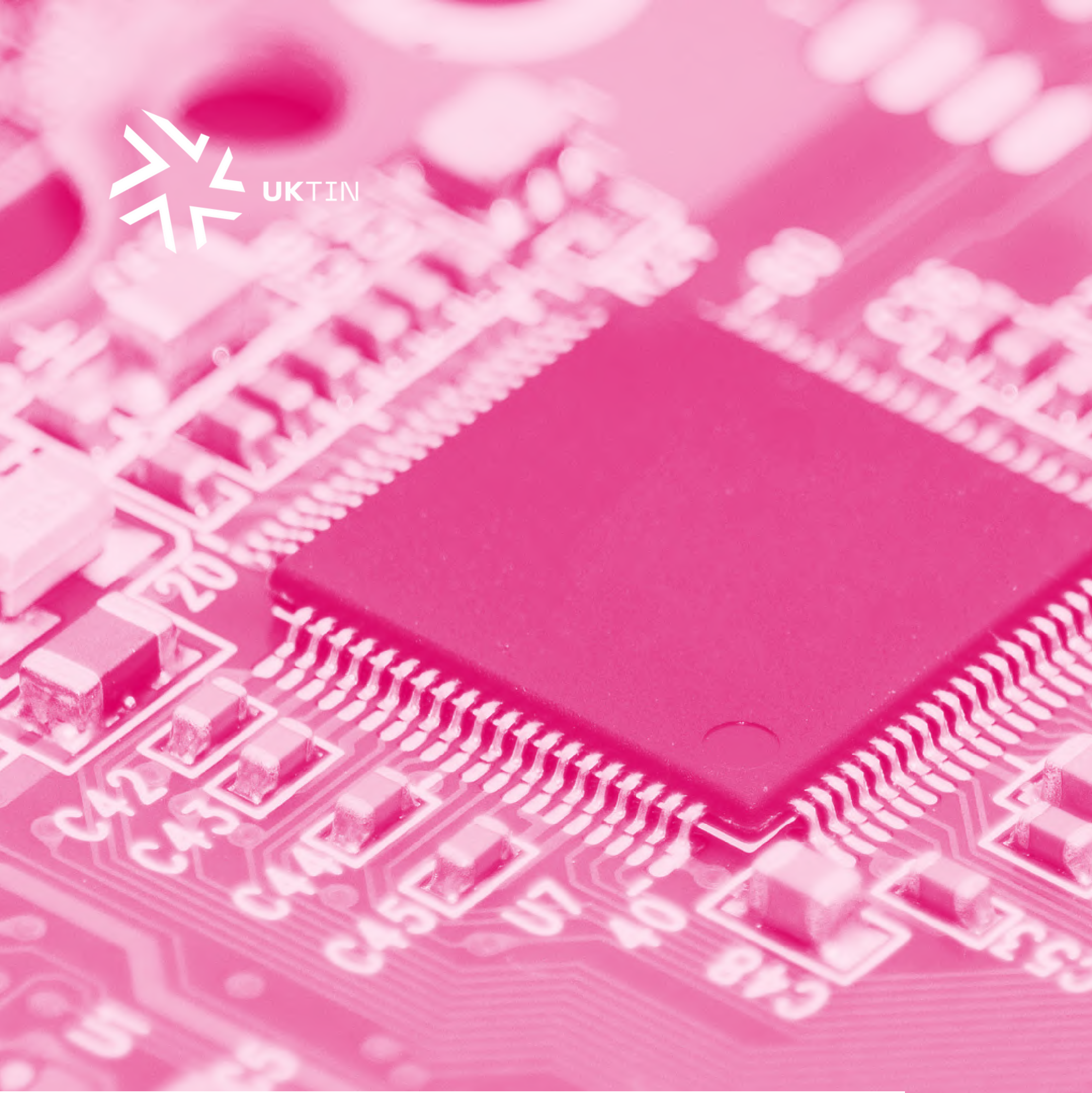

Market Research Insight Report: Semiconductors

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Abbreviations

AI	Artificial intelligence
AlGaInAs	Aluminium gallium indium arsenide
ASIC	Application-specific integrated circuit
CSA	Compound Semiconductor Applications
GaAs	Gallium arsenide
GaN	Gallium nitride
eV	Electron volt
EV	Electric vehicle
HEMT	High-electron-mobility transistor
IC	Integrated circuit
InGaN	Indium gallium nitride
InP	Indium phosphide
IoT	Internet of things
LDMOS	Laterally-diffused metal-oxide semiconductor
LiDAR	Light detection and ranging
mmWave	Millimetre-Wave
nm	Nanometre
PIC	Photonics integrated circuit
R&D	Research and development
R&D&I	Research and development and innovation
RF	Radiofrequency
Si	Silicon
SiC	Silicon carbide
SiGe	Silicon germanium
UKRI	UK Research and Innovation

Introduction

This report provides a concise overview of semiconductor-related research, development, and innovation (R&D&I) activities within the UK telecoms sector. This document is designed to offer a non-technical perspective on the current state of R&D&I efforts in this critical area.

Specifically, the scope is as defined in the introduction to UKTIN's Future Capabilities Paper: Semiconductors for Telecoms[1]. As in that report, we have taken into account the UK's strengths in compound semiconductors, noting the synergies with closely related technologies such as photonics and radio-frequency (RF) engineering, and also consider some overlapping domains beyond pure telecoms applications, such as military communications.

The report's insight and commentary on UK semiconductor R&D&I activities is derived from:

- Primary data sourced in academia and industry interviews: in-depth interviews with key telecoms sector stakeholders including professionals from leading telecoms companies who are at the forefront of industry advancements, and academic insights gathered through interviews with experts associated with prestigious institutions. These interviews provided valuable qualitative data and perspectives, helping to form a comprehensive understanding of current trends, challenges, opportunities and innovations within the field
- Secondary data from comprehensive desk research and the UKTIN R&D&I AI discovery tool[2]: review and analysis of the latest publications, reports, and articles covering the relevant industrial and academic fields, and of a filtered list of semiconductor research projects identified using the AI discovery tool (funded projects from 2017 to the present with a clear telecoms or communication application).

Annex A describes the research methods in more detail. Descriptions of semiconductors, compound semiconductors and telecoms applications of semiconductors are provided in Annex B.

