under the European Chips Act.

Even if the UK wanted to move in the same direction, there is no manufacturing base on which a larger industry could be built. In examining why semiconductor production has declined more steeply in the UK than in other European countries, this paper puts some weight on the lack of consistency in government policy towards the industry, especially in the period between the 1970s and 1990s. But it also notes that government support in Germany did not prevent Siemens, the country's principal semiconductor firm, from running into financial problems at the end of the 1990s, prompting the company to withdraw from the industry.

The survival of the three European companies has been due not so much to government support as to their ability to identify and exploit opportunities in sectors of the market which are less directly exposed to Asian competition. Some of these opportunities lay in European industries, notably the automotive industry, which have provided a large market for European-made chips and served as a base for supplying global markets,

1. National semiconductor strategy, Department for Science, Innovation and Technology, May 19 2023

especially in Asia; China's fast-growing car makers have become important customers.

The UK cannot hope to replicate what the European firms have done, but there is an opportunity, not in silicon chips, but in compound semiconductors. Devices based on these materials, which include silicon carbide and gallium nitride, are increasingly replacing or supplementing silicon in a range of applications, because of their low power consumption and other advantages. The UK already has competitive strengths in this part of the industry, but there is a missing ingredient: an open access foundry which could play the same sort of role for firms that design or make compound semiconductors as silicon-based foundries play in Europe, the US and Asia.

Such a facility would almost certainly need government support, but it should also attract investment from semiconductor design firms and from compound semiconductor users. It could be built on a greenfield site, or adjacent to an existing fabrication plant.

If the government decides to support such a venture, it needs to do so on a sufficient scale, and on the basis of a long-term commitment. One clear lesson from the semiconductor story set out in this paper is that it is better for governments not to intervene at all than to do so half-heartedly or intermittently.

Introduction

How can the UK strengthen its semiconductor industry? This is a question that came to the fore in 2020, when the worldwide chip shortage exposed the fragility of the UK's semiconductor supply chain; several important industries, notably the car makers, were badly affected. Then came an intensification of hostilities between China and the -US, causing further disruption in semiconductor trade.

The UK government responded to these events by commissioning a study of the industry, leading in 2023 to the publication of its semiconductor strategy. This document set out a number of steps aimed at reducing the risk of supply shortages, protecting national security and growing the domestic industry. How that third objective was to be achieved was left unclear.

If the Labour government wants to go further in semiconductors as part of its new industrial strategy, the starting point has to be a realistic assessment of where the UK now stands in relation to its international competitors. Crucial to such an assessment are comparisons with other European countries.

Although Europe has lost ground in semiconductors over the past few decades to Asian and American competitors, there are three large European manufacturers - Infineon, NXP and STMicroelectronics - which have survived the ups and downs of the last twenty years and retain a strong position in parts of the market. There is no such company in the UK.

UK-based firms have done well in other parts of the industry, notably Arm, whose processor design is widely used in mobile phones and many other electronic devices. Arm is the star of the UK semiconductor industry, but it is not a manufacturer; it makes its money through licence fees and royalties. Production is where the UK has lagged behind, a fact that became very evident during the world semiconductor shortage. Subsequent events, including the subsidy programmes introduced in the US and the European Union, have left the UK on the sidelines, unable to participate in the expansion of semiconductor production that is taking place in other countries.

How did the UK get itself into this situation, and what can be done about it?

To answer these questions this paper starts with a brief review of the world semiconductor industry since the 1950s: US leadership in the early years; the challenge from Japan and later from other Asian countries; and the emergence of a complex, largely Asia-dominated global supply chain.

The paper then turns to Europe. It examines the events that led to the decline of semiconductor production in the UK and shows how the three European companies have survived and prospered. The concluding part suggests a way forward, based on supporting and expanding a part of the industry – compound semiconductors – in which the UK-based firms are well placed to compete.

1. Background: the world semiconductor industry

The US takes the lead

The first semiconductor device, the transistor, was invented at Bell Laboratories in the US in 1947. Used initially as a replacement for the thermionic valve, it was a more efficient device for amplifying and switching electrical signals in radio sets and other electronic goods. The first transistors were based on germanium, but this material was soon displaced by silicon, which has become the preferred starting material for most of the world's semiconductor production. There is also a growing demand for compound semiconductors, such as silicon carbide and gallium nitride, which can deal with higher voltages than silicon and operate at higher frequencies.[2] Compound semiconductors account for up to 20 per cent of total semiconductor production.

The industry was dominated in the early years by American companies, which built on Bell's original invention and made innovations of their own. The growth of the industry during that period relied on demand from the federal government, principally the Department of Defence and the National Aeronautics and Space Administration. For missiles and other military equipment, and for space exploration, these agencies wanted smaller and more reliable electronic components, and they were willing to pay high prices; they were also sponsors of research, although most of the key technical advances came out of company-financed research, not from government contracts. By the early 1970s the importance of government orders had declined, and the computer industry had become the industry's biggest customer.[3]

At the start the leading manufacturers in the US were diversified electronics companies such as RCA and General Electric, which made semiconductors for use in their own equipment as well as for outside sale. IBM and A T & T were also major producers, but entirely for internal use. As demand for semiconductors increased the industry attracted new entrants. Some of them, like Motorola and Texas Instruments, were established firms which had other businesses but focused mainly on semiconductors. Others, such as Intel, which was founded in 1968, were start-ups which did not make electronic equipment but designed and manufactured semiconductors only for external customers; they were described as merchant producers.

A major technological change at the start of the 1960s was the invention

2. Compound semiconductors also offer optical/photonic properties for sensing and quantum applications.
3. Richard N. Langlois and W. Edward Steinmueller, The evolution of competitive advantage in the worldwide semiconductor industry 1947-1996, in David C. Mowery and Richard R. Nelson (eds), Sources of industrial leadership, Cambridge 1999.

of the integrated circuit, a device that packed a large number of transistors on a single wafer and made possible a higher degree of miniaturisation. This marked the start of the Large Scale Integration (LSI) era, paving the way for two semiconductor devices which were to play an important role in the subsequent growth of the industry: a memory chip for storing information - the Dynamic Random Access Memory (DRAM) - and a logic chip, the microprocessor, which processes information and is often described as the brains of the personal computer. These two categories, memory chips and logic chips, currently account for about 70 per cent of world semiconductor revenues, with the remainder consisting of a wide variety of semiconductor types.[4] Standard integrated circuits are made in volume for a range of customers; application-specific integrated circuits (ASICs) are customised to meet the needs of particular users.

The semiconductor industry grew rapidly as new applications were developed, not only in electronic equipment such as computers and mobile phones, but in other industries such as automobiles, where semiconductors came to be used in braking systems, power steering, and many other functions. It was an intensely competitive but also highly cyclical industry, with periods of over-investment leading to excess capacity, followed by a slump in prices when demand grew more slowly than expected.

The challenge from Asia

European electronics firms were quick to take up the transistor, licensing the technology from Bell, but they began to fall behind the Americans after the introduction of the integrated circuit. By exporting from the US and building European factories American firms rapidly increased their share of the market, forcing European governments to look for ways of helping their companies catch up. These efforts had only limited success.

The first successful challenge to US leadership came in the 1970s from Japan. Thanks to a combination of government support and large-scale investment by electronics companies such ss NEC, Hitachi and Toshiba, the Japanese industry launched an attack on the memory chip market. Through economies of scale and a rigorous attention to manufacturing efficiency and quality, they soon overtook their American rivals. Even Intel, which had been the leader in memory chips for several years, withdrew from that business; it shifted to microprocessors, a market that was less exposed to Japanese competition and in which it was later able to build a dominant position.

The rise of the Japanese came as a shock to the US government. There were fears that an industry which was seen as essential to national security might go the same way as consumer electronics, which had been overwhelmed by Japanese competition. A government-supported programme, known as Sematech, was put in place to help the industry regain lost ground. The US industry subsequently staged a comeback, although the recovery probably owed less to government intervention than to the refocussing by Intel and others on higher-margin, design-

4. Semiconductors are classified into three categories: logic chips, including microprocessors, accounting for 42 per cent of industry revenues; memory chips (26 per cent), including DRAMs, and a miscellaneous category - discrete, analog and other chips (DAO) - which accounts for 32 per cent of total revenues; this third category includes what came to be known as "internet-of-things" devices, which connect and exchange data with other devices in a wide range of industrial and consumer applications. Boston Consulting Group and the Semiconductor Industry Association, Strengthening the semiconductor global supply chain in an uncertain era, April 2021.

intensive chips which were less dependent on low production costs and economies of scale.

After the Japanese came the Koreans and the Taiwanese, relying in part on the same government-supported catch-up strategy that had been pioneered in Japan. Because of their low labour costs, Asian countries had previously attracted investment from foreign companies in what was called the back-end part of the manufacturing process: assembly, test and packaging. By the 1980s they were moving up the value chain. Drawing at the start on technology licensed from established manufacturers, Asian firms began to invest, with strong support from their governments, in designing their own chips and building fabrication plants.

This was a period in which the structure of the industry was changing, with the rise of a new type of semiconductor firm: the independent foundry. These were firms which did not design chips but made them to order either for companies that did not have enough fabrication capacity or for companies that focused entirely on semiconductor design; the latter came to be known as fabless firms, a separate category from the integrated device manufacturers (IDMs), such as Intel, which designed, made and sold their own chips.

The importance of foundries increased as the manufacturing process became more complex and more demanding. As users of chips pressed for ever smaller and more powerful chips, older semiconductor factories, based on the 200mm wafer size, could not provide what was needed; lithography tools, in particular, became very expensive as transistor dimensions shrank. The move to 300mm fabrication plants offered higher volume production and economies of scale but they were much more expensive.[5] This created an opportunity for the independent foundry, concentrating all its effort on improving the manufacturing process, investing in new technologies and achieving economies of scale through serving a range of customers.

Some of the integrated device manufacturers went entirely fabless. A notable example was Advanced Micro Devices (AMD), an American company which had been Intel's principal rival in microprocessors; in 2008 it sold its fabrication plants to Global Foundries, a US-based company which was to become the leading non-Asian foundry operator. Other IDMs began to use foundries for an increasing proportion of their wafer needs, moving in what was called a "fablite" direction. In some cases they joined forces with foundry companies to build 300mm plants, with the construction costs and the output shared between the two partners.

The most successful exponent of the foundry model was a Taiwanese company, the Taiwan Semiconductor Manufacturing Company (TSMC). Founded in 1985 with financial and technical help from Philips, the Dutch electronics company, TSMC became a key supplier to fabless firms in the US. Other foundry companies were set up in Taiwan to serve the fabless sector. As the Taiwanese semiconductor industry took shape, it became "less a competitor of the American industry than a symbiotic extension of it".[6]

5. Fabrication plants are classified according to wafer size, which determines how many chips can be fabricated on one unit, and by process node, a measure in nanometres (nm) of transistor density. Most 200mm plants operate in a range from 180nm to 65nm; these are sometimes described as legacy chips. Production of the most advanced chips, with a process node of 10nm or less, is confined to TSMC, Samsung in South Korea and Intel.

