UKTIN

Future Capability Paper

Semiconductors for Telecoms

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Executive Summary

This paper was prepared by the Semiconductor Expert Working Group for the UK Telecom Innovation Network (UKTIN) as part of a series of telecom future capability papers for UKTIN's Future Telecoms Strategy group.

The working group brings together the collective expertise of semiconductor specialists to explore the opportunities, gaps and challenges in the UK telecoms ecosystem. We aim to establish where the UK can advance research, development and innovation towards 2030 and beyond.

Most semiconductors are fabricated from the element silicon, creating a silicon chip, which accounts for around 80% of modern semiconductors. Compound semiconductors are formed from more than one element. While they are more complex to manufacture than silicon, they offer much greater performance for particular applications than silicon on its own.

Although this paper focuses on semiconductors for telecoms, the semiconductor EWG worked closely with expert working groups considering other technologies to build a pipeline for end-to-end telecom system integration. This is particularly important in supporting the diversification activity in open networks. This paper is the first of two commissioned by UKTIN.

The focus of this paper is expressly on semiconductors for telecoms, concerning the wider use of semiconductors[1] in adjacent applications. The second paper will address roadmaps, research areas and future priorities.

1. The semiconductor and electronics sector is a critical and fundamental enabler of the UK economy. In 2021, it contributed £12 billion in turnover, 8% of gross value added and 12% of research and development spend in the UK[2]

2. Globally, the semiconductor industry is the 4th largest in the world behind oil production, automotive and oil refining and distribution, and revenue from semiconductors accounted for 0.5% of global GDP in 2020[3]. More than 1.1 trillion semiconductors were sold in 2021, and the sector generated more than $500 million in revenue[4].

3. The UK has significant strengths in semiconductors, especially those related to telecoms. The UK's strengths in the design and manufacture of compound semiconductors align well with our expertise in radio frequency (RF) and photonics, creating opportunities to exploit powerful synergies. As the telecom industry moves to higher frequencies, such as mmWave for 6G and >6GHz for WiFi 6 and beyond, it will require performance that only compound semiconductors can provide. Silicon Catalyst UK estimates there are more than 200 design centres in the UK industry developing semiconductor systems. These are not only startups but also organisations designing chips. It also identifies 14 semiconductor unicorn exits since 2014, with a total exit value of $264 billion in 2024 terms (the largest of which was Arm; excluding that the value is $72 billion in 2024 terms).

4. Although the UK does not have industrial-scale silicon fabrication capability, for complementary metal-oxide semiconductor (CMOS) logic and memory chips, the UK has strengths in digital design, especially processor design and semiconductor system design, and is home to Arm, a world-leading fabless chip design company. With the right support, these strengths will be critical to keeping the UK at the forefront of next-generation semiconductor design.

[1] UKESF-Semiconductor-Skills-campaign.pdf
[2] ONS Blue Book 2021, quoted in Make UK Electronics Sector Bulletin: UK Manufacturing, The Facts 2022 | Make UK
[3] BEIS Select Committee Report, published in Nov 2022: The semiconductor industry in the UK - Business, Energy and Industrial Strategy Committee (parliament.uk)
[4] Semiconductor Industry Association 2022, https://www.semiconductors.org/global-semiconductor-sales-units-shipped-reach-all-time-highs-in-2021-as-industry-ramps-up-production-amid-shortage/

The EWG identified the need for long-term, coordinated and well-funded semiconductor initiatives, with telecoms as a key segment. These initiatives should be delivered across three strands:

- Supply chain
- Skills
- Scale-up

a) Supply Chain

Although the UK no longer has a vendor of large system-level products, such as macro-cell base stations or broadband routers, there remain significant players in the supply chain producing components, subsystems, small cells and test equipment. The challenge is to develop and implement a strategy for both strengthening this supply chain and filling the areas where significant gaps are apparent.

This may be achieved either by encouraging existing suppliers to expand into new product areas or by supporting innovative start-ups in the UK. Another option is to nurture partnerships with suppliers in other countries.

The UK is recognised for its strengths in semiconductor design, with Silicon Catalyst [5] identifying more than 200 commercial semiconductor design teams. In addition, whilst not world-class in scale, the country does have more strengths in semiconductor manufacture than is often appreciated. There are approximately 25 semiconductor fabs with world-class capability. We recognise the need to tailor support to specific aspects of the supply chain.

[5] SiliconCatalyst.UK

There is an opportunity for a win-win situation, combining UK strengths in telecom design, including photonics, RF and baseband processing, with compound semiconductor manufacture and silicon prototyping. These two intersect and create scope for a virtuous circle of expertise and investment – design expertise feeding off process knowledge, and business opportunities driving volume.

The supply chain consists of more than just the semiconductor die, including dependencies on "ingredients" and essential suppliers (chemicals, electronic design automation tools) and necessary technologies (advanced packaging) where the UK is not strong but might have opportunities.

There are concerns on the vulnerability of the UK supply chain, given the lack of domestic suppliers. This suggests the need to review supply chains from a security perspective. For example, the country needs to hold stock in the event of disruptions (especially for critical national infrastructure) and to be more careful on security implications.

b) Skills

It was striking how many working group members identified skills as a key issue and how many discussions kept leading back to this topic. There is a desperate shortage of engineers in both telecoms and semiconductors at all levels – apprentices, technicians, graduate engineers and postgraduate researchers.

The telecom industry requires a long-term, wide-ranging skills programme that addresses shortages at all levels, starting with encouraging the uptake of STEM subjects at school from the age of four.

The UK has a reputation for producing high-quality research and innovation. According to the QS World University Rankings[6], the UK is home to over 10 of the top 100 universities in the world for electrical and electronic engineering. This places the UK second, behind the USA, which has over 30 of the top 100 universities and ahead of China, which has less than 10 of the top 100 universities. Likewise, the Shanghai Ranking[7] reports that the UK is home to 11 out of the top 100 universities in the world for telecommunication engineering research. This places the UK third, behind China with 31 of the top 100 and the USA with 23 of the top 100.

However, the low number of graduates and the lack of diversity in the sector are major concerns. In 2021, 3,245 UK students enrolled on degrees in electronic and electrical engineering, including only 335 women.

In 2020/21 there were 12,320 students studying electronic and electrical engineering in higher education, comprised of 6,980 undergraduate students (first degree and other undergraduate) and 5,340 postgraduate students. Electronic and electrical engineering courses were the second most popular choice for undergraduate degrees in engineering and technology in 2020/21, representing 15.8% of all engineering and technology entrants at this level. Of these, 13.5% were women, 35.2% were from minority ethnic groups, 8.8% had a known disability, 13.0% were from low higher education participation areas[8].

While other areas of engineering have had growing applications, electrical engineering has declined, from 17% of engineering applicants in 2012 to 13% in 2021.
[9]

[6] QS World University Rankings by Subject 2023: Electrical and Electronic Engineering, https://www.topuniversities.com/university-rankings/university-subject-rankings/2023/electrical-electronic-engineering?&page=6&tab=indicators&sort_by=rank&order_by=asc
[7] Shanghai Ranking, 2022 Global Ranking of Academic Subjects, https://www.shanghairanking.com/rankings/gras/2022/RS0206
[8] Engineering UK, https://www.engineeringuk.com/media/318869/engineering-in-higher-education_elec_euk_march23.pdf
[9] UCAS, Undergraduate sector-level end of cycle data resources 2021, https://www.ucas.com/data-and-analysis/undergraduate-statistics-and-reports/ucas-undergraduate-sector-level-end-cycle-data-resources-2021

In the opinion of the EWG, there are several reasons for the low number of graduates: [10]

- Telecom and semiconductor-related courses are more expensive to offer than other university courses, but charge the same fees, creating pressure on universities to reduce their number
- Lower levels of prior academic attainment, including in STEM subjects
- Lower levels of science capital
- Negative perceptions or misperceptions of engineering
- Patchy, socially stratified access to careers education and work experience
- Schools in disadvantaged areas are less likely to offer triple science, potentially affecting students' ability to study engineering-facilitating A-Level subjects such as physics
- Shortage of suitable teaching staff
- Engineering courses are perceived to be difficult by students and generally seen by parents as having lower status compared with other professions such as medicine or law

It needs a concerted effort to improve the poor image of engineering university courses, influencing the 'influencers' as well as the learners, including parents, teachers, career advisors, and lecturers.

Other initiatives that would help include:

- more resources for universities to support the higher costs of specialist courses
- practical experience for undergraduates and graduates in integrated circuit design, for example through placements, internships and design academies
- "conversion courses" from related disciplines such as physics or mechanical engineering

While domestic numbers are low, there are a lot of foreign students. This helps university finances (a desirable thing) but doesn't necessarily aid the workforce. Given the skills shortage, it may be appropriate to issue visas for skilled overseas students in specific subjects to help address the shortage.

Several new skills initiatives were announced during the preparation of this paper, including:

- UKTIN Talent Advisory Group
- The Semiconductor Advisory Panel skills sub-group
- The CSA Catapult future telecoms skills fore-sighting initiative

[10] This is anecdotal but reflects inputs from UKTIN Working Group on Skills, UKESF and other organisations in the sector.

We welcome these initiatives and will work with these groups to consider a comprehensive and coordinated response.

c) Scale-up

This paper reviews the history of the UK's telecom industry, highlighting how many large companies have closed, reduced in size or been acquired by overseas companies.

The UK is very strong at research and development, creating the highest number of spinouts and start-ups in Europe, but very few of them scale up in the UK. While the amount of venture capital funding for seed and series A is very strong, and organisations such as Silicon Catalyst and Deeptech Labs are very good accelerators, the UK is notably weaker on the ratio of funds available for growth stage funding. [11]

Given the high cost and long time to profit of both semiconductor and telecoms startups, it is no surprise that venture capitalists are wary. This is true in all countries, but the UK seems to be disproportionately weak. The general strength of the early-stage ecosystem does not compensate for the weakness of later stage funding. According to Silicon Catalyst, the UK ranked sixth in Europe for semiconductor investment, behind Switzerland[12].

The lack of scale-up has created a deficit of major tier 1 system companies, 'hollowing out' the UK telecoms industry. The lack of domestic customers presents a challenge to UK companies developing semiconductors and sub-systems.

The lack of scale-up can be partly attributed to the availability of funding, with a ceiling on growth stage funding limiting the transition from start-up to scale-up or global scale. This is especially true for both semiconductor and telecom companies, which are capital-intensive and have long development times. Hopefully, initiatives such as Mansion House reforms will help here.

The EWG welcomes recent investment in two Innovation and Knowledge Centres (IKCs) focused on supporting the transition of research into industry, with centres led by the Universities of Bristol and Southampton.

[11] Lake Star, Walden Catalyst and dealroom.co 2023, The 2023 European Deep Tech Report, https://dealroom.co/uploaded/2023/09/The-European-Deep-Tech-Report-2023.pdf
[12] SiC.UK_GSA2024_Booklet_ForWeb.pdf (squarespace.com)

d) Recommendations

Recommendation 1:
The new national semiconductor institute to coordinate semiconductor activity across artificial intelligence, future telecoms, semiconductors and quantum technologies and deliver a long-term strategy with funding.

Note: The EWG welcomes the recent announcement to create a national semiconductor institute. The group believes that this will be a very positive step, with an important role to be the voice of the industry, as a single point of contact and to promote investment.

Recommendation 2:
Establish initiatives to ensure telecom operators develop resilience strategies such as holding stock to maintain critical national infrastructure in the event of sustained supply chain disruption.

Recommendation 3:
Set up strong and commercially binding strategic international partnerships in areas where the UK is reliant on overseas semiconductor suppliers, guaranteeing both security of supply and technical cooperation.

Recommendation 4:
Evaluate setting up a trusted foundry programme (similar to the US Defense Microelectronics Activity) so that designers can be assured that their chip has not been tampered with during fabrication.

Recommendation 5:
Set up a long-term, strategic, funded programme to address the skills shortage in electronic engineering by attracting new applicants and students at all levels. This could also include conversion courses from adjacent STEM domains or a program similar to CyberFirst.

Recommendation 6:
Target funding for universities to deliver courses in strategically important degrees, such as in semiconductors and telecoms. This should include funding for specific centres for doctoral training (CDTs) in semiconductors and telecoms and in other priority areas identified in the future telecoms strategy.

Note: While preparing this paper, the Department for Science Innovation and Technology announced 65 CDTs, representing an investment of over £1bn. The EWG welcomes this announcement and the support it will give.[13]

[13] https://www.ukri.org/news/1-billion-doctoral-training-investment-announced/

Recommendation 7:
Encourage and support diversity in the electronic engineering and telecoms industry by funding efforts to improve the perception of engineering and address the difficulties faced by female, minority ethnic and other poorly represented professional engineers throughout their career in engineering.

Recommendation 8:
Set up a bold ten-year national-level programme that builds the skills, talent and leadership in the UK for 21st-century engineering education and expertise. This could include a chip design academy covering practical integrated circuit design skills supported with industrial placements and international internships.

Recommendation 9:
Encourage more private sector investment in high-risk and venture capital-funded firms with proposals such as the Mansion House reforms. The proposals around Mansion House Reform and pension funds investing in Venture Capital are an excellent start, but thought should be given so that those investments align with the national priorities and critical technologies.

Recommendation 10:
Review and potentially reform government incentive schemes, including the Enterprise Management Incentive and research and development tax credits

Recommendation 11:
Draw up technology roadmaps identifying the key semiconductor technologies required to deliver a resilient telecom network from 2025 to 2035 and highlighting where the UK has expertise.

Recommendation 12:
Provide specific financial support to help UK companies develop the telecom and semiconductor technologies identified in the technology roadmaps described in recommendation 11.

Recommendation 13:
Review the rules governing capital expenditure and operating expenses to ensure that grants available to UK companies allow them to address the commercial opportunities identified in the technology roadmaps.

INTRODUCTION, SCOPE AND CONTEXT

The semiconductor and electronics sector is a critical, fundamental, enabler of the UK economy.

According to the Semiconductor Industry Association, worldwide sales of semiconductors totalled $137.7 billion during the first quarter of 2024, an increase of 15.2% compared to the first quarter of 2023[14].

Semiconductors are essential components of modern electronics. The vast majority of the world's semiconductors are built from silicon (hence the "silicon chip"), primarily as complementary metal-oxide semiconductor (CMOS) logic and memory. However, some semiconductors combine two or more elements to create a compound semiconductor, for example, gallium and arsenic to form gallium arsenide (GaAs).

The UK has particular strengths in compound semiconductors, and they are especially relevant for telecoms. Compound semiconductors are more complex to manufacture but they outperform pure silicon in applications such as power electronics, radio frequency (RF) and some aspects of photonics (e.g. light generation) for optical fibre communications. Market forecasts show compound semiconductors growing at around 10-15% a year (depending on material) compared with silicon, with growth rates of around 3-5% a year. The higher growth rate for compound semiconductors is partly attributed to them providing functions that cannot be delivered with silicon.

This paper has been prepared by the Semiconductor Expert Working Group of UK Telecom Innovation Network (UKTIN) as part of UKTIN's future telecoms strategy.

Although our focus is expressly on semiconductors for telecoms, many of the topics are broader and have a wider relevance.

The UK has significant strengths in semiconductors, and this is particularly so in telecoms. The Government has identified semiconductors as one of the five critical technologies and has published a strategy[15].

The UK strengths in compound semiconductors for design and manufacture align well with our expertise in RF and photonic semiconductors and systems to create powerful synergies.

[14]First-Quarter Global Semiconductor Sales Increase 15.2% Year-to-Year; March Sales Tick Down 0.6% Month-to-Month - Semiconductor Industry Association
[15] DSIT 2023, National semiconductor strategy, https://www.gov.uk/government/publications/national-semiconductor-strategy/national-semiconductor-strategy

The movement to higher frequencies, mmWave in WiFi 6 and beyond, >6GHz in LTE and increasingly in 6G, align well with those strengths.

Meanwhile, the lack of CMOS logic or memory manufacturing is a serious concern for the supply chain and must be mitigated. This, however, does not compromise the UK's strengths in design (especially processor design) and semiconductor systems. Instead, it emphasises the need for partnerships to mitigate supply chain risks.

Our scope is telecoms semiconductors. Some of the discussion covers adjacent areas, and some recommendations apply more broadly across other uses of semiconductors.

We have one over-arching recommendation on the necessity for a coordinated, long-term, well-funded semiconductor strategy (with telecoms as a key segment). Beyond that, recommendations fall into three categories:

- Supply chain
- Skills
- Scale-up

This strategy needs an owner who can bring together the various parties – government (in various forms), industry and the many industry bodies, and academia.

We have reviewed several other reports and recommendations as discussed in Annex 3 (for example TechWorks, UK Electronic Skills Foundation (UKESF), Department for Business, Energy and Industrial Strategy (BEIS) select committee) and interviewed individuals. However, most of the content and recommendations come from members. Other reports tend to be on semiconductors in general, so the group considered those and emphasized semiconductors for telecoms (though many of the points are aligned and consistent).

a) Semiconductors as systems

Consideration of semiconductors as systems is sometimes overlooked. Developing a complex chip requires expertise from many domains. Development does not finish with the delivery of a packaged integrated circuit. Testing and validation, printed circuit board, reference designs, embedded software and application software are all essential parts of the whole product and cannot be neglected. This matters because the UK is very good at this integration.

Both the USA and the EU are supporting their domestic markets with funding. For example, the US Chips Act allocates $52.7 billion[16], including $39 billion for domestic manufacture and $13 billion for semiconductor research and workforce training. Similarly, the EU Chips Act's €43 billion of policy-driven investment will support the sector until 2030 and will be broadly matched by long-term private investment[17].

Both telecoms and semiconductors are expensive, long term and capital intensive. It requires long-term funding commitments of sufficient scale to "move the needle" and have meaningful impact. However, relatively small amounts of money, if well targeted, could have significant effects. In other cases, it is not only a question of more government money but more of removing blocks or unlocking private sector funding.

b) Scope

The Semiconductor Expert Working Group forms part of a coordinated programme established by the Department for Science Innovation and Technology (DSIT) to represent the UK Telecom Innovation Network (UKTIN). It is one of eight expert working groups arranged within the following UKTIN structure:

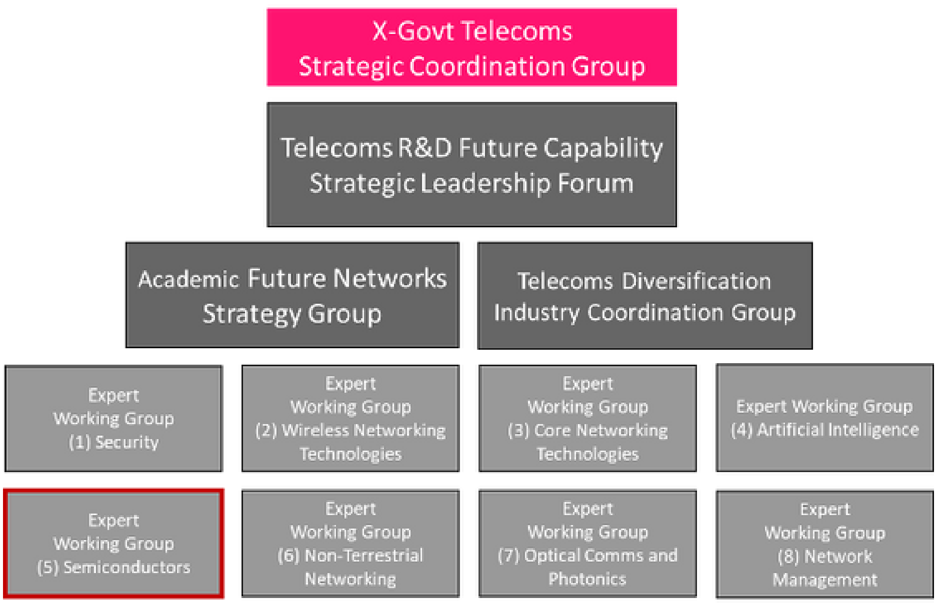


Figure 1 UKTIN and EWGs

[16] Wikipedia, https://en.wikipedia.org/wiki/CHIPS_and_Science_Act
[17] European Commission, European Chips Act, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en

There are also two groups representing skills and standards.

The scope of the Semiconductor Expert Working Group is to review the use of semiconductors in telecommunications to understand how emerging trends and techniques will lead to new ways of operating. The working group decides which topics to consider by taking full account of industry priorities, including:

- advances in research and development in semiconductor components
- diversification and innovation in the supply chain from material sourcing to disposal
- sustainability and environmental impact of the supply chain

As a starting point, the group considered:

- RF front ends (RFFEs): including antennas, low noise amplifiers (LNAs), power amplifiers (PAs), filters, analog-to-digital converters (ADC) and digital-to-analog converters (DAC), up/downconverters, baseband digital signal processing
- optical components – optoelectronics, transceivers, switching, lasers
- memories and other data storage
- applications of quantum technologies
- sensors: charge-coupled device (CCD) arrays
- processors, central processing unit (CPU) architectures: ARM, RISC-V, and others
- any other programmable hardware: including field programmable gate arrays (FPGA), graphics processing units (GPU), intelligence processing units (IPU)

Working with the other expert working groups, opportunities were indentified for:

- diversification of, and innovation in, the electronic component supply chain, from chips, or system-on-chip hybrids with specialised functions, to simpler components
- security of the semiconductor supply chain
- any other applications
- UK to develop next-generation semiconductors for telecoms, considering our role in research and development, design, intellectual property and fabrication

c) Synergies and dependencies in UKTIN

We have identified clear synergies with the other UKTIN expert working groups, which are ranked as follows:

EWG	Synergy	Notes
7. Optical communications and photonics	High	Both compound semiconductors and silicon photonics. Strong synergies, opportunity to cross reference recommendations. Recommend continual dialog to avoid duplication, gaps and contradiction.
1. Security	High	Lots of implications, both in terms of vulnerability in operation (chips being hacked) but also in supply chain (devices tampered with during manufacture).
6. Non-terrestrial networking	Med	Explored space versus ground-based, the need for radiation-hardened semiconductors: mixed signal RF and optical. Trends include RF beam forming, low-power/high data rates, all optical processing and data storage. Need different frequencies to avoid interference between terrestrial/non-terrestrial networks. Not just data: high voltage, high power and photovoltaics.
2. Wireless networking technologies	Med	Some dependencies and relationships. Frequency bands, specialised processes, compound semiconductors, supply chains, skills. However, unlike photonics or non-terrestrial networks, more of these are predictable or well defined and hence lower risk. Refer to white paper as appropriate.
4. Artificial intelligence	Med	AI requires significant processing. It is possible future AI approaches will require technologies beyond standard CMOS. In the longer term, AI is expected to move to analog computing as the energy demands of digital processing become unsustainable. Discussed CMOS and non-CMOS architectures, such as spiking neuromorphic, analog compute, optical compute and quantum compute. Fastest changing working group.

EWG	Synergy	Notes
3. Core networking technologies	Low	While core networking technologies require significant semiconductor activity, this is relatively predictable and risks are identified and understood (processors, memory). No real dependency or synergy.
8. Network management	Low	While network management requires significant semiconductor activity, this is relatively predictable and risks are identified and understood as mainstream (processors, memory). No real dependency or synergy.
Other UKTIN groups	**Synergy**	**Notes**
Skills	High	High degree of overlap.
Standards	Low	No real dependency or synergy.

Figure 2 Synergies with other EWGs

In this paper 'photonics' can include both compound semiconductors and silicon; while there are clear differences, which are important in some contexts, the UK is strong in both areas and there are attractive opportunities in both areas. UK strengths in photonics and compound semiconductors lead to win-win synergies on the supply side.

The importance of silicon photonics for future telecom networks cannot be overstated. This technology is required to drive up data transmission rates, especially within data centres, while driving down energy usage and reducing latency.

The UK has strengths in research and innovation in this area, including leading universities, packaging capabilities around South Devon, which were spun out from Nortel Networks, and the recently announced Innovation & Knowledge Centre (IKC) the 'CORNERSTONE Photonics Innovation Centre (C-PIC)' led by the University of Southampton. However, the lack of industry-standard pilot line capability is inhibiting scale-up and adoption, holding back a technology where the UK could achieve a global leadership position in research, design and fabrication, particularly because silicon photonics manufacturing does not require that most advanced fabrication technology nodes. There are opportunities for UK strengths in silicon photonics design and prototyping to form part of the imminent EU Pilot Line activities.

3) SWOT ANALYSIS

The semiconductor and electronics sector is a critical, fundamental, enabler of the UK economy.