[1] Future Capability Paper: Semiconductors In Telecoms
[2] UKTIN Discovery Tool Kit

Introduction

It is important to note from the outset that much semiconductor R&D&I activity is not aimed solely at telecommunications applications, because semiconductors are used within multiple parts of the telecoms industry. Foundational research and development may have telecoms applications, but equally may be used in other areas. Examples include projects that relate to fundamental semiconductor materials properties, or to manufacturing processes for semiconductor devices. The nature of semiconductor devices, including those designed explicitly for telecoms use, means that design and manufacturing are very closely aligned. This makes counting and valuing ‘relevant’ research problematic. Our approach has been to take into account only those projects where a clear link can be inferred with telecoms applications.

Semiconductor-Related R&D&I in Telecoms

2.1/ Overview of Relevant Global Trends

The following broad global trends and themes were identified from the primary research as influencing UK semiconductor R&D&I activities for telecoms applications[3]:

- Challenges to real-world implementation of 5G. While 5G technology is expected to revolutionise connectivity with speeds potentially reaching up to 510 gigabits per second, challenges with real-world implementation, particularly when considering the practicality and limitations of mmWave technology, have become apparent. Although this high-frequency spectrum is hyped for its ultra-fast speeds and low latency, its deployment is often not cost-effective for widespread use. The limited range and poor penetration through obstacles like walls result in poor indoor performance and significant coverage issues in areas like buildings, underground spaces, and moving environments such as trains.
- Advances in materials science for compound semiconductors. Work in this field is critical in driving the next wave of 5G/6G, higher data rate photonics modules and beyond. Gallium nitride and indium phosphide have emerged as key materials that outperform traditional silicon in several applications in RF, and PICs are a major photonics future trend. All interviewees acknowledged significant potential for compound semiconductors in the telecoms sector.
- Compound semiconductor advances for photonics and power electronics. Indium phosphide is particularly advantageous for power amplifiers and photonics components where silicon falls short, offering enhanced energy efficiency and performance. Compound semiconductors like gallium nitride are increasingly recognised for their role in photonics and power electronics. They are central to reducing size and improving energy efficiency in 5G systems and have the potential to become critical as the industry eyes 6G.

[3] Interviews conducted by: Compound Semiconductor Applications Catapult and University of Bristol

- Compound semiconductors for RF. There was a suggestion that for RF, instead of competing directly with silicon, compound semiconductors should be differentiated by their unique advantages in specific niche applications.
- Optimising manufacturing processes for photonics. Balancing size, cost, power, and performance remains a complex challenge in the field of photonics. As integrated photonics devices mature in the telecommunications space, quality and reliability of mass-produced photonic components are growing concerns. Integrated solutions that combine emitters, detectors and ASICs (Application-Specific Integrated Circuits) are crucial for addressing these concerns while enabling scalable and cost-effective manufacturing.
- The slowdown in Moore's Law[4]. Moore's Law has historically guided semiconductor advances. Current chips are produced using a 12nm process, but future generations are targeting even smaller nodes, including 7nm, 5nm, and eventually 3nm, pushing the boundaries of semiconductor technology.
- New and growing areas of application, adjacent or complementary to telecoms. For the overall semiconductor industry, 6G, artificial intelligence, space communications, healthcare, environmental monitoring, LiDAR and integration of solar PV with satellite and optical wireless communications were mentioned as applications or areas of growing interest.

Desk research confirmed that a major relevant global influence on R&D&I is the move from silicon to compound semiconductors in numerous telecoms application areas, in particular radio frequency (RF) devices. Silicon has been the dominant semiconductor material in the telecoms sector for its properties, established supply chain, and economies of scale. However, compound semiconductors, owing to their superior properties, are gaining attention to address specific performance requirements in certain applications within the telecoms sector.

Figure 1 presents an overview of the RF semiconductor technology landscape in terms of output power and frequency. According to technology insights provider Yole[5], the RF market is currently dominated by Si LDMOS technology; however, gallium nitride is expected to take over in the next few years. Gallium arsenide is the choice of material for low-power (<70W) and low-frequency applications (<100GHz). Gallium nitride and silicon carbide are suitable for high-power and high-frequency applications. Indium phosphide is another compound semiconductor for higher-frequency applications up to 300GHz.

[4] "Moore's Law is the observation that the number of transistors on an integrated circuit will double every two years" (Intel)
[5] RF GaN Compound Semiconductor Market Monitor, Yole, 2024

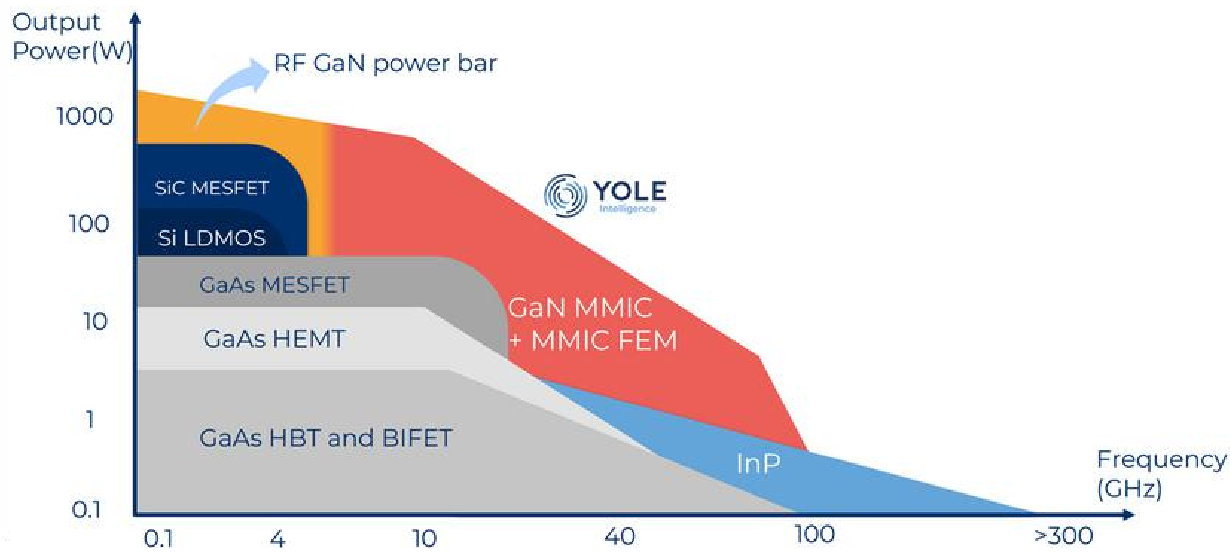

Figure 1: RF semiconductor overview: power vs. frequency characteristics. Image credit: Yole[6]