6. Langlois and Steinmueller, The evolution of competitive advantage, op cit.

TSMC built its foundry operation around the CMOS process (complementary metal oxide on silicon), which was emerging as the dominant technology, especially for logic chips; it was a generic technology and one that lent itself to continuous improvement, making possible ever smaller devices[7]. By mastering this technology TSMC established itself as the world's leading supplier of the most advanced chips. Samsung in South Korea, which designs and makes its own chips as well as operating a foundry business, was its nearest competitor.

De-integration, globalisation, and the rise of China

The greater use of foundries was part of a wider trend towards de-integration: a greater willingness on the part of semiconductor makers to rely on outside suppliers for parts of the manufacturing process. Philips, for example, had traditionally designed and manufactured the machines that use photolithography to transfer transistors on to the silicon wafer. In 1985 that business was put in the hands of an independent company, later called ASML, which went on to become the world leader in lithography equipment.

In a different part of the industry, Arm in the UK introduced a novel processor design that proved well suited for mobile phones and other low-power devices.[8] Instead of building its own factories, Arm licensed the design to chip manufacturers, generating income through license fees and royalties. With the shift to specialisation and global inter-dependence, "the biggest manufacturers were open to paying a small royalty for something that would otherwise have taken many millions of dollars to develop themselves".[9] ASML and Arm now rank among the world's most highly valued semiconductor firms; the latter, refloated on NASDAQ in 2023, has seen its shares rise sharply, mainly because of its role in the development of chips for artificial intelligence applications (Table 1).

7. John A. Mathews and Dong-Sung Cho, Tiger technology, the creation of a semiconductor industry in East Asia, Cambridge, 2000.
8. Arm, originally known as Advanced RISC Machines, was founded in1990 as a spinout from Acorn Computers, a Cambridge-based maker of home computers.
9. James Ashton, The everything blueprint: the microchip design that changed the world, Hodder, 2023.

Table 1 Market value of some leading semiconductor companies

Company	Market value $bn (12/11/24)	Headquarters	Type of business	Employees
Nvidia	3,640	US	Fabless	29,600
TSMC	839	Taiwan	Foundry	76,478
Broadcom	823	US	Fabless	40,000
ASML	249	Netherlands	Maker of lithography equipment	42,416
AMD	233	US	Fabless	26,000
Qualcomm	182	US	Fabless	49,000
Arm*	147	UK	Licensor of technology	7,096
Micron	115	US	IDM	48,000
Intel	104	US	IDM	124,800
NXP	57	Netherlands	IDM	34,200
Infineon	38	Germany	IDM	58,600
STMicroelectronics	23	France/Italy	IDM	51,323

*'*Arm was listed on the London Stock Exchange from 1998 to 2016, when it was acquired by SoftBank, a Japanese financial group. In 2023 Arm went public again on NASDAQ, with SoftBank retaining a majority of the shares.*

What began to take shape in the early 2000s was a semiconductor supply chain made up of specialist firms in several different countries, each of them responsible for a technology, a system or a key component that could be sold to the semiconductor manufacturer and built into the manufacturing process.[10]

Alongside de-integration came globalisation, with the rise of semiconductor production in Asia. By 2019 Taiwan, South Korea and China between them accounted for 55 per cent of the world's wafer fabrication capacity, compared to 13 per cent in the US and 8 per cent in Europe (Table 2). The US still had Intel, the world's largest integrated device manufacturer, and Micron, a leader in memory chips, as well as several suppliers of chip-making equipment and software tools, but the most profitable part of the American industry came to consist of design-only firms which conducted their research and development in the US but had their chips made in foundries, mainly in Asia. Nvidia, the leading designer of chips for artificial intelligence, has become the world's most highly valued semiconductor firm.

10. The increasing reliance on complex global supply chains is not unique to semiconductors, but the semiconductor industry is an extreme example of this phenomenon.

Table 2 Global wafer fabrication capacity in 2019 (%)

US	13
China	16
Taiwan	20
South Korea	19
Japan	17
Europe	8
Other	7

Source: Boston Consulting Group/ Semiconductor Industry Association, Strengthening the global semiconductor supply chain in an uncertain era, April 2021.

Asian firms were becoming major producers not only of chips but also of consumer electronic products – laptop computers, smartphones and the like – many of them made under contract for Western firms such as Apple. China, with its huge domestic market and its ample supply of labour, was a major beneficiary from this process, with important consequences for the world semiconductor industry.

After China joined the World Trade Organisation in 2001, the flow of inward investment by Western and Japanese electronics companies increased, as did the creation of new electronics firms by Chinese entrepreneurs. As China's production of electronic goods increased, so did its demand for chips. In the early 2000s there was little semiconductor production in China, and the few Chinese semiconductor firms were technologically far behind the leading international suppliers. The dependence on imports was seen by the Chinese government as a serious weakness, prompting a series of measures aimed at boosting Chinese production and upgrading the technological capacity of Chinese semiconductor firms.

De-globalisation

The rise of China as a major player in semiconductors might have been accommodated without disrupting what was seen as a well-functioning global production system, had it not been for a deterioration in relations between the US and China.[11] The most contentious issue was China's determination to take control of Taiwan, by force if necessary. There was also growing resentment in the US, articulated most strongly by Donald Trump, about the damage caused to American industry by Chinese imports. The focus on "America first", a rejection of globalisation, was a winning theme for Trump in the 2016 election campaign.

What followed, first under President Trump and then under President Biden, was the imposition on tariffs on Chinese imports, together with an increasingly hostile attitude towards what was seen as China's ambition, not only to take over Taiwan, but also to undermine US power in East Asia and elsewhere. Among the anti-China measures were restrictions on the ability of American companies to supply China with technology that might have a military application, and tighter scrutiny of Chinese takeovers.

11. Chad P. Bown, How the United States marched the semiconductor industry into its trade war with China, Peterson Institute for International Economics, WP20/16, December 2020.

These geopolitical tensions threatened to interfere with the free flow of technology, capital and products across national borders on which the industry had relied. Another disruptive event was the worldwide semiconductor shortage which first became evident in 2020; it was not fully corrected until 2023. This was a direct consequence of the Covid19 pandemic. When the pandemic struck most governments imposed lockdowns which led to offices and factories being closed. The impact on the motor industry was especially serious. As car sales fell the manufacturers cut back their orders for chips; when the market recovered, the chip makers were unable to satisfy the sudden increase in demand, forcing cutbacks in several car assembly plants. The consequence of the shortage was to make governments more aware of the importance of semiconductors to a wide range of industries, and to national security.

These two events – the US-China trade war and the semiconductor shortage – have led to an unprecedented degree of government intervention in the industry's affairs.[12] In the US the Chips and Science Act, passed in 2022, has provided generous subsidies to American and non-American semiconductor makers (including TSMC and Samsung) to build fabrication plants in the US. Although Donald Trump was critical of the Chips Act, the expectation in the US is that Federal support for the industry will continue in some form under the new administration.

As the next section will show, the European Union has been moving in the same direction. Through the European Chips Act, which was announced in 2002 and came into force in the following year, national governments have been encouraged to subsidise investment in new fabrication plants; the aim is to achieve what the Commission calls strategic autonomy in semiconductors. While not everything has gone to plan, a wave of construction is now under way, principally in Germany, France and Italy.

12. Chad P. Bown and Dan Wang, Semiconductors and modern industrial strategy, Peterson Institute for International Economics, WP24/3, January 2024.

2. The European semiconductor industry: struggling to catch up

Since the introduction of the integrated circuit European semiconductor makers have for the most part played a subordinate role in the world semiconductor industry. Despite support from national governments and the European Commission, they fell behind their international competitors in the 1980s and 1990s; the two largest European producers, Siemens in Germany and Philips in the Netherlands, pulled out of the industry. From the early 2000s onwards, as the balance of power shifted to Asia, European manufacturers largely withdrew from the most technically demanding and fastest-growing sectors of the market.[13]

During this period Europe's lag in semiconductors was a matter of some concern in the European Commission. There were suggestions that the leading European companies should get together to achieve economies of scale, as the aircraft makers had done with the creation of the Airbus consortium, but no moves were made in this direction.[14] It was not until after 2020 that decisive action was taken to strengthen the industry. Part of the purpose of the European Chips Act is to increase Europe's share of world semiconductor production from less than 10 per cent to at least 20 per cent by 2030.

Whether the 20 per cent market share is an appropriate target has been questioned, mainly on the grounds that Europe will continue to need a range of different semiconductor types, based on different technologies and supplied by different countries; even after the new plants that are under construction come on stream, Europe will still be dependent on imports.[15] Nevertheless, the subsidies that are now available have generated a surge of investment by European and non-European firms.

The most spectacular new entry from outside Europe is that of TSMC from Taiwan, which is building its first European fabrication plant in Dresden. This €10bn project, backed by government subsidies in line with the European Chips Act, is due to start production in 2027. It will not make the most advanced chips, with a node size of less than10nm, which will continue to be sourced from Taiwan, but the less complex chips, with a node size from 28nm to 12nm, for which there is a large demand from the European automotive industry. Two of the leading European suppliers of automotive chips, Infineon and NXP, together with Bosch, the German automotive component maker, have each invested €500m to take a10 per cent stake in the TSMC plant, and they will be entitled to the same proportion of the output.

13. Jan-Peter Kleinhans, The lack of semiconductor manufacturing in Europe, Stiftung Neue Verantwortung, March 2021.
14. Neelie Kroes, European Commissioner for the digital agenda, speech before the IMEC Technology Forum, May 24, 2012.
15. Jan-Peter Kleinhans, The missing strategy in Europe's chip ambitions, Stiftung Neue Verantwortung, July 30, 2024.

Against that, there has also been a serious disappointment. In 2022 Intel announced plans for a $33bn semiconductor manufacturing complex at Magdeburg, with part of the finance coming from the Federal government; it was hailed as the largest foreign investment in Germany's post-war history. Since the announcement Intel has run into severe financial problems and in September it announced that the Magdeburg project would be delayed for about two years.[16]

The Intel decision is a blow to the EU's semiconductor ambitions. However, the TSMC project in Dresden is going ahead, as are several plants under construction by European firms. Prompted and supported by the Commission – and by the fear of being left behind by the US - the European semiconductor industry is making a big leap forward, a leap in which the UK is playing no part.

The UK

Differences with the US

In the first two decades after the invention of the transistor the UK's fledgling semiconductor industry was at a disadvantage compared to the US for several reasons. First, the home market was much smaller. Although there was some demand from the Ministry of Defence, the scale of government purchases was far less than in the US; the American market was also largely closed to foreign suppliers. Another important customer in the US was the fast-growing computer industry; that industry was much slower to get started in the UK.