Strengths	Weakness	Opportunities	Threats
• Research institutions • Innovation hubs • Government support • Skilled workforce • Quality standards • VC ecosystem • Processor design • Advanced materials/compound semis • Semiconductor systems	• Limited manufacturing • Supply vulnerability • Brain drain • High costs • Graduate shortage • Technician deficit • Academic shift • Capital gaps • Scale-up support • Competition from international government initiatives such as US Chips Act and EU Chips Act • Weak OEMs • Short-termism from investors	• Infrastructure investment • Market segments • Academic leverage • Design strength • 6G disruption • Geopolitical need • Beyond CMOS • Quantum (requires different semiconductors)	• Geopolitical tensions • Global competition • Brexit impact • Tech evolution • Supply risk • Acquisition threat • Skills gap worsens

Figure 3 SWOT of UK telecoms semiconductors.

Strengths:

1. Robust research institutions: the UK is home to several world-class universities and research centres, offering specialised programmes in electronics and telecommunications.

1. Innovation hub: the presence of technology clusters and hubs, for example, the "Silicon Fen" in Cambridge, and "Western Gateway" (Bristol-South Wales) in promoting tech start-ups and semiconductor innovation.

2. Government structure: simple bureaucracy, tax incentives (Enterprise Investment Scheme/Seed Enterprise Investment Scheme, Enterprise Management Incentives for options, patent box) and grants (Innovate UK and now Horizon), supporting tech and innovation sectors. Especially true at early stage.

3. Skilled workforce: access to a highly educated and technically skilled workforce, often trained by leading institutions in the UK.

4. Quality standards: strict adherence to quality standards and regulations ensures high-quality semiconductor products.

5. Strong venture capital eco-system at early stage, with both capital and expertise to support start-ups or spinouts. Strong at spinout/seed/Series-A.

6. Strong in processor design and semi-design in general (Arm, IMG, Graphcore, design centres for RISC-V from Codasip, SiFive, and Rivos).

7. Good presence in compound semiconductors and other advanced materials, with start-ups, universities, Catapult and industry.

8. Semiconductor systems: ability to create reference designs and complete systems for others to manufacture. This is especially relevant in markets such as telecoms where "system" approach is essential.

Weaknesses:

1. Limited domestic manufacturing: heavy dependence on imported semiconductors and no major player in semiconductor manufacturing.

2. Supply chain vulnerabilities: lack of a fully integrated end-to-end domestic supply chain, making the industry sensitive to global disruptions.

3. Brain drain: many skilled professionals move to countries with larger tech and semiconductor hubs for better opportunities.

4. High costs: operational costs, including wages and rents, can be a deterrent for some semiconductor companies.

5. Skills: despite the quality of universities, too few technically skilled graduates.

Opportunities:

1. Investment in infrastructure: Focusing on improving semiconductor R&D and manufacturing infrastructure can help bridge the domestic production gap.

2. New market segments and the ability for startups to capitalise on them.

3. Build on the strength of academia to have more students and grow the sector.

4. Build on the strength of processors and design.

5. The advent of both 6G and mmWave RF (related but can be independent) is potentially disruptive and creates opportunities for UK suppliers.

6. Geopolitics. The need for new supply chains and new suppliers creates opportunities for UK businesses.

7. Investment in semiconductors beyond CMOS (compound semiconductors but also other non-traditional materials) is relatively cheap but would play to UK strengths.

Threats:

1. Geopolitical tensions: rising global tensions, especially between major semiconductor producers such as the US, China, and Taiwan can affect supply.

2. Competition: growing competition from other nations developing their semiconductor capacities.

3. Economic uncertainties: economic challenges post-Brexit might impact investment in the sector.

4. Rapid technological changes: continuous need to invest in R&D to keep up with the fast-paced evolution of the sector.

5. Supply chain dependence could worsen suddenly.

6. The relatively few UK companies could be bought, with risk to both industrial strength but also potential security concerns.

7. Intensified skills shortage: given demographic issues in the sector, there’s a major concern that insufficient talent is entering the sector to replace an ageing demographic.

4) SUPPLY CHAIN

The EWG discussed how support should be tailored to specific aspects of the supply chain.

In preparing this paper, the EWG considered other relevant initiatives, including the Government's national semiconductor strategy, the Institute for Manufacturing's UK Semiconductor Infrastructure Initiative, the work of the Semiconductor Advisory Panel, and the work of the other expert working groups.

We made every effort to coordinate, identify areas of alignment, cross-reference or re-iterate their comments, or expand and explain where our opinions differed.

This report is on telecoms specifically. While some areas have wide applications (CMOS logic and design, processors, memory) others are unique to telecoms (RF, photonics). Telecoms has the potential to be a UK strength and there is scope for win-win synergies. This is true both of manufacturing (compound semiconductors) and design, building on UK strengths with innovative startups.

a) Strengthening and diversifying the supply chain

We must look at what steps can be taken to fortify and diversify the UK's semiconductor supply chains, to ensure resilience and minimal disruption in the telecom sector.

Our supply chains, without a fully integrated end-to-end domestic framework, are particularly susceptible to global disruptions. This can impact the steady deployment and functioning of our telecom services. To what extent does this require domestic manufacture? If so, how can that best be achieved (sectors, technologies)? What are alternative mitigation strategies, particularly in today's geopolitical situation?

Telecoms is especially challenging compared to other industry segments. The semiconductor requirements are unusually diverse. It is not only about digital technology but also analogue, mixed-signal and support components (filters, antenna).

The Government has recognised this with its [18] strategy on 5G supply chain diversification – although the same logic applies to fixed line and broadband networks. This has obvious significant impacts on the supply chain including semiconductors. There is little point in diversifying at the system level if there is still a single dependency at the semiconductor level.

[18] DSIT 2020, 5G Supply Chain Diversification Strategy, https://www.gov.uk/government/publications/5g-supply-chain-diversification-strategy/5g-supply-chain-diversification-strategy

Supply Chain

Although the UK no longer has a domestic vendor of large system-level products (for example, macro base stations or broadband routers), there remain significant players in the supply chain producing components, subsystems, small cells and test equipment. The challenge is to develop and implement a strategy for both strengthening this supply chain and filling the areas where significant gaps are apparent.

This may be achieved either by encouraging existing suppliers to expand into new product areas or by stimulating the establishment and scale-up of new suppliers through supporting innovative start-ups in the UK. Another option is to nurture partnerships with suppliers in other countries.

As the national semiconductor strategy and IfM have stated, the UK will not have volume domestic CMOS logic or memory fabs, so partnering with other countries to protect supply chains becomes critical. A UK Sustainable Investment and Finance Association (UKSIF) study suggests that a UK semiconductor innovation, prototyping and piloting facility for silicon and advanced packaging (WP1 and 2 in the IfM study) could provide an anchor for international collaboration with other larger semiconductor nations.

The BEIS select committee report on semiconductors recommended: "The Government should work more closely with allies in the EU and the US, and elsewhere, to safeguard the security of supply, both of finished products and of the materials needed for production in the UK. The Government should at the same time be working to represent the UK's expertise and to entrench and expand the UK's role in global semiconductor supply chains."

The UK could provide leading niche innovations in return for guaranteed fab access, similar to the way the Interuniversity Microelectronics Centre (IMEC) in Belgium collaborates with large fabs globally. The key thing is to identify those niche innovations.

Telecoms has a particular requirement for compound semiconductors. They are essential for RF and photonics. Gallium arsenide (GaAs) has been a mainstay of RF for decades and Gallium Nitride (GaN) is now increasing in importance. Indium Phosphide (InP), Indium Phosphide Arsenide (InPAs), and GaN are a mainstay for photonics (there are other more esoteric ones). If the UK focuses on those speciality processes (which could include speciality silicon) it has a stronger opportunity to create some genuine differentiation and unique value, rather than yet another sub-scale commodity CMOS fab.

There is an opportunity for a win-win synergy. UK has two strengths – in design for telecoms (including RF and photonics) and in specialist semiconductor manufacture (notably compound semiconductors, but also in silicon photonics). These two intersect, and there is scope for a virtuous circle of expertise and investment – design expertise feeding off process knowledge, and business opportunities driving volume.

This is different to CMOS logic. While UK design skills and architectural expertise are very important for CMOS, there is limited scope for a UK CMOS logic fab given the significant cost of a fab. The maturity of design processes and large role of electronic design automation (EDA) means that there is far less interaction between design and manufacture of CMOS than there is for telecoms (RF and photonics), and hence less scope for synergies.

Government support for manufacturing has increased, but it focuses mainly on funding for industrial challenges (often synonymous with market sectors) rather than on the enabling technologies or the establishment of manufacturing supply chains. The key enabling elements for the telecoms industry are the materials, devices and modules on which the next generation of advanced products depend.

The lack of investment further up the technology readiness levels (TRL) and the lack of domestic customers and original manufacturers higher up the value chain contribute to the failure to scale many excellent technology innovations, especially at the global level.

An important caveat is that any support should consider both domestic suppliers (helping them to grow) and international operators (encouraging them to invest). Both have benefits – but any support should not disadvantage one at the expense of the other.

It is important to stress that the supply chain for a semiconductor product is very much broader than the semiconductor die itself. Japan's 2011 Fukushima earthquake disrupted supplies of various speciality chemicals, many of which were single sourced and essential to chip manufacture. For some companies the disruption lasted two years. [19]

Advanced packaging, where Europe's share of the market is even smaller than the share of the wafer fab market, is a significant concern. However, that might also be an opportunity for the UK to develop scale in an essential sector and develop strength.

[19] MIT News 2011, https://news.mit.edu/2011/japans-supply-chain

b) Taxonomy

Every electronic product, including those used in telecoms, requires a variety of semiconductor chips, each with a different function. Semiconductor chips can be categorised according to their function and the material used in their fabrication. Figure 4 shows a top-level taxonomy of semiconductor materials (silicon, compound and emerging), while Figures 5 and 6 provide more detail on the functions that can be fabricated in silicon and compound semiconductors. The chips ringed in red are typically used in telecom applications, both infrastructure and consumer devices such as smartphones. The glossary in the annexe explains the acronyms.

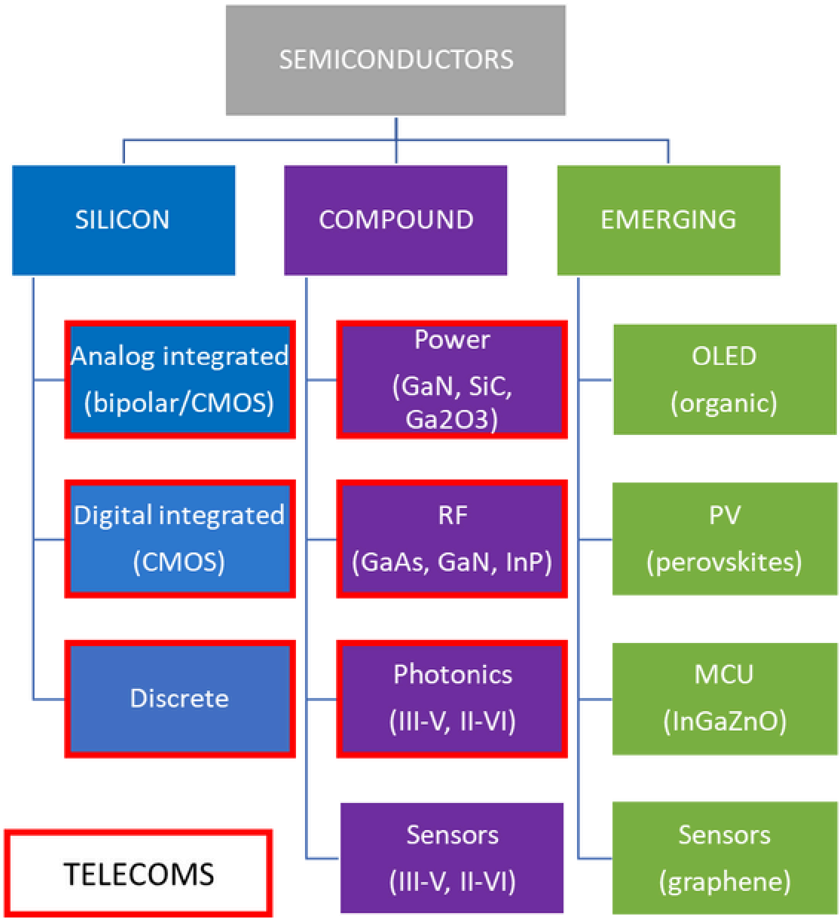


Figure 4 Semiconductor taxonomy segmented by material then function

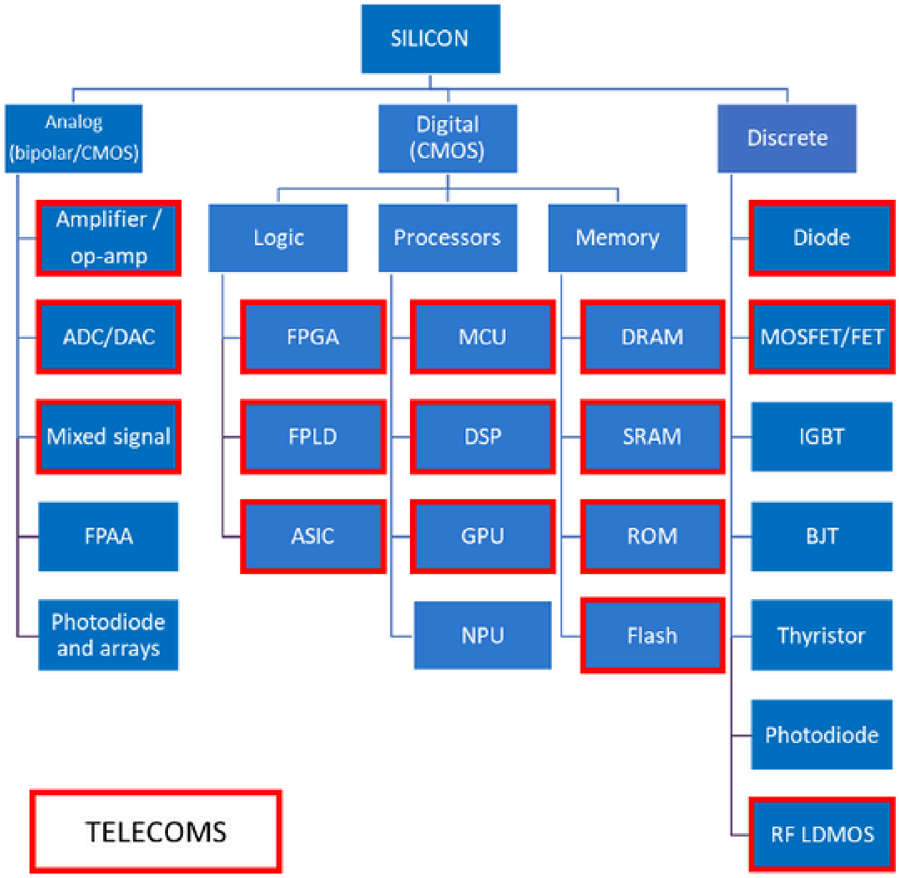


Figure 5 Silicon semiconductor taxonomy

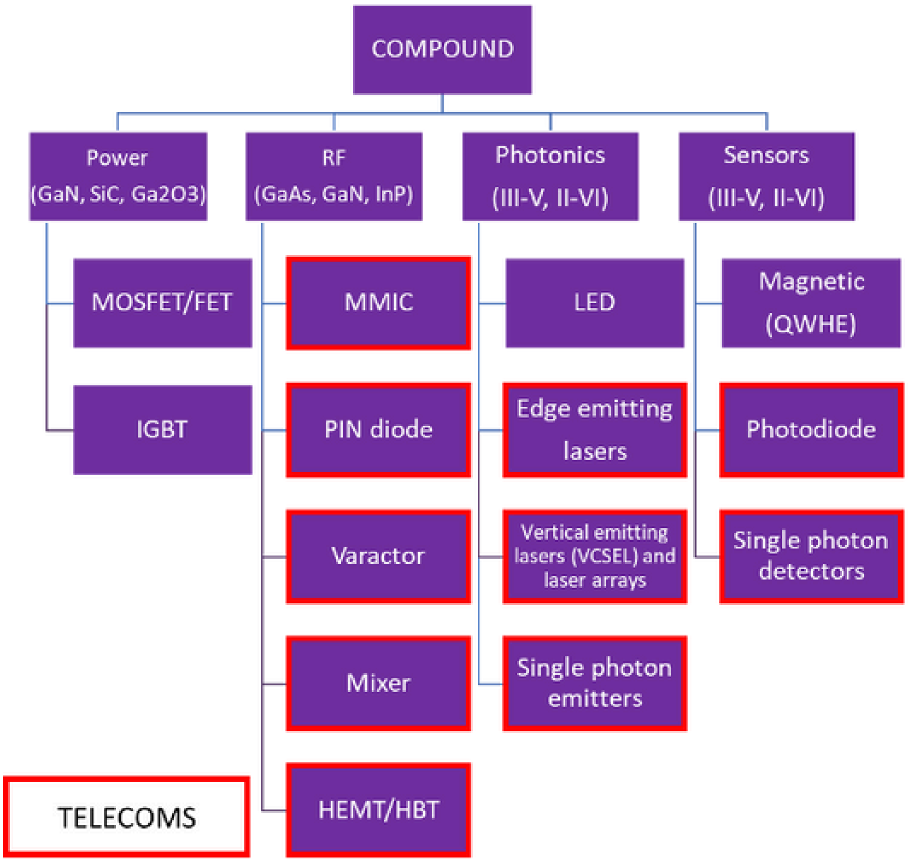


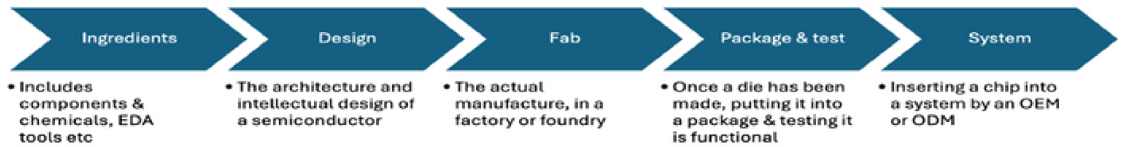
Figure 6 Compound semiconductor taxonomy

Figures 4, 5 and 6 demonstrate how many different functions there are for telecoms. Crucially, many of these rely on different processes, not just CMOS silicon.

The UK semiconductor supply chain has critical dependencies but it is important to see that there are significant strengths (design, compound semiconductor) that span several segments – but also systemic weaknesses, which, again, affect all segments.

c) UK supply chain today

Figure 7 describes UK capabilities at different stages of the supply chain for different types of semiconductors: today



	Ingredients	Design	Fab	Package & Test	System
CMOS logic	🙁 (a)	🙂 (b)	🙁 (d)	🙁 (f)	😐 (h)
Memory	🙁 (a)	🙁	🙁 (d)	🙁 (f)	😐 (h)
RF	🙁 (a)	🙂 (c)	😐 (e)	😐 (g)	😐 (h)
Photonic	🙁 (a)	🙂 (c)	😐 (e)	😐 (g)	😐 (h)
Discrete	🙁 (a)	?	?	?	😐 (h)

Where the symbols mean the following:
🙂 **– UK has (potential) strengths and opportunity**
😐 **– Neutral**
🙁 **– UK is weak and unlikely to develop significant capacity.**

Figure 7 Value chain for semiconductors today

Supply Chain

a) The UK has no indigenous industry in most of the components and no capability in electronic design automation (EDA) for the development process or the supply chain for fabs.

b) Semiconductor design and, in particular, processor architecture is a national strength and one that was recognised in the national semiconductor strategy.

c) Although less well-known than digital design (and not expressly mentioned in the strategy), design skills around RF and photonics are strong and should be celebrated.

d) The UK has no fabs for advanced CMOS nodes (logic or memory).

e) But there is capability for compound semiconductors and other non-traditional in volume.

f) Similar to above, limited packaging and testing.

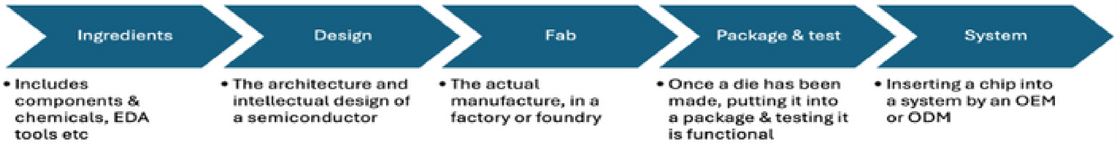
g) The UK does have expertise and capability in RF and photonics manufacture, especially in low-medium volume and in some areas of high value and low volume.

h) The UK has several innovative small companies in the space but limited scale.

It is worth emphasising that the UK has particular expertise in semiconductor systems in the telecoms area, not just in the individual devices but in their integration and system-level understanding. That is hard to capture in the table, but it is something that can be built upon and creates significant opportunities. While some countries or some sectors are focused on segments in narrow silos, the UK semiconductor companies are often more expansive, developing system-level reference designs or having vertical market applications understanding.

d) UK supply chain – potential for 2028

There is an opportunity for the UK to significantly improve the situation by minimising risk and building on strengths, for example:



	Ingredients	Design	Fab	Package & Test	System
CMOS logic	🙁 (a)	🙂 (b)	😐 (c)	😐 (e)	🙂 (g)
Memory	🙁 (a)	🙁 (a)	😐 (c)	😐 (e)	🙂 (g)
RF	🙁 (a)	🙂 (b)	🙂 (d)	🙂 (f)	🙂 (g)
Photonic	🙁 (a)	🙂 (b)	🙂 (d)	🙂 (f)	🙂 (g)
Discrete	🙁 (a)	?	?	?	🙂 (g)

Where the symbols mean the following:
🙂 **– UK has (potential) strengths and opportunity**
😐 **– Neutral**
🙁 **– UK is weak and unlikely to develop significant capacity.**

Figure 8 Value chain for semiconductors: potential 2028

Supply Chain

a) This is unlikely to change. Mitigation and stockholding is required to reduce risk.

b) This is a national strong capability and one that was recognised in the national semiconductor strategy. With investment, it could become a global-level strength and create powerful national advantage.

c) It is unlikely UK will have domestic fabs for advanced CMOS nodes (logic or memory), but partnership (whether contractual or investment) would mitigate risk.

d) As identified in the national semiconductor strategy and by the IfM, there is an opportunity to develop strength, invest and scale.

e) As (c) but different partners.

f) As (d) – opportunity but need to invest and grow scale in backend packaging and testing as well as fab.

g) Opportunity to grow scale and expertise, building on national strengths and supply chain.

e) Application of compound semiconductors in telecoms

Component	Telecoms applications	Current situation UK	Vulnerability	Future Interventions/ Actions
GaAs vertical cavity surface emitting lasers (VCSEL): custom wavelengths for quantum applications	850nm: short range active optical cables for parallel data comms in eg datacentre environments. 9xxnm: facial recognition in smart phone handsets is well established- migration to longer wavelengths in progress. >1200nm- eyesafe addressable arrays for high bandwidth LiFi, longer range FSO. Quantum: ultra-precise atom-cell atomic clocks for synchronisation of network infrastructure, satellite communications, GPS systems, and broadcasting services.	Well-established ecosystem based on UK indigenous capability. Very little UKRI investment in telecoms components for 20 years, but modest recent investment for quantum technology applications via targeted UKRI challenge fund investment. World-leading player in epitaxy with multiple mature fabrication and packaging options, which can be scaled up on a viable business case. Test capability is widespread and covers reliability and is starting to address standardisation for quantum technology systems.	The commercial VCSEL market is rapidly growing driven by consumer electronics, deployment of LIDAR and demand from comms. Ongoing development for telecoms transmission applications is lower volume than sensing, but there are still attractive business cases for investment. Emergent quantum applications will get ignored without a 'killer volume' quantum technology system application, UK preferred procurement or ongoing UK quantum technologies programme support to further evolve and maintain the supply chain.	Further development of manufacturing readiness levels and supply chain- further focus on yield, reliability and standardisation across a collaborative supply chain to address global opportunities. Extension of supply chain to qualify discrete VCSEL chip packaging in industry standard formats. Extension of UK capability to include integrated chip-scale packaging to drive miniaturisation. Collective focus on UK opportunities to support the UK systems industry- highly customised solution in datacoms, LiFi, defence comms applications.

Figure 9 Possible application areas for compound semiconductors

f) Complex, fragmented supply chains

No single country, including the UK, possesses a complete semiconductor supply chain specifically tailored to the telecoms industry (or any other sector), making them vulnerable to supply disruptions. The UK's telecoms sector, which is heavily reliant on semiconductors, faces challenges due to the absence of large-scale silicon fabrication, limited access to essential materials, constrained outsourced assembly and testing (OSAT) capabilities, and lack of advanced packaging capacities. There's also a disconnect between the older technology and niche products from UK fabs and the advanced semiconductor needs of the telecom industry.

While complete onshoring the semiconductor supply chain is impractical, the UK could enhance resilience by leveraging its strengths and forging secure partnerships, possibly adopting a cooperation model. This approach could mitigate reliance and strengthen the telecom sector's semiconductor supply chain, which is reflected in recommendation 2 on the need for a strategy on international partnership and cooperation.