2.2/ Status of the UK's Semiconductor R&D&I

The findings from the primary research[7] are summarised below:

The UK's strengths in semiconductors for the telecoms sector

- There was a consensus among the interviewees that the UK is recognised for its exceptional research capabilities in high-frequency electronics. The country's strength lies in its ability to lead cutting-edge research and development, particularly in areas requiring specialised knowledge and advanced technological skills.
- One of the key areas where the UK excels is in niche markets that demand complex engineering solutions. These markets often involve high levels of customisation and innovation, where UK companies and research institutions have the expertise to develop tailored, high-performance products and systems. This expertise is especially evident in sectors such as defence, aerospace, telecommunications, and medical devices, where precision, reliability, and advanced functionality are important.
- The UK's strength further lies in its strong foundation in materials research, which is crucial for the development of next-generation technologies. The country is home to some of the world's leading research institutions and universities that are pioneering work in materials science, particularly in semiconductors. This includes advancements in wide band gap materials like gallium nitride and silicon carbide, which are key to the future of telecommunications[8].

[6] Ibid.
[7] Interviews were conducted by Compound Semiconductor Applications Catapult (industrial) and the University of Bristol (academic)
[8] Reviewing relevant funded projects indicates that the universities (in alphabetical order) of Bath, Bristol, Cambridge, Cardiff, Durham, Glasgow, Imperial College, Heriot-Watt, Newcastle, Sheffield, Southampton, Strathclyde, Swansea, University College London and Warwick are particularly strong in various fields of semiconductor research for telecoms and related applications

Key challenges

- Most interviewees mentioned that the UK faces a significant challenge in semiconductor manufacturing, particularly in producing advanced materials such as gallium nitride, which are crucial for next-generation wireless communication technologies. The lack of the necessary infrastructure and facilities to compete globally in semiconductor chip manufacturing limits the country's ability to scale production and innovate within the sector. This gap makes the UK reliant on imports for critical components, putting it at a disadvantage in the global semiconductor supply chain.
- The current level of funding allocated to semiconductor research is considered inadequate to bridge the gap between theoretical research and practical applications. Despite the critical role semiconductors play in emerging technologies, securing the significant financial backing needed for their full-scale development continues to be a major challenge.
- It is believed that the national strategy lacks cohesiveness, and that research efforts have been fragmented. Although significant consultations have taken place, the UK's progress in implementing the semiconductor strategy has been slow, leaving it lagging behind global competitors. Furthermore, the lack of an integrated framework to connect the country's R&D facilities is limiting innovation. The UK's semiconductor strategy is also seen as outdated and failing to address the needs of this fast-paced industry.
- The shortage of a skilled workforce in the UK semiconductor industry is hindering growth and innovation. This shortage is worsened by the challenges of attracting and retaining talent post-Brexit, as new immigration policies have made it more difficult for companies to recruit skilled professionals from outside the UK. The government's approach to apprenticeship schemes is also criticised as being overly restrictive. There is a significant gap between what universities teach and the skills needed in the commercial world, particularly in highly specialised and complex technologies. This disconnect means graduates are often not fully prepared for the demands of the industry. The universities struggle to offer competitive salaries, so retaining talent is difficult.
- Concerns over intellectual property rights pose significant challenges to collaboration between the UK's semiconductor industry and universities. Companies are often hesitant to partner with academic institutions because of the complexities involved in IP ownership and commercialisation, which can hinder innovation and delay technological progress. The universities often lack expertise and resources for patent protection.
- International trade and collaboration are seen as more challenging post-Brexit as UK companies face increased bureaucracy and paperwork, complicating their operations. The complexity and cost of complying with new regulations have become significant barriers, particularly for smaller companies that lack the resources to manage these changes effectively.

- The lack of large-scale end-user customers in the UK affects the domestic market for advanced wireless technologies, making it difficult for local companies to achieve the necessary scale for commercial success.

Growth opportunities

- The rapid evolution of music and video consumption, driven by the double-digit annual growth[9] of streaming services and high-definition content, offers a great opportunity for the UK telecoms sector. As consumers demand faster speeds and greater bandwidth (global Internet bandwidth rose by 22% in 2024[10]) to support the operation of these services, telecoms companies can capitalise by upgrading their infrastructure to offer enhanced services. By doing so, UK telecoms providers can attract new customers, increase revenues, and strengthen their role as essential players in the digital entertainment ecosystem.
- The global semiconductor shortage presents a unique opportunity for UK-based telecoms companies to expand their global footprint. Global supply chains need diversified and reliable sources of semiconductors, and UK companies can explore new partnerships, invest in domestic production, or even acquire international businesses. These expansion strategies would enable UK firms to play a more prominent role in the global semiconductor market, strengthening the UK telecoms sector's position on the global stage.
- Satellite communications is another opportunity highlighted during the interviews. The ongoing challenges of maintaining reliable network connectivity and coverage, especially in difficult environments such as moving trains, present a significant opportunity for the UK telecoms sector. Satellite networks could be the key to overcoming these limitations. By investing in and developing satellite-based solutions, telecoms companies can provide consistent and high-quality coverage in areas where traditional terrestrial networks struggle.

Barriers or constraints

- The UK telecoms sector struggles to match the cost structures of other countries, particularly those with lower operational and labour costs. This can make it difficult for UK-based companies to compete on price.
- Access to adequate funding when compared to the US and some European countries is seen as a threat to the ability of the UK companies to invest in cutting-edge technology. As per the responses during the interviews, the impression is that the UK has fewer large-scale venture capital options and government-backed funding initiatives, which are critical for fostering innovation and supporting startups.

[9] See, for instance, IFPI Global Music Report 2024
[10] Telegeography's IP Networks Research Service

- A lack of engagement with international initiatives like the EU and US Chips Acts[11,12], could leave the UK significantly disadvantaged in accessing funding and collaboration opportunities.
- In response to funding limitations and talent shortages, some UK telecoms companies are considering opening subsidiaries in EU countries or, in some cases, relocating their headquarters. The EU Chips Act, which offers significant funding opportunities for semiconductors and related technologies, is a strong incentive for companies to move. This could lead to a loss of jobs, tax revenue, and innovative capacity within the UK.
- The trend of UK telecoms companies being acquired by US firms poses a threat. While these acquisitions can bring in capital and new technologies, they often result in job losses, the closure of UK-based operations, and a shift in strategic focus away from the UK.
- The UK's stringent visa policies and post-Brexit immigration challenges have made it difficult for telecoms companies to attract and retain international talent. In response, some companies are setting up production facilities in other countries with more favourable immigration policies. While this strategy helps them sidestep visa issues, it also means that investment, jobs and innovation are being shifted out of the UK.