Second, the size and growth of the US market, together with the buying policies of government agencies, encouraged new entrants. In the UK the industry remained in the hands of diversified electrical companies, led by General Electric Company (GEC), Plessey and Ferranti. GEC was the largest of the three; it was put together in the 1960s by a series of mergers masterminded by Arnold (later Lord) Weinstock, who as GEC's managing director was to become the dominant figure in UK electronics until his retirement in the mid-1990s.

The dynamism of the US industry came, not from established companies such as RCA, but from firms such as Motorola and Texas Instruments which concentrated wholly or mainly on semiconductors, and from start-ups like Intel and AMD. Entrepreneurial new entrants of this sort were virtually non-existent in the UK, and the same was true in other European countries.

The British semiconductor firms relied at the start on licenses obtained from the US, but as the industry grew they began to invest in their own research. Ferranti, in particular, which was described at that time as the most technologically progressive of the British firms, had some success in making chips for computers, but it lacked the resources for a full-scale research effort in integrated circuits.[17]

There was some support for semiconductor-related research from the Ministry of Defence during the 1950s, but no concerted attempt to

16. Financial Times, September 16, 2024. Another American company, Wolfspeed, which had planned to build a silicon carbide plant in Germany, with government support, has recently suspended this project, partly because of a slower than expected uptake of electric vehicles. Financial Times, October 23, 2024.

17. Franco Malerba, The semiconductor business, Pinter 1985, p116.

match what was happening in the US. The MoD was content to rely on American suppliers for advanced semiconductors. In 1957 it persuaded Texas Instruments to build a plant in Bedford to make silicon grown-junction transistors, devices that were needed by the military and were not available from UK suppliers.[18]

This was the first of a wave of investments by American companies in UK semiconductor production. Many of these factories were located in Scotland, creating what became known as Silicon Glen; the government saw them as a way of creating employment in areas that had been hard hit by the decline of Scotland's heavy engineering industries. The effect was to increase the domination of the UK market by non-British suppliers.

At the start of the 1970s more than half the market for integrated circuits was in the hands of Texas Instruments, Motorola and SGS-Fairchild, a joint venture between Fairchild of the US and SGS, the leading Italian semiconductor firm. The British-owned companies mostly concentrated on "specials", producing application-specific chips in relatively low volume and steering clear of the high-volume standard chips – principally memories and microprocessors - where the Americans were far ahead.

The government intervenes, and then withdraws

When Conservative governments were in power (1951-1964 and 1970-1974) they were generally reluctant to intervene directly in industry, except when they were faced with a major crisis such as the imminent bankruptcy of Rolls Royce. Labour, during its two periods in office (1964-1970 and 1974-1979), adopted a much more active industrial policy, especially in high-technology industries. One of the first interventions was in computers, where the government engineered the creation of a national champion, International Computers Limited (ICL), which, it was hoped, would compete more effectively against IBM.

Semiconductors came to the fore during Labour's second term. The government had created a new agency, the National Enterprise Board (NEB), one of whose tasks was to support important companies that were in danger of financial collapse. In 1975, when Ferranti had run into a financial crisis through an ill-judged acquisition, the NEB stepped in and took a temporary shareholding in the company.

Although Ferranti's problems were not related to semiconductors, the rescue came at a time of growing concern about the state of the British electronics industry and the danger of losing ground to other countries, some of which, notably France, were actively supporting the sector. The UK's position was particularly weak in semiconductors. A list of the world's fifteen largest producers in 1975 (Table 3) contained four European companies – Philips from the Netherlands, Siemens from Germany, SGS-ATES from Italy and Thomson from France – but none from the UK.

18. One historian has suggested that the MoD deal with Texas Instruments pointed the industry in the wrong direction, towards an over-reliance on inward investment and a failure to nurture domestic capabilities in advanced semiconductors. P. R. Morris, The growth and decline of the semiconductor industry within the UK, 1950-1985, Open University, December 1994.

Table 3 World microcircuit leaders in 1975 (sales in $m)

Texas Instruments (US)	300
National Semiconductor (US)	168
Philips (Netherlands)	160
Fairchild (US)	153
Motorola (US)	120
Intel (US)	111
Rockwell (US)	75
NEC (Japan)	60
Hitachi (Japan)	56
Siemens (Germany)	33
Toshiba (Japan)	29
SGS-ATES (Italy)	21
Thomson (France)	20

Source: Financial Times January 17, 1977, based on independent market estimates

In considering how to correct this situation, the NEB had three options:[19]

a. To accept that the domestic industry was too far behind its major competitors and to rely on international partnerships or inward investment.
b. To encourage mergers among the existing UK companies to secure economies of scale.
c. To establish greenfield ventures in areas not covered by existing UK companies.

In semiconductors, the NEB chose the third option. The argument was that the established British firms, by focusing on low-volume semi-custom chips, were leaving a gap which would put the UK electronics industry at a disadvantage. In the NEB's view, a nationally owned capability in advanced chips was essential.

In 1978 the NEB supported a proposal put forward by a British scientist-entrepreneur, Iann Barron, and an American, Dick Petritz, who had been a co-founder of Mostek, one of the early leaders in the US, to set up a new Anglo-American semiconductor company. It was based on a technology known as the transputer that offered a novel approach to the design of memories and microprocessors, avoiding head-on competition with the Americans.[20]

The NEB's initiative was criticised by Conservative politicians. They questioned whether it was prudent or feasible to try to match the American and Japanese semiconductor firms in volume production of general-purpose computer chips.[21] But the plan was approved by the government in July 1978, and the company, which was called Inmos, received the first £25m of an agreed £50m subvention. The headquarters and technology

19. W. B. Willott, The NEB involvement in electronics and information technology, in Charles Carter (ed). Industrial policy and Innovation, Heinemann 1981.
20. Mick McLean and Tom Rowland, the Inmos saga, Quorum Books, 1985.
21. Financial Times, June 21, 1978.

centre were established in Bristol.

The Inmos intervention came at a time when other European companies, and their governments, were looking for ways of countering American and Japanese competition. Siemens and Philips made acquisitions in the US to strengthen their position, and British firms were thinking along the same lines. Plessey had merger talks with General Instrument in the US and although these came to nothing Sir John Clark, managing director, was open to other partnerships. "We do not feel", he said, "in this area of very high technology that it is a practical solution to go it alone".[22]

GEC formed a joint venture with Fairchild in 1979 to make advanced memory chips at a new factory at Neston in Cheshire; the project was to be partly funded by the government. A management team was appointed and by the start of 1980 construction of the Neston factory was under way. In the meantime, however, Fairchild had been acquired by Schlumberger, the American oil services firm, which decided that the Neston project was not viable. The joint venture was dissolved, and the factory was converted to make defence equipment.

Meanwhile the future of Inmos had been thrown into doubt by the general election in May 1979, which brought Margaret Thatcher's Conservative Party to power. The new government was hostile to state intervention in industry and had no interest in creating or preserving taxpayer-funded national champions. Although it provided funding for the Inmos factory (which was built not in Bristol but in Newport, South Wales, where it could take advantage of regional grants), it soon set about transferring the company to the private sector.

In 1984 the government persuaded Thorn EMI, a British consumer electronics company, to buy Inmos. However, there was not much logic in this acquisition and in 1989 Inmos was put up for sale again. It was bought by the recently formed Franco-Italian semiconductor group, SGS-Thomson; the head of that company, Pasquale Pistorio, believed that the transputer could become a standard technology throughout the industry. The sale was strongly opposed by the Labour opposition on the grounds that it would weaken a strategically important industry.

Another potential buyer had been Plessey, which had become more confident about the future of its semiconductor business. It had been run since 1980 by an ex-Motorola executive, Doug Dunn, who was determined to make Plessey a stronger force in the industry. Dunn wanted to buy Inmos, but was overruled by the Plessey board, which regarded the transaction as too risky.

Opinions differ as to whether a well-funded Inmos, if it had stayed under British control, could have helped to create a stronger British semiconductor industry. While some were sceptical about the transputer, others believed that Inmos could have become a second Intel. Iann Barron, one of the founders, later described Inmos as "a glorious failure". It had enormous technical successes, he said, and the transputer was a unique design, but, in his view, it was undermined by the political argument over ownership.[23] Yet Inmos did leave a lasting legacy, including the Newport

22. Financial Times June 29, 1979
23. Iann Barron, Inmos and the transputer (part 2), The Bulletin of the Computer Conservation Society, Issue No 33, Spring 2004.

factory, which still exists, and a cluster of semiconductor design firms in the Bristol area.

The sale of Inmos has been criticised as an example of the Thatcher government's reluctance to support potentially important new technologies.[24] Although the government sponsored a research programme in information technology, known as the Alvey programme[25], it cut back the support scheme for semiconductors that its Labour predecessor had introduced. That decision prompted an angry response from the industry. The trade association warned that the UK was in danger of dropping from the top of the second division in semiconductors to the third.[26] It argued that the industry needed help from government because it had neither a large home market like the US nor a protected home market like Japan. To make matters worse, the association said, the City did not seem interested in financing the long-term, high-risk investment needed for success in electronics.

Mergers and acquisitions

With the government largely withdrawing its support, the semiconductor makers had to find their own way through what had become, as a result of Japanese and Korean competition, an increasingly demanding world market. One possible response was to get bigger. This is what Thomson, the state-owned French electronics group, did in 1987 when it merged its semiconductor division with SGS of Italy. (The merged company, SGS-Thomson, was later renamed STMicroelectronics.)

There were mergers and acquisitions in the UK, but only one major trans-European deal, which in the end came to nothing. In 1985 GEC launched a takeover bid for Plessey, which would have brought most of the British-owned semiconductor industry under Weinstock's control. However, the Monopolies Commission blocked the deal on the grounds that it would reduce competition in defence electronics.[27] The Commission also saw no advantage in putting Plessey and GEC together. "Both companies appear at the present time to be generally successful, financially sound and profitable".

The failure of the bid left Doug Dunn at Plessey free to pursue his ambitions in semiconductors; in 1987 he bought Ferranti's semiconductor business. However, Weinstock continued to believe that a broader rationalisation of the electronics industry was needed. In 1989 he persuaded Siemens to collaborate in a joint bid with GEC for control of Plessey.

In justifying the bid the chief executive of Siemens, Karlheinz Kaske, pointed to the increasingly intense international competition in electronics – accelerating technological change, the need for huge expenditure on research, and the domination of the market by large global companies.[28] He also emphasised the need for manufacturers of electronic systems, like Siemens as well as GEC and Plessey, to have close ties with leading-edge semiconductor makers.