The UK's fragmented supply chain has key processes such as chip fabrication in Taiwan, testing in Asia or the Netherlands, and packaging elsewhere. This dispersion complicates logistics, raises costs and challenges quality control. It also exposes the sector to geopolitical risks and supply disruptions. The reliance on different regions for various production stages makes the industry vulnerable and less agile while conditions are good – but introduces risks in the event of serious disruption. This exposure necessitates a strategic reassessment, potentially restoring critical capabilities to bolster resilience and maintain competitiveness in the fast-paced technological landscape.

The shortage of any one component in a system will mean the entire system cannot ship. As an example, the chip crisis in the automotive industry was triggered by a classic supply chain problem. At the beginning of the COVID-19 pandemic, car manufacturers expected a slump in demand, revised their production plans and passed this information on to their suppliers. Suppliers of electronic components in turn cancelled orders with chipmakers.

During the initial lockdowns in 2020, semiconductor companies redirected capacity previously reserved for the automotive industry to meet the demand for chips for higher margin customers and those that had grown rapidly during the initial shutdowns. However, once lockdowns eased the automotive companies tried to increase production, but found they could no longer access supply of semiconductors.

As chips are now used in many areas of the car, from electric windows to the engine control unit, large numbers of vehicles can no longer be completed. There were many cases where a $50,000 car could not be shipped for lack of a $0.05 component.

The same situation will occur with telecoms – with the added risk that while waiting for a new car might be irritating, waiting for a new comms link for a failed cellular base station might impact critical national infrastructure.

The manufacturing flow for a modern chip can be astonishingly complicated, as illustrated below..

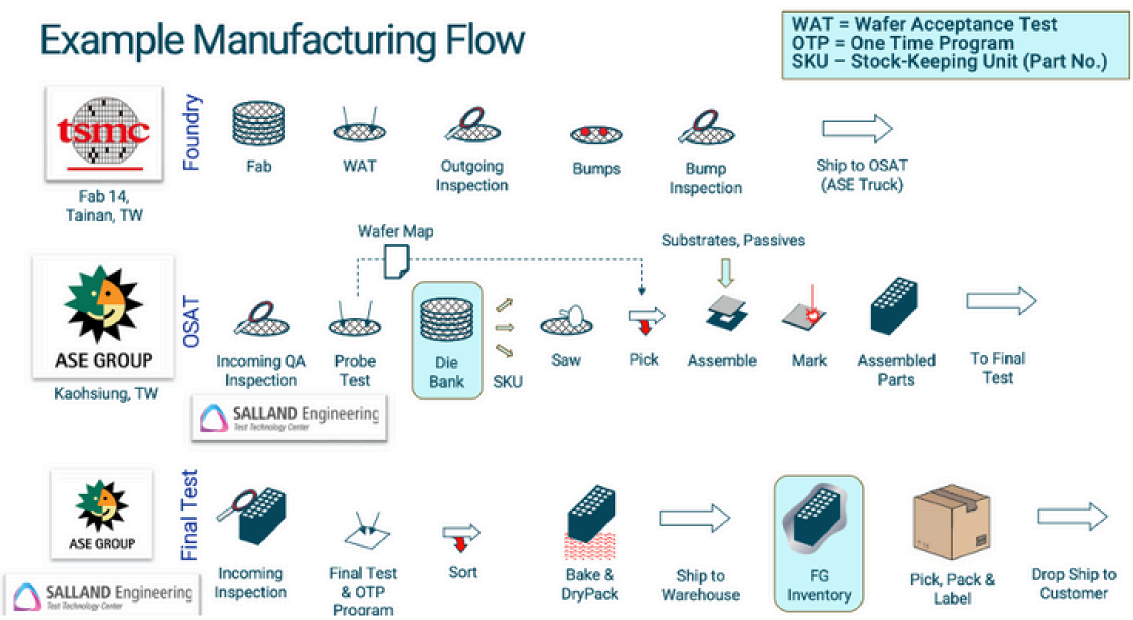


Figure 10 Supply chain for a typical semiconductor device

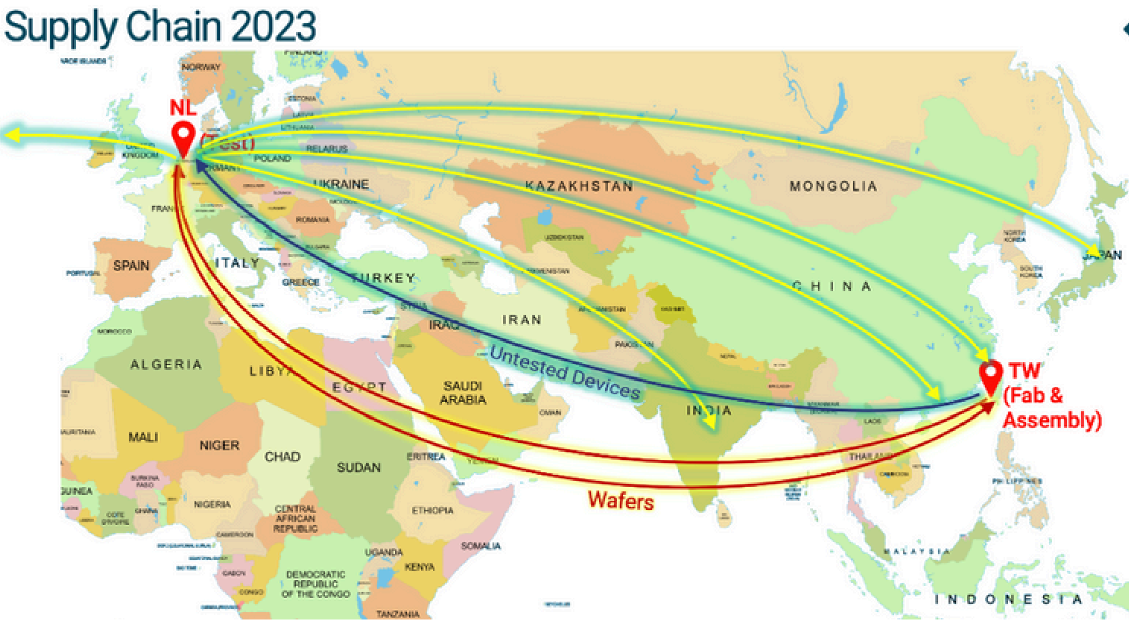


Figure 11 The geographic travel for the above 5G cellular base station chip supply chain. Note: this is for low/medium volume –at high volumes with more dedicated equipment, flows will be optimised more

This involves seven companies in five countries:

- IMEC, Belgium
- Salland, Netherlands
- TSMC, Taiwan
- ASE, Taiwan
- PHASIX ESD, UK
- Reltech, UK
- Kyocera, Japan (package substrates)

g) Long life cycle and long funding cycle

It is important to stress the long development cycles for both semiconductors and telecoms, which has major implications for funding.

It will typically take five years from founding a semiconductor start-up to shipping semiconductor chips that generate revenue. Considering working capital, and the time to ramp-up sales, into account, means that profit is further delayed beyond five years. The company requires funding until it reaches profitability.

Telecoms is similar to semiconductors. For example, each "G" in cellular is about a decade of research and development before launch, with 4G launched in 2009, 5G in 2019 and 6G expected "at the end of the decade".

A semiconductor chip for telecoms infrastructure might take five years from design to initial sales. This chip will likely be in volume production for five more years. After that, there will be requirement for support and ongoing maintenance, which might require a commitment to seven years of availability. In other words, a semiconductor chip might have a lifetime of 17 years, but only generate revenues for part of that time.

Semiconductors used in consumer products, such as smart phone, tend to have faster cycle times. For example, the design phase might take two to three years, followed by five years in service, which is a significant funding commitment.

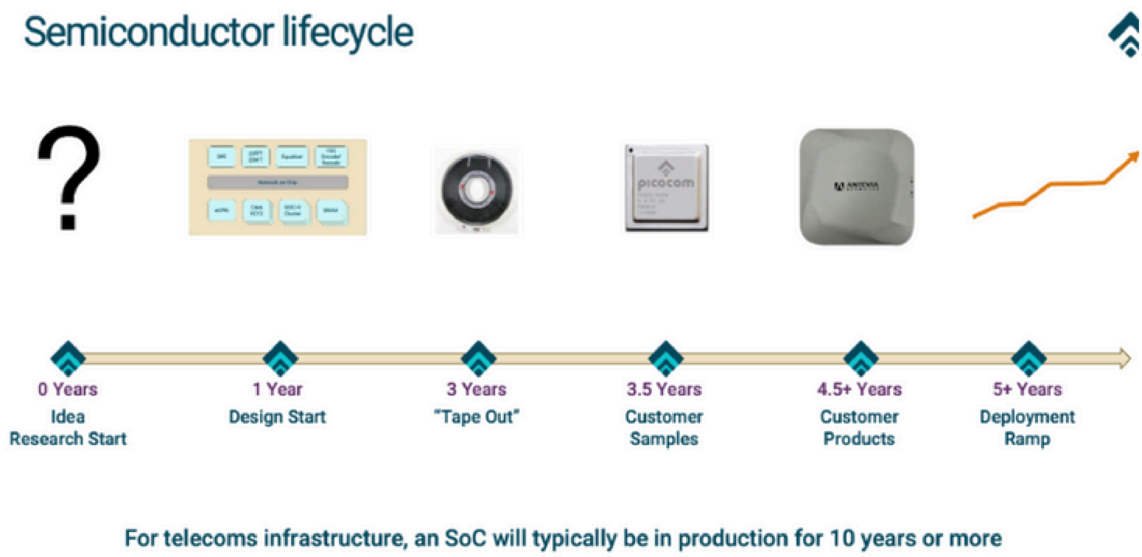


Figure 12 Example semiconductor lifecycle for an infrastructure device

h) Security

Semiconductors by design and use can be a source of security threat, and this nearly always involves an element of connectivity or communication. Telecoms systems are critical national infrastructure and a major target for disruption. There are increasingly strict regulations on systems that must be implemented in semiconductors. Although this topic is mostly out of the scope of this report, it is considered in detail by the security expert working group.

There are also connections with the UK National Quantum Strategy[20].

There is significant activity around the design of a new, more secure hardware and software ecosystem, which is very relevant to telecoms. This is an area of UK strength (for example, capability hardware-enhanced RISC instructions [CHERI] or Arm's memory tagging extension [MTE]) and one that merits attention.

However, there is one aspect of security that the group feels is important and maybe has not been appreciated enough. A trusted foundry for semiconductors mitigates the risk of tampering with design and ensures supply chain security. Trusted foundries, such as those certified by the Defense Microelectronics Activity (DMEA) in the USA, are crucial for preventing intentional or unintentional modification of integrated circuits and safeguarding against supply disruptions.

The risk of technology corruption, tampering and cyberattacks underscores the need for trusted suppliers to maintain the integrity of the integrated circuit manufacturing process. This is particularly vital for national security-critical components, as trusted foundries provide an assured "chain of custody" for integrated circuits and prevent unauthorised attempts at reverse engineering, ensuring the reliability and security of semiconductor design.

[20]National quantum strategy - GOV.UK (www.gov.uk)

Whilst not fully confirmed, and in a different technology area, the risk of a supply chain introducing backdoor and security vulnerabilities has been highlighted by the Supermicro server board reports [21][22].

The absence of a DMEA equivalent in the UK poses a significant risk to the integrity and security of the semiconductor supply chain. The potential threat of hostile actors tampering with semiconductors, as highlighted in the UK's National Semiconductor Strategy, underscores the need for robust measures to safeguard against tampering and cyberattacks. This vulnerability necessitates proactive strategies to mitigate risks, enhance supply chain resilience, and protect against potential compromises in the semiconductor manufacturing process.

Our recommendation for an initiative similar to the US Trusted Foundry Programme is strongly supported by the UKTIN Security Expert Working Group. It says that a significant portion of the world's fab capability is now at risk because of natural or political risks.

i) SECURE SUPPLY CHAIN: Security EWG Response to Semiconductor EWG

Recommendation 4:
The EWG recommends initiatives similar to the US Trusted Foundry Program, whereby designers can be assured that their chip has not been tampered during fabrication. This recommendation has synergies with the Innovate UK Digital Security by Design (DSbD) programme.

Rationale 4:
Security of supply has an additional meaning: can the fab itself be trusted? The US is taking steps with its 'Trusted Foundry Program' and the UK should have a similar program. As this requirement primarily applies to CMOS digital logic, and less to UK compound semiconductor devices, it will need international cooperation.

The security EWG strongly supports recommendation 4 and the underlying rationale.
There is a fundamental problem with semiconductor security globally. Over the last 50 years the focus has been on disaggregating/segmenting the supply chain to drive down costs and deliver the necessary economies of scale that have made possible the stunning advances in the field that we have witnessed.

However, this has come at significant cost, and the blunt fact is that a significant portion of the world's fab capability is now at risk either because of natural or political risks. Prior to the start of UKTIN, certain members of our group were already in discussion with DCMS/DSIT to consider what might be done. Since the UK is almost certain not going to be building its own cutting edge fab, this reinforces the importance of your recommendation and considering national security in the supply chain – especially when it comes to critical national infrastructure.

[21] Bloomberg 2018, https://www.bloomberg.com/news/features/2018-10-04/the-big-hack-how-china-used-a-tiny-chip-to-infiltrate-america-s-top-companies
[22] The Register 2021, https://www.theregister.com/2021/02/12/supermicro_bloomberg_spying/

5) SKILLS AND RESEARCH

It was striking how many of the working group identified skills as a key issue, and how many of the other discussions kept leading back to this topic.

"There is no point in fixing funding if we cannot hire any engineers if we had the money", and "We need to solve both finance and skills" were typical remarks.

There is a desperate shortage of engineers in both the telecoms and semiconductor sectors. This is true at all levels – apprentices, technicians, graduate engineers and postgraduate researchers.

Long-term change must be considered across all levels. Many of these concerns originate in schools teaching STEM subjects, so any strategy should start from age four.

However, a consequence of "long term" is that the shortages will not be quick to address. Even if graduate entry into Electronic Engineering could be boosted for the next UCAS year, those students will not graduate until 2029 or 2030 (with an internship) and will not be adding material value until a decade from now.

This is not a quality issue. The UK has a global reputation for producing high-quality research and innovation. According to the Times Higher Education, the UK is home to more than 10 of the top 100 universities in the world for electrical and electronic engineering. This places the UK second, behind the USA with more than 30 of the top 100 universities and ahead of China with less than 10 of the top 100 universities. Likewise, the report states that the UK is home to 11 out of the top 100 universities in the world for telecommunication engineering research. This places the UK third, behind China with 31 of the top 100 and the USA with 23 of the top 100.

The supply of graduates is a concern as the number is small and is not growing. There were 3,245 UK students enrolled on degrees in electronic and electrical engineering in 2021 according to the Universities and Colleges Admissions Service (UCAS). Of these, only 335 were women. This was less than half the number of students starting mechanical engineering degrees (7,050). [23]

[23] UCAS, Undergraduate sector-level end of cycle data resources 2021, https://www.ucas.com/data-and-analysis/undergraduate-statistics-and-reports/ucas-undergraduate-sector-level-end-cycle-data-resources-2021

Telecoms and semiconductors fare even worse for three reasons:

- Cost: these courses are unusually expensive to teach so universities will, quite rationally, deprioritise them
- Lack of teaching expertise
- Student perception that courses are difficult

The first of these can only be addressed by targeting funding.

The sector suffers from a lack of diversity and demographic issues, meaning the shortages will get worse in the medium term. According to research from the skills group of UKTIN, only 3% of the telecoms sector workforce is female and over 60% is aged over 50.

Skills development is a long-term challenge. If student recruitment were to increase in 2025 entry, the intake would graduate with an MEng in 2029 (2030 with placement) and it would take another few years before they were productive. Replacing those retiring in the next few years is a significant concern.

Part of the problem is awareness and image. School students are not considering the subject and not applying. We are seeing outstanding and highly relevant courses (such as the degree apprenticeship at the University of South Wales for semiconductors) being suspended due to a lack of learners selecting it. We must influence the 'influencers' as well as the learners – parents, teachers, career advisors, and lecturers.

There is evidence that some young people are dissuaded from a subject that they perceive as being 'hard'.

This was covered extensively in the Science Education Tracker 2023 report[24]

It was also summarised well in a 2023 Civil Engineering Surveyor report[25] which found almost half (47%) of 11-19-year-olds said they knew little or almost nothing about what engineers did and their limited knowledge was often distorted. Not only was engineering seen as difficult, complicated and dirty, but it was also often considered a male profession. It also found that 62% of 16- and 17-year-olds in the UK felt that subjects like science and maths were more difficult than non-STEM subjects.

[24] Verian, The Royal Society, Engineering UK, Science Education Tracker 2023, https://royalsociety.org/-/media/policy/projects/science-education-tracker/science-education-tracker-2023.pdf
[25] Civil Engineering Surveyor 2023, The State of Engineering Report, https://journals.cices.org/ces/ces-april-2023/features/the-state-of-engineering-report

Other things that would help, and be cost-effective, could include:

- Practical experience for undergraduates and graduates in integrated circuit design (through things such as placements, internships and design academies)
- "conversion courses" from related STEM disciplines such as physics or mechanical engineering
- A bursary scheme similar to the CyberFirst programme

This is not just a UK problem. Many other countries (for example, USA) have identified the same problems.

Graduate engineers can earn very high salaries and enjoy fulfilling careers, but this does not seem to be communicated to potential students or motivating them to apply. It is interesting to compare the UK to other geographies where engineering is perceived much more positively by students and parents.

Although politically sensitive, it is likely to require greater immigration of skilled workers for these segments from countries who produce more engineering graduates. This could also include overseas students who are studying here on these shortage subjects, making it easier for them to stay if they work in relevant sectors. However, there is an issue that skilled worker visas are still very difficult to acquire and far more expensive than peer countries.

This "hostile attitude to immigration" is significant impediment to growth.[26] While talent development (apprenticeships, university) is essential in the medium term, it cannot quickly deliver the skills that are required in the next few years.

One employer the group spoke to said: "I've just done an analysis of France vs UK visa costs. To hire four people with three dependents, it costs circa £11,000 in France, with average timescales of six to eight weeks. In the UK, the cost would be just over £45,000. If the whole process goes smoothly – and it rarely does – the timescale from applying for a licence to hiring someone is circa five months. So, we expanded our French site instead of the British one. Spain and Portugal are even easier for visas."

[26] https://www.bloomberg.com/news/articles/2024-06-24/hostile-migration-policy-threatens-uk-chip-industry-bosses-say?

a) University research expertise

The UK's strength in semiconductors is its academic research base.

Government funding through the Engineering and Physical Sciences Research Council (EPSRC) has ensured that several universities maintain world-leading research and, in some cases, success in spinning out research into private companies.

However, relatively few students consider going into research. We need better pathways and support for UK students to encourage more to go into PhD research. We should also look at attracting students from adjacent degrees (for example, physics) into this research, perhaps with focused cross-training.

The UK has a global reputation for producing high-quality research and innovation.

The leading focus for III-V materials (containing elements from groups III and V in the periodic table) research is the EPSRC National Epitaxy Facility, a collaboration between the universities of Sheffield, Cambridge and University College London (UCL). It supports a full range of group III-V semiconductors and silicon-germanium-based group IV materials using both molecular-beam epitaxy (MBE) and metalorganic vapour-phase epitaxy (MOVPE) techniques for UK academics and industrial customers interested in LEDs, lasers, quantum circuits, transistors, advanced detectors and solar cells. The partner labs at UCL have also developed growth techniques using III-V semiconductors on silicon substrates for silicon photonics and other hybrid devices.

The Cambridge Centre for Gallium Nitride sits alongside Sheffield as a leading centre for III-V research. Besides a full suite of growth and characterisation equipment, it has been successful in spinning out a higher number of companies. These include CamGaN Ltd, which pioneered the growth of GaN on silicon, later acquired by Plessey Semiconductors Ltd. Anvil Semiconductors Ltd is developing cubic GaN materials for LEDs. Poro Technologies Ltd has a novel porous GaN technique. Cambridge GaN Devices Ltd is commercialising GaN on silicon technology for use in power electronics. It is a spinout from the Electrical and Engineering Department. Paragraf Ltd has developed a process that enables graphene to be produced directly onto substrates such as silicon, silicon carbide, sapphire and gallium-nitride for very high-sensitive sensor devices and other applications.

Skills & Research

Cardiff University's Institute of Compound Semiconductors leads the Future Compound Semiconductor Manufacturing Hub, which was launched in October 2016 to capitalise on the academic expertise at Cardiff, Manchester, Sheffield and UCL. It aims to change the approach to research by thinking about how solutions can be manufactured. The hub's base in Cardiff takes advantage of Europe's "5th semiconductor cluster" in South Wales, which is home to semiconductor company IQE. The institute is now building a state-of-the-art 8-inch fabrication line within a new translational research hub.

Other universities doing leading research in III-V material fields include Glasgow, Bristol, Bath and Sussex. In fields that use compound semiconductor materials, such as photonics (lasers and opto-electronic devices) and power electronics, there are also several key universities. For example, the universities of Southampton and Strathclyde have established particularly strong reputations in photonics. Notable centres in the field of power electronics using GaN and silicon carbide materials in next-generation products include Warwick, Newcastle and Nottingham.

Many of the researchers undertaking PhD research and many post-docs are non-UK nationals, very often Chinese. This is not necessarily bad as international research links create valuable network. Nonetheless, the commercial benefits are likely to be overwhelmingly exploited outside the UK in countries that have an industry that can exploit the research.

On the positive side, some of the research carried out by foreign nationals at UK universities is spun out in the UK, taking advantage of the strong incubation and funding infrastructure. The solution is not to prevent foreign nationals from coming to study in the UK but to make it worthwhile for UK nationals to study as well.

The University of Bristol have recently received funding for an Innovation Knowledge Centre (IKC) known as REWIRE, which will focus on power conversion of wind energy, electric vehicle, smart grids, high temperature applications, device and packaging, and improving the efficiency of semiconductor device manufacturing.

Another recently funded IKC, the CORNERSTONE Photonics Innovation Centre (C-PIC) led by the University of Southampton in collaboration with the University of Glasgow and the Science & Technology Facilities Council (STFC – the home of EUROPRACTICE in the UK), aims to support researchers taking silicon photonics technologies from lab to fab, highlighting the strengths in silicon photonics research in the UK, building on the world-leading capabilities of the CORNERSTONE silicon photonics prototyping foundry.

b) Innovation hubs and clusters (Catapults etc.)

Innovation hubs are crucial to the UK's semiconductor sector, fostering collaboration, research, and commercialisation. The burgeoning compound semiconductor industry benefits significantly from these hubs, particularly in regions such as South Wales and Cambridge, where specialised facilities accelerate growth. Catapults, such as the Compound Semiconductor Applications Catapult (CSAC), play a pivotal role by bridging the gap between academia and industry. They provide access to cutting-edge facilities, expertise, and partnerships, driving technological advancements in power electronics, RF, and photonics. Examples from other countries, such as ITRI in Tawan, ETRI in Korea, and the Fraunhofer in Germany, show how powerful this can be. Although relatively recent innovations, the activities and support of these hubs are significant for successful UK innovation in semiconductors.

c) Skills, talent development and retention

The global semiconductor industry is wrestling with a skills shortage. As technology shifts towards more complex, integrated circuits and next-generation materials, the required skill set changes, leading to a dearth of qualified personnel. The talent shortage is a major problem from Silicon Valley to Hsinchu Science Park.

This is not a recent problem, nor is it one with a quick fix. Any solutions must focus on the long-term attractiveness of the sector and start from an early age. Indeed, the changes need to start at primary school. Any plans or support need to be viewed as long-term.

This skills shortage is present and a concern in many countries. However, it is especially evident in the UK and, more specifically, in the UK telecoms sector, partly due to demographic reasons.

This applies at all levels. While the focus is often on graduate-level talent, the role of technicians is equally crucial. These are the hands-on experts who convert theoretical designs into tangible, operational systems. They are the linchpins of practical engineering and, without them, even the most brilliant of designs remain mere blueprints. Their absence forms a significant roadblock in the practical application of semiconductor technology.

As academic institutions withdraw, the pipeline that feeds skilled labour to the industry dries up. This, in turn, further exacerbates the skills shortage, resulting in a downward spiral that not only puts the telecoms sector at risk but also diminishes the UK's competitiveness on the global stage.

We need multi-stakeholder interventions, ranging from government incentives and industry partnerships to academic revamps. Solutions could include:

- subsidies for specialised programs
- corporate sponsorships for labs
- educational alliances that facilitate the exchange of expertise

The situation is dire and, without immediate, concerted efforts, the sector risks slipping into a chasm of obsolescence from which recovery could be painstakingly slow or, worse, impossible.