2.3/ Academic-Focused Government R&D&I

2.3.1/ National Semiconductor Strategy

The National Semiconductor Strategy, announced in May 2023, is a comprehensive plan aimed at strengthening the UK's position in the global semiconductor industry. The strategy is a response to the increasing importance of semiconductors in various high-tech industries, including telecommunications[13]. Key elements include the following:

Investment in R&D and innovation

- Objective: The UK government has committed to investing up to £1bn over the next decade to support semiconductor research, design, and innovation.
- Focus areas: This investment is targeted at areas where the UK has existing strengths, such as compound semiconductors, advanced chip design, and semiconductor manufacturing processes.
- Impact: By boosting R&D, the UK aims to foster innovation in semiconductor technologies that are critical to next-generation telecommunications infrastructure, including 5G and 6G networks.

[11] European Chips Act
[12] CHIPS and Science Act – funding update
[13] National Semiconductor Strategy, UK Government.

Strengthening the semiconductor supply chain

- Objective: Enhance the resilience of the UK's semiconductor supply chain by encouraging domestic production and reducing dependence on foreign suppliers.
- Actions: The strategy includes plans to support the growth of domestic semiconductor manufacturing, particularly in compound semiconductors, which are crucial for high-frequency telecommunications applications.
- Impact: A stronger supply chain ensures that the UK's telecommunications sector has reliable access to the advanced chips needed for network infrastructure and devices, minimising disruptions caused by global supply chain issues.

Support for the semiconductor ecosystem

- Objective: Develop a robust ecosystem that includes academia, industry, and government collaboration to drive semiconductor innovation and commercialisation.
- Actions: The strategy focuses on creating partnerships between UK universities, research institutions, and semiconductor companies to accelerate the development of cutting-edge technologies. It also includes investment in higher education to support high-quality teaching and provide facilities, especially in engineering, physics and electronics to nurture the talent required for the semiconductor sector.
- Impact: A vibrant semiconductor ecosystem in the UK can lead to breakthroughs in telecommunications technology, including more efficient and powerful semiconductors for mobile networks, IoT devices, and other telecoms applications.

National security and strategic autonomy

- Objective: Protect the UK's national security interests by ensuring secure and reliable access to semiconductor technology.
- Actions: The strategy emphasises the importance of securing semiconductor supply chains and protecting sensitive technologies from foreign control or interference.
- Impact: For telecommunications, this means enhanced security and resilience of the networks that underpin critical national infrastructure, reducing vulnerabilities associated with relying on foreign semiconductor sources.

Global partnerships and trade

- Objective: Strengthen international partnerships and trade relations to secure access to global semiconductor markets and technologies.
- Actions: The UK plans to engage in strategic partnerships with key countries, participate in international semiconductor alliances, and ensure that UK companies are well-integrated into global supply chains.
- Impact: By participating in global semiconductor networks, the UK can ensure its telecommunications industry has access to the latest technologies and can compete effectively on the world stage.

The impact of the National Semiconductor Strategy on specific areas of telecommunications is as follows:

5G/6G networks

- Relevance: Semiconductors are at the heart of 5G and future 6G networks, enabling high-speed data processing and signal transmission, and efficient power management.
- Impact of strategy: The UK's focus on compound semiconductors, which are ideal for high-frequency applications, directly supports the development and deployment of advanced telecommunications networks.

Internet of Things (IoT)

- Relevance: IoT devices, which are expected to proliferate with the expansion of 5G, require specialised, low-power semiconductors.
- Impact of strategy: By fostering innovation in semiconductor design and manufacturing, the UK strategy supports the development of chips that can power the next generation of IoT devices, enhancing connectivity and smart infrastructure.

Telecoms network security

- Relevance: The security of telecommunications networks is increasingly dependent on the integrity and origin of the semiconductors used.
- Impact of strategy: By focusing on securing the semiconductor supply chain and ensuring strategic autonomy, the UK's strategy contributes to the overall security and resilience of its telecommunications infrastructure.

Telecoms manufacturing and jobs

- Relevance: A strong semiconductor sector can boost the domestic manufacturing of telecommunications equipment and create high-skilled jobs.
- Impact of strategy: The strategy's emphasis on building a robust semiconductor industry could lead to growth in telecoms equipment manufacturing within the UK, fostering job creation and economic growth in the sector.

2.3.2/ UKRI

The UK has spent around £1.8bn in 2006–24[14] on semiconductors in RF, power and photonics projects, as well as on underlying materials research. A map highlighting the distribution of regional investment in large projects around the UK is shown in Figure 2.