The GEC-Siemens bid was opposed by Plessey, and there was a

24. Willam Walker, National Innovation Systems: Britain, in Richard R. Nelson (ed), National innovation systems: a comparative analysis, Oxford 1993.
25. Robin Oakley and Kenneth Owen, Alvey, Britain's strategic computing initiative, MIT Press, 1989.
26. Financial Times, January 29, 1985.
27. Monopolies and Mergers Commission August 1986.
28. Financial Times, April 7, 1989.

possibility that the Monopolies Commission might block the deal as it had done with the earlier GEC bid. But on this occasion the Commission approved the takeover, subject to conditions -which the bidders accepted - relating to competition in defence equipment.

The plan for semiconductors was that a new company would be formed, GEC Plessey Semiconductors (GPS), which would be jointly owned by the two acquirers but managed by Siemens. This arrangement was later dropped as a result of objections from the Ministry of Defence, which was concerned about the transfer of militarily sensitive semiconductor technology into non-British hands. Siemens withdrew and the semiconductor business became a GEC-owned subsidiary.[29] Weinstock persuaded Dunn to take on the job of chief executive.

Dunn now had under his control the bulk of the British-owned semiconductor industry. While the new company was smaller than the three leading European companies - Siemens, Philips and SGS-Thomson - Dunn believed that small size was not a disadvantage, and that the business could continue to prosper by concentrating on markets that were not dominated by the Asian producers.[30] The creation of GEC Plessey Semiconductors, he said, marked a new dawn for the industry.[31]

There were other reasons for optimism in the early 1990s. Non-British semiconductor companies were continuing to invest in the UK. Two of the biggest investments, both of them in the North-East of England, were from Fujitsu and Siemens. The latter was geared to the production of high-volume memory chips, a sector of the market which the British firms had neglected.

The new dawn turned out to be a false one. The second half of the 1990s saw a change in strategy at GEC and a drastic deterioration in the world semiconductor market.

Weinstock had assured Dunn that he intended to develop and expand GEC's semiconductor business; in 1994 he approved an £100m investment in Plessey's Plymouth fabrication plant.[32] Two years later, however, Weinstock retired, paving the way for a radical transformation in the way GEC was run.

This was a period in which investors were hugely excited about the prospects for internet-related businesses – what came to be called the dot-com boom. To cater for what was expected to be a massive demand for telecommunications equipment, Weinstock's successor, George Simpson, decided that GEC should concentrate almost entirely on this sector, partly financed by the sale of non-core businesses. The semiconductor division was put up for sale and in 1998 it was bought by Mitel, a Canadian electronics company, for $225m.

Meanwhile bad things had been happening in the foreign-owned part of the industry. The world market for semiconductors entered a deep recession in the late 1990s, made worse by the Asian economic crisis and aggressive price-cutting by the Korean producers. In 1998 Fujitsu and Siemens closed their plants in the north-east.[33] Several of the companies that had invested in Scotland pulled out; not much was left of Silicon Glen.

29. Siemens later also withdrew from the planned co-operation with GEC in telecommunications equipment, effectively ending the alliance which the two companies had formed when they bid for Plessey in 1989.
30. Financial Times October 16, 1990.
31. Financial Times, April 4, 1990.
32. Financial Times, September 28, 1994.
33. The Fujitsu plant, after several ownership changes, was acquired in 2017 by an American electronics firm, II-VI (later renamed Coherent). A key customer was Apple, which used a Coherent chip, based on gallium arsenide, in the iPhone. When that contract was terminated in 2023, the future of the business was in doubt. However, the plant also made a specialized chip for the UK Ministry of Defence, and in 2024, to safeguard supplies of what was seen as a critical component in the defence supply chain, the plant was taken over by the government. The Siemens plant was bought in 2000 by Atmel of the US; in 2007 this company adopted the "fablite" model, outsourcing most of its production to foundries, and the ex-Siemens plant was closed.

Semiconductors in the UK after 2000

The early years of the new century brought further disappointments. Mitel had bought GEC's semiconductor business because it needed additional manufacturing capacity for the CMOS chips that could be supplied by Plessey's Plymouth plant. It was mainly interested in Plessey's communication portfolio, and some of the other businesses were likely to be divested. But Mitel's strategy was upset by the dotcom/telecoms crash in 2001, leading to a drastic fall in demand for semiconductors. The response was to put Mitel's semiconductor business into a separate company, Zarlink Semiconductors, which adopted the fabless model. The four fabrication plants were sold to different owners, none of whom had the ambition or capacity to create the sort of company that Doug Dunn had tried to build at Plessey.

Of those four, the principal survivor is the plant in Plymouth, now run by a private company called Plessey Semiconductors. Its strategy is to concentrate in specialist areas, using differentiated technology to establish a profitable place in the market. In 2012 it acquired a Cambridge University spin-out, CamGan, which had developed a novel technology for making high-brightness light-emitting diodes (LEDs) based on gallium nitride. To develop this technology further, Plessey needed a strategic partner, and in 2020 it formed a commercial agreement with Meta (formerly Facebook) in the US, which was working on augmented reality glasses and other consumer products based on micro LED technology. That partnership remains in place and could lead to substantial new investment at the Plymouth plant.

If the outcome of the GEC/Mitel deal was disappointing, so too was the purchase of Inmos by SGS-Thomson. The Inmos transputer did not become a world standard as Pistorio had hoped; he sold the Newport fabrication plant in 1992. In 2015, after several further changes in ownership, the factory passed into the hands of the German company, Infineon.[34] Two years later it was put up for sale again, and it was bought by a newly formed British company which planned to use it as an integral part of the Compound Semiconductor Cluster that was taking shape in South Wales.

The head of the new company was a scientist-entrepreneur, Drew Nelson, who was also the driving force behind the cluster.[35] His plan was to convert the Inmos factory, now known as Newport Wafer Fab, into an open access foundry to serve compound semiconductor makers in South Wales and elsewhere. That plan was thrown off course by a downturn in the semiconductor market in 2019; Nelson was forced to look for new sources of capital.

What followed was the purchase of Newport by a Dutch semiconductor company, Nexperia. This company, originally part of Philips, was a large manufacturer of power semiconductors for the automotive industry and other industrial customers. It had fabrication plants in Hamburg and Manchester, and it bought Newport because it needed additional capacity. However, in 2019 Nexperia was acquired by a Chinese electronics group, Wingtech Technology. The Johnson government, using new powers under

34. In 2002 Newport Wafer Fab had been acquired by International Rectifier of the US, which used the plant as its global R & D and product development centre; one of the technologies it worked on was gallium nitride. Infineon bought International Rectifier in 2015 and transferred the gallium nitride business to its plant in Austria. The Newport factory was put up for sale.

35. Drew Nelson was the co-founder and chief executive of IQE, a Cardiff-based manufacturer of compound semiconductor wafer products. The Compound Semiconductor Cluster had been founded with government support in 2015.

the National Security and Investment Act, blocked the Nexperia/Newport deal on the grounds that Chinese ownership of the UK's largest wafer fabrication factory was a threat to national security.[36] In 2023 Newport was resold for $177m to Vishay Intertechnology, a well-established US manufacturer of electronic components.[37]

One of Vishay's principal customers is the automotive industry, which in recent years has been making increasing use of silicon carbide chips. Vishay has been building up this side of its business, partly by acquisition, and it plans to use Newport for this purpose. This will involve reequipping the factory, which is currently almost wholly devoted to silicon chips. A sizeable investment will be needed, and Vishay has applied to the Automotive Transformation Fund, the government agency charged with promoting the shift to electric cars, for financial support. If the application is successful, Vishay will begin the reequipment process, the first phase of which is likely to cost about £260m. At a later stage, Vishay plans to introduce gallium nitride at Newport. In the meantime, Vishay will improve the profitability of Newport by transferring to it some of the silicon chips that it currently outsources to foundries.

Semiconductor production in the UK

After the closures, withdrawals and ownership changes of the last thirty years, the UK still has a semiconductor manufacturing industry, but it is small and fragmented. Apart from Vishay at Newport (which currently employs slightly less than 500 people) and Nexperia's long-established plant in Manchester (which has some 1,000 employees), most of the 25 fabrication plants specialise in serving niche market segments. There are also several promising new entrants, some of them supported by government. Last year the government-owned UK Infrastructure Bank, together with private investors, supported a £182m capital-raising for Pragmatic Semiconductor, a manufacturer of flexible integrated circuits.[38] In the non-manufacturing side of the industry there is Arm, a powerful force in semiconductors, and an array of semiconductor design firms, some of them descended directly or indirectly from Inmos.[39]

What the UK does not have is a large, broad-based, integrated device manufacturer comparable to the three European companies that are described in the next three sections. These companies have gone through crises of their own, some of them requiring drastic remedial measures, but they have survived.

Germany

Compared to the UK, Germany had one advantage as the semiconductor industry took shape. Siemens, the leading electronics company, was larger than any of the British firms, and strongly oriented towards science, technology and innovation. Together with Philips in the Netherlands, it seemed well equipped to keep pace with the American semiconductor leaders. However, as international competition increased Siemens lost ground. In April 1999 it hived off its semiconductor business into a

36. For an account of these events see Geoffrey Owen, Semiconductors in the UK: searching for a strategy, Policy Exchange, June 27, 2022.
37. Vishay, which has plants in Germany, Asia, Israel and the US, had a turnover of $3.4bn in 2023. It has 23,500 employees.
38. Financial Times, December 26, 2023.
39. In 2023, following publication of the Semiconductor Strategy, the UK government set up ChipStart, an incubator programme designed to support innovative startup firms.

separate company. That company, Infineon Technologies, after a difficult start, has been able to build a large and profitable semiconductor business. One of its biggest markets today is the automotive industry, where the trend towards low-emission technologies and the use of electronic devices to improve driving performance has increased the demand for semiconductors.

Early success, then falling behind

In the 1950s the leading producers of transistors in Germany were Siemens and AEG-Telefunken, followed by Valvo, a Philips-owned component maker. Thanks to a combination of in-house research and licences obtained from the US these firms were internationally competitive during the transistor era. It was after the invention of the integrated circuit that they began to lose ground. Siemens started research on integrated circuits in the early 1960s, partly to serve its fledgling computer business, but production did not begin till the end of the decade. By 1971 the share of American firms in the German semiconductor market had risen to 51 per cent.

Siemens believed that a strong in-house capability in integrated circuits was essential for the competitiveness of its final electronic products. During the 1970s it invested in new production and research facilities in Germany and Austria. It also sought access to the American market and American knowhow through acquisitions, joint ventures and licensing agreements. It bought a 20 per cent stake in Advanced Micro Devices (AMD) and acquired a microprocessor licence from Intel.