The creation of the skills group within the Semiconductor Advisory Panel is a welcome recognition of the importance of the issue.

d) Undergraduate

UK participation in and leadership of technological advances is being limited by a chronic skills shortage in semiconductor design and more broadly electronic engineering, the foundation discipline for both telecoms and semiconductors.

For many years, too few students have been studying electrical and electronic engineering, and this means that there are insufficient graduate engineers to drive forward innovation and progress. This shortage is particularly acute in the sphere of semiconductor ("chip") design.

As shown in Figures 13, and 14 the number of Electronic Engineering students has declined, even as student numbers in other related areas increased.

Over 80% of UK companies involved with chip design have unfilled vacancies. Global competition for talent in semiconductors is fierce, and other nations, such as the USA, are already investing heavily. If the UK aspires to sovereign capability, urgent action is required to tackle semiconductor design skills.

The only way for the UK semiconductor industry to sustainably grow and thrive in the long term is to increase the number of students studying electronics at the degree level.

The UK must develop a coherent, national strategy to create a semiconductor skills pipeline starting at school. That requires initiatives to ensure more school children are aware of semiconductors, electronics and engineering, and to make it an explicit part of their education. Children, their parents and teachers need to be aware that there are exciting and worthwhile careers available as designers and engineers in the semiconductor sector.

Similarly, undergraduates could be encouraged to pursue careers in semiconductors with support in their professional development, so they are equipped with work-ready skills and experience. The country needs to provide relevant and focused postgraduate study to develop key areas of technical knowledge and understanding so they contribute to innovation-led businesses and future semiconductor research and development.

If there are no teachers with the necessary skills or capacity to teach triple science in schools or lecturers within the higher education sector then the courses cannot be taught, so the pipeline of postgraduates and lecturers is broken. If students are not incentivised or provided with the resources, education and support to take the "hard" courses, then they will not be offered. Schools in disadvantaged areas are less likely to offer triple science, potentially affecting students' ability to study engineering-facilitating subjects at A level, such as physics.

To address the skills shortage and reap the considerable benefits a more diverse workforce can offer, more must be done as a community to support young people from disadvantaged backgrounds to study and excel in electronics engineering.

Work is needed to tackle barriers that may inhibit them from pursuing engineering. These include:

- lower levels of prior academic attainment, including in STEM subjects
- lower levels of science capital
- negative perceptions or misperceptions of engineering
- patchy, socially stratified access to careers education and work experience
- schools in disadvantaged areas are less likely to offer triple science, potentially affecting students' ability to study engineering-facilitating subjects at A level, such as physics

Acceptances from UK Domiciled Students on Engineering & Computer Science Degree Courses 2012/2021[2]

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
All UK Domiciled Students										
Civil Eng HE Acceptances (H2)	3,100	2,990	2,805	3,115	3,315	3,450	3,440	3,255	3,430	3,485
Mech Eng HE Acceptances (H3)	5,260	5,800	6,070	6,690	6,750	6,515	6,545	6,425	7,030	7,050
E&E Eng HE Acceptances (H6)	3,210	3,425	3,350	3,525	3,510	3,330	3,150	2,965	3,105	3,245
General Engineering (H1)	2,730	3,110	3,780	4,085	4,010	4,165	4,025	4,260	4,115	4,305
Engineering HE Acceptances (H)	19,050	20,660	22,325	24,000	24,015	23,880	23,430	23,215	24,195	24,675
E&E Eng as % of overall	17	17	15	15	15	14	13	13	13	13
Computer Science HE Acceptances (I1)	11,190	12,820	13,825	15,410	15,700	15,620	15,430	15,110	15,975	15,765
UK Females										
Overall HE Engineering	2,245	2,415	2,990	3,510	3,685	3,755	3,840	3,915	4,035	4,240
E&E Eng HE Acceptances	225	240	265	280	310	295	305	255	290	335

Figure 13 Acceptances from UK-domiciled students on engineering courses (2012-2021)

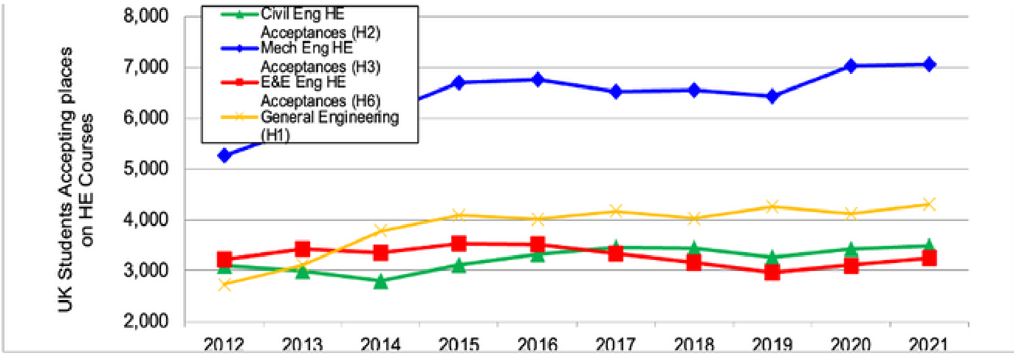


Figure 14 Acceptances onto engineering degrees 2012-21

e) Technician and apprenticeship

The UK needs more highly skilled technicians and production line operators to support growth in manufacturing. Whilst higher education has received much attention in recent years, the apprentice schemes that the industry offers to train such staff also need support.

A recent Engineering UK inquiry led by Lord Knight and Lord Willetts, Fit for the future: Growing and sustaining engineering and technology apprenticeships, found that employers needed more flexibility in how they spent funding obtained from the Apprenticeship Levy scheme and recommended reform of the scheme to better match the needs of industry in training and skills development[27].

Employers in our sectors are supportive of apprenticeships, and many have run programmes for decades.

Since 2015, the "trailblazer" group of employers (responsible for developing occupational standards of an apprenticeship) has developed new apprenticeship standards for telecoms. These are level six and seven apprenticeships, which are at degree standard.

In general, engineering apprenticeships are expensive, and telecoms and semiconductor apprenticeships are even more expensive. It can cost an SME more than £100,000 to train a level three apprentice, and much of the cost is front-loaded. However, both for the employer and the provider, the phasing of the Government contribution to costs is not front-loaded. It leads to a cash constraint and consequent disincentive to use the apprenticeship model.

[27] Engineering UK, Fit for the future: Growing and sustaining engineering and technology apprenticeships for young people, https://www.engineeringuk.com/research-policy/fit-for-the-future-growing-and-sustaining-engineering-and-technology-apprenticeships-for-young-people/

This is particularly acute for cash-poor SMEs. To make matters worse, a residual contribution from the government is retained until after the end-point assessment (EPA). This is substantially beyond the point at which costs were incurred. When these assessments are delayed, that further stretches cash. In the event the apprentice fails their EPA, the funds are withheld.

Generally, technicians enter employment via vocational routes including apprenticeships. However, currently there is no apprenticeship standard in England specifically for semiconductor manufacturing technicians. Consequently, employers can't offer apprenticeships to future semiconductor technicians.

Before employers can develop an apprenticeship standard for an occupation, there needs to be an occupational standard. It is all quite involved and comes under the governance of the Institute for Apprenticeships and Technical Education (IfATE).

As skills are devolved, there are some national occupational standards and apprenticeships in semiconductors in Wales.

There are also no suitable and relevant standards for telecoms and semiconductors at level four and level five (previously these were based on HNC, HND and foundation degree). The principle of ‘employer-led’ standards is good in theory. However, in practice, the development process for new standards through IfATE is time-consuming, bureaucratic and complex.

The long-term value and benefit of apprenticeships versus costs is not always well appreciated. We know of senior industry leaders who joined large companies as apprentices. After 30 or 40 years in the industry, they observe that a significant proportion of senior colleagues also joined as apprentices. Whilst it may not be that employees remain in the same company for as long as they did in the past, properly investing in the core skills at the apprenticeship level is a significant factor in the development of exceptional senior management, particularly in the technology and engineering fields.

The tax-take from the Apprentice Levy is also not hypothecated to apprenticeship training. We understand that the majority of levy funds end up in general taxation and are not ring-fenced for skills and training.

f) Postgraduate and research

The centres for doctoral training (CDTs) in the UK represent a commendable system of academic and industry collaboration, offering numerous benefits. These CDTs, supported by business and industry, aim to create a cohort of highly skilled and talented researchers through multi-year commitments to research and PhDs in universities.

By providing a balanced portfolio of CDTs aligned with identified skills needs, they produce future leaders and experts in various fields, including artificial intelligence, sustainable energy and geoscience. The CDTs' innovative and flexible, cohort-based training programs, in collaboration with industry, equip students with the necessary expertise to address the evolving challenges in their respective domains, making them an invaluable asset to the UK's research and innovation landscape.

Expanding CDTs is imperative, particularly for the UK's telecom and semiconductor sectors. The alignment between academia and industry in CDTs is key to fostering long-term research and innovation. Given the increasing demand for wireless communication and the adoption of advanced semiconductor technologies, as well as the challenges posed by the highly fragmented and competitive nature of the telecom sector, CDTs can serve as catalysts for driving innovation and addressing critical skills gaps.

By emphasising the development of expertise in compound semiconductors, radio frequency (RF), and mixed-signal technologies, CDTs can play a pivotal role in equipping researchers with the necessary knowledge and skills to tackle the complexities associated with higher bandwidths, increased sensitivity, and higher frequencies. This strategic expansion of CDTs will not only fortify the UK's research and development capabilities but also contribute to the resilience and competitiveness of its telecom and semiconductor industries in the global landscape.

The EWG welcomes the Department for Science Innovation and Technology's recent announcement of a £1 billion investment in 65 CDTs[28] in the five critical technologies in the Science and Technology Framework: artificial intelligence, engineering biology, future telecoms, quantum and semiconductors.

A good example of a CDT is the Centre for Doctoral Training in Photonic and Electronic Systems jointly established by UCL and University of Cambridge.

[28] UKRI 2024, £1 billion doctoral training investment announced – UKRI

g) International comparison

Other countries have very similar concerns.

More electronics everywhere and more intelligence in those electronics require new chip architectures, more hardware-software co-design, and more cross-training of engineers in disciplines that traditionally have been siloed.

Geopolitical rivalries and pandemic-related supply chain glitches are prompting governments to pour massive resources into training and education to on-shore and re-shore both key components and materials and the expertise to design, verify, manufacture and package advanced chips.

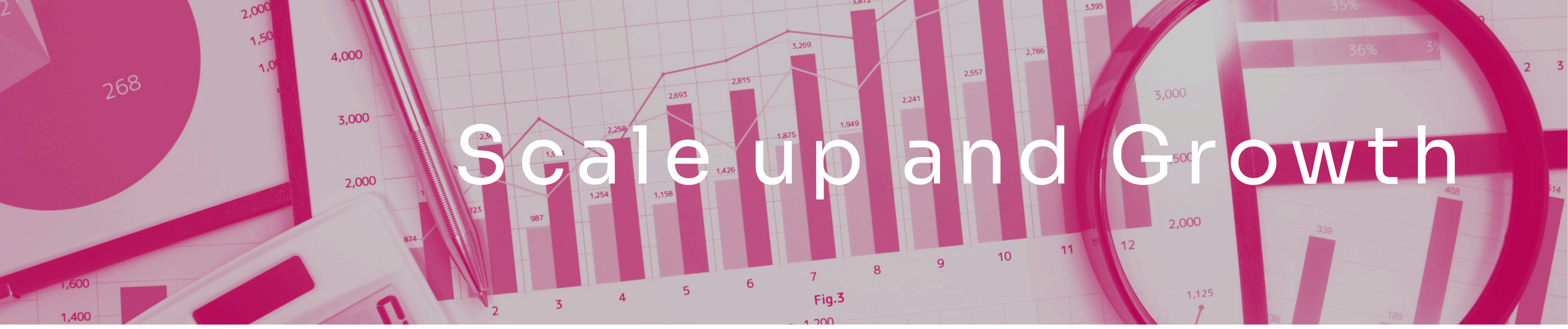
Cyber-security threats in safety and mission-critical applications, including longer lifetimes for chips in markets such as automotive and medical, require a much deeper understanding of how to build secure devices and how to keep them updated and resilient. This is compounded by the growing number of connected devices, which significantly widens the attack surface.

The required bank of skills increasingly includes:

- multi-physics design and verification
- 3D integration
- integrated circuit manufacturing process development, testing and inspection, and an understanding of how chips and chipsets can operate in an advanced package

In addition, there are more partnerships focused on developing technology-related to AI and machine learning, 5G, quantum computing, and sustainability.

For example, an article in Electronic Design AI's Impact on Engineering Jobs: What Can We Do About It? expresses concern about the falling number of electrical engineering (including telecom) undergraduates – and the notably low participation of women. It provides an interesting summary of data about the number of engineering students and graduates in the USA (albeit the data is only up to 2018). Two parallels with the UK are that mechanical engineering is by far and away the most popular sub-discipline of engineering and that electrical/computer engineering is relatively the most unpopular sub-discipline for females.



6) SCALE UP AND GROWTH

How can the country leverage research and development strengths to support the incorporation of new technologies and innovations into the UK's semiconductor landscape for telecommunications? How does the country better support scale-up and growth?

As technologies such as 5G and 6G, photonics, the Internet of Things, and AI evolve, they present new opportunities for semiconductors. The UK could be at the forefront of developing and commercialising technologies to stay competitive. The UK has great strengths in research and development and early-stage company growth. How can it best leverage those strengths? Despite those strengths, the UK has few world-class telecom companies at global scale. However, in the past two decades, the UK has failed to create any large organisations in this segment. How can this be better addressed to improve funding for growth-stage companies?

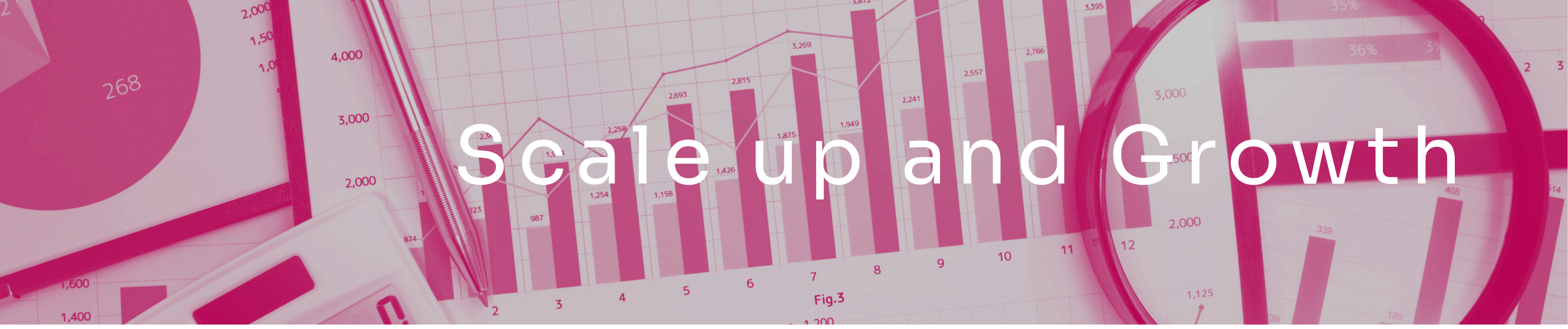
There is an absence of major UK-owned telecoms or semiconductor companies in the UK. There were several but they have mostly closed, shrunk substantially or become part of foreign companies. This represents a hollowing out or market failure of UK telecoms infrastructure. The lack of domestic customers does force UK component suppliers to think globally (a benefit) but hinders them in terms of customer closeness and engagement and works against the creation of industry clusters.

This is especially true for both semiconductors and telecoms as they are capital-intensive and have long development times. The ceiling on start-up growth, scale-up and the transition to a global scale is a bigger issue.

While the UK does very well on early-stage funding and venture capital funding (second only to the US and China), it drops to the bottom of the G7 on the ratio of growth-stage venture capital to early-stage funding. The UK has 30.8% late-stage funding as a percentage of the total funding compared to the USA at 50.8% or Germany at 48.8%. The ScaleUp Institute estimates there is a ‘growth capital gap’ of around £15 billion a year in UK funding required to properly realise growth ambitions[29].

This shortage disproportionately hurts semiconductor and telecoms investment because they are capital intensive and long term (long time to profit). Investors are sensibly wary of getting involved at an early stage unless they can be confident of later-stage funding materialising. Since the UK is relatively short of late-stage funding, few early safe companies get started. Even though early-stage venture capital support is available it will, in general, avoid those sectors.

[29] ScaleUp Institute, Innovate Finance and Deloitte, The Future of Growth Capital, 2020, https://www.scaleupinstitute.org.uk/reports/the-future-of-growth-capital/



Scale up and Growth

As a result, the UK is ranked sixth in Europe for semiconductor funding.

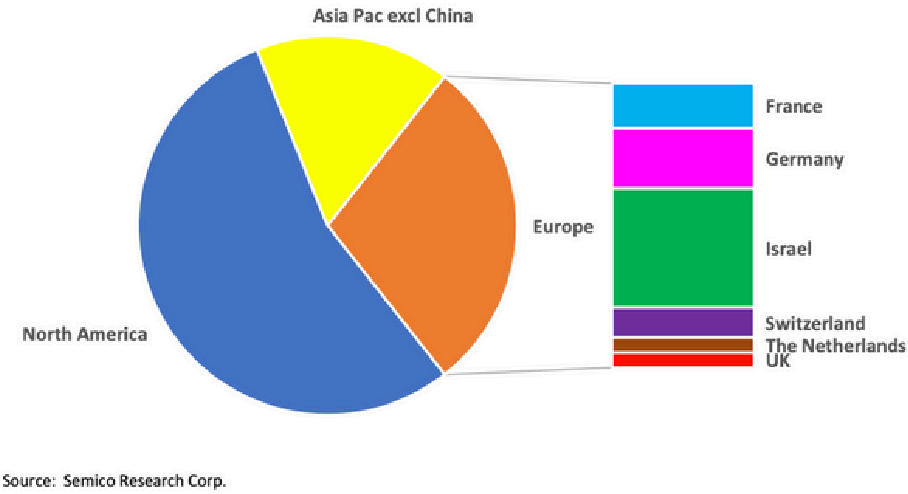


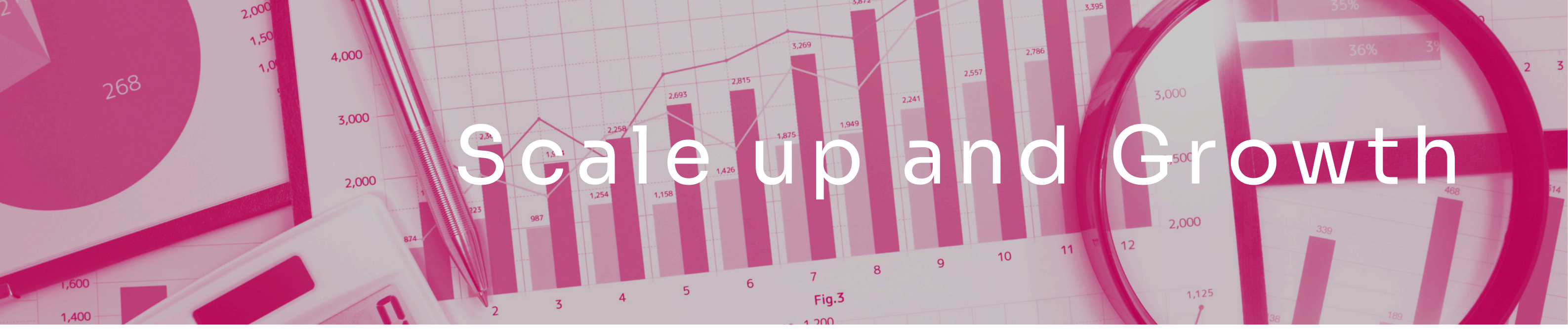
Figure 15 Funding for semiconductor startups by country

Although Silicon Catalyst has identified 35 "significant" exits in the UK, including 14 unicorn sales (in 2024), the rate of these has not accelerated in recent years. The last one was Dialog in 2021.

‘The UK Semiconductor Industry – Our Opportunity’ published by Techworks Semiconductor Leadership Group in March 2023 calls for intervention to increase patient investment both across the whole supply chain and at each stage of company development (incubation, seed, early stage, growth and scale-up).

The Confederation of British Industry (CBI) has written extensively on this funding gap[30] and says there is a market failure in the UK as even profitable companies with a track record struggle to raise the necessary investment (equity or debt) due to a lack of patience and market understanding in the finance community.

[30] CBI, Institutional Investment into Science and Technology Scaleups, 2023, https://www.cbi.org.uk/media/rnrjzmbg/12837-institutional-investment-for-scale-ups.pdf



Scale up and Growth

While regulatory reforms (such as the Mansion House reforms to enable the financial services sector to provide greater support to promising industries[31]) are necessary, they are not sufficient. A lot also depends on awareness and understanding of the industry. For example, the chip design, development and production cycle usually take two or more years, and upgrading a production site can also take around two years to complete. Realising the increased net profit to repay the investment can take more than five years, which is beyond traditional investors' expectations of return. However, if these companies can maintain their lead through appropriate investments, they are often highly successful in the long term.

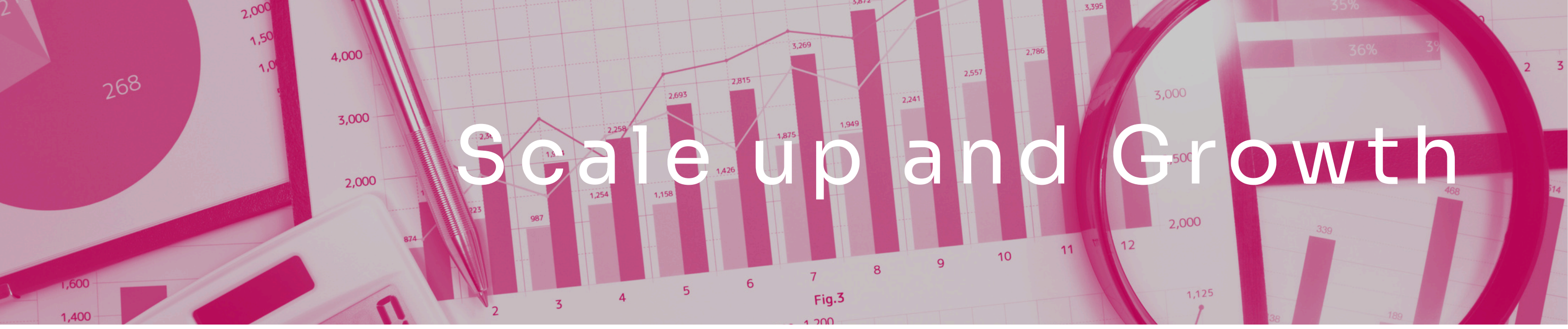
The demise of the major UK equipment companies has left the UK instead with many small innovation-led companies. However, they lack scale and have difficulty raising finance. They must also contend with an entrenched investor mentality that focuses on near-term profit rather than longer-term growth. To overcome this, new approaches to the way companies work together should be considered.

This problem exists much less in Europe as each of its major economies has retained one or more national champions, for example, Philips, Siemens, Ericsson and ST Micro. Each of these has its own powerful supply chain, and each can also engage in open innovation, so that they acquire innovation start-ups when necessary.

The UK boasts a robust ecosystem for early-stage company formation, with ample support at the seed and series A stages. However, challenges arise when these start-ups seek to progress to the series B or C stage, as funding becomes scarce. While early-stage businesses benefit from various funding options, including government grants, equity financing, and tax-advantaged schemes, the transition to later stages demands additional support. Indeed, in many cases the rules of those schemes specifically act to cap the growth of those companies and make it hard to scale.

An important example is provided by UK Research and Innovation and Innovate UK. All such programs are limited to £315,000 per funded company over three years through the minimal financial assistance exemption to the Subsidy Control Act 2022. If UKRI wishes to provide more funding, there is a maximum of £1 million possible. However, the project must be referred to the Subsidy Advice Unit and, even then, the funding is often insufficient to achieve the desired goals.

[31] HM Treasury, 2023, https://www.gov.uk/government/collections/mansion-house-2023



The decline in investment activity and the scarcity of funding at the series B and C stages pose obstacles to the growth of these start-ups, particularly in sectors such as deep tech, telecoms and semiconductors. Addressing this funding gap is key to sustaining the momentum of early-stage companies and fostering their long-term success in the UK.

Start-ups also face issues taking their new technologies through the technology readiness levels (TRL). Companies such as Rockley Photonics have been forced to do most of their late TRL development work with research and technology organisations in Finland and Ireland, spending tens of millions of pounds, often with the help of local research funding bodies that invest in both enabling technologies and critical equipment to leverage the research and development investment. These organisations have invested heavily in applied research to advance the TRL levels. This is something that the UK Catapult centres could potentially help with but so far have not done.