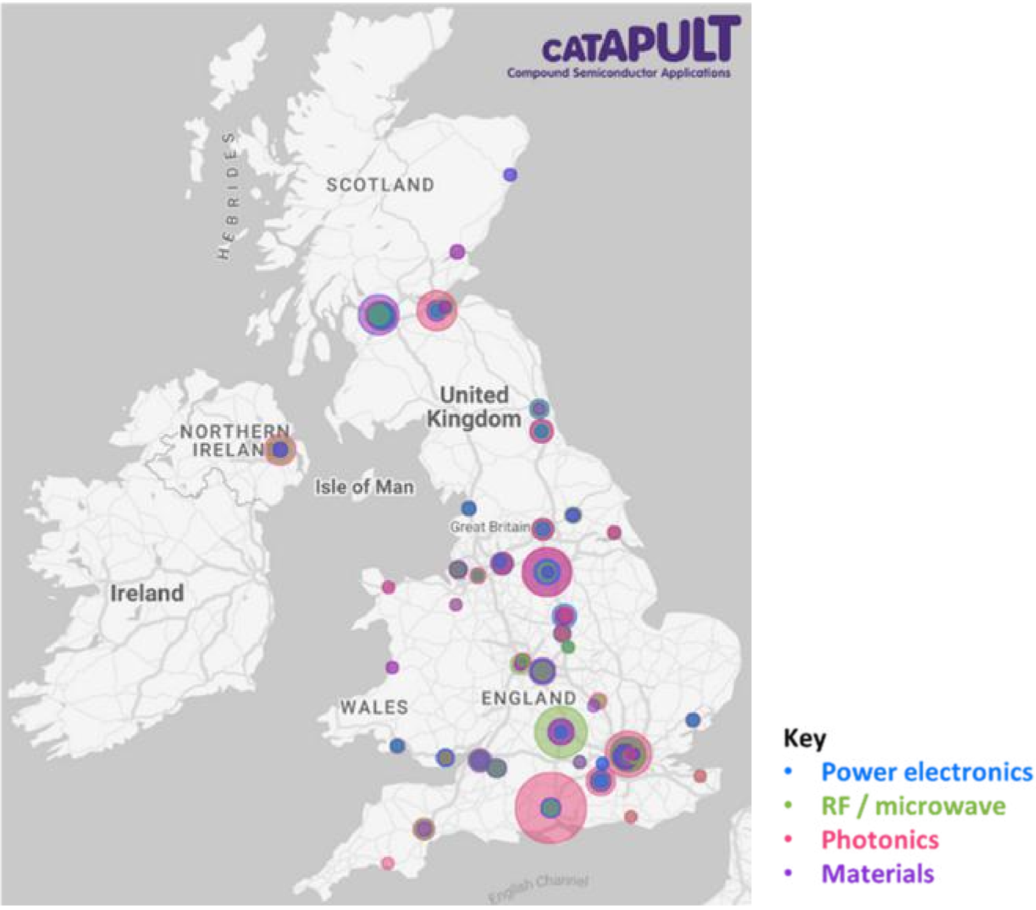

Figure 2: Academic semiconductor investments around the UK[15]. Image credit: CSA Catapult

In terms of semiconductors, the research councils have invested in major facilities for semiconductors; examples of major facilities are:

- University of Glasgow – James Watt Nanofabrication Centre
- University of Southampton – Optoelectronics Research Centre – CORNERSTONE
- University of Sheffield – National Epitaxy Facility
- Cardiff University – Institute for Compound Semiconductors
- Swansea University – CISM

Assessment of the historic funding database available through UKRI the funding for semiconductors from 2017 onwards has been ~£550mn of investment into telecommunications R&D&I projects/programmes with semiconductor technology at their heart[16].

[14] UKRI Funding Database
[15] CSA Catapult
[16] Innovate UK Funded Project Databases, UKRI

Semiconductor-Related R&D&I

Much activity within these projects and programmes is supporting research into telecommunications devices and advanced materials for future development. Major telecoms research hubs have been developed, and these have been recently funded with a new EPSRC-funded collaborative network project called JOINER. JOINER is the UK's first national accelerator programme towards 6G and beyond. It is a national R&D platform interconnecting academic institutes, research labs and industrial partners to enable innovation within a collaborative experimental environment[17].

These multi-partner hubs include TITAN (Platform Driving the Ultimate Connectivity), CHEDDAR (Communications Hub for Empowering Distributed Cloud Computing Applications and Research) and HASC (Hub on All-Spectrum Connectivity).

EPSRC, as the major research council funding R&D for telecommunications relevant research, is currently funding relevant research in a range of relevant semiconductor-focused research areas. The most relevant research areas and currently funded projects are listed below. Details of projects funded can be found on EPSRC's website[18,19].

[17] JOINER, University of Bristol
[18] What EPSRC has funded
[19] EPRSC funding outcomes

Optical communications: Currently funding 26 projects with £75mn investment. The table below showcases the top 10 funded projects by size in this category.

Project name	Lead organisation	Grant £
Joint Open Infrastructure for Networks Research (JOINER)	University of Bristol	12,560,513
Future communications hub in all-spectrum connectivity (combined funding)	University of Oxford	11,561,004
Terahertz frequency devices and systems for ultrahigh capacity wireless communications	University of Leeds	7,097,283
Transforming networks - building an intelligent optical infrastructure (TRANSNET)	UCL	6,105,916
National Dark Fibre Facility	UCL	5,700,543
Terabit Bidirectional Multi-user Optical Wireless System (TOWS) for 6G LiFi	Kings College London	3,692,896
Interferometric and Multiband Optical Parametric Amplifiers for Communications (IMPAC)	Aston University	1,193,138
Silicon-rich silicon nitride Nonlinear Integrated Photonic Circuits & Systems (Junipers)	University of Southampton	1,123,975
OptoCloud: Ultra-fast optically interconnected heterogeneous Data Centers	UCL	1,120,128
Towards a revolution in optical communications	University of Southampton	1,055,483

Digital signal processing: Currently funding 34 projects with £65mn investment. The table below showcases the top 10 funded projects by size in this category.

Project Name	Lead Organisation	Grant £
Terahertz frequency devices and systems for ultrahigh capacity wireless communications	University of Leeds	7,097,283
Transforming networks - building an intelligent optical infrastructure (TRANSNET)	UCL	6,105,916
Fluid Antenna Systems for 6G Wireless Communications: Implementation, System Optimisation and Theoretical Analysis	UCL	1,352,407
All-Raman optical amplification for next Generation ultra-wideband Optical Networks (ARGON)	Aston University	978,033
6G Metasurfaces: Signal Processing and Wireless Communications by Coding on Metamaterials	UCL	933,826
Reconfigurable Intelligent Surfaces 2.0 for 6G: Beyond Diagonal Phase Shift Matrices	Imperial College London	891,185
Overcoming Resolution and Bandwidth limit in radio-frequency Signal digitisation (ORBITS)	UCL	877,216
Transmission Channels Measurements and Communication System Design for Future mm Wave Communications (mm Wave TRACCS)	Durham, University of	786,349
Extremely Wideband Optical Fibre Communication Systems	UCL	738,958
EPSRC-SFI: Energy Efficient M Communication using Combs (EEMC)	Aston University	634,133

RF & microwave communications: Currently funding 53 projects with £113mn investment. The table below showcases the top 10 funded projects by size in this category.