The German government did not intervene directly in the industry, as the UK did with the creation of Inmos, but it recognised that mastery of semiconductor technology was essential if German industry was to remain competitive in world markets. What mattered was not autarky or independence from the US – companies were free to obtain technology from overseas – but sufficient investment in research and development to ensure that the German industrial base was not put at risk.[40]

Support for semiconductor research began in 1967 as part of the Data Processing Programme, which was mainly directed at the computer industry. It was extended in 1974 with the launch of a coordinated programme of government-funded research in integrated circuits. Yet the technological gap between Germany and the US continued to widen, and the rise of the Japanese producers put the German industry in an even weaker position. Japanese competition was the principal spur to the moves towards European cooperation in semiconductors that began in the 1980s. A major project, partly financed by the German and Dutch governments, brought Philips and Siemens together to develop the next generation of memory chips, a market which was dominated by the Japanese at that time.

This plan, known as the Megaproject, was more difficult to implement than the partners had expected. Philips, which was in financial difficulty for other reasons, pulled out of the project in 1990. Siemens turned to

40. J. Nicholas Ziegler, Governing ideas: strategies for innovation in France and Germany, Cornell 1987.

Toshiba and later to IBM for technical support. These links were criticized in Germany on the grounds that public funds were being used to acquire foreign technology, but Siemens persisted. Before the entry of Samsung from South Korea, it was the only non-Japanese firm selling high-volume memory chips on the open market.

Siemens was now optimistic about the future of its semiconductor business and confident enough to undertake two major investments: the plant in the UK, which was discussed in the last section, and a new manufacturing and research facility in Dresden, Saxony. The latter was announced in 1992, two years after German reunification, and production began in 1995. This investment marked a step towards creating in Dresden what was to become one of Europe's most productive semiconductor clusters, now known as Silicon Saxony.

Dresden had been the centre for microelectronics research in the former East Germany and it had a pool of well-trained scientists and engineers. Investment in the region after 1990 was supported by the federal government as part of the drive to modernise East German industry. The attractions of Dresden were also strongly promoted by Kurt Biedenkopf, the Prime Minister of Saxony. After the Siemens investment Biedenkopf had another success in 1994 when Advanced Micro Devices from the US announced that it would build its first overseas fabrication plant in Dresden.

The German semiconductor industry seemed set for a prosperous future, but in the second half of the decade the world semiconductor market entered a period of turbulence that had a disastrous impact, not only on Siemens, but on many other producers. A cyclical fall in demand, aggravated by the Asian economic crisis and aggressive price cutting by the fast-growing Korean producers, led to a drastic drop in memory chip prices and heavy losses in Siemens's semiconductor division.

These events coincided with a period of internal reorganisation within Siemens. The company had been criticised by investors as a slow-moving, over-diversified bureaucracy, and its share price had lagged behind that of other leading German companies. In 1998 the chief executive, Heinrich von Pierer, responded to the criticism with a ten-point plan, designed to streamline the organisation and to withdraw from businesses which could not generate consistent profits. The portfolio would be radically reassessed based on the principle "buy, cooperate, sell or close".

As part of the reorganisation, von Pierer announced that the semiconductor division would be divested and floated on the stock market as an independent company. In future, he said, Siemens would buy its semiconductors from outside suppliers. This was a remarkable departure from the company's earlier insistence that a major producer of electronic equipment needed to have an in-house source of leading-edge chips, but von Pierer said that he could no longer inflict the ups and downs of the semiconductor cycle on investors.

Infineon: a difficult start, then recovery

The British plant was closed down, only two years after it had been opened, but the new company, Infineon, continued to operate the Dresden plant as well as the older facilities at Regensburg in Bavaria and Villach in the Carinthian region of Austria. Infineon also had a continuing commitment to memory chips, which represented more than half of its revenue. There was some discussion after the new company was formed about putting this business into a joint venture, perhaps with a Japanese firm, but as prices began to recover this was not pursued.

Other parts of the portfolio inherited from Siemens were profitable and could be built on. Two of the strongest businesses were power and logic semiconductors for industrial and automotive applications. Before the spin-off Siemens had made chips for its own vehicle components subsidiary, and Infineon continued that relationship. But it also won business from other German component makers and from overseas customers such as Delphi in the US and Denso in Japan. It later developed direct links with the car makers, as they began to exert tighter control over what was becoming an increasingly important component in their vehicles.

Infineon went public in March 2000, at a time when the dotcom boom was in full swing. The shares were listed on the Frankfurt exchange at €35 and rose to €85 by the end of the day. However, the bubble burst later in that year and by 2001 the whole technology sector was in retreat. The price of memory chips, which had been recovering when Infineon went public, now fell sharply; the average price of a 128 Megabit chip fell from $15.00 in September 2009 to $1.45 a year later. This was a foretaste of the price volatility which was to dog Infineon for the first decade of its independent existence.

Demand picked up over the next two years, and in 2004 Infineon made a small profit. It was strong enough to invest $1bn in its first Asian fabrication plant, at Kulim in Malaysia; it started production in 2006. Yet the memory chip business was still a drag on Infineon's performance. A new chief executive, Wolfgang Ziebart, who had spent most of his previous career in the auto industry, came in at the end of 2004, and he believed that a more radical approach was necessary. As he told shareholders, the business models for memory chips and logic chips were diverging. For memory products, he said, time-to-market, manufacturing efficiency and direct access to capital markets were essential. For logic products, what mattered was a profound understanding of customers' individual requirements as the basis for building a long-term relationship; there was also much greater price stability.[41]

Since there was little synergy between these two sides of Infineon's business, it made sense to separate them. Ziebart announced in 2006 that the memory chips operation, to be known as Qimonda, would become a separate company and would be floated on the New York Stock Exchange. Investors would have a choice between investing in the cyclical memory chip business and the more stable business in non-memory chips.[42]

The flotation went ahead, but memory prices were falling yet again and

41. Infineon Press Release November 17, 2005.
42. Financial Times May 10, 2006,

the flotation raised less money than had been hoped. Moreover, Infineon retained 86 per cent of the Qimonda shares and so was still exposed to the fluctuations in the memory chip market. It had hoped to reduce its shareholding to less than 50 per cent, but Qimonda continued to make losses. In 2008 Infineon put together a rescue package which included a substantial subvention from the state government of Saxony - Qimonda was a large employer in Dresden – but other lenders declined to participate and negotiations on the package broke down. The federal government did not intervene.

In 2009 Infineon, dragged down by Qimonda's losses, was in a critical financial situation. The share price had collapsed, making the company vulnerable to takeover. Strenuous efforts were made to cut costs, to raise new capital through a bond issue and to sell off parts of the portfolio. One of the biggest disposals was the sale of the Wireless Solutions Business, which was bought by Intel for $1.4bn.

By 2010 Infineon was over the worst. Peter Bauer, who had taken over as chief executive from Ziebart, told shareholders that the demise of Qimonda (which was put into liquidation), together with other disposals, "marked the conclusion of a massive corporate restructuring programme stretching over a number of years".[43] For the 2010 fiscal year the company paid its first dividend for 10 years.

After the disposals Infineon had a less diversified portfolio, consisting of three segments – Automotive, Industrial and Multimarket, and Chip Card and Security – in all of which the company had a leading market position. With a range of semiconductor types to serve these markets, Infineon aimed to provide its customers with "entire semiconductor solutions", rather than individual components.

Under Bauer and his successor, Reinhard Ploss, chief executive from 2012 to 2022, Infineon staged an impressive recovery. As its finances improved, it was able to expand internationally. It made two large acquisitions in the US - International Rectifier in 2015 and Cypress in 2020 – and increased its presence in Asia. Today its revenues are broadly spread, with just over half coming from Asia, excluding Japan, 26 per cent from Europe, the Middle East and Africa, 13 per cent from the Americas and 10 per cent from Japan.

Manufacturing strategy

During the recovery period Infineon adapted successfully to two changes in the world semiconductor industry: the increasing importance of compound semiconductors as an alternative to silicon and the greater use of foundries.

Infineon was one of the first semiconductor companies to introduce a silicon carbide diode; this type of chip is now widely used in the automotive industry, especially for electric cars where they allow for higher operating temperatures and longer driving range. Infineon recently opened a 200mm silicon carbide plant at its manufacturing site in Malaysia. This plant will also make chips based on gallium nitride, which has become an important

43. Infineon 2011 Annual Report, Letter to Shareholders.

addition to Infineon's range of power semiconductors, partly because of its energy-efficient characteristics.[44]

In manufacturing, Infineon's strategy is to outsource the production of standard CMOS chips to foundries. It has also formed partnerships with foundry operators for the co-development of smaller chips for which it does not have in-house capacity. Last year it announced an agreement with a Taiwanese foundry company, United Microelectronics Corporation (UMC), for the manufacture of a new type of microcontroller to serve the automotive industry; the chips will be made at UMC's Singapore plant. Similar long-term arrangements have been made with TSMC and with Global Foundries. As noted earlier, Infineon is a 10 per cent shareholder in the new foundry which TSMC is building in Dresden.

Meanwhile Infineon is continuing to invest in its own fabrication plants, three in Europe, two in the US and one in Malaysia. These plants are mainly used for non-standard products based on proprietary technology where close control of the manufacturing process is essential. The latest addition is a new Dresden facility now under construction, due to come on stream in 2026. This is a €5bn project, partly financed by the government, and is described as the largest single investment in Infineon's history; it will add about 1,000 jobs to the 3,250 that Infineon currently employs in the region.

Sources of success

Infineon has built on the legacy left by Siemens but to survive it has had to make radical changes in what it inherited. It withdrew from businesses where it lacked the scale to compete, notably memory chips and chips for wireless and wireline communications. It made good use of its location in a country which has Europe's largest automotive industry and an array of engineering companies which needed power semiconductors to support investment in automation and other electronics-based systems. Infineon is now the world market leader in automotive chips, which account for just over half of its total revenue.

The Netherlands

Philips, the Dutch multinational, faced the same set of challenges in semiconductors as Siemens, and the outcome was similar. After investing large sums in semiconductor development and production in the early post-war decades, it withdrew from the industry in 2006 and set up a separate semiconductor company. This company, NXP Semiconductors, has gone through difficult times, but is now one of the three leading European semiconductor manufacturers.

NXP built on the legacy inherited from Philips, but that legacy has been highly productive in other ways. Among the businesses that were created within Philips and later became independent companies, the biggest success has been ASML, the dominant supplier of lithographic equipment for semiconductor production. As the home base for several other successful semiconductor-related firms – many of them based in and

44. Infineon recently announced that it had developed the world's first 300mm power gallium nitride wafer technology, marking a major advance in efficiency and cost over 200mm wafers. Infineon press release, September 11, 2024.

around Eindhoven, where Philips had its headquarters - the Netherlands remains a powerful force in the world semiconductor industry.