Both the USA and EU have responded to the importance of semiconductors with funding, including:

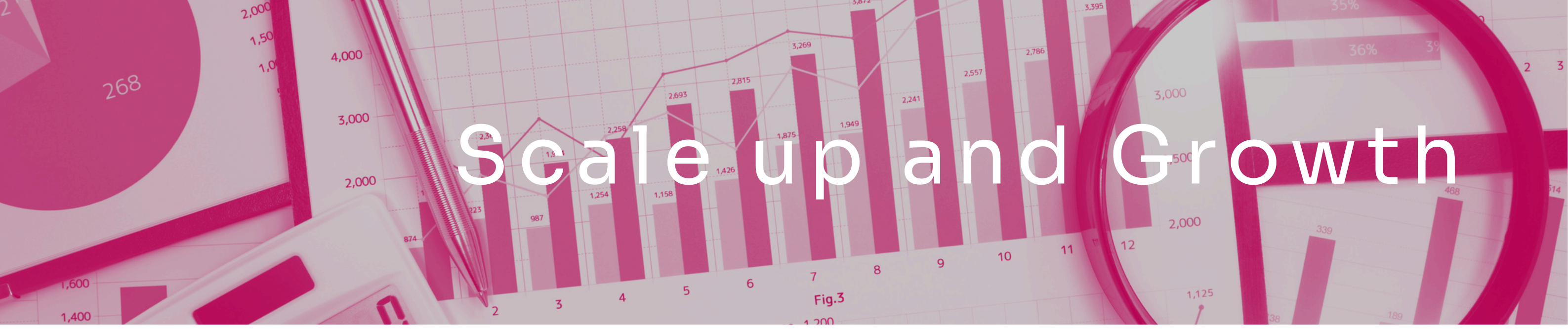
- US Chips Act of $52.7 billion ($39 billion for domestic manufacture and $13 billion for semiconductor research and workforce training)
- EU Chips Act of €43 billion of policy-driven investment up to 2030, which will be broadly matched by long-term private investment

a) EU state aid limits

EU governments have been hindered in their ability to fund or invest in new technologies at the later TRL stages due to EU State Aid Rules. These rules state that near-to-market development may only have up to 20% state aid. This is a major reason the European semiconductor and microelectronics industries have been at a disadvantage with competitors in Asia, which enjoy strong state support.

After the European share of global semiconductor production had fallen from 23% to 8%, the European Commission invited a group, the High-Level Group for Key Enabling Technologies, to propose a solution. The group identified the state aid rule as the biggest handicap they faced. To remove it, they proposed a little-known scheme called an IPCEI (Important Projects of Common European Interest), which made it possible for exemptions from the rule.

The IPCEI scheme for the microelectronics industry came into law at the beginning of 2019. Since then, the German government has committed to provide over €1 billion to its industry, France €800 million and Italy €500 million. In total, EU has allocated over €40 billion through the EU Chips Act without being constrained by the state aid rules.



Paradoxically, the UK has not taken advantage of any Brexit freedoms in this respect, nor has it adopted the mechanisms that existed in the EU, while losing out on both IPCEI and EU Chips Act funding.

b) Late-stage investment

A criticism of the government is that technology support has been concentrated at the earlier TRL stages when what is also needed, even more urgently, is support nearer to the market. The Government, for example, has not taken advantage of the EU invoking the IPCEI clause to remove state aid restrictions for late-stage investment in microelectronics industries. Its removal ought to open the way for the government to take a more proactive role in supporting strategic investment in the industry.

The semiconductor industry is a good candidate for the Government's Strength in Places programme. Regions where the industry concentrates are South Wales, Glasgow-Edinburgh, and the North East. There are also clusters in the South and South West (Southampton, Torbay and Plymouth).

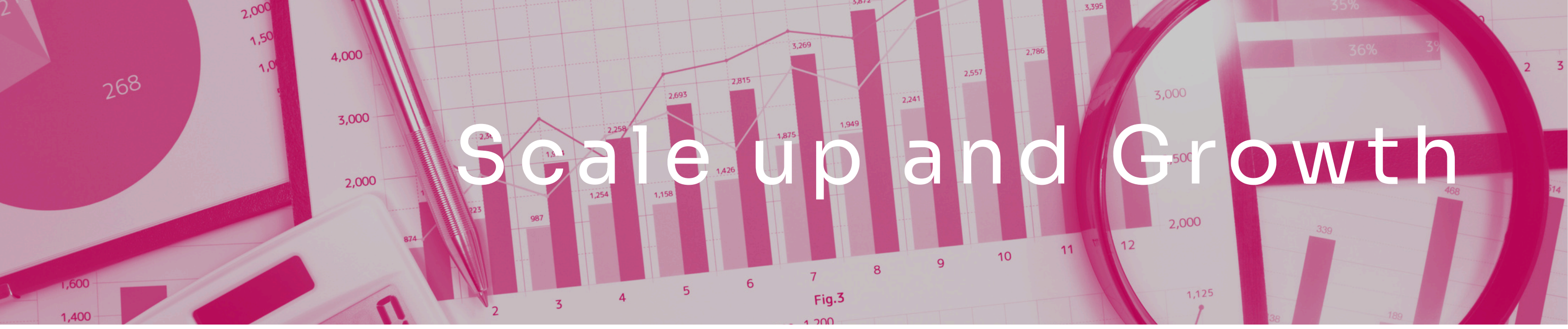
The UK is strong in venture capital funding. For example, in 2022 investment in UK tech firms was $29.9 billion, making it the third largest country for tech investment behind the US and China.

Pan-European research from the Digital Catapult reveals that 25% of investors view the UK as the deep tech centre of Europe, although Germany is hot on its heels (24%). The UK ($ 3.4 billion), France ($3.2 billion), and Sweden ($ 3.2 billion) have received the most deep tech funding in Europe.

However, as noted above, this deep tech investment has not impacted semiconductors (sixth in Europe) or telecoms.

There is a consensus that the UK underperforms against other countries in the pace of scaling up promising companies. Indeed, data suggests that while UK and US venture capital investment as a percentage of GDP over the last few years has been broadly comparable, a gap opens with follow-on investment.

Other data shows how the UK performs well in the early stage but comes last among G7 countries for later-stage venture capital investment as a proportion of total venture capital investment and performs relatively poorly even on absolute amounts.

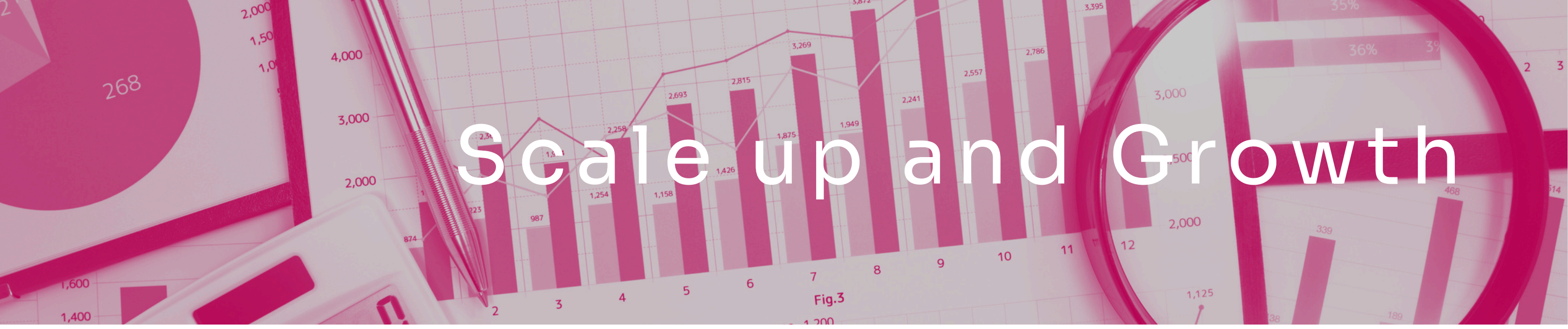


Scale up and Growth

Table 1. VC investment by country and development stage (2022)[8]

Country	Development stages	VC investment ($ millions)	VC investment (%)
Canada	Total	6,917	100.0
	Seed	655	9.5
	Start-up and other early stage	2,958	42.8
	Later stage venture	3,303	47.8
France	Total	3,823	100.0
	Seed	185	4.8
	Start-up and other early stage	1,554	40.7
	Later stage venture	2,084	54.5
Germany	Total	3,605	100.0
	Seed	305	8.5
	Start-up and other early stage	1,758	48.8
	Later stage venture	1,542	42.8
Italy	Total	745	100.0
	Seed	86	11.5
	Start-up and other early stage	370	49.6
	Later stage venture	289	38.8
United Kingdom	Total	3,526	100.0
	Seed	375	10.6
	Start-up and other early stage	2,027	57.5
	Later stage venture	1,124	31.9
United States	Total	190,502	100.0
	Seed	22,794	12.0
	Start-up and other early stage	71,150	37.3
	Later stage venture	96,558	50.7

Figure 16 CBI Report on Institutional investment in science and technology scale-ups



Scale up and Growth

Across the developed world, many countries have direct support schemes in place to address the funding gap, with grants ranging from 20% to around 50% of costs. There are also numerous schemes, including in the UK, to use public investment to encourage private-sector funding. However, public follow-on funding is often not enough, as a lead investor from the private sector must still be found to take the largest stake and secure a syndicate of other investors. There are few such investors with enough market understanding to take on such a role.

This situation is of major concern to UK-owned and operated companies. They need to upgrade their facilities to compete globally against companies that may already receive significant support in their own countries.

However, this is also a concern shared by the UK-based leadership of non-UK-owned companies with significant operations in this country. Employing many skilled UK taxpayers, these operations also compete internationally with related operations in other countries to win projects and new production opportunities and ultimately remain strategically important. To secure such commitments from their headquarters, grow their headcounts and upskill their workforce, they too must find ways to invest in future capability. Again, in many regions outside the UK, public bodies offer incentives that skew the playing field away from the UK.

Much of the emphasis on semiconductors is on their high capital expenditure, but operating expenses are high too. Energy, water and gas supplies and the maintenance of highly complex production equipment are expensive. It is also expensive to stay competitive, since producers must grow their sales to fill their production capacity so that the high cost of operation is covered, and they can realise a net profit.

However, as the market volume grows due to more applications for the technology, global competition also increases, and the market price naturally decreases. To stay competitive, chip producers must expand their capacity and continue to keep their facilities full and operating efficiently as they follow the global market growth. They achieve this through periodic upgrades and capacity expansion.

The necessary expenditure to carry out such upgrades is significantly less than the original investment to build the fab but is not trivial. If equipment has a five-year life, then depreciation will be 20%. That could be many billions for a state-of-the-art fab but will still be tens of millions for the types of fab in the UK.

7 CONCLUSIONS AND RECOMMENDATIONS

a) Strategy

The expert working group applauds DSIT for publishing the National Semiconductor Strategy establishing the Semiconductor Advisory Panel and the recent announcement of the Semiconductor Institute[32]. However, the EWG is concerned that support is spread across different organisations, including UKTIN, and quantum and AI-focused initiatives, and is not fully coordinated. The situation is similar in industry, where there are multiple bodies.

A coordinating body needs to deliver a long-term strategy with funding. It does not need to match the scale of US or EU chips acts, but it must be meaningful and recognise the central role of semiconductors in delivering four of the Government's five critical technologies – artificial intelligence, future telecoms, semiconductors and quantum technologies. We hope the institute will have the resources and remit to deliver on this opportunity and take responsibility for innovation coordination, technology road-mapping and international partnerships across all the technologies.

Recommendation 1:
The new national semiconductor institute should coordinate semiconductor activity across artificial intelligence, future telecoms, semiconductors and quantum technologies and deliver a long-term strategy with funding.

The EWG welcomes the recent announcement of the National Semiconductor Institute (which happened during the editing cycle of this document).

b) Supply chain

Any supply chain disruption is likely to have serious implications for telecoms. The 2021 disruption to automotive production due to a shortage of relatively basic semiconductors shows what can happen. It is improbable that UK companies could supply all telecom technologies and capabilities. However, as telecom networks form part of the UK's critical national infrastructure, they are more important and warrant additional resilience and robustness. As future supply shocks might not pass quickly, there is a need for mitigation strategies, such as holding stock.

Recommendation 2:
Establish initiatives to ensure telecom operators develop resilience strategies such as holding stock to maintain critical national infrastructure in the event of sustained supply chain disruption.

[32] DSIT, 2024, https://www.gov.uk/government/news/new-independent-institute-to-steer-uk-semiconductor-innovation-and-support-semiconductor-strategy

As the UK cannot have a complete supply chain across all technologies, especially advanced node CMOS logic and memory, there must be an emphasis on trusted friends and nations. This might involve some financial commitment to ensure guaranteed capacity, whether in the form of investment or commercially guaranteed access.

The telecoms industry is reliant on these components, but the country cannot afford a domestic supply. As such, a partnership or cooperation model is essential and should be prepared with a deliberate strategy. Friendly countries might include Taiwan (critically important, although with geopolitical risk), Korea, Japan, USA, India and Germany. Telecoms use various CMOS node sizes, each with different economics, which demands a variety of partnerships.

One country that may be especially relevant is Ireland. It is geographically close, with advanced CMOS technologies, strong cultural ties, minimal geopolitical risk and potentially very complementary technology strengths. It is worth exploring partnerships with Intel's leading-edge Intel 4 CMOS fab in Leixlip, Ireland, with cross-border university links and the 'best of both worlds' status of Northern Ireland.

Another possibility would be IMEC in Belgium ("the world's leading non-profit semiconductor research centre"), which has some very sophisticated capabilities. IMEC has recently opened a UK centre of excellence[33] with a remit to work on system-technology co-optimization (STCO), design-technology co-optimization (DTCO), optical IO, wireless design and compute system architecture.

The partnerships could involve collaboration in research and innovation, financial commitments and co-investment to ensure committed capacity, but must ensure the supply of components and systems to maintain telecom infrastructure.

Recommendation 3:
Set up strong and commercially binding strategic partnerships in areas where the UK is reliant on overseas semiconductor suppliers, guaranteeing both security of supply and technical cooperation.

Security of supply includes whether the fab itself can be trusted. The US is taking steps with its trusted foundry program and the UK should have a similar program. As this requirement primarily applies to CMOS digital logic and less to UK compound semiconductor devices, it requires international cooperation.

[33] IMEC Cambridge UK, https://www.imec-int.com/en/uk

Recommendation 4:
Evaluate setting up a trusted foundry programme (similar to the US Defense Microelectronics Activity) so designers can be assured that their chip has not been tampered with during fabrication.

UK Research and Innovation's digital security by design programme seeks to support a new, more secure hardware and software ecosystem and is a good example of how such programs might operate.

c) Skills

Without interest from schools, there will be no undergraduates and no engineers. More focus is needed on STEM at primary and secondary schools, including better industrial engagement and improved career advice. For example, the Scottish Government has pledged to increase undergraduates in engineering and physical sciences by 40%. The skills shortage is clear in graduate engineers and technicians across engineering, but student numbers are particularly low and falling in electronic engineering.

We need a programme to encourage school students to study subjects such as computer science, electronic engineering and material science. This programme could involve reforming the Apprenticeship Levy to provide employers with more spending flexibility to overcome the current cap on the number of apprenticeships an employer can offer. There should be greater emphasis on and funding for further education colleges to support technicians for electronic and electrical engineering and telecoms, ensuring that undergraduates have an opportunity to gain practical workplace experience to complement their academic learning.

A possibility might be a semiconductor bursary, similar to the CyberFirst bursary[34], as a way of increasing electronic and electrical engineering undergraduates numbers who will go on to work in semiconductors.

Recommendation 5:
Set up a long-term, strategic, funded programme to address the skills shortage in electronic engineering by attracting new applicants and students at all levels. This could include conversion courses from adjacent STEM domains or a bursary scheme modelled on CyberFirst.

[34] National Cyber Security Centre, https://www.ncsc.gov.uk/cyberfirst

Universities often close expensive courses in telecoms and semiconductors due to the cost of specialised equipment, the need for expensive labs and staff and the perceived difficulty of the courses. Targeted funding is required to support both undergraduate and postgraduate students.

CDTs provide a 'win-win' solution by aligning the needs of the industry with the latest academic research. They are a cost-effective way of supporting translational research and delivering upstream benefits such as spinouts and enhanced undergraduate teaching. Their relatively long-term nature enables the industry to be involved as partners and academic institutions to build institutional expertise.

This recommendation calls for a 'top-up' to the recent round of CDT applications for areas identified by the Government as specific priorities. For example, a semiconductor CDT could focus on components for RF and photonics, using both compound semiconductors and silicon.

Recommendation 6:
Target funding for universities to deliver courses in strategically important degrees, such as in semiconductors and telecoms. This should include funding for specific centres for doctoral training (CDTs) in semiconductors and telecoms and other priority areas identified in the future telecoms strategy.

Note: While preparing this paper, the Department for Science Innovation and Technology announced 65 CDTs, representing an investment of over £1bn. These CDTs support the five critical technologies in the Science and Technology Framework, namely Artificial Intelligence, Engineering Biology, Future Telecoms, Quantum and Semiconductors. The EWG welcomes this announcement.

Women represent around 3% of employees in the telecoms sector. Increasing the number of women and other poorly represented groups studying electronics and electrical engineering will increase the number of qualified engineers entering the sector.

Recommendation 7:
Encourage and support diversity in the electronic engineering and telecoms industry by funding efforts to improve the perception of engineering and address the difficulties faced by female, minority ethnic and other poorly represented professional engineers throughout their career in engineering.

The measures above are tactical and can be acted on quickly and produce results relatively quickly. However, the group believes this is a long-term problem requiring a more strategic solution.

The issues of engineering education in the UK have long been discussed, dating back to the Finniston report of the 1980s. While other countries have shortages and concerns, the UK's situation appears to be worse than comparable economies such as Germany, Taiwan and Singapore. A long-term approach across the whole sector and at all levels is required.

This programme should produce a talent pipeline from schools and FE colleges to universities and industry. It should include upskilling and reskilling in the current workforce and work in a coordinated way with employers, skills bodies, charities and professional institutions such as the Royal Academy of Engineering. This recommendation is based on the vision[35] of Professor Bashir M Al-Hashimi FRAEng, a trustee and director of the UK Electronics Skills Foundation.

Recommendation 8:
Set up a bold ten-year national-level programme that builds the skills, talent and leadership in the UK for 21st-century engineering education and expertise. This could include a chip design academy covering practical integrated circuit design skills supported with industrial placements and international internships.

d) Scale-up

The semiconductor and telecom industries are capital-intensive, requiring late-stage investment. The UK successfully funds early-stage and spinouts, but late-stage funding, including 'mezzanine' and 'growth stage' funding, is hard to find. Companies in the semiconductor and telecoms sectors could benefit from recent government initiatives to unlock domestic investment from pension funds.

Recommendation 9:
Encourage more private sector investment in high-risk and venture capital-funded firms with proposals such as the Mansion House reforms.

[35] The Engineer, Engineering's skills gap demands a radical solution, 2023, https://www.theengineer.co.uk/content/opinion/comment-engineerings-skills-gap-demands-a-radical-solution/

Government incentive schemes often constrain growth due to funding ceilings and other unintended consequences. These should be reviewed to check they deliver good value for money and that they do not conflict. For example, some schemes only support capital expenditure, others operating expenditure, making it hard to launch a project that requires both.

Recommendation 10:
Review and potentially reform government incentive schemes, including the Enterprise Management Incentive and research and development tax credits.

Support must be focused on where the UK has a competitive advantage, such as photonics, RF and mixed-signal, building on UK research strengths and opportunities to commercialise. This would leverage the synergies between compound semiconductors and manufacturing clusters in South Wales and Scotland and silicon RF/silicon photonics. For example, road mapping work could be undertaken by the new National Semiconductor Institute.

Recommendation 11:
Draw up technology roadmaps identifying the key semiconductor technologies required to deliver a resilient telecom network from 2025 to 2035 and highlighting where the UK has expertise.

Long telecoms and semiconductor development cycles demand long-term programmatic funding, similar to the UKRI Challenge Fund[36]. These funds offer non-dilutive grants and tend to crowd in venture capital funds. Programmatic funds could be coupled with a dedicated investor fund, as is done in some countries, or an expansion of the existing Investor Partnership Program, where investments by qualifying venture capitalists are matched to address the segment.

[36] UKRI Challenge Fund, https://www.ukri.org/what-we-do/UKRI-challenge-fund/

Recommendation 12:
Provide specific financial support to help UK companies develop the telecom and semiconductor technologies identified in the technology roadmaps described in recommendation 11.

Universities can apply to the Engineering and Physical Sciences Research Council for capital funding without operational expenses, whereas companies can apply to Innovate UK for operational expenses without capital funding. The UK state aid laws were based on EU rules. The EU has liberalised them while the UK has not. We have a paradox where Brexit was supposed to liberalise laws, but they are more restrictive in some instances. Both telecoms and semiconductors are capital-intensive with relatively long investment times, so these rules have a disproportionate impact on the sector.

This might involve a review of the Subsidy Control Act and a review of UK companies' access to Horizon funding, for example.

Recommendation 13:
Review the rules governing capital expenditure and operating expenses to ensure that grants available to UK companies allow them to address the commercial opportunities identified in the technology roadmaps.

1) ANNEXE

2) SEMICONDUCTOR EXPERT WORKING GROUP MEMBERSHIP

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3) REVIEW OF COMPLEMENTARY STUDIES

There is currently considerable interest in 'semiconductors' as they are one of five critical technologies in the UK Science and Technology Framework published by the Department for Science Innovation and Technology (DSIT). For reference, the other critical technologies are: artificial intelligence; engineering biology; future telecommunications and quantum technologies.

At the time of writing, there are several initiatives relating to semiconductors. This section references these initiatives and their relevance to the EWG.

a) UK National Semiconductor Strategy

In May 2023, the Department for Science Innovation and Technology (DSIT) published the UK Semiconductor Strategy[37]. The strategy highlights UK strengths in R&D, design/IP and compound semiconductors, and promises to deliver the following initiatives:

- the formation of a semiconductor advisory panel
- a semiconductor incubator
- up to £200 million investment over the years 2023-25 and up to £1 billion in the next decade
- a UK Semiconductor Infrastructure Initiative to improve access to infrastructure to boost UK commercial innovation for start-ups/SMEs

The Semiconductor Advisory Panel was announced on 3 August 2023 and there has been liaison with the EWG (both formal and informal). The panel is keen to review the EWG semiconductor white paper.

The semiconductor incubator was launched by Silicon Catalyst on 12 October 2023 as 'Chip Start UK'. It supported 12 semiconductor start-ups in the first year, with seven companies developing technologies involving compound semiconductors.
The UK Semiconductor Strategy is generic, covering all industry sectors. It does not include specific challenges related to semiconductors in telecoms. As such, differences between it and this EWG report include:

[37] DSIT 2023, National semiconductor strategy, https://www.gov.uk/government/publications/national-semiconductor-strategy/national-semiconductor-strategy

- The National Semiconductor Strategy has a focus on digital CMOS and a focus on compute/AI, but a limited mention of RF or photonic which are critical to telecoms and where the UK has strengths.
- Analog and mixed signals are critical to telecoms in addition to digital CMOS logic and memory.
- The UK has significant (but often under-appreciated) strengths around those technologies and compound semiconductors. There are strong synergies here with manufacturing and design that could be exploited.

b) IfM Engage Consortium

The IfM Engage consortium was commissioned by the Department for Science, Innovation and Technology (DSIT) to undertake a study into infrastructure to grow the UK semiconductor industry, as announced in the semiconductor strategy. The study was conducted by the consortium illustrated below, which was led by the Institute for Manufacturing (IfM) at Cambridge University.

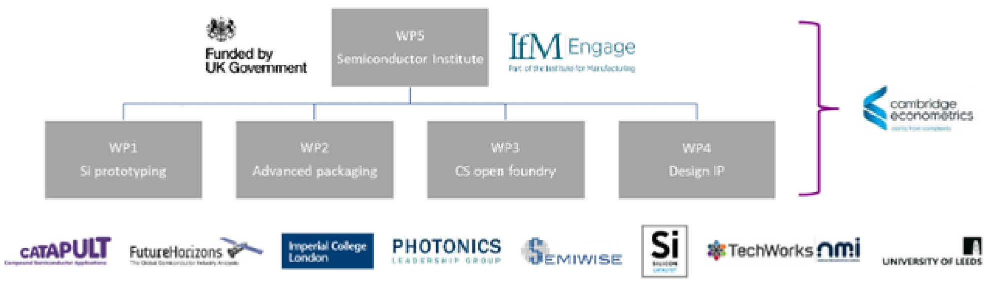

Figure 17 IfM study & relationships

The consortium consulted around 400 individuals and 185 organisations, assessing the economic feasibility of investing in four interventions:

1. silicon prototyping fab
2. advanced packaging facility focussing on 2.5/3D integration
3. compound semiconductor foundry
4. support for design/IP

At the time of writing, the EWG understands the above interventions will be considered within the next spending review.