Project Name	Lead Organisation	Grant £
REWIRE Innovation and Knowledge Centre: Transforming Net Zero with Ultrawide Bandgap Semiconductor Device Technology	University of Bristol	11,748,844
Future communications hub in all-spectrum connectivity (combined funding)	University of Oxford	11,561,004
EPSRC Centre for Doctoral Training in Future Open SecuRe NeTworks (CDT-FORT)	University of Surrey	7,955,648
Terahertz frequency devices and systems for ultrahigh capacity wireless communications	University of Leeds	7,097,283
Terabit Bidirectional Multi-user Optical Wireless System (TOWS) for 6G LiFi	Kings College London	3,692,896
6G Sub-Terahertz Software Defined Radio Testbed	University of Sheffield	2,379,292
Secure Wireless Agile Networks (SWAN)	University of Bristol	2,335,708
Midlands mm-Wave Lab: A versatile electromagnetic characterisation suite for future RF to millimetre-wave communication and sensing systems	University of Birmingham	1,485,619
Satellite Ground Station Research Facility	Heriot-Watt University	1,042,525
Guiding, Localising and IMaging confined GHz acoustic waves in GaN Elastic waveguides and Resonators for monolithically integrated RF front-ends	University of Bristol	962,654

ICT networks and distributed systems: Currently funding 92 projects with £202mn investment. The table below showcases the top 10 funded projects by size in this category.

Project Name	Lead Organisation	Grant £
TITAN extension	University of Cambridge	10,612,161
CHEDDAR: Communications Hub for Empowering Distributed Cloud Computing Applications and Research - TMF uplift	Imperial College London	8,558,479
EPSRC Centre for Doctoral Training in Future Open SecuRe NeTworks (CDT-FORT)	University of Surrey	7,955,648
Transforming networks - building an intelligent optical infrastructure (TRANSNET)	UCL	6,105,916
Terabit Bidirectional Multi-user Optical Wireless System (TOWS) for 6G LiFi	Kings College London	3,692,896
UKRI National Federated Compute Services NetworkPlus	Queen Mary University of London	3,105,203
ECCS-EPSRC: NeuroComm: Brain-Inspired Wireless Communications -- From Theoretical Foundations to Implementation for 6G and Beyond	Kings College London	990,142
UKRI-India Future Networks Initiative	University of East Anglia	806,362
High Dimensional Wireless Passive Optical Networking for Access Deployment (PON-HD)	University of Glasgow	730,355
Cell-free massive MIMO for future wireless networks	University of York	597,293

Due to its increasing importance, academic funding for research into telecommunications, IoT and connectivity has become a major area of research within EPSRC-funded institutions with world-leading academic centres of excellence.

2.3.3/ Industrial R&D Funding

Telecommunications funding for industrial R&D has traditionally been provided by DSIT (formerly BEIS) agencies such as Innovate UK, and DCMS. In recent years the main funding has been focused on the diversification of UK supply. The 5G Telecoms Diversification Strategy was published in 2020 and has funded projects to develop a wider ecosystem for major network players to purchase equipment for future RAN networks, specifically through the FRANC funding call.

Future RAN Competition (FRANC) 2021 [20]

- Overview: The UK government launched the Future RAN Competition (FRANC) in 2021 as part of its wider efforts to diversify the telecommunications supply chain and promote the development of Open RAN technologies.
- Funding: £30mn was allocated to support projects that develop and deploy open and interoperable RAN solutions, which are seen as crucial for the evolution of 5G and future networks.
- Focus: The funding supports innovations in areas like Open RAN, which allows greater flexibility, cost reduction, and the ability to mix and match components from different vendors. This initiative is also linked to national security concerns, aiming to reduce dependency on a small number of large telecoms equipment providers.
- 14 projects were funded as part of this competition.

SBRI: Future Telecommunications Challenge (October 2023)[21]

- Overview: This was a funding initiative to drive advancements in telecommunication technologies that can be integrated into functional prototypes and comprehensive system solutions.
- Funding: £28mn was allocated to support projects.
- 18 projects were funded.

Semiconductor Industry Skills and Training (Feb 2023)[22]

This was an IUK competition for investment of up to £5mn to address skills shortages across the semiconductor industry. It aimed to create and deliver course content and materials that will support skills, talent and training across semiconductor manufacturing and supply chain. Its primary focus was to raise awareness of semiconductor production and applications while addressing critical talent and training shortages in the UK's skilled workforce in this sector.

Future funding

Future funding for industrial R&D for telecommunication is currently unclear and does not have a dedicated government strategy. This is because it falls within the purview of several strategies; in the National Semiconductor Strategy one element is a focus on UK sovereign capability for telecommunications.

[20] Future RAN: Diversifying the 5G Supply Chain, UK Government
[21] SBRI: Future Telecommunications Challenge, UK Government
[22] Semiconductor industry skills and training

International Funding of UK Telecoms Semiconductor R&D&I

In addition to UK funding, collaborative cross-border projects relevant to semiconductors in telecoms are significantly funded and coordinated by European bodies and initiatives including

- **EU Horizon 2020 and Horizon Europe**[23]
- **5G PPP (Public-Private Partnership)**[24]
- **CELTIC-NEXT**[25]
- **European Space Agency (ESA)**[26]
- **COST (European Cooperation in Science and Technology)**[27]
- **ETSI (European Telecommunications Standards Institute)**[28]

Further, the European Chips Act[29] aims to support the European semiconductor industry through a range of measures including enhancing R&D, and identifies critical sectors in which it aims to reduce European dependence on non-European semiconductor suppliers. The scope of the Act includes safeguarding supply chains for semiconductors for 5G and 6G infrastructure, edge computing, IoT, and cybersecurity in telecoms.

There are additionally several major global industrial telecoms research programmes whose scope explicitly or implicitly determines the scope of semiconductor-focused R&D&I by specifying or influencing performance parameters for applications, systems, devices and components that will be realised using semiconductors. The most significant of these programmes are

- **Next Generation Mobile Networks (NGMN) Alliance**[30]
- **6G Flagship Program (Finland)**[31]
- **DARE (Distributed AI for Resource-constrained Industrial Networks)**[32]
- **Next Generation Internet (NGI) Initiative**[33]
- **National Spectrum Consortium (USA)**[34]
- **Beyond 5G Promotion Consortium (Japan)**[35]
- **5G Forum and 6G Research Initiatives (Korea)**[36]

[23] Horizon 2020 and Horizon Europe, European Commission
[24] 5G-PPP
[25] CELTIC-NEXT – Next Generation Telecommunications
[26] The European Space Agency
[27] European Cooperation in Science and Technology
[28] European Telecommunications Standards Institute
[29] Chips Joint Undertaking, European Union
[30] NGMN.org
[31] 6G-Enabled Wireless Smart Society & Ecosystem
[32] Dare, Artificial Intelligence Applications and Innovations
[33] Shaping Europe's digital future, European Commission
[34] The National Spectrum Consortium
[35] Beyond 5G Promotion Consortium
[36] Ministry of Science and ICT, Korea

Conclusion

The primary research highlights the pivotal role of advanced materials, innovative design, and integrated photonics in shaping the future of wireless communication technologies, particularly as 5G and beyond continue to evolve. While 5G promises exceptional connectivity speeds, its implementation faces significant challenges, especially with mmWave technology's limitations in cost, range, and indoor performance. The rise of compound semiconductors like gallium nitride and indium phosphide offers promising alternatives to traditional silicon, particularly in niche applications requiring enhanced energy efficiency and performance. As the industry progresses towards smaller, faster, and more efficient components, these emerging technologies and materials will be crucial in overcoming the limitations of current technologies and driving the next wave of advancements in telecommunications.