The reshaping of Philips, and its exit from semiconductors

Philips in the 1950s was a large, diversified group, with a big stake in consumer electronics. It had manufacturing subsidiaries in several European countries, all of which made germanium transistors during the 1950s, partly for use in Philips-made radio and TV sets and other electronic products. Production of integrated circuits began in the early 1960s, first at Nijmegen in the Netherlands and then at Mullard, its British subsidiary.

Like Siemens, Philips needed direct access to the US market to keep abreast of the technological advances that were being made there. In 1975 it acquired Signetics, which was then the ninth largest US semiconductor maker. This deal lifted Philips into third place in the world semiconductor league, behind Texas Instruments and Motorola. Philips was also active in Asia, where Korean and Taiwanese firms were looking for partners to help develop their semiconductor industries. In 1985 Philips agreed to supply capital and technology to Taiwan Semiconductor Manufacturing Company (TSMC), which as an independent foundry was to become a leading supplier of advanced semiconductors to fabless firms. It was the start of a long-lasting relationship between Philips and the Taiwanese company.

As Japanese competition increased in the 1980s Philips looked for ways of cutting costs and narrowing down what had become an over-diversified portfolio. Among the non-core businesses that were divested at that time was the manufacture of lithography equipment; these are the machines which use light to transfer the tiny components that make up an integrated circuit onto the silicon wafer. Improving this process was time-consuming and expensive, and in 1984 Philips put the lithography business into a separate company, ASML. At the start it was 50 per cent owned by Philips but in 1995 it became a fully independent public company, listed on the Amsterdam and New York stock exchanges.

The divestment of ASML relieved Philips of a financial burden, but its most expensive commitment in the 1980s was the joint venture with Siemens in memory chips. As noted in the last section, that project proved more difficult than the partners expected, and Philips withdrew in 1990. The parent company was then in dire financial straits, and several of its larger businesses, including computers, were sold.

After painful surgery Philips recovered from the crisis and by the mid-1990s the semiconductor division seemed poised for growth. It was pushing strongly into Asia, and by the end of the decade some 40 per cent of its sales came from that region. In 1999 it formed a joint venture with its Taiwanese partner, TSMC, to build a 200mm fabrication plant in Singapore, the Dutch company's first front-end investment in Asia.

Then came the dotcom boom-and-bust and by 2001 Philips was facing another financial crisis. This time the remedy was more drastic.

A new chief executive, Gerard Kleisterlee, took over in 2001. Three years later he announced a plan to transform Philips into a healthcare and lifestyle company, no longer tied to electronics.[45] Businesses which had been part of Philips for many years but were now loss-making would be sold or closed. Without such measures, Kleisterlee said, Philips would not "survive or break the downward spiral of seemingly never-ending restructuring".

In 2006 Kleisterlee did what Siemens had done six years before: he divested the semiconductor business as a separate company. Instead of floating the new company on the stock market as Siemens had done, he sold it to a group of mostly American private equity firms. Philips retained a 19.9 per cent stake in what was called NXP Semiconductors, with the ultimate intention of withdrawing completely.[46]

NXP and private equity

The new owners of NXP, in line with established private equity practice, planned to improve the profitability of the company and then sell it or float it on the stock market. But the exit took longer than expected. They had paid too much for NXP, mostly with debt, and as the semiconductor market turned down there was an urgent need to cut costs. A partial exit was achieved in 2010, when NXP was listed on the NASDAQ stock exchange in New York, and the withdrawal was completed with further share disposals in the next few years.

The private equity episode was later described by a senior NXP executive as a gamble that paid off, both for the investors and the company. In his view, the disciplines imposed by the private equity firms had kept the company afloat in 2008-09 when the business was in difficult financial straits.[47]

During this period NXP withdrew from several businesses inherited from Philips and made greater use of foundries. It retained some wholly owned fabrication plants but relied on foundry operators for the supply of advanced chips that needed to be manufactured on a scale that NXP on its own could not justify.

After the private equity firms withdrew and NXP became a normal public company, it adopted a product and marketing strategy which targeted sectors that did not depend on large capital investment but where NXP could offer distinctive technological solutions. One example was the security business, the use of chips in credit cards, e-passports and transport ticketing. Another was "smart lighting", where NXP chips were used to improve energy efficiency and reduce wastage.

The automotive industry was a key customer, and in 2015 an opportunity arose for expanding this business when Freescale in the US was put up for sale. Freescale had been part of Motorola, and, like NXP, had been sold in 2004 to a group of private equity firms which were now looking for an exit. NXP bought Freescale for just under $12bn, partly in cash and partly in shares. The purchase brought with it three US fabrication plants.

45. Financial Times, August 25, 2004
46. The chairman of NXP was a British businessman, Sir Peter Bonfield, who had previously been head of BT. He remained in that post until his retirement in 2023.
47. Guido Dierick, The private equity experience, NXP, September 2, 2013.

In the following year, while the integration of Freescale was under way, NXP received an unexpected approach from Qualcomm, one of the largest American fabless firms. Qualcomm offered to buy NXP in a $44bn deal which, had it happened, would have been the largest in the history of the semiconductor industry. It would have brought together a leader in the supply of chips for smartphones and a major supplier of automotive and industrial chips.

Because of the size of the deal and its possible impact on competition it was closely scrutinised by regulators. The merger was cleared in the US and the European Union, but the Chinese authorities studied the deal for more than a year and in the end did not approve it. The reasons were not clearly spelt out, but the decision was assumed to be linked to the increasingly acrimonious trade dispute between the US and China.

The Qualcomm affair was a distraction, and the failure of the bid came as something of a relief for the NXP management. The lengthy regulatory process had been exhausting, said Richard Clemmer, chief executive, "I don't want to put our organisation through that again". NXP was now free to pursue smaller deals which had been deferred while the Qualcomm bid was under investigation.[48]

NXP's manufacturing strategy

At the time of the Qualcomm episode NXP had three European fabrication plants, at Nijmegen in the Netherlands, Hamburg in Germany and Manchester in the UK. About 80 per cent of the company's revenue came from what it described as "highly differentiated application-specific semiconductors and system solutions". The other 20 per cent consisted of standard products sold to a wide range of customers, often on a catalogue basis.

In 2016 the standard products business, which included the fabrication plants in Hamburg and Manchester, was sold for $2.75bn to a group of Chinese financial investors. Renamed Nexperia, it was resold in 2019 to a Chinese electronics company, Wingtech. (As noted in the UK section, Nexperia acquired Newport Wafer Fab in 2019, but this transaction was blocked by the government on the grounds that Chinese ownership of the UK's largest wafer fabrication plant posed a threat to national security.)

The sale of Nexperia left NXP with one wholly owned European fabrication plant, at Nijmegen. It is a 200mm plant, as are the three US plants which NXP acquired when it bought Freescale. NXP has chosen not to invest in its own 300mm plants, preferring to use foundries for the smaller chips which it needs. It describes its manufacturing strategy as "hybrid", based on close partnerships with selected foundry operators. In line with this policy NXP recently announced plans to build a 300mm fabrication plant in Singapore in partnership with a Taiwanese company, Vanguard International, at a cost of some $7.8bn. Vanguard, in which TSMC is a major shareholder, will hold 60 per cent of the joint venture and NXP 40 per cent. The same logic lies behind NXP's decision to acquire a 10 per cent stake in TSMC's new Dresden plant.

48. Financial Times, July 26, 2018.

NXP currently derives 40 per cent of its wafer requirements from its own fabrication plants, with 60 per cent supplied externally. The external proportion is expected to rise to 80 per cent by 2030; this will involve some rationalisation of the existing 200mm plants in Europe and the US. At the back end of the production process, assembly and test, NXP relies to a greater extent on wholly owned plants, most of which are in Asia.

NXP in Europe

NXP's business is strongly oriented towards Asia, in terms of employment and sales (Tables 4 and 5). Yet NXP is a European company. It has its roots in the Netherlands. Its head office is in Eindhoven, where Philips used to be based. It has research and development activities, though not manufacturing, in other European countries, some of them dating back to the days when Philips had a network of manufacturing plants around Europe. It has close links with IMEC, the microelectronics research institute based at Leuven in Belgium. As an investor in TSMC's Dresden plant, It is directly involved in the drive to raise Europe's share of world semiconductor production.

Table 4 NXP employment by region in 2023 (%)

Netherlands	7
Rest of Europe, Middle East and Africa	14
Americas	17
Asia	62

Table 5 NXP sales by region in 2023 (%)

China	34
Asia Pacific excl. China	28
Europe, Middle East and Africa	23
Americas	15

France and Italy

Quest for independence

Of the larger European countries France has been the most dirigiste in its approach to industrial policy, and the most determined to maintain national independence in high-technology industries. In electronics, the French industry in the early post-war years was weak and fragmented; it did not have a company comparable to Siemens in Germany, around which a stronger industry could be built. If France was to achieve a greater degree of autonomy in what was seen as a strategically important sector, the government would need to intervene.

In semiconductors the starting point was small-scale transistor production by two French firms which were later brought together under the control of a diversified electronics group, Thomson-CSF. That company played a prominent part in the government-led rationalisation of the electronics industry which began in 1966 with the launch of Le Plan Calcul. As part of the plan the government created a national champion in computers, to be supported, like ICL in the UK, with subsidies and preferential procurement on the part of government agencies. It was recognised that the success of the new computer company depended on access to advanced semiconductors, preferably supplied by French-owned producers. That was the role given to Thomson.

Despite government support, Thomson made little headway in the semiconductor market; even the government-supported computer company continued to buy many of its chips from American suppliers. The lack of progress prompted a change of policy under the administration led by Giscard D'Estaing (1974-1981). Instead of focusing support on a single company the government brought in new entrants and encouraged them to make technology agreements with American companies.[49]

This more liberal approach to industrial policy did not last. It was scrapped in 1981 when Francois Mitterrand's socialist government entered office. As part of a sweeping nationalisation programme, most of the country's leading industrial companies, including Thomson, were brought into public ownership, and the government embarked on an ambitious sector-based industrial policy. Thomson was designated as the chosen instrument for making France a world leader in semiconductors.

Again the results were disappointing. Japanese competition was increasing, and there were fears that Thomson did not have the necessary technical strength, or scale of production, to survive. In 1987, in a move that came as a surprise in France and in the industry at large, Thomson announced that its non-military semiconductor activities would be merged with an Italian company, SGS-ATES.

The case for the merger was that the world semiconductor industry was becoming concentrated in the hands of a small number of large groups, and that Thomson was in danger of being squeezed out of the market. The agreement with SGS-ATES "indicated unprecedented acceptance of the view that international market share was important enough to justify dilution of national control".[50]

The Franco-Italian partnership

SGS in Italy had been created in 1957 to make transistors under license from American companies. In 1960 it formed a partnership with Fairchild, but that arrangement did not last, and SGS became part of a state-owned semiconductor group. This company, SGS-ATES, was technically strong but poorly managed; it was kept alive by government support. The turning point came in 1979 when the government persuaded Pasquale Pistorio, an Italian engineer who had been a senior executive in Motorola, to take on the role of chief executive.