As part of the study, the consortium considered the role of a national semiconductor institute in coordinating the activities of the infrastructure investments. We understand the institute is likely to be responsible for producing semiconductor roadmaps and potentially issuing innovation funding calls.

Although the study was sector-agnostic, rather than telecom-specific, it considered strategic rationale and the contribution of each intervention to supply chain resilience and sovereign capability. It was noted that telecoms form critical national infrastructure and semiconductor requirements for telecoms are similar to those for defence in many instances. Based on this observation, it is likely that the above interventions would be highly relevant to telecoms.

c) DSIT Economic model of the UK semiconductor industry

In October 2023, DSIT commissioned a study to create an economic model of the UK semiconductor industry. The study is led by Perspective Econometrics, and the economic model is based on the supply chain below.

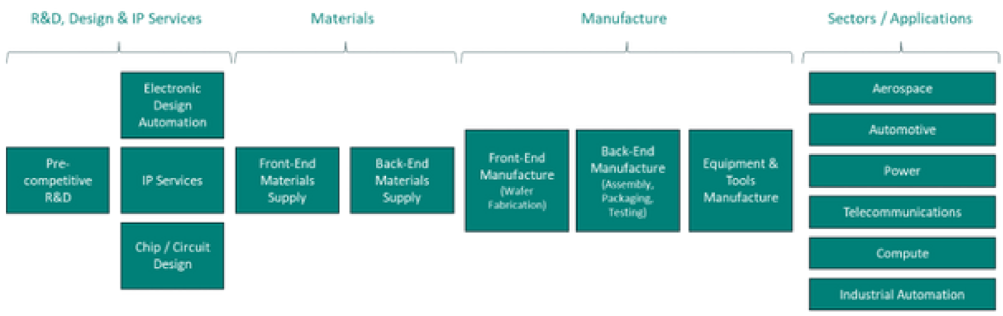

Figure 18 Economic model of UK semiconductor ecosystem

The economic model will:

- estimate the semiconductor sector's contribution to the UK economy (revenue, employment, GVA, trade, investment, R&D spend) via definition and taxonomy, supply chain analysis, analysis of trade flows, importers/exporters, impact on wider sectors, contribution of academic and research expertise
- understand the market sector maturity (competition, market structure, funding and investment)

The study includes an analysis of the semiconductor contribution to the telecom sector. The study is expected to report its findings by the end of quarter one 2024.

d) BEIS select committee: The semiconductor industry in the UK

In response to the semiconductor shortage during the COVID pandemic, the Department for Business Energy and Industrial Strategy (BEIS) launched an inquiry into the strengths and weaknesses of the semiconductor industry about UK supply chains. The inquiry considered written evidence and took oral evidence during two sittings on 7 June and 5 July 2022.

The final report published on 22 November 2022 concluded: "The UK has a comparatively small semiconductor industry by comparison with the US or countries in Asia, but our products have global reach, and we have world-leading capabilities in certain fields such as design, intellectual property and compound and advanced material semiconductors. The UK does not, however, have an end-to-end supply chain. Supplies were seriously disrupted during the pandemic, and they remain potentially vulnerable to significant disruption from geopolitical factors, for instance, if China were to invade Taiwan and disrupt the export of semiconductors. The UK is particularly exposed to future disruption in global supplies of semiconductors and is falling behind other governments in mitigating such risks. Failure to do so could result in significant economic shocks to UK business. The Government should therefore work more closely with allies, in particular with the EU and the US, to safeguard the security of supply, both of finished products and the materials needed for production in the UK."[38]

Royal Academy of Engineering

The Royal Academy of Engineering is exploring the UK semiconductor innovation system and UK semiconductor challenges and solutions. It has developed a series of critical conversations on the Government's critical technologies. [39]

It is also involved in strategy around spinouts and scale-ups and has a new 'state of the nation' report on deep tech.

[38]BEIS Select Committee 2022, The semiconductor industry in the UK, https://committees.parliament.uk/publications/31752/documents/178214/default/ and government response 2023 https://committees.parliament.uk/publications/33823/documents/184679/default/

[39] Royal Academy of Engineering, https://raeng.org.uk/news-and-events/events-series/critical-conversations

e) TechWorks

TechWorks has prepared several policy statements and suggestions around semiconductors, including funding, tax policy and education.

'The UK Semiconductor Industry – Our Opportunity' published by TechWorks Semiconductor Leadership Group in March 2023 calls for intervention to increase patient investment both across the whole supply chain and at each stage of company development (incubation, seed, early stage, growth and scale-up).

f) UKESF

UK Electronics Skills Foundation is a charity focused on encouraging school children to study electronic engineering, supporting students and running internship programs for students to find work placements. It has published several notable papers on skills and how the government could support industry.

g) eFutures

EPSRC commissioned eFutures to scan the horizon of research in semiconductors and electronics emerging from universities. This study started in 2024 and is likely to report its findings in 2025.

h) Quantum infrastructure study

On 6 June 2024, the Royal Academy of Engineering published its Quantum Infrastructure Review[40], which includes the role of quantum technologies in future telecom networks. As quantum technologies are highly dependent on compound semiconductors, the review draws similar conclusions to the working group, including support for:

- compound semiconductors
- silicon photonics
- advanced packaging / heterogeneous integration
- diamond and superconductors

The Quantum Infrastructure Review identified significant synergies between the quantum infrastructure requirements and the Semiconductor Infrastructure Initiative led by IfM, highlighting the importance of the Compound Semiconductor Applications Catapult.

[40] Royal Academy of Engineering 2024, https://raeng.org.uk/quantum-infrastructure-review

i) Wireless Infrastructure Strategy

In April 2023 the Government published its Wireless Infrastructure Strategy committing to a "world-class telecommunications infrastructure".
As well as commitments to wider 5G coverage and improving broadband connectivity, a significant aspect is the emphasis on open access and supply chain diversification. The EWG pointed out limitations in supply chain diversification if alternative system suppliers are dependent on a single semiconductor supplier.

j) UK Telecoms Lab

UKTL is the telecoms security lab, established by the Department for Science, Innovation and Technology (DSIT) and operated by NPL. This national facility, located at the heart of the fast-growing West Midlands technology hub in the Metropolitan Borough of Solihull, will provide test and evaluation capability to enhance confidence in the resilience and security of telecom systems deployed in the UK.

k) TechUK

TechUK has prepared several policy statements and suggestions around semiconductors, including on funding, tax policy and education. For example, [41] "Building a competitive and sustainable semiconductor sector in the UK: challenges and opportunities" identifies skills, capital allocation, facilities & supply chain as key issues.

l) Bessemer Society

The Bessemer Society is a membership network and forum for CEOs and founders of innovation-led companies involved in manufacturing. Its purpose is to encourage and support its members to succeed in developing the key enabling technologies that will help solve global challenges.

It recently prepared a position paper submitted to the Government on the UK compound semiconductor industry.

[41] Tech UK 2024, Building a competitive and sustainable semiconductor sector in the UK: challenges and opportunities, https://www.techuk.org/resource/building-a-competitive-and-sustainable-semiconductor-sector-in-the-uk-challenges-and-opportunities.html

m) Centre for Policy Studies

The Centre for Policy Studies has also recently written a report on semiconductors. 'Cashing in our chips: How to strengthen the UK's semiconductor sector'[42] sets out a series of proposals to boost this key industry that plays to the UK's existing advantages, and which have low upfront costs and can be implemented almost immediately. An additional advantage of these measures is that they would benefit other R&D-intensive industries and emerging technologies, beyond simply semiconductor manufacturing.

n) Black Talent & Leadership in STEM

The Black Talent and Leadership in STEM[43] programme is a cross-industry initiative delivered in collaboration with CW (Cambridge Wireless): Homerton Changemakers; University of Cambridge; 10,000 Interns Foundation and Synergy Solutions. It is focused on empowering and growing Black talent in STEM.

o) Individuals interviewed

Several individuals were interviewed for this paper.

The working group is very grateful for their time and contributions. Those opinions informed us and are reflected here but are not expressly quoted or attributed.

4) OVERVIEW OF THE UK TELECOMS INDUSTRY

The UK telecoms industry, a pivotal component of the country's digital economy, exhibits a complex ecosystem encompassing a wide array of players, from manufacturers and wireless operators to fixed-line networks. This industry not only drives technological innovation but also significantly contributes to the nation's employment and economic stability.

Since the 1960s, these all have depended critically on semiconductors. Indeed, few sectors rely more on semiconductors – and certainly, telecoms require a uniquely broad range of different semiconductor technologies and approaches from the single chip power devices in high-power transmitters through to multi-billion devices in cellular base stations.

[42] Centre for Policy Studies, https://cps.org.uk/research/cashing-in-our-chips/
[43] Black Talent and Leadership in STEM, https://www.blacktalentleadership.com/

At the time of BT's privatisation, in 1984, its research laboratories led the world in optical fibre communications, working together with companies such as GEC-Marconi, Pirelli, Plessey and Standard Telecommunications Laboratories (STL), which invented the optical fibre at its R&D labs in Harlow but failed to exploit it. After the dot com bubble, the UK network equipment operations of organisations, such as Nortel Networks and Ericsson, were consolidated back to parent headquarters, predominantly in North America.

In the late 20th century, the UK was a major player in the global telecoms market. British companies such as GEC-Plessey Telecommunications, Racal and STC were involved in exporting hardware to telecom operators around the world in addition to supplying the UK's own needs. Multinational wireless infrastructure OEMs – including Motorola, Lucent Technologies and Ericsson – also had a significant manufacturing presence here.

The UK's presence was eroded over the intervening decades, which the EWG attributed to strategic exits by Motorola and industry consolidation from mergers and acquisitions.

BT awarded the majority of is its '21Century Network' core equipment investment to Huawei, passing over UK suppliers such as Marconi, who, with no local customers, shut. There were now no UK equipment companies left. BT was left dependent on Huawei for its optical fibre transmission network (until the recent government decision to remove Huawei from participation on security grounds). There remains, nonetheless, deep expertise in the UK, especially in optical fibre technologies, one reason why Huawei wanted to make the UK the centre of its optical fibre operations in Europe.

Part of the reason that Huawei had grown its UK footprint was a 2005 decision by British Telecom (BT) to award Huawei a significant share of a £10 billion contract for renewing its telecommunications infrastructure. This move also accelerated the demise of Marconi, which was excluded from the list of suppliers despite having pinned its future strategy on continuing to be a prime contractor to BT.

Globally, a limited number of equipment providers still compete, of which the big three are Huawei, Ericsson and Nokia, with other providers such as Samsung chiefly serving their home markets. These companies can hold on to markets because when network infrastructures are upgraded, the next-generation network is overlaid on the previous generation, favouring market incumbents and presenting a barrier to new entrants. There is thus a degree of market failure.

There are changes, however, most clearly in the form of the content providers, such as Google and Facebook, who are behind the ‘cloudification’ of the network, along with the development of open standards, such as Open Radio Access Networks (Open-RAN), Open White Box and the Telecom Infra Project.

Following a review in 2020, the Government published the Telecom Security Act in 2021, banning high-risk vendors, including Huawei, from the network, and the removal of legacy equipment by 2027. The Government declared that "the future will be Open-RAN", creating an opportunity for companies to fill the "huge hole" left by Huawei, given the right incentives and regulatory framework. The opportunity furthermore is much larger than 5G, which only covers the ‘radio edge’ (base stations), as it includes backhaul, core and quantum networks, all of which will require compound semiconductor chips. The UK market may be relatively modest, but it provides a springboard for specialist companies to expand into global supply chains.

At present, BT specifies what it needs in consultation with the network equipment providers. BT is obliged to use at least two providers to ensure inter-operability and network resilience Over the last few years BT has been replacing Huawei with Ericson. Under Open-RAN, BT will specify the network requirement and many more companies will have the opportunity to supply the key parts such as base stations.

Although the UK does not have a recognised OEM provider of mobile network equipment at scale, many UK companies develop specialised mobile subsystems that are supplied to OEMs and world-leading companies that develop base station test equipment, such as Spirent and VIAVI. By adopting open standards, UK companies will see increased opportunities.

This presents an opportunity for the semiconductor industry, whose products will be used at multiple points across all these networks.

However, a key conclusion is that decisions by companies, government and investors over the last two decades mean UK telecoms manufacture has largely 'hollowed out'. There are no system-level manufacturers of telecoms equipment at scale, nor any large domestic semiconductor suppliers. Amongst peers, this is unusual. Many countries (Korea, Japan, Sweden etc) have industry leaders, but other countries will have significant presence from subsidiaries. This gap has major impacts on both supply chain and for R&D.

Supply chains and manufacturers

The UK telecoms sector supply chain is global owing to the intricate network of components required for advanced telecommunications equipment. Manufacturers, predominantly international entities, play a vital role, supplying essential hardware such as routers, switches and base stations. Prominent players include Huawei, Ericsson, and Nokia, which have established themselves as key suppliers for UK operators. The reliance on global supply chains, however, exposes the industry to potential disruptions, as witnessed during the COVID-19 pandemic and recent geopolitical tensions. This has spurred discussions around diversifying supply sources and increasing domestic manufacturing capabilities to mitigate risks.

Wireless operators

Wireless operators in the UK are at the forefront of deploying cutting-edge technologies, including 5G networks, which promise to revolutionise various sectors through higher speeds and lower latency. Major operators such as EE, Vodafone, O2 and Three have been instrumental in driving this transition. The rollout of 5G, while promising, poses challenges in terms of spectrum allocation and infrastructure upgrades. Moreover, the operators are under continuous pressure to balance investment in new technology with competitive pricing strategies to retain and grow their customer base.

Fixed-line networks

Fixed-line networks, though overshadowed by the rapid growth of wireless technologies, remain a cornerstone of the UK's telecommunications infrastructure. Companies such as BT and Virgin Media are key providers, offering broadband and telephone services. The ongoing efforts to enhance broadband speeds through fibre-optic technology represent a significant investment area. The Government's ambition to achieve nationwide gigabit-capable broadband by 2025 underscores the importance of fixed-line networks in achieving digital connectivity goals.

There is potential for useful disruption to proprietary suppliers such as Cisco, Nokia, Juniper and others via open, disaggregation efforts undertaken through the Open Compute Project (OCP) and the Telecom Infrastructure Project (TIP). Both the OCP and TIP provide open hardware specifications and detailed common technical requirements documents (RFIs) that are agreed across peer engineering teams in telecommunications operators (TELCOs) and hyper-scalers alike.

Employment and market capitalisation

The telecoms industry is a substantial contributor to UK employment. It directly employs over 200,000 individuals and supports many more jobs indirectly through its supply chains and related services. The industry's market capitalisation, a reflection of its economic weight, is substantial, with major operators and service providers collectively valued at several billion pounds. This capitalisation reflects not only the current revenue streams but also investor confidence in the industry's future growth prospects, driven by ongoing digital transformation and technological advancements.

The UK telecoms industry is a dynamic and integral part of the national economy, marked by its complex supply chains, innovative wireless operators and robust fixed-line networks. Its contribution to employment and its significant market capitalisation underscores its economic importance. Moving forward, the industry faces challenges including supply chain diversification, technology deployment, and maintaining global competitiveness. Addressing these challenges effectively will be crucial for the sustained growth and resilience of the UK telecoms sector. Crucially all of these impinge directly on semiconductors.

5) IMPORTANCE OF SEMICONDUCTORS

Note: Although the title is "Semiconductors" it should be "semiconductors and advanced materials" – things like SAW filters and hybrid circuits share many of the features and are considered in the UK telecoms semiconductor ecosystem.

a) Semiconductor industry, structure, supply chain and disaggregation

When the semiconductor industry was young most of the participants were vertically integrated, meaning that they did essentially everything to produce a chip, and some of them were part of a larger company that integrated them into subsystems and even complete systems, and so were captive suppliers. As the industry matured and the complexity of chips increased, however, the industry began disaggregating, meaning that specialist companies emerged to focus on and "take over" specific parts of the supply chain.

Disaggregation is economically very efficient and beneficial for the industry, but it does complicate the supply chain and creates issues when the supply chain involves companies that are offshore, and even more complicated when these offshore companies are controlled or influenced by strategic adversaries. If you lose any part of a disaggregated supply chain, you cannot produce an end product. For instance, you can have the most advanced design capability on the planet, but if you cannot get all the design tools the product cannot be made. Or you can build a £20 billion fabrication plant (commonly called a fab), but if one does not have designs to run in the fab it is useless.

Also important is that the US essentially controls much of the semiconductor supply chain, which is exactly the reason for the US-China trade war and the Chinese Government's interest in acquiring semiconductor assets globally, especially outside of the US, since it has largely been blocked by CFIUS (the Committee on Foreign Investment in the United States) – Imagination Technologies and Newport Wafer fab are obvious examples.

Figure 19 below depicts a simplified view of the disaggregated semiconductor supply chain today. The disaggregated elements are:

Electronic design automation (EDA) tools,
which are software used to design chips. EDA tools are critical because the most complex chip today has over two trillion transistors and advanced systems on a chip often have around 30-40 billion transistors, all clearly needing automation to design efficiently. Synopsys and Cadence are the most well-known EDA companies, followed by Siemens with its acquisition of Mentor Graphics. In RF and microwave, Keysight and Ansys are important players, along with Cadence (since its acquisition of AWR)

Licensable design IP
which are elements of a system on a chip that are designed by one company and licensed to others to integrate with EDA tools to complete a system on a chip. Arm is the most well-known pure design IP company, along with Imagination Technologies. Synopsys and Cadence also have significant Design IP businesses

Chip design
which are companies that use EDA tools and licensed design IP to create and sell systems on chips along with complementary software. Graphcore and Nvidia are examples of chip design companies. Most chip design companies today are "fabless", meaning that they do not have manufacturing capabilities themselves and consequently outsource manufacturing to "foundries" (contract manufacturers) such as TSMC

Capital equipment and materials
which are the machines and materials that are developed for manufacturing semiconductor chips. ASML is a well-known semiconductor capital equipment company that provides the most advanced lithography tools that enable the most advanced node manufacturing (so-called nanometre (nm), 5nm, and eventually 3nm, 2nm, and 1nm)

Manufacturing
which is typically broken down into epitaxial wafer growth, chip fabrication and chip "packaging" and testing, the latter two taking finished semiconductor wafers from a fab and putting them in electronic packages and testing to create a finished chip product that can be assembled on a printed circuit card and ultimately put in an electronic system. As noted above, most manufacturing is outsourced to companies such as TSMC, which is the world leader in foundry and dominates the most advanced fabrication technologies (7nm and below). When manufacturing is captive to one supplier, it is called an integrated device manufacturer, or IDM – for example, ST has fabs in France and Italy but only for ST products.

This became especially newsworthy with the acquisition of Newport Wafer Fab by Nexperia, and its transition to serving only Nexperia and its parent company Wingtech in China. This was blocked by the Government and Newport Wafer Fab has now been bought from Nexperia by Vishay[44].

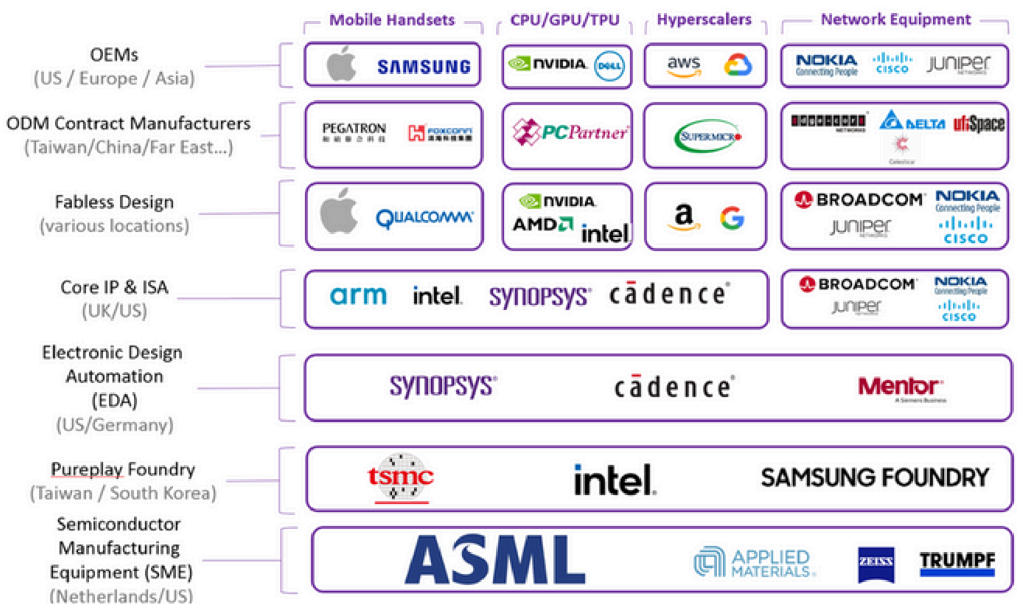

Figure 19 The semiconductor supply chain feeding into telecoms

[44] China Research Group, 2022, https://chinaresearchgroup.org/research/briefing-takeover-of-newport-wafer-fab

Rank	Company	2023 Revenue	% of Industry Revenue
1	Intel	$51B	9.4%
2	NVIDIA	$49B	9.0%
3	Samsung Electronics	$44B	8.1%
4	Qualcomm	$31B	5.7%
5	Broadcom	$28B	5.2%
6	SK Hynix	$24B	4.4%
7	AMD	$22B	4.1%
8	Apple	$19B	3.4%
9	Infineon Tech	$17B	3.2%
10	STMicroelectronics	$17B	3.2%
11	Texas Instruments	$17B	3.1%
12	Micron Technology	$16B	2.9%
13	MediaTek	$14B	2.6%
14	NXP	$13B	2.4%
15	Analog Devices	$12B	2.2%
16	Renesas Electronics Corporation	$11B	1.9%
17	Sony Semiconductor Solutions Corporation	$10B	1.9%
18	Microchip Technology	$8B	1.5%
19	Onsemi	$8B	1.4%
20	KIOXIA Corporation	$7B	1.3%
N/A	Others	$126B	23.2%
N/A	**Total**	**$545B**	**100%**

Figure 20 2023 semiconductor revenues

These are companies that sell chips ("semiconductor systems" companies), not pure wafer fab, (so not TSMC) not packaging/test. It also excludes integrated companies such as Apple or Google who do not "sell" chips externally.

6) UK SEMICONDUCTOR INDUSTRY

a) History of the UK Semiconductor Industry

The history of semiconductors in the UK, particularly about the telecoms sector and radio, is a testament to the country's pioneering role in the field of electronics. This journey reflects a blend of innovative design and manufacturing prowess.

In the early 20th century, the UK's foray into semiconductors was intertwined with the development of radio technology. The discovery of the thermionic valve, or vacuum tube, by Sir John Ambrose Fleming in 1904, marked a significant milestone. This invention, crucial for radio receivers, laid the groundwork for the semiconductor industry. However, it was the invention of the transistor in 1947 by Bell Labs in the US that revolutionised the field. The UK's response to this was swift and robust, particularly in research and development.

During the 1950s and 1960s, the UK semiconductor industry was characterised by a focus on germanium transistors, which were essential for early radio and telecom applications. Companies such as Mullard, a major UK electronic components manufacturer established in 1920, played a key role. They were among the first in Europe to manufacture transistors and contributed significantly to the UK's telecom sector.

One notable company in the UK's semiconductor history was Plessey, which was a British electronics, defence, and telecommunications company that originated in 1917 and grew into electronics and semiconductor manufacturing. Plessey played a significant role in the development of both silicon and compound semiconductors, and their applications in the telecoms sector and radio. Work on solid-state silicon crystal growth and purification began at the Plessey Research Centre at Caswell in 1952, leading to rectifier diode production and further development programmes during the 1950s and early 1960s in radiation detectors, photocells and solar cells. It has been widely acknowledged – even by Jack Kilby himself – that the concept of the integrated circuit resulted from discussions between Geoffrey Dummer of the Government's Telecommunications Research Establishment (TRE, later RSRE) at Malvern and Geoffrey Gaut of Plessey Caswell in 1952. Considerable work had already been completed on integrating resistors and inductors by the time one of the key engineers, J T Kendall, left Caswell to work for TI. It was only months later that TI announced the realisation of the world's first integrated circuit. Silicon integrated circuit development began in earnest at Caswell in 1958 and continued until 1991.

Many world-class linear integrated circuits went into production at the Plessey Semiconductors plant at Cheney Manor in Swindon, which had opened in the mid-1950s to manufacture transistors. If silicon dominated Caswell's research projects during the 1960s, then compound semiconductors, particularly GaAs, became the flagship technology of the 1970s and 1980s, spawning a manufacturing unit in Towcester. Scientists at Caswell developed the first reliable technique for producing GaAs in thin films, paving the way for world leadership in Gunn diodes in the late 1960s and to the invention of the GaAs MESFET and the MMIC in the 1970s.