The UK's telecoms and semiconductor sectors possess strengths in high-frequency electronics research, niche markets requiring complex engineering, and advanced materials science. The country's leadership in these areas is supported by its world-class research institutions and expertise in emerging technologies like wide band gap materials. These strengths position the UK as a global leader in sectors such as defence, aerospace and telecommunications, where innovation and precision are paramount. However, the sectors face significant challenges, particularly in scaling semiconductor manufacturing, bridging the gap between academia and industry, and overcoming post-Brexit barriers to trade and talent acquisition.

Despite these challenges, there are promising opportunities for the UK to strengthen its telecoms sector and expand its global semiconductor presence. The growing demand for high-speed Internet and the rise of streaming services present opportunities for UK telecoms companies to upgrade their infrastructure and explore new markets. The global semiconductor shortage provides a strategic opportunity for the UK to diversify supply chains and invest in domestic production. However, constraints such as high operational costs, limited funding, and talent shortages, aggravated by post-Brexit policies, pose risks to the long-term growth and competitiveness of the UK's telecoms and semiconductor industries.

Conclusion

It was also highlighted during the interviews that to remain globally competitive, the UK must shift its focus from military-driven innovations to high-volume applications across diverse sectors, supported by an IP pool model that enhances industry–academia collaboration through global licensing of university-generated IP. Strengthening leadership in advanced semiconductor manufacturing will require substantial financial incentives, particularly in defence and healthcare. Addressing the skills shortage through more accessible engineering education, expanded apprenticeships, and streamlined visa processes is crucial for developing a robust talent pipeline, according to industrial and academic experts.

Funding for the telecommunications sector goes hand in glove with that for semiconductor developments, due to the nature of the underlying technology. The UK has been at the forefront of many research breakthroughs, and funding for academic research must grow for the UK to capitalise on the needs for future telecommunications and data centre requirements and also to help underpin innovative technologies required for future quantum secure Internet developments. Industrial R&D funding as part of the semiconductor strategy is key to the development of the supply chain for UK sovereign capability, especially for innovative new products where the UK can grow exports, and reduce the reliance on imports for the development of national infrastructure.

Annexes

Annex A: Research Methodology and Limitations

Primary Research

The primary research focused on gathering qualitative data through detailed, in-depth interviews with key stakeholders in the telecoms industry. This included professionals from leading telecoms companies. These individuals provided critical insights into current trends, challenges, and opportunities shaping the sector. Additionally, the primary research extended to interviews with academic experts from prestigious institutions, contributing valuable theoretical perspectives. The combination of industry and academic viewpoints provided an enhanced understanding of both the practical and innovative developments within the telecoms ecosystem.

Interview questions from the primary research were:

1. What do you think the next generation of chips (photonic/RF/digital) will have in terms of their performance over current devices in circulation today?
2. Where do you think the UK excels in terms of semiconductor capabilities and/or research compared to the rest of the world?
3. What are the challenges that the UK faces to compete with Europe and the US who have received significant funding from the government to invest in reshoring semiconductor production?
4. In a post-pandemic/Huawei world do you see synergies for semiconductor requirements for telecoms and defence applications?
5. What interventions or investments would be desirable within your sector of the telecoms semiconductor supply chain to succeed?
6. Are there skills shortages in the semiconductor industry in the UK that could be addressed through academia or investing through training schemes such as apprenticeships?

Annex A

Secondary Research

Secondary research involved reviewing industry reports from respected market and technology research firms. These reports offered data-driven insights and forecasts regarding market dynamics, technology trends and evolution, and competitive landscapes within the telecoms sector. The desk research also included an examination of government publications, providing an understanding of government initiatives such as the National Semiconductor Strategy.
The funding data has been sourced from publicly accessible databases, including the official websites of organisations and councils such as UK Research and Innovation (UKRI), the Engineering and Physical Sciences Research Council (EPSRC), the European Commission, as well as several UK government platforms and both UK and global project websites.

Regarding UKRI funding, historic semiconductor funding data from 2006 to 2024 has been analysed by CSA Catapult and is provided for context, along with a subset of funding from 2017 onwards sourced from the UKRI database. The EPSRC data is from 2017 onwards and is for currently live projects with data taken from the EPSRC grant database and project details scraped for the top projects in each category, some duplications were deleted across categories to show the breadth of projects. Some EPSRC CDT programmes were not included as telecommunications was a small subset of the overall CDT, and a focus on major projects related to telecommunications was used to select the top ten. European and global project information has been captured from official council and project websites through desk research.

The AI Discovery Tool was used to identify relevant R&D&I projects. An Excel spreadsheet (which should be considered part of this Annex) contains a list of funded projects categorised according to their relevance to telecoms, and filtered according to project start date. This informs the lists of projects listed and assessed in the main body of the report.

Limitations

- This report relies on publicly available data and therefore focuses on public funding for R&D&I.
- The primary research analysis is based on data gathered from eight interviews.
- Private company R&D&I data is generally considered commercially sensitive, with limited access, making web scraping techniques unsuitable for collecting this information.
- The data from public sources is presented as a representative overview of semiconductor-related R&D&I in telecoms, rather than a comprehensive or complete listing of projects and funding.
- Varying methodologies, particularly the use of different keywords, can produce different outcomes.
- Much semiconductor R&D&I activity is not aimed solely at telecommunications applications; foundational research on material properties or manufacturing processes may equally be relevant to other areas such as solar PV, sensors, quantum computing or power system engineering.

Annex B: Semiconductors and Their Telecoms Applications

Semiconductors are materials that have electrical conductivity between that of a conductor such as copper, and an insulator such as glass[37]. This unique property allows them to control the flow of electricity in electronic devices, making them essential for modern electronics. Silicon is the most commonly used semiconductor material due to its abundance and effective properties, but other materials like gallium nitride and silicon carbide are also used for specific high-performance applications[38].