49. Ziegler, Governing ideas: strategies for innovation in France and Germany, op cit.

50. Ziegler, Governing ideas, op cit.

Pistorio believed that the Italian company, despite its poor performance under state ownership, could become a bigger and more profitable business. Determined to build an Italian world leader in a US-dominated industry, he set about a drastic reorganisation, based on what he had learned at Motorola. By the early 1980s SGS-ATES was making profits. But Pistorio recognised that the company was too small, and he welcomed the owners' decision to join forces with Thomson in France.

In the light of his record at SGS, Pistorio was a logical choice to be chief executive, and in the seventeen years of his leadership he achieved a remarkable transformation of what had been regarded at the start as an also-ran. With two governments as shareholders there was obvious scope for political interference, and Pistorio was careful to ensure that the balance between France and Italy, in terms of employment, investment and research, was kept as even as possible. Thanks in large part to support from Alain Gomez, Thomson's chief executive, Pistorio was given the freedom to run the business as he thought fit.[51]

The early years of Pistorio's tenure were not easy. The company was hit hard by the semiconductor recession of the early 1990s, and Pistorio briefly explored the idea of merging SGS-Thomson with either Philips or Siemens. There was not much interest in such a deal on the part of the other two companies, and as the semiconductor market recovered the idea of a European mega-merger went off the table.

By 1994 the company was solidly profitable, and strong enough to permit the owners to make a public offering of its shares; the company was floated on the Paris and New York stock exchanges, with the two governments retaining 80 per cent of the equity. Shortly after the flotation the name of the company was changed to STMicroelectronics. The company was later listed on the Milan stock exchange.

The period between 1994 and 2000 saw revenue and profits increasing at an impressive rate, and STMicroelectronics established itself as one of the three big European semiconductor producers. Pistorio's approach was to steer clear of commodities such as memory chips and to focus on application-specific integrated circuits where success depended on close relationships with customers. His plan was to have about ten strategic partners in each segment; they included companies such as Nokia in mobile phones and Bosch in vehicle components.

An advantage for STMicroelectronics was that, unlike Siemens and Philips, it was a merchant producer; it did not make its own electronic equipment and so was not in competition with its customers. It was also highly diversified, aiming for leadership in carefully chosen market segments where it had a technological advantage, and which were not subject to extreme price volatility. STMicroelectronics withstood the 2000/2001 dotcom/technology crash rather better than its rivals.

Pistorio was determined that STMicroelectronics should be a global player. Before the merger SGS had been one of the first Western companies to shift labour-intensive assembly, test and packaging operations – the back-end part of the manufacturing process - to low-cost locations in Asia;

51. Oral history of Pasquale Pistorio, interviewed by Doug Fairbairn, Computer History Museum, April 26, 2010.

this was followed by a much bigger investment, a fabrication plant in Singapore. Pistorio also built up the company's business in the US, partly through acquisitions; by 2000 the company derived about a third of its sales from Europe, a third from the Asia-Pacific region and 25 per cent from the Americas.

On the manufacturing side, the SGS -Thomson merger came at a time when semiconductor makers were making greater use of foundries. Pistorio believed that in-house control of manufacturing was a source of competitive advantage; his policy was to outsource no more than 10-15 per cent of the company's wafer production. After the merger some sub-scale plants were closed down, but during the 1990s the company's fabrication capacity in Europe was expanded and modernised. A new 200m plant was built at Crolles, near Grenoble, which was to become one of the company's largest manufacturing sites. In 2002 a second Crolles plant was built in partnership with Philips and Motorola; that alliance was subsequently dissolved, leaving STMicroelectronics as the sole owner. There were four other large manufacturing facilities, at Rousset in southern France, Tours in the Loire valley, Agrate near Milan and Catania in Sicily.

During Pistorio's leadership, from 1987 to 2004, the company increased its revenues from less than $1bn to $8.9bn and moved from losses in the early years to solid profitability. While it could not escape the cyclicality of the semiconductor business, more than half its sales in 2004 came from differentiated products which were based on stable relationships with selected customers. Pistorio showed that a well-managed European company could survive and prosper against Asian and American competition, without the upheavals that investors and employees in Siemens and Philips had to endure.

STMicroelectronics after Pistorio

The years immediately following Pistorio's retirement were difficult, partly because of persistent overcapacity in the industry and downward pressure on prices. Then came the world financial crisis of 2008-09, which led to a sharp fall in semiconductor demand.

The response from Carlo Bozotti, Pistorio's successor, was to make the company less capital-intensive, with a greater use of foundries. He also slimmed down the portfolio, withdrawing from scale-intensive businesses where the company was too small to compete against the market leaders.

Nokia, the mobile phone manufacturer, had been a large customer, but after the launch of the Apple iPhone in 2007 that company was losing ground. The leading suppliers of chips for the new smartphones were Qualcomm in the US and Samsung in South Korea, with STMicroelectronics some way behind. Bozotti tried to achieve economies of scale by buying NXP's mobile phone business and then forming a joint venture with Ericsson in Sweden, but this operation made losses for several years and was closed down in 2012.

After the withdrawal from the Ericsson venture, Bozotti announced a new strategic plan, based on leadership in five areas, of which the most important was automotive products. The focus was on making driving "safer, greener and more connected", with ST components used to control a range of functions including power steering, door locks and in-car entertainment.

Over the next few years, following losses in 2012 and 2013, the company's financial performance steadily improved. By 2017, the thirtieth anniversary of the company's foundation, the changes made by Bozotti were bearing fruit. A measure of its improved status in the eyes of investors was its return to the CAC 40, the Paris stock exchange's index of the most highly valued shares, from which it had been dropped in 2012.

Bozotti was succeeded as chief executive in 2018 by Jean-Marc Chery, who had worked closely with Bozotti in the restructuring of the company that followed the dismantling of the Ericsson joint venture. Profits and revenue continued to grow, with the automotive sector accounting for just under half the company's revenue; in 2023 its ten largest customers included two car makers, Hyundai and Tesla. But the company also had a range of technologies outside the automotive and industrial field; an important non-automotive customer was Apple, which used specialised imagers from ST Microelectronics in the iPhone.

The improving trend was halted in 2024, partly because of the slow-down in the take-up of electric vehicles, especially in Europe; on the basis of results for the first three quarters of the year, net revenues are expected to be some 23 per cent down on 2023. Jean-Marc Chery told shareholders that he believed the downturn would be temporary, and that demand for electric cars would recover as current anxieties on the part of consumers - over residual value, charging stations and price – began to ease.[52]

New European projects

While more than half of STMicroelectronics' sales now come from the Asia-Pacific region, Europe remains its main manufacturing base. Of the three leading European companies, ST has the largest proportion of its employees based in Europe, most of them in France and Italy (Table 6); only 20 per cent of its silicon production is subcontracted to external foundries.

The commitment to Europe is increasing as a result of two new projects that are now under way, both of them partly funded by government within the framework of the European Chips Act.

At Catania in Sicily the company is planning to build a 200mm silicon carbide manufacturing facility for power devices, mainly to serve its automotive and industrial customers. The projected investment is €5bn, of which €2bn will be provided by the Italian government. It will be a fully integrated operation, encompassing research and development, manufacturing, and test and packaging. The new facility is due to start production in 2026.

At Crolles in France ST has joined forces with Global Foundries to build a 300mm fabrication plant based on silicon-on-insulator technology; the output will be shared between the two partners. The total cost will be

52. Jean-Marc Chery, Statement to shareholders, October 31, 2024.

close to €7.5bn, of which the French government will provide €2.9bn. The Crolles project was described by the French finance minister, Bruno Le Maire, as France's "biggest investment in recent decades outside the nuclear industry and a big step forward for our industrial sovereignty". [53]

Table 6 STMicroelectronics employment by region in 2023

France	11,958
Italy	12,561
Rest of Europe	1,198
Americas	828
Mediterranean (Malta, Morocco, Tunisia)	5,923
Asia	18,855
Total	**51,323**

What was different about the UK?

Why is the UK playing no part in all this? Could the decline in UK semiconductor production have been avoided if governments had been more supportive, or if companies had made different decisions?

On government policy, the swing from intervention to non-intervention in semiconductors between the 1960s and the 1990s was certainly unhelpful and may have discouraged investment in the industry. The Thatcher government was in too much of a hurry to find a private sector buyer for Inmos. (It was, after all, an entrepreneurial venture which should have appealed to the Prime Minister.) However, the Inmos transputer did not gain as much acceptance as the founders of the company had hoped. It is far from certain that Inmos, even if it had been supported by government more generously and over a longer period, would have formed the basis for a stronger British semiconductor industry.

Inmos aside, the Thatcher government did not have a strategy for semiconductors. There was little direct support for the industry under the Conservative and Labour governments which held office in the 1990s and early 2000s. The obvious contrast is with France, where the government adopted a semiconductor strategy in the 1960s, revised it in the 1970s and changed it again in a more dirigiste form in the 1980s. Although the outcome was not what the government had intended, the Franco-Italian alliance – thanks in no small part to the management skills of Pasquale Pistorio – ensured that France has retained a strong position in the European semiconductor industry.[54]

In Germany and the Netherlands, there was government support for the industry in the 1970s and 1980s, mainly in the form of subsidies for research, but it was not part of a state-directed, interventionist strategy. Moreover, the support that was provided did not prevent Philips and Siemens from running into trouble in the late 1990s and early 2000s, leading both companies to withdraw from semiconductors. The two

53. Financial Times, July 11, 2022.

54. The French government has supported the industry in other ways, notably through CEA-Leti, the Grenoble-based microelectronics research centre. That centre has produced a number of spin-outs, including Soitec, which was founded in1992 and is now a world leader in semiconductor materials.

successor companies, Infineon and NXP, were largely left to fend for themselves. The German government did not rescue Infineon's memory chip subsidiary, Qimonda, when it faced a financial crisis. The Dutch government played no role in the sale of NXP to private equity firms, or in the attempted merger with Qualcomm, although it remained closely interested in the health of the Dutch semiconductor industry; it supported ASML when that company was in financial difficulty.

The Thatcher government and its successors have also been criticised for relying too heavily on inward investment and for allowing too many promising British firms to be bought by foreign acquirers. Several non-British firms built semiconductor plants in the UK, but these were branch factories, easy to close when the market turned down, which is what happened in the 1990s.