The shift from germanium to silicon transistors in the 1960s marked a new era in semiconductor design and manufacturing. Silicon's superior properties, such as higher temperature stability, made it the material of choice for integrated circuits. The UK, however, faced stiff competition from the US and Japan, which were rapidly advancing in silicon technology. Despite this, UK companies such as Plessey and Ferranti made notable contributions, especially in military and telecom applications. In the late 1970s, Inmos was funded to develop integrated circuit technology: Although no longer existing as a company, many of the UK's strengths in design (the Bristol cluster) and manufacture (their Newport site) originate with this.

The 1980s and 1990s saw the UK semiconductor industry's focus shift towards design over manufacturing. This was partly due to the high costs and technical challenges associated with semiconductor fabrication. Companies such as Arm, founded in 1990 as a spinout of Acorn, epitomised this shift. Arm's business model, based on designing and licensing intellectual property rather than manufacturing, revolutionised the semiconductor industry globally, including in the telecom sector.

However, this did mean that much of the manufacturing capacity in UK either closed or focused on niche markets, particularly military. Companies such as Mullard, STC, Ferranti, Marconi, GEC all closed. Plessey survived in various smaller entities and factories.

In recent years, the UK has continued to play a significant role in the semiconductor design, particularly for telecoms. The emergence of 5G technology has seen UK companies, both established and start-ups, contributing to the design of advanced semiconductor technologies necessary for the next generation of telecom networks.

However, it's important to note that while the UK has been strong in semiconductor design, especially in the telecom sector, its presence in semiconductor manufacturing has been relatively limited compared to global giants such as the US, South Korea, and Taiwan.

In summary, the UK's semiconductor industry has evolved from early radio components to cutting-edge telecom technologies, with a distinctive shift from manufacturing to design. This evolution reflects broader global trends in the semiconductor industry and underscores the UK's enduring impact in this vital sector[45].

b) UK semiconductors: regional strengths

The primary semiconductor clusters for design (Cambridge and Bristol) and for manufacture (South Wales, Scotland) are well known, but there are many more around the country – and with particular relevance for telecoms.

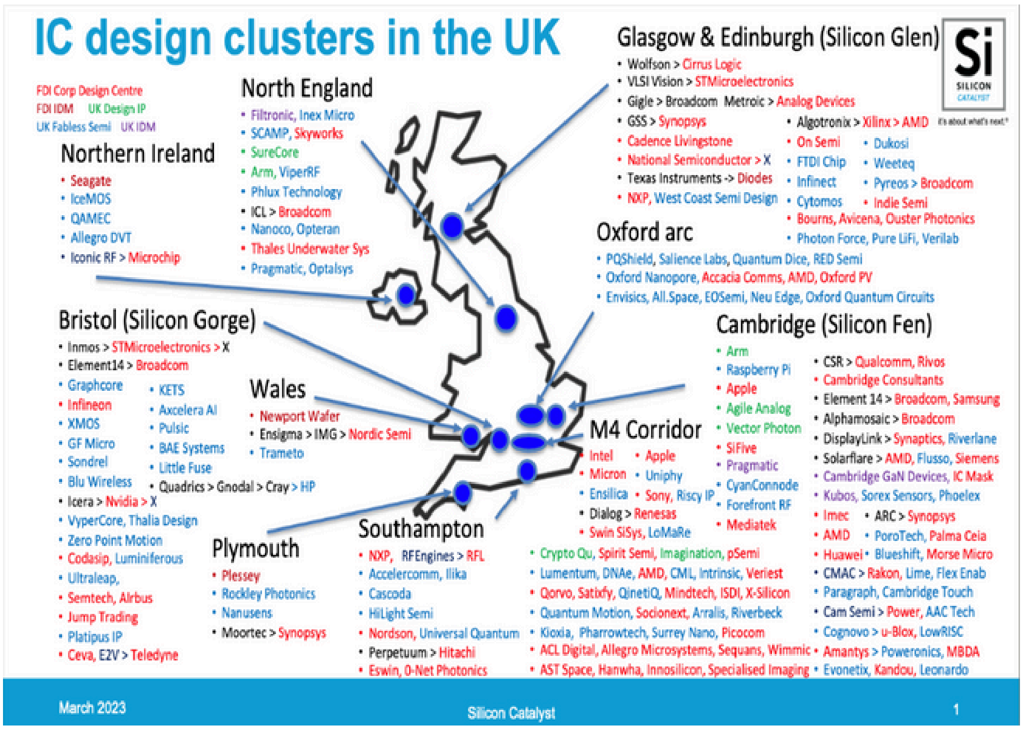

Figure 21 Map of UK Semiconductor Design Expertise

[45] Much of this section draws on: https://www.microwavejournal.com/articles/37420-the-rfmicrowave-industry-in-the-uk-and-ireland-birthplace-of-radar-and-the-gaas-mmic?page=2 and is quoted with gratitude.

i) Cambridge

Cambridge is the best-known and probably most significant semiconductor cluster in the UK, due to its leading technology ecosystem, two prominent universities, and a multitude of global companies. The cluster has been a source of inspiration and attraction for world-leading companies, fostering a culture of innovation and collaboration. With over 5,300 knowledge-intensive companies and a diverse range of industries, including life sciences and advanced manufacturing, the cluster's annual turnover exceeds £18 billion and employs more than 67,000 people. The region's significance is further underscored by its continuous growth, making it one of the world's most successful technology clusters, and its substantial impact on the UK's economy and society.

Arm is crucial for semiconductors (and remember their success all started with mobile phones), but the region's telecoms semiconductor heritage includes Cambridge Silicon Radio (now part of Qualcomm), Alphamosaic (now part of Broadcom), UltraSoC (now part of Siemens) and many more.

There are several consultancies with both telecoms and semiconductor expertise: PA Technology, TTP Group and Cambridge Consultants (which have spun out more than 20 start-ups including both CSR and AlphaMosaic). PRFI, a consultancy near Cambridge, specialises in designing MMICs, RFICs, and mmWave modules up to 100 GHz, while newcomer Forefront RF innovates mobile phone front-ends with its space-saving adaptive passive cancellation technology. In terms of international cooperation worth mentioning that IMEC has opened a centre in Cambridge, with ambitions to grow a team of around 100 engineers.

ii) Bristol

Bristol ("Silicon Gorge") has emerged as a significant semiconductor hub and is the only rival to Cambridge for semiconductor design, with fabless semiconductor designers and major players such as Broadcom, Imagination Technologies, and Qualcomm. At one time, the region boasted more integrated circuit designers than anywhere outside Silicon Valley. With strong digital media supply chains and a rich history of semiconductor-related ventures, Bristol's semiconductor cluster is a key contributor to the UK's technology landscape. The area's strategic location is notable. To the West, it is part of the "Western Gateway" and closely tied into the South Wales cluster, while to the East, it is connected to Oxford, Bath, and Swansea.

Telecoms semiconductor companies such as Graphcore, Xmos, RanSemi, and BluWireless illustrate this.

Much of the basis of UK semiconductors is grounded in Bristol, with Inmos doing design in the city and having a fab in Newport. The Inmost transputer was revolutionary at the time and many of its design concepts are hugely influential today. Companies with roots in Inmos include Element14 (now Broadcom), Icera (acquired by Nvidia), Picochip (now a key part of Intel's 5G/6G product line), Graphcore and Xmos. [46]

iii) South Wales

South Wales is the UK's primary semiconductor manufacturing cluster with exceptional strength in compound semiconductors. Anchored by the Compound Semiconductor Applications Catapult (CSAC) and world-class research at Cardiff and Swansea Universities, the region boasts cutting-edge facilities and a highly skilled talent pool. The South Wales Semiconductor Cluster fosters close collaboration between academia and industry, driving innovations in power electronics, RF, and photonics. By nurturing a strong ecosystem of startups, SMEs, and established companies, South Wales solidifies its position as a leader in compound semiconductor technology, pioneering advancements that set new global standards for efficiency, performance, and commercialization.

Note: Some people group Bristol and the South Wales cluster as the "Western Gateway".

iv) London Area

The Greater London and home counties are not known for it but do have some significant semiconductor/telecoms presence.

The National Physical Laboratory (NPL) in Teddington is the U.K.'s national measurement institute and is instrumental in electromagnetic measurements crucial for technologies such as 5G. Its work ensures accurate, SI-traceable measurements essential for testing and validating innovations. Also in London, TMD Technologies produces microwave power modules and other components for a range of applications, from radar to medical.

[46] This Wired article has an interesting history of Silicon Gorge.

Surrounding London, the home counties contain several microwave expertise hubs. Chelton, based in Buckinghamshire and Suffolk, offers design, manufacturing and testing facilities for antennas and RF components, including an anechoic chamber in Marlow for antenna testing. It recently added a research facility in Surrey for ground-penetrating radar and communications technology development.

Surrey University is well-known for its 5G centre and work on 6G. In addition, there is strong research on space and non-terrestrial wireless. API Tech in Milton Keynes focuses on radar systems and high-reliability components for defence and space, while Spaceships in Harpenden aims to innovate the space industry with high-throughput processors and transponders.

In Stevenage, Viavi Solutions produces the TM500 Network Tester, and industry-standard tool for wireless base station manufacturers, while Anritsu in Luton also does significant development. Lime Microsystems in Guildford is noted for its programmable RF transceivers and software-defined radio technology, while Surrey Satellite Technology Ltd. (SSTL), an Airbus subsidiary, also in Guildford, designs and manufactures small satellites.

The Watford and Kings Langley area is perhaps the third key cluster for semiconductor design, with Imagination and Apple doing very significant work. Indeed, critical parts of Apple's latest M3 processor were designed in St Albans.

v) East Midlands

Northamptonshire has a 20-mile area rich in semiconductor and telecom history. Stowe Nine Churches hosts a plaque commemorating the 1935 radar feasibility experiment by Robert Watson-Watt and Arnold Wilkins. Nearby is Bletchley Park, where World War II codebreakers deciphered German communications, including the Enigma machine, significantly impacting the war's duration.

The region also houses Caswell, the birthplace of the first commercial RF GaAs FET in 1970, led by Jim Turner. This site continued innovating until 2004, influencing numerous microwave companies in the area. These companies specialise in various RF technologies, from GaN power amplifiers to RF surveillance systems and passive components. The legacy extends to manufacturing facilities for stealth technologies, connectors, and antennas, contributing to a diverse RF and microwave industry cluster.

Similarly, the Lincoln area, influenced by former GEC-Marconi sites, hosts businesses developing advanced microwave and mmWave subsystems for Satcom, defence, and industrial applications.

vi) South West

Devon and Cornwall are home to waveguide specialists Quasar Microwave Technology and Flann Microwave, respectively. Spirent Communications in Devon focuses on testing solutions, recently launching a service for Galileo's high-accuracy positioning.

Although no longer doing telecoms-related products, the Plessey fab in Roxborough, Plymouth, is notable. This is arguably one of the largest and most sophisticated fabs in the UK. It is now owned by Meta, developing GaN-on-silicon micro LEDs for their AR/VR goggles.

Also of note is Nanusens in Plymouth, which develops sophisticated MEMS devices, which have applications in telecoms.

vii) Yorkshire

Yorkshire is not a major semiconductor cluster, but an area with strong telecoms expertise, largely influenced by late 20th-century microwave research at the University of Leeds. Filtronic, founded in 1977 by Leeds Professor David Rhodes, emerged from this environment and became notably successful, now specialising in E-Band mmWave transceiver modules and offering custom microelectronics services from its Sedgefield facility. Filtronic was once described as "the most successful company ever spun out of a UK university" and is notable for being one of the few surviving UK technology manufacturers at scale its remarkable claim that 99.9% of its products are exported. The region has nurtured many related companies, with roots in Leeds University or Filtronic. These include Radio Design, Slipstream Design, Teledyne Defence and Space, SARAS, BSC Filters and Diamond Microwave in Yorkshire, focusing on components for wireless communications, radar, and defence.

viii) North East

A significant cluster for manufacture and compound semiconductors exists in the North East.

Viper RF is a MMIC designer and manufacturer based in Newton Aycliffe, County Durham. Newcastle in is home to INEX Microtechnology Ltd, which produces nanotechnology and compound semiconductor products. INEX was established in 2014 as a commercial unit of Newcastle University and has since developed collaborative relationships with partners and customers to deliver devices that include power transistors for SSPAs to X-Band from its 6-inch GaN line.

INEX has 400 m2 of class 1000 cleanroom for front-end processing and 150 m2 of class 10,000 cleanroom for back-end processing, packaging, testing and characterisation.

ix) Scotland

Some years ago, Scotland was home to a cluster of telecoms, defence and semiconductor companies, earning the corridor between Edinburgh and Glasgow the nickname "Silicon Glen". In recent years, many of these facilities have either closed or scaled down, but there is still a significant presence, with major companies such as Dialog Semiconductor (now Renesas), Cadence, Synopsys, Analog Devices, Cirrus Logic, and ST Microelectronics drawn by the region's design expertise.

In the telecoms/RF areas, Trak Microwave, now a Smiths Interconnect brand based in Dundee, designs and manufactures RF and mmWave passive components for defence and space applications. NXP still operates at the former Motorola/Freescale site in Glasgow but now focuses on automotive applications such as ADAS.

However, Scotland is also one of the world’s leading centres for photonics. The sector enjoys over £1.2 billion in turnover a year and employs 6,400 people in high-value-added jobs. 97% of the sector’s output is exported. Scotland’s modern optical industry was created with the founding of Barr & Stroud in the late 19th century.

The area still hosts silicon semiconductor fabrication facilities, including Shin-Etsu, Semefab, and Diodes, along with the Scottish Microelectronics Centre. But more notable beyond silicon, Scotland excels in compound semiconductors, leveraging its photonics background to form a 40-50 company supply chain focusing on defence, space, communications, and more. Supported by a robust academic and translational infrastructure, including Fraunhofer CAP and the James Watt Nanofabrication Centre, Scotland's semiconductor cluster is a significant asset to the U.K.'s industry.

x) Ireland

Northern Ireland is notable for their contributions to microwave and mmWave technology. Arralis, with facilities in Belfast, Limerick, and Swindon, excels in mmWave components for communications, satellite, aerospace, and defence, recently deploying a Ka-Band transceiver in a CubeSat. Farran Technology, with over 40 years in the industry, develops mmWave systems and subsystems for a range of sectors, including 6G technology development. Skyworks, an analog semiconductor leader, operates a design centre in Cork, supporting the region's robust microwave technology ecosystem.

But probably most significant is Intel's presence at the Leixlip campus in Ireland. This is one of the most sophisticated CMOS logic fabs in the world. Its new €17 billion facility Fab 34 doubles its manufacturing capacity in Ireland and is the first time that its Intel 4 technology has been used for high-volume mass production in Europe. In terms of potential cooperation for access to advanced node logic, this is potentially highly significant.

c) UK Semiconductor fabs

The UK has around 25 commercial semiconductor fabrication facilities (chip fabs), as illustrated below.

Figure 22 Locations of semiconductor fabs in the UK

The UK does not compete with the CMOS mass-volume chip fabs in the far east (primarily Taiwan) and other locations (USA, Ireland, increasingly in Germany). This is a major concern for access to logic and memory, as discussed in Section 4 on supply chains and as Recommendation 2 the country will need to partner with friendly countries.

Instead, UK fabs have focused on specialist high-value niche markets, such as compound semiconductors, which have proven to be commercially successful, supplying uniquely innovative and valuable products across the globe.

DSIT has commissioned Perspective Econometrics to create an economic supply chain model, assessing UK fab capacity, GVA, and import and export metrics.

Existing fabs in the UK work in emerging and strategically valuable markets, such as compound semiconductors (new materials, other than traditional silicon) for:

- Power electronics in electric vehicles and renewable energy and radio communication for 5G and radar,
- Photonics (light and optical processing) for augmented reality, high-performance computing and communications and MEMS (Micro-Electro-Mechanical Structures) – in other words with tiny moving parts for sensors in life science, automotive and robotics

The UK has world-leading innovation in these areas and currently exports many millions of such devices – but these are primarily focused on smaller-scale production.

Semiconductor manufacturing is an incredibly capital-intensive enterprise, fraught with high operating expenses that include energy, water, gas, and complex machinery maintenance. Sustaining profitability isn't merely a matter of cutting costs but also demands scaling production to offset these costs. However, expansion isn't a cure-all. As the technology finds new applications and the market balloons, competition increases and drives down prices. This puts companies into a Sisyphean cycle: expand to stay competitive, then expand more to maintain the new baseline and a boom/bust cycle. This all requires large amounts of cash: both to fund the investment and then sustain the business through the downcycle.

Upgrading a facility, though less expensive than initial construction, still requires a substantial outlay —often £20 and £30 million every few years for even a modestly sized fab. Traditional investment channels have limited utility here. Investment is stymied by two elements: the duration of the semiconductor lifecycle, often over two years, and the protracted timeline, exceeding five years, required to realise a return on these investments. These exceed standard investor patience, leading to a market failure even for profitable, established firms.

Various governments try to bridge this financing gap with grants covering up to 50% of costs and schemes to match public and private investment. However, these measures are often merely palliative, failing to address the core issue: the lack of lead investors with sector-specific knowledge willing to assume the largest stake.

This situation is doubly precarious for the UK, impacting both domestic and locally operated international firms. While these companies are vital contributors to the UK economy, they are forced to compete on an unlevel playing field against global competitors often buoyed by more generous support schemes in their home countries.

7) GEOPOLITICS AND REGULATORY FRAMEWORK

a) Trade tensions

China's extensive state subsidies, questionable IP practices, and forced labour have raised concerns, leading the US and EU to identify its semiconductor capabilities as a strategic threat. The UK and EU have stopped potential acquisitions by China in the semiconductor sector, recognising the need to safeguard their technological interests. The US and EU's efforts to build up their semiconductor industries reflect the heightened strategic competition and the need to ensure supply chain resilience. The rising trade and national security-based policies to limit China's semiconductor industry dominance continue to pose challenges for the global semiconductor market, affecting sales and supply chains, including those in the UK and Europe.

The escalating trade tensions between the United States and China have profoundly impacted the global semiconductor industry. Export restrictions and trade disputes have led to a slowdown in the sector, affecting players worldwide. The US-China semiconductor trade conflict has deepened, with both sides imposing export limits, straining supply chains. The industry's exposure to the US-China trade dynamics has caused a decline in integrated circuit imports in China, affecting the global semiconductor supply chain.

The geopolitical uncertainties have created stress, impacting chip supply, demand and trade flows globally, not just in the US and China but also in other countries.

In many respects, the two ecosystems have fragmented. Few Chinese semiconductor companies sell into Western markets, while the embargoes on leading-edge products mean China is buying less.

The Chinese response to trade tensions on semiconductors is interesting. According to JW Consulting, in 2021-2022 nearly $300 billion was allocated to Chinese industry, of which $100 billion was for semiconductor equipment and materials.This period was when Huawei developed its Kirin 9000s chip used in its Mate 60 phone. According to the Financial Times, Huawei and SMIC received around $3 billion state funding in 2020-2022. There have been suggestions that this rapid increase has meant that the Kirin chips are perhaps twice as expensive [as competitors made at TSMC], but its capabilities are on a par with one–two-year-old US chips.

This impacts the UK only indirectly. We are very much part of the Western ecosystem and supply chains.

b) Geopolitical aspects

In contrast, a very much more salient concern is that of Taiwan.

The semiconductor industry in the UK and Europe is significantly affected by geopolitical tensions and China's growing semiconductor capabilities. The risk of China invading Taiwan and disrupting semiconductor exports is a potential threat, impacting global supply chains.

UK companies such as Graphcore, RanSemi and many others (as well as the majority of Arm's customers) all rely on Taiwan Semiconductor Manufacturing Co (TSMC).

As part of this, TSMC is making significant investments outside Taiwan in Japan, Germany and the USA.

Recently, TSMC announced it would create, with Bosch, Infineon and NXP, a new company called European Semiconductor Manufacturing Co (ESMC) in Dresden, Germany, to provide semiconductor manufacturing services for the integrated circuit needs of the automotive and industrial sectors in Europe. TSMC is said to contribute € 3.5 billion (US$3.8 billion) and is expected to own a 70% stake in the new venture. The EU is expected to contribute 5 billion euros, under the framework of the European Chips Act, with the three partner companies each controlling 10%.

ESMC plans to build a 300mm fab that is expected to have a monthly production capacity of 40,000 12-inch wafers using TSMC's 28/22 nanometre planar CMOS and 16/12 nanometre FinFET process technologies. Although these fabrication technologies are not the most advanced in TSMC's portfolio, they fit precisely with ESMC's target industry segments. The fab is expected to create 2,000 high-tech jobs, with construction to begin in the second half of next year and reach volume production by the end of the year.[47]

We rely on these devices and have no UK supply and no possibility of UK supply.

This must be addressed. The UK needs to arrange supply security through partners and friendly nations (Germany, USA, Japan, Korea – and most interestingly Ireland). This could be in the form of investment, financial commitment (guaranteed capacity) or some other cooperation model.

c) Standards

Telecoms are dominated by international standards: organisations such as ITU, and IEEE 802.x, 3GPP and IETF. The development of international standards for telecoms was led by European telcos (such as Ericsson and Nokia), which led to significant contributions to R&D in the telecoms sector in Europe. This results in so-called standards-essential patents (SEPs) which are highly valuable as to implement the standard you must infringe the patent. This has led to patent licensing, either directly between entities (there is a framework to manage this), or patent pools (e.g. Avanci). This results in a big flow of value back to the originators (e.g. Ericsson and Nokia). The EU is in the process of adopting an SEP regulation which has been massively criticised by European telcos for reducing the value of the IP they have developed.

This is a consequence of the necessity for international interoperability and for global scale from global standards.

For the last two decades, this system has worked well. However, there are signs it is failing, and there will be a division, with different standards bodies on geopolitical boundaries. One example is the pressure that Huawei should not be represented within IEEE – leading to fragmentation and incompatible standards.

As a related example, the ITU members prevented the appointment of a Russian Federation candidate as the next president because of fears of Internet fragmentation. While that was not about semiconductors it does illustrate how global standards issues are becoming increasingly politicised.

[47] Taipei Times 2023, TSMC to expand fabs globally,https://www.taipeitimes.com/News/editorials/archives/2023/08/12/2003804603

Finally, there is concern within the USA that China could leverage the RISC-V standard to establish dominance in the processor market. [48]

This is a debate for the wider industry, but as the UK is firmly part of Western/US ecosystem there is little change – nor is there a specific impact on strategy.

8) TECHNOLOGY AREAS

a) Processors

Processor design is an area in which the UK has undeniable world-class expertise. Processors are at the core of every segment and every layer of telecoms. Whether it is a dedicated high-speed digital signal processor (DSP) for photonics, a deeply embedded microcontroller, a large server-class 64-bit processor for control plane switching in a base station or an optimized AI accelerator (neural processing unit - NPU) – they are all processors. The introduction of ever more complex standards such as 6G usually increases the processing requirements.
There are several ways to consider the market.

i) Architecture

While DSP and NPU architectures are quite varied, CPU architectures are converging to one of three main ones:

x86:
Predominantly known for its x86 architecture, Intel has made strides in the telecoms sector mainly through its data centre solutions – though AMD is gaining traction. Their CPUs are often associated with centralised server infrastructure ("cloud RAN"). As an interesting side note to illustrate UK expertise in processor design, the latest Intel XEON processors include several instructions specifically designed to optimise the operation of 5G. Those instructions were designed and architected in the UK

[48] Reuters 2024, US is reviewing risks of China's use of RISC-V chip technology, https://www.reuters.com/technology/us-is-reviewing-risks-chinas-use-risc-v-chip-technology-2024-04-23/

Arm:
Arm's strength lies in its low-power designs. With the increasing edge computing demands in telecoms, Arm's architecture has found widespread adoption. The desire to reduce power consumption in data centres also pushes for increased adoption, and this is impacting telecom networks that now rely on architectures similar to data centres. This architecture is most famous in mobile phones, which although incredibly important in telecoms is largely irrelevant in a UK context. However, the UK is very strong in system-on-a-chip design for specific applications, and today these overwhelmingly use Arm

RISC-V:
an open-standard instruction set architecture. RISC-V is gaining traction. It is competing with Arm as an IP design but has benefits from openness and greater flexibility/customisation. RISC-V IP processor vendors start to propose designs with performance approaching those of Arm processors

ii) Application

Over recent decades there have largely been three classes of processors that mattered in telecoms:

- high performance: discrete chips from primarily Intel (and increasingly Arm – through Marvell, Ampere or Amazon's internal system on chip) for servers in core, management and control plane. RISC-V is not yet a player here although it is expected in the medium term
- embedded standard CPU: primarily from Arm, though RISC-V is gaining ground here fast. For microcontrollers through to medium performance, with companies such as Rivos and Ventana leading the way
- embedded proprietary, often for DSP or microcontrollers. As Arm & RISC-V gain presence, these are slowly being designed out to be replaced by optimised devices based on those standard instruction set architectures

iii) Delivery/path to market

Merchant market silicon:
off-the-shelf chips produced in bulk. Companies such as Intel provide these, where clients purchase ready-made solutions. These are standardised, and widely accepted, but might not cater to specific needs. This is what most people think of as a "processor". This segment has historically been dominated by Intel and AMD with x86 products, but Arm is now making inroads through Ampere and Marvell. RISC-V offers prospects here with Rivos, Tenstorrent and Ventana. There are no British companies in this segment.