In electronic devices, semiconductors are used to make components like transistors, diodes and integrated circuits, which are the building blocks of everything from smartphones to computers and advanced medical equipment. These components can amplify, switch, or regulate electrical signals, enabling the complex operations required in today's technology. Semiconductors are crucial for innovation in fields such as telecommunications, computing and renewable energy, driving the development of faster, more efficient, and more powerful devices.

Semiconductors in telecommunications are used in fibre optic networks (as sources and detectors for 1310nm and 1550nm wavelengths used in data transmission) or as the RF sources for mobile signals (4G/5G/6G) from base stations to mobile phones.

Compound Semiconductors

Compound semiconductors are materials made from two or more elements, either from the same or different groups in the periodic table[39]. Examples include gallium arsenide (GaAs), gallium nitride (GaN), indium phosphide (InP), aluminium gallium indium arsenide (AlGaInAs), indium gallium aluminium phosphide (InGaAlP), indium gallium nitride (InGaN) (all from groups III-V), as well as silicon carbide (SiC) and silicon germanium (SiGe) (from group IV-IV). A description of the mainstream compound semiconductors is included in the next section.

The primary reason for using compound semiconductors in various industries is their ability to offer superior properties compared to silicon in specific applications. For example, while silicon remains dominant in power electronics, emerging materials like SiC and GaN are gaining traction as research and development efforts lower costs and improve manufacturability.

[37] What is a semiconductor? Sumitomo Electric Industries, Ltd
[38] Compound Semiconductor Applications (CSA) Catapult
[39] What is a compound semiconductor?, Sumitomo Electric Industries, Ltd

Figure A1 compares silicon with two widely used compound semiconductors, silicon carbide (SiC) and gallium nitride (GaN). Both SiC and GaN have a wider band gap, higher breakdown voltages, and greater electron mobility, making them ideal for high-speed and high-power applications. They are more efficient than silicon, generate less heat, and reduce cooling requirements, allowing for more compact and lighter devices.

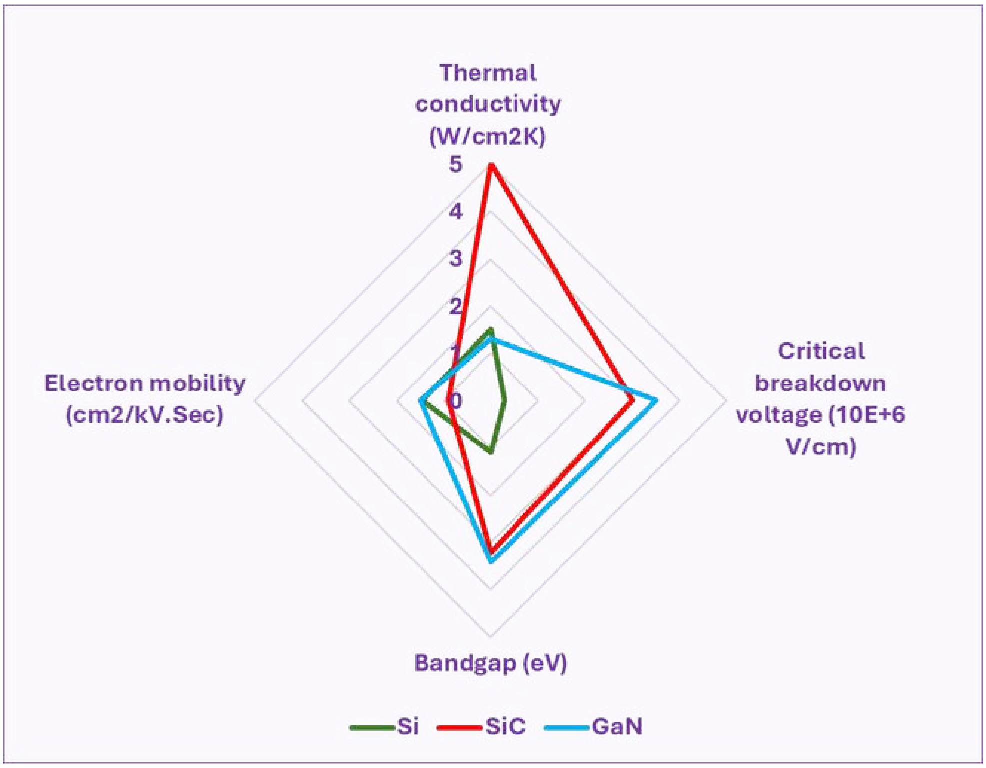

Figure A1: Characteristics comparison: silicon carbide vs gallium nitride vs silicon. Data credit: AVNET [40]

Mainstream Compound Semiconductors

The properties and applications of the most significant mainstream compound semiconductors are described below.

Silicon carbide (SiC)

SiC compound semiconductors offer several advantages over silicon, including higher voltage capability, faster switching frequencies, lower power losses, enhanced thermal stability, and the ability to operate at high junction temperatures. With a band gap that is three times larger and a breakdown voltage that is ten times higher than that of silicon, SiC semiconductors are well suited for high-voltage applications[41].

[40] The undeniable advantages of SiC technology over Si, AVNET
[41] Wolfspeed, Evolution of Silicon Carbide in Power Electronics

SiC finds applications in various sectors, such as the automotive sector where it can be found in converters for electric vehicles (EVs), hybrid electric vehicles, electric bikes, electric-motorcycles, and EV charging; in the industrial sector in applications such as uninterruptible power sources (UPSs), motor drives, and industrial power supplies; in the railway sector; in wind and photovoltaic applications in the energy sector; in datacentres, servers and base stations in the telecoms and infrastructure sector; and in aerospace and medical sectors. SiC is primarily used for power electronics; however, SiC devices are being considered for wider telecommunications markets owing to their fast electrical switching properties.

Gallium nitride (GaN)

GaN delivers superior performance compared to silicon, with its high switching frequencies, 3.5x higher breakdown voltage, and 3.4x band gap, all while being capable of operating at higher temperatures. These characteristics make GaN devices ideal for systems with smaller inductance and capacitors. GaN semiconductors find applications in diverse fields, from power devices to RF components, lasers and photonics, where their superior performance and efficiency provide a crucial edge in today's fast-paced technological landscape[42].

Power GaN

Typical power GaN devices are discrete GaN