Inward investment can help to rejuvenate a weak industry, but only if it involves the transfer of technology and management and a willingness on the part of the investor to make a long-term commitment. The outstanding example is Nissan, which came to the UK in the mid-1980s and has continued to invest in its Sunderland factory, making it the company's European production centre for electric cars. This did not happen in semiconductors; there was probably too much focus on job creation and not enough on the need to embed the foreign investor in the local economy.[55]

As for foreign takeovers, the Thatcher government saw no merit in preserving British ownership of supposedly strategic companies - hence the sale of Inmos in 1989. The same approach was followed by later governments, Labour as well as Conservative. When GEC sold its semiconductor business to Mitel in 1998, the Labour government raised no objection. When SoftBank, the Japanese financial group, acquired Arm in 2016, the takeover was welcomed by the government as a vote of confidence in the UK economy, although others took a different view. The SoftBank deal was strongly criticised by Hermann Hauser, a co-founder of Arm. He described it as "a sad loss of independence", making the UK a smaller player in the technology sector.[56]

Whether the semiconductor industry would have benefited from a more nationalistic approach to foreign takeovers is open to question. It would have involved a degree of government intervention which might have deterred desirable investment. Moreover, the global character of the semiconductor industry, dependent (at least until recently) on the free flow of capital and technology across national borders, reduced the scope for protectionist policies.

Apart from government, another possible culprit for the decline in UK semiconductor production is the financial system. Were investors too short-termist, too reluctant to back ventures that would only pay off in the long-term?

A case can be made that Plessey's semiconductor business might have survived as an independent company if it had been supported on an adequate scale by the City. Yet in the period before Plessey was taken over

55. For the importance of "embeddedness" in attracting foreign investment, see Max Munday, Robert Huggins, Wanxiang Cai, Niko Kapitsinis and Annette Roberts, The transformative potential of inward investment in industrial cluster development: the case of the semiconductor industry in South Wales, European Planning Studies, 32/7, February 2024.

56. Financial Times, July 18, 2016. SoftBank recently bought another British semiconductor company, Graphcore, which designs chips for artificial intelligence applications.

by GEC and Siemens in 1989, that division was not obviously handicapped by lack of access to finance. It had to compete for funds with other parts of the parent company, but it was able to make some sizeable investments, including the fabrication plant in Plymouth and the purchase of Ferranti's semiconductor business. It is true that Plessey's managing director, Sir John Clark, was cautious about plunging too deeply into semiconductors - hence the decision not to bid for Inmos – and the division may have been too reliant on semi-protected domestic markets in defence and telecommunications.

In 1998, when the post-Weinstock management at GEC decided to withdraw from semiconductors, the sale to Mitel may not have been the only possible option. This was a period in which investors were clamouring to buy shares in high-tech, preferably internet-related, companies. Arm, which was floated in that year, saw its share price rise by 46 per cent in the first day's trading; the value of the company continued to soar, reaching £6bn at the end of 1999, when the internet boom was in full swing.[57] But the GEC-Plessey semiconductor business would not have been as highly rated as Arm, and it was substantially smaller than the businesses that later constituted Infineon and NXP. A stock market flotation (or a sale to private equity) was probably not feasible.

As for GEC itself, the company's long-serving managing director, Arnold Weinstock, has often been criticised for being too risk-averse and too reluctant to invest in high-growth, technically demanding industries. Yet Siemens in Germany spent a great deal of money – more than UK investors would have found acceptable - in an attempt to become a world leader in semiconductors, before giving up. Weinstock, perhaps more conscious of his responsibility to shareholders, was wary about making too big an investment in a sector where the chances of making consistent profits seemed poor. As he once remarked, "people wanted me to go into things which have lost a lot of money for those who did go into them".[58]

What the UK lacked during the 1960-1990 period was a flow of new entrants into semiconductor manufacturing comparable to those that drove the growth of the industry in the US. But the American companies had the advantage of a huge domestic market, massive demand from the military, a fast-growing computer industry which needed advanced chips, and a financial system that was well equipped to support start-up firms in new industries. Those conditions could not be replicated in the UK, or in any other European country.

Any European new entrant would have to have been global from the start, as Arm was from 1990 onwards. Robin Saxby, chief executive from 1991 to 2001, was determined to make the Arm chip a global standard. Arm never seriously considered becoming a manufacturer – a boom to bust business, as Saxby once remarked. "When the prices collapse", he said, "you lose a lot of money, you have to lay off a lot of people".[59] Compared to Inmos in the 1970s, Arm in the 1990s also had the advantage of operating in an environment in which semiconductor makers were more willing to buy in technology from outside suppliers.

57. Ashton, The everything blueprint, op cit.

58. Financial Times, July 9, 1992.

59. Sir Robin Saxby interviewed by Richard Sharpe, May 10, 2017, Archives of IT.

On the manufacturing side, Ferranti in the early years was regarded as the most flexible and technologically progressive of the British-owned semiconductor makers. Although its subsequent record was erratic, it was for a time the world market leader in semi-custom devices known as Uncommitted Logic Arrays (ULAs).[60] What happened then, as the managing director explained, was the invasion of market by much larger American and Japanese companies. "People urged us to put up plants all over the world, but there was no way of doing that on any terms that would have made sense".[61]

Mistakes were certainly made by British companies, and opportunities missed. But it is hard to see how they could have resisted the tide that was sweeping semiconductor production from Europe (and the US) to Asia. The three European companies discussed in this paper did better, not because of government support, but because they skilfully targeted sectors of the market that were outside the line of fire from the Asian producers.

For the UK government, a lesson from these events is that if it wants to support an industry for economic or strategic reasons it must do so in a consistent, predictable way, based on a realistic assessment of what state intervention is likely to achieve. It is better not to intervene at all than to do so half-heartedly or intermittently.

60. Franco Malerba, The semiconductor business, Pinter 1985, p116 and p170.

61. Interview with Derek Alun-Jones, managing director of Ferranti, Financial Times, November 4,1988.

3. Compound semiconductors

The Sunak government's semiconductor strategy, published in 2023, set out three objectives: to mitigate supply chain disruption; to protect the country's national security; and to grow the domestic sector. An important question, not fully answered in the document, is how far the achievement of these three objectives, and especially the third, requires an expansion of UK manufacturing capacity.

As the strategy document acknowledged, there is no case for the UK to build advanced silicon-based fabrication plants of the sort which the EU has encouraged TSMC to build in Europe. There are, however, opportunities in another part of the industry: compound semiconductors.

Over the last few years there has been substantial investment in this sector, some of it supported by research grants from the government. What has been lacking is investment in manufacturing on a scale that would make the UK a more credible player in a sector which is growing rapidly and has been targeted by some of the world's leading semiconductor companies. The shift to compound semiconductors such as silicon carbide and gallium nitride has been gathering pace in power semiconductors for automotive and industrial markets and in many other applications.

What is needed for UK-based firms to exploit this opportunity is a new facility, or the repurposing of an existing plant, which would serve as an open access foundry, manufacturing chips for design-only firms that focus on compound semiconductors and for start-up firms that are looking for ways of scaling up.[62] The UK has considerable strengths in the design side of the industry, and a university-based research capability out of which several promising firms have emerged. A UK-based foundry would make it more likely that the output of academic research would be commercialised in the UK rather than overseas.

An open access foundry could play the same sort of role in compound semiconductors – on a much smaller scale and at a much lower cost – that TSMC, the Taiwanese company, plays in advanced silicon chips. It could be built on a greenfield site, or adjacent to an existing fabrication plant. The Plessey factory in Plymouth, currently manufacturing compound semiconductor display technology, could be suitable for this purpose. At Newport there is an under-utilised building, known as Fab 10, which could be a possible foundry location. Vishay, which owns the site, is an integrated device manufacturer and is unlikely to invest as a partner in a foundry, but it is open to the idea of Fab 10 being used for this purpose.

The cost of an open access foundry for compound semiconductors would depend on the site, on whether pre-existing facilities were available, and

62. The feasibility of an open access facility for compound semiconductors was examined in a study by the Institute for Manufacturing, commissioned by the Department for Science, Innovation and Technology. UK Semiconductor Infrastructure Initiative Feasibility Study, Summary of Findings, IFM, 31 October 2023.

on an assessment of likely demand. According to estimates from industry experts consulted by the author, a high-volume plant might involve capital spending in the £500m-£800m range. (By contrast, TSMC, the Taiwanese company, will receive up to $6.6bn from the US government for its planned third fabrication plant in Arizona.[63]) One could imagine a public/private arrangement, with a consortium of semiconductor firms and private investors financing two thirds of the project, with the rest coming from the state; this could be channelled through the new National Wealth Fund, which will be set up by the new government to bring together the British Business Bank and the UK Infrastructure Bank.

The government would have to be convinced that the wider benefits of an open access foundry, serving a range of customers and concentrating mainly on high-margin, customised chips rather than commodities, justify support from the taxpayer.

In a different industry, the outgoing Conservative government invested sizeable sums of taxpayers' money to subsidise the construction of battery factories for electric cars. The most recent recipient is Tata, which is building a battery plant in Somerset to supply its subsidiary, Jaguar Land Rover. Part of the purpose of the battery programme (launched by Theresa May's government in 2017) was to reduce the risk of UK-based car assemblers deciding to build their electric cars elsewhere. The necessary investment in batteries, in the government's view, could not be left entirely to the private sector.[64]

Any subsidy for a semiconductor plant would need to be justified on broader grounds, linked to changes in the global environment which have increased the economic and strategic importance of the industry. In contrast to batteries for electric cars, there are no captive or potentially captive customers for UK-made chips. However, the Ministry of Defence is a large buyer of chips, principally from overseas, and it has a particular interest in compound semiconductors. The MoD recently decided to acquire a factory in Newton Aycliffe, County Durham, which makes a specialised gallium arsenide chip for military applications. This factory was in danger of closure, and the MoD bought it (for about £20m) in order to safeguard the supply of a component that was seen as critical to the defence supply chain.[65]

Apart from the military, there are important semiconductor-using industries, including those linked to the net zero programme, such as electric cars and wind turbines. Current and future communication systems are also likely to make greater use of compound semiconductors. This compound semiconductor market, with a large number of sub-markets, little standardisation and many new emerging applications, is more open and less likely to be dominated by a handful of giant companies than the silicon-based industry.

A compound semiconductor foundry will not in itself reduce the UK's imports of silicon chips; like the rest of Europe, the UK will continue to rely on the global semiconductor supply chain. But it would give the UK more bargaining power as it engages in supply chain discussions

63. This will bring the company's total investment in Arizona to over $65bn. TSMC press release, April 8, 2024.

64. The battery strategy included government funding for the creation of the UK Battery Industrialization Centre, where manufacturers of batteries and battery components can test their new products in advance of commercialization.

65. Ministry of Defence Press Release, September 27, 2024. For the earlier history of the Newton Aycliffe plant, built by Fujitsu in 1991, see footnote 33, page 17.

with overseas manufacturers; Continental Europe is likely to become a more important supplier when the plants now under construction come on stream. Support for a foundry as part of a coherent programme to strengthen the UK's position in advanced technologies would be a signal to entrepreneurs and investors that the government takes the semiconductor industry seriously.

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