IP into ASIC or SOC:
here a company licenses the architecture (such as Arm or a RISC-V IP vendor) and designs its chips as application-specific integrated circuits (ASIC), application-specific standard products (ASSP) or systems on a chip. This allows for customisation tailored to exact requirements. ASICs are designed for specific applications – for example, a cellular modem. British companies include RanSemi (the new name for Picocom UK) and Accelercomm.

	Merchant Market	IP Licensing
x86	The traditional CPU market. Intel, AMD.	N/A
Arm	Historically not strong but now growing e.g. Ampere	Has been dominant but faces challenge from RISC-V.
RISC-V	Has not existed but emerging e.g. Ventana, Rivos	Growing importance
Proprietary	Historically very strong, now limited to niches	Historically significant, increasingly replaced by RISC-V

Figure 23 Segmentation of processor market

Design service companies:
Some companies do not have the necessary teams to create complex ASICs or systems on chips themselves and work with external design houses that provide this capability as a service. These companies can even sometimes manage the interface to the foundries to fabricate the chips and deliver completely packaged and tested chips to their customers. Some British companies, such as Ensilica or Sondrel, are recognised as valuable players.

UK strength in processor design:
The UK has historically been a powerhouse in processor design, largely credited to Arm, headquartered in Cambridge – though Imagination in Watford and the Bristol cluster are also important. While Arm dominates on a commercial scale, the UK's expertise extends beyond Arm, with companies such as Imagination, SiFive, Rivos, and Codasip having a strong presence, and numerous start-ups, research institutions, and design houses contributing.

Semiconductor systems and reference design
It is important to stress that in many markets you cannot deliver a chip in isolation. It must be supported with reference design, support components etc. The UK has strength in this "semiconductor systems" realm. In some respects, this closes the gap in the market from not having tier-one system integrators.

b) Baseband

See Wireless Expert Working Group for more details.

This segment is dominated by fabless firms that primarily rely on TSMC as a fab. However, unlike graphics processor unit (GPU) or AI, the UK has significant design expertise in this area and several fabless companies that compete on the world stage, whether as UK companies (Accelercomm) or UK design centres of foreign companies (Parallel Wireless, Picocom).

A key aspect of baseband, and an area that the UK is strong at, is semiconductor systems. This is a semiconductor supplier version of the skills of integration owned by a tier one OEM but is especially important in markets that expect reference designs and where the chip company must deliver a system-level solution that is suitable for manufacture. Examples include mobile phones (everyone except the big three), WiFi access points, GPS terminals, wired modems (DSL, cable or FTTH), small cell base stations and the like.

To quote an interview from a baseband chip supplier:

"We need to understand our customers' requirements and our customers' customers' requirements. For us, a customer is a telecoms equipment vendor, and customers' customers are generally mobile network operators. This requires people with product management experience in our market.

"We also need to understand, and potentially influence, international standards. This means that we need systems engineers who are well-embedded in the standardisation process.

"Our component forms part of a system. This will be true for almost any semiconductor company. We need to integrate with the other components in the system. This means that we need to provide reference designs that include them, so we need to have engineers who understand RF and the software protocol stacks that our software needs to be integrated with. For example, we don't need to know how to design a GaN power amplifier component, but we do need to know how to design a GaN power amplifier into a system that includes our chips.

"Our systems engineers need to understand all of the above and also architect our chips to form a part of the overall system, working with product managers to ensure that nothing is missed, and we have a cost-optimised, power-optimised solution."

"An operations team. This includes test and product engineers who can work with packaging and test houses and other subcontractors to put production testing in place, qualify the chips (including accelerated lifecycle testing, etc), deal with failure analysis and monitor/improve yields. We also need people to manage the supply chain (forecasts, orders, logistics) and deal with export control.

"(Very importantly) A global sales team (including reps and distributors) that has established relationships with our customer base. It's pointless having a product if you don't have the means to sell it.

"Then there's the detailed silicon design (frontend and backend), which is the thing that some people talk about as if it's all you need.

"A semiconductor company can outsource a certain amount, but you can't outsource things that you don't understand, so you need the expertise in-house even if you are primarily managing subcontractors."

To emphasise, the combination of skills is hard to find but essential for telecoms chip solutions and an area in which the UK is unusually strong.

The UK has and has had significant centres of expertise both in the past and currently in the field of wireless baseband processing. A non-exhaustive list of examples is summarised in the table below (from Wireless EWG).

Body	Application	UK-based current and previously active companies (currently active highlighted in Bold)
3GPP	Mobile Cellular Systems	Infrastructure: Picochip (3G/4G DSP/SoC – acquired by Mindspeed, 2012, then on to Intel as part of acquisition of Mindspeed small cell business, 2014) **Picocom (4G/5G DSP/SoC)** **AccelerComm (baseband IP)** **Parallel Wireless UK (RAN products)** Handset: Icera (DSP software/SoC/RFIC – acquired Nvidia, 2011)
Bluetooth SIG (Also WiFi, GPS/GNSS etc)	Wireless Connectivity Systems	CSR plc (acquired by Qualcomm, 2015, various wireless assets sold to Samsung Electronics, 2012)
Other	Lifi	Growing importance

Figure 24 Examples of UK commercially exploited expertise in baseband processing and processors (non-exhaustive list). From Wireless EWG

c) RF & mixed signal (both semiconductor and other)

This is a key area and (together with photonics) is what differentiates telecoms from other applications that use semiconductors.

Note: while semiconductors are an essential part of the RF/mixed-signal area, other components are critical too. Items such as antennas and filters cannot be ignored.

One key aspect of RF is how frequencies are increasing, both to accommodate higher data rates and as usage increases. Technologies such as WiFi7, 802.11ay and 6G – as well as longer-term ones such as THz.

This fits well into UK strengths in compound semiconductors which can support those higher frequencies. While CMOS radios are increasing the range they can support, compound semiconductors are better for power, sensitivity (low noise) and frequency.

When the global system for mobile communication (GSM) was first standardised in the early 1990s it was only 900MHz. Then personal communications service (PCS) added 1800MHz, universal mobile telecommunications system (UMTS) was at 2.1GHz and over time more and more frequency bands have been added – with a growing emphasis on higher frequencies (and wider bandwidths).

These pose ever more severe challenges for the RF front end and transceiver stage, requiring ever more innovation – and more opportunities for chips made with Compound Semiconductors.

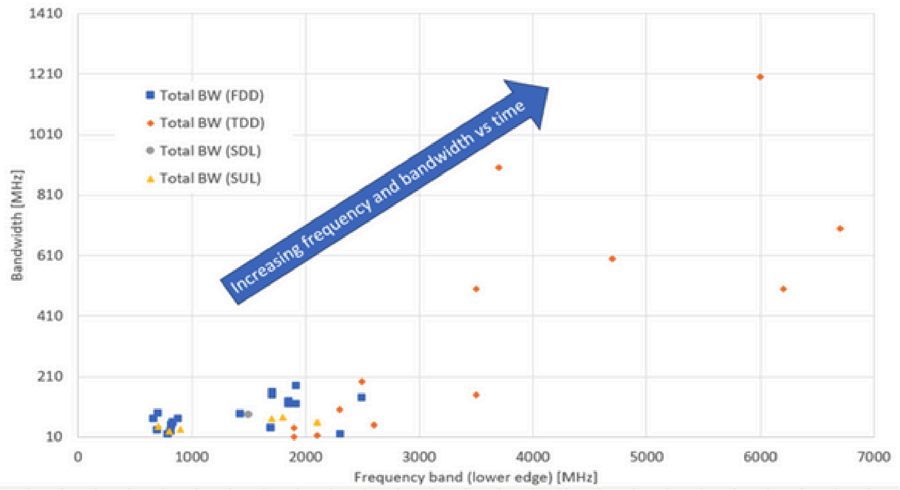

Figure 25 Frequency bands in 5G cellular from 3GPP [49]

LTE introduced even higher frequencies and mmWave to cellular: higher bandwidth, wider channels and much higher carrier frequencies.

[49]Source: Professor Simon Saunders: 3rd edition Antennas and Propagation for Wireless Communication Systems Hardcover by Simon R. Saunders (Author), Alejandro Aragón-Zavala (Author)

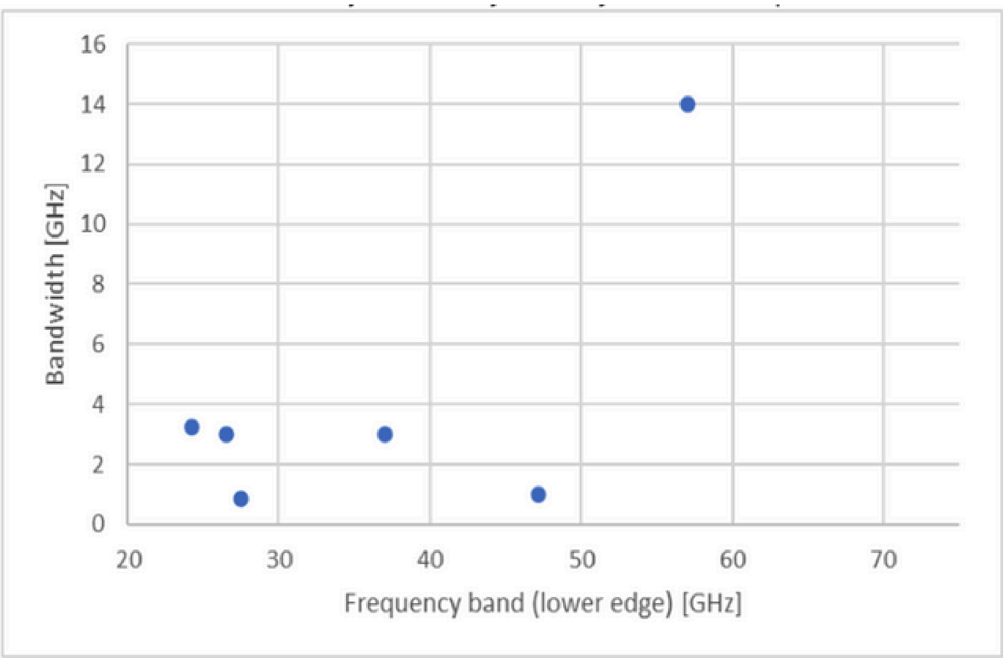

Figure 26 3GPP FR2 bands as of TS38.101

d) Photonics

Please refer to the Optical Communications and Photonics Expert Working Group for more details.

Photonics plays a pivotal role in addressing the escalating demands of data communications and telecommunications, particularly in the context of burgeoning data centres and the need for high-speed, short-range communication links to support AI and other data-intensive applications. The increasing data rates, projected to surge from 100G to 400G and beyond, necessitate advanced technologies such as compound semiconductors to enable the development of high-capacity data communications.

Compound semiconductors have a prospect of "win: win" for the UK with both supply-side expertise in specialist fabs and manufacturing, with clusters of expertise (particularly in South Wales and Scotland) converging with the design skills from universities and various businesses.

While compound semiconductors are important and have potential, it is not the only area, and silicon photonics should not be neglected.

This offers a promising solution, with its high miniaturisation capacity and potential for compact devices with high bandwidth density, making it well-suited for next-generation data and telecom applications.

This is especially the case since the UK has strengths in silicon photonics, with several academic groups in the UK being recognised as world-leading (for example Southampton, Bristol) as well as a growing number of start-ups and SMEs (for example, Salience Labs, Wave Photonics, Rockley Photonics) alongside nascent interest in the field from large manufacturing facilities (for example, Newport Wafer Fab, Seagate).

The UK also has expertise in silicon photonics prototyping via the CORNERSTONE foundry hosted by the universities of Southampton and Glasgow. CORNERSTONE is the first UK foundry invited into EUROPRACTICE, the pre-eminent brokerage service for multi-project-wafer semiconductor manufacturing.

It is important to note that silicon photonics can be fabricated in a CMOS facility using the same toolset as electronics. The attraction of the technology is that state-of-the-art circuits can be built in 28-65 nm node sizes due to the significantly larger dimensions of photonic integrated circuits relative to electronics. There is a discussion on the opportunity for the UK to establish a global position in silicon photonics prototyping and small-volume manufacturing.

e) Memory

The memory sector in semiconductors encompasses dynamic random-access memory (DRAM), static random-access memory (SRAM) and non-volatile memories such as NAND Flash. The geographic concentration of the memory semiconductor market is significant, with major players located in regions such as the United States, South Korea, and Japan (SK Hynix, Samsung, Micron). These are all vertically integrated (IDM) with a very close relationship between design and fab.

The UK, however, does not have a significant presence in the memory semiconductor market and is unlikely to have any. While the UK has strengths in semiconductor design, intellectual property and research, it lacks large British-owned semiconductor manufacturers comparable to those in other countries. The recent focus on strengthening the domestic semiconductor industry in the UK has primarily been on areas such as design, IP, and compound semiconductors, rather than memory semiconductor manufacturing.

Given the cost and scale of the memory segment, it is unlikely this will change. Accordingly, the UK strategy needs to focus on partnerships to get access to technology and to secure supply chain resilience.

f) GPU and AI processors

Similar to baseband the GPU and AI segments are dominated by fabless firms that primarily rely on TSMC as a fab. Nvidia comprehensively dominates but Intel, AMD, Cerebras, Groq and others have a place. In addition, there is significant in-house/captive activity from Google, Meta etc.

The UK does have a "unicorn" in this segment in the shape of Graphcore, but in general, it is safe to say that all AI activity will be done on foreign chips, designed in the USA and made in Taiwan.

UK does have expertise in GPU design and AI technology, not only with Graphcore but also Arm, Codasip, Imagination and Apple's design centre near Watford.

This is relevant for telecoms because AI is an increasingly critical part (e.g. 6G will be "native AI"). This technology will be designed into the digital chips, either as dedicated logic (playing to UK strengths in design) or as IP licensed from Arm or others.

g) MEMS, SAW, filters etc

Whilst not "semiconductors" as such, Surface Acoustic Wave (SAW) filters and Micro-Electro-Mechanical Systems (MEMS) are integral to modern telecommunications technology. SAW filters enable precise frequency selection and signal processing, ensuring high-quality, interference-free communication in increasingly crowded RF environments. MEMS devices, with their miniaturized sensors and actuators, provide high performance and low power consumption, critical for 5G networks and the Internet of Things (IoT). Together, they empower advanced wireless technologies, enhance spectrum efficiency, and drive the miniaturization of telecom equipment. Their continued evolution is crucial for supporting the exponential growth in data traffic and the rollout of next-generation telecom networks.

9) POTENTIAL PARTNERS FOR COLLABORATION

US
- DARPA
- University of Villanova (Tommaso Cappello)
- University of California, Santa Barbara (James Buckwalter)
- NYU (Ted Rappaport)
- Stanford
- Texas Uni Austin (Robert Heath)
- IBM
- Intel

Europe
- IMEC
- United Monolithic Semiconductors (UMS)
- Ferdinand-Braun-Institut
- Fraunhofer
- University College Dublin
- Tindall
- Twente University, Netherlands
- Science Foundation Ireland
- Oulu
- Dresden
- Linkoping
- Aachen

Elsewhere
- Win Semi
- Sony (Japan)
- Korea

10) LIST OF SEMICONDUCTOR SUPPLY CHAIN MANUFACTURERS

Substrates	Technology Area	Region	Ownership
IQE	CS epi wafers	South Wales	-
Pegasus Chemicals	CS precursor chemicals	NW	-
Epivalence	CS Precursor chemicals	NE	-
Foundaries			
Newport Wafer Fab	Silicon and GaN chips	South Wales	China (20%)
Semefab	Silicon (GaN on road map)	Scotland	-
CST Global	CS wafer and laser chips	Scotland	Sweden (acq)
Clas-SiC	Silicon Carbide chips	Scotland	-
INEX Microtechnology	RF GaN	NE	-
Kelvin Nanotechnology	E-Beam lithography, prototyping photonics and quantum components	Scotland	-
Advanced Epi	SiC fabrication	West Midlands	-
Plessey Semiconductors	BiPolar, GaN	South West	US (acq)
Lumentum Caswell	InP	-	USA

Semicon Manuf.	Technology Area	Region	Ownership
Nexperia	GaN FETs	NW	China (acq)
Diodes Zetex	MOSFETs	NW	USA (acq)
Diodes Inc	CMOS, BiPolar	Scotland	USA
Dialog Semiconductors	IC transceivers; fabless	South East	-
II-VI	Photonic devices, sensors	NE	USA (acq)
HiLight Semiconductors	Optical Transceiver ICs	South East	-
Lumentum	Optical transceivers	East Midlands	USA (acq)
Cambridge GAN Devices	GaN transistors	East	-
Bourns	Power Semiconductors	South East	USA
IXYS UK Westcode	Power Semiconductors	South West	USA (acq)
Cambridge Microelectronics	Power Semiconductors	East	-
Nexperia	GaN FETs	NW	China (acq)
Diodes Zetex	MOSFETs	NW	USA (acq)

Semicon Manuf.	Technology Area	Region	Ownership
Nexperia	GaN FETs	NW	China (acq)
Diodes Zetex	MOSFETs	NW	USA (acq)
Diodes Inc	CMOS, BiPolar	Scotland	USA
Dialog Semiconductors	IC transceivers; fabless	South East	-
II-VI	Photonic devices, sensors	NE	USA (acq)
HiLight Semiconductors	Optical Transceiver ICs	South East	-
Lumentum	Optical transceivers	East Midlands	USA (acq)
Cambridge GAN Devices	GaN transistors	East	-
Bourns	Power Semiconductors	South East	USA
IXYS UK Westcode	Power Semiconductors	South West	USA (acq)
Cambridge Microelectronics	Power Semiconductors	East	-

Device Packaging	Technology Area	Region	Ownership
Microchip	IC packaging	South Wales	USA
Dynex Semiconductors	IGBT packages	East	China (acq)
TT Electronics		South East	-
Merlin PCB	IC packaging	North Wales	-
RAM Innovations	Power device packaging	North Wales	-
Turbo Power Systems	Power modules	NE	-
TT Semelab	Power modules	South East	-
Pulse Power and Measurement	Power modules and RF components	South West	
Custom Interconnect (CIL)	Wire bonding; chip/dye	South East	-
Micross	Interconnect packaging	East	USA
Solid State	OE Modules	South West	-
Alter Technology	Package & assembly	Scotland	Germany (acq)
Optocap	Front end packaging	Scotland	-
Gooch & Housego	Optical modules	SW, Scotland	-
Helia Photonics	Optical coat, die singulation	Scotland	-
Optoscribe	Fiber coupled connectors	Scotland	-

Production Tools	Technology Area	Region	Ownership
SPTS	PECVD	South Wales	USA (acq)
Aixtron	MOCVD	East	Germany
Oxford Instruments	CVD	Oxford/Global	-
Edwards Vacuum	Clean Room vacuums	South East	USA (acq)
Logitech	Optical polishing equipment	Scotland	USA (acq)
Wentworth Labs	Wafer probes	South East	-

* A much wider group of companies is available from:

CSA Catapult

Photonics Leadership Group

AESIN (TechWorks)

11) GLOSSARY OF TERMS (INCLUDING PROCESS & UK PRESENCE)

Device	Material	UK capability	GLOSSARY - description
MCU	Si / Emerging	Chip design No Si fabrication, but fabrication using emerging semiconductors	A Microcontroller Unit (MCU) or microprocessor is a generic machine designed to run software. MCUs are very flexible and can be used in multiple applications, although they not optimised to solve a particular function. Some MCUs include memory on the chip. MCUs typically cost $10m-$100m to design and sell for $1-$50 per device. Conventional MCUs are fabricated in Si, although a new technique has been developed using emerging semiconductor materials.
DSP	Si	Chip design No fabrication	A Digital Signal Processor (DSP) is a specialised version of an MCU that has been optimised to process digital signals such as voice or video. One form of optimisation is to queue the instructions in a pipeline; another form of optimisation is multiplication followed by addition, as these operations are repeated many millions of times. Some DSPs include memory on the chip.
GPU	Si	Chip design No fabrication	A Graphics Processor Unit (GPU) is an optimised DSP that is designed to process high resolution video signals. Some GPUs include memory on the chip.
IPU/AI	Si	No design or fabrication	An Intelligent Processor Unit (IPU) is a specialised version of a GPU that has been optimised to mimic the neural function of a brain to run artificial intelligence (AI) algorithms. One form of optimisation is to perform weighted multiplications and additions, as these operations are repeated many millions of times in a neural network. Some IPUs include memory on the chip. IPU design is likely to exceed $100m.
FPGA / FPLD	Si	No design or fabrication	A Field Programmable Gate Array (FPGA) or Logic Device (FPLD) is a generic chip that can be programmed to provide the functionality of chips such as MCUs, DSPs etc. It's possible to combine several chips within the same FPGA, limited by its capacity. The main advantage is that FPGAs can be reconfigured, providing a high degree of flexibility.
DRAM	Si	No design or fabrication	Dynamic Random Access Memory (DRAM) is a form of fast access memory. DRAM is very compact, enabling very high data storage on the chip, but it requires periodic refreshing to maintain the contents. DRAM is volatile, meaning it loses its contents when power is removed.
SRAM	Si	No design or fabrication	Static Random Access Memory (SRAM) is a form of fast access memory which requires more chip area than DRAM, but does not require periodic refreshing. SRAM is volatile, meaning it loses its contents when the power is removed.
ROM	Si	No design or fabrication	Read Only Memory (ROM) is a form of memory that retains its contents when power is removed (it is non-volatile), although some variants can only be programmed once.
FLASH	Si	No design or fabrication	Flash memory is a form of ROM that can be reprogrammed, they are typically used in USB sticks.
OP-AMP	Si	Some chip design and fabrication	Operational amplifiers (op-amps) are integrated circuits providing precision amplification.
ADC	Si	Some design & fabrication for specialist applications	An Analog to Digital Converter (ADC) converts analog signals into digital numeric values for processing by an MCU, DSP etc

Device	Material	UK capability	GLOSSARY - description
DAC	Si	Some design & fabrication for specialist applications	A Digital to Analog Converter (DAC) converts digital numeric values into analog signals.
MIXED-SIGNAL	Si	Some design & fabrication for specialist applications	A mixed signal chip combines digital circuitry with analog circuitry for highly specialist applications, such as power management.
FPAA	Si	No design or No fabrication	A Field Programmable Analog Array is a chip containing multiple op-amps that can reconfigured by the user to deliver analog computational functions, such as integration or differentiation.
DIODE	Si / CS	Chip design and fabrication	Diodes are basic discrete devices that only conduct current in one direction.
BJT / FET / THYRISTOR	Si	Chip design and fabrication	Bipolar Junction Transistors (BJTs), Field Effect Transistors (FETs) and THYRISTORS are a class of discrete devices used for signal amplification and switching.
MOSFET	Si / CS	Chip design and fabrication	A Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is a highly efficient form of transistor used in switching applications.
IGBT	Si / CS	Chip design and fabrication	An Insulated Gate Bipolar Transistor (IGBT) combines the benefits of a MOSFET with those of a BJT to form a highly efficient power switch.
DETECTOR	Si / CS	Chip design and fabrication	A DETECTOR is used to convert optical signals into electrical signals for processing by an MCU. Detectors are characterised by their sensitivity at wavelengths within the optical spectrum.
LED	CS	Chip design and fabrication	A Light Emitting Diode (LED) is a highly efficient light source that generally emits a single wavelength (colour) of light.
LASER	CS	Chip design and fabrication	A LASER is a powerful, coherent, focused and polarised source of light tuned to a specific wavelength (colour).
DETECT-ARRAY	Si / CS	Chip design and fabrication	A DECTECT-ARRAY is an array of detectors used to create an image of an optical source.
LCD	Emerging	No design or fabrication	A Liquid Crystal Display (LCD) is a highly efficient form of display which relies on ambient light to produce a monochrome display.

Device	Material	UK capability	GLOSSARY - description
OLED / AMOLED	Emerging	No design or No fabrication	An Organic Light Emitting Diode (OLED) is an array of large area LEDs used in laptops and mobile phone displays. An Active Matrix OLED (AMOLED) is an improved technology.
PV	Si / CS / Emerging	No design or No fabrication	A Photovoltaic (PV) cell is a means of converting optical energy, generally from the sun, into electrical energy.

Other Abbreviations

TSMC	Taiwan Semiconductor Manufacturing Company
DSbD	Digital Security by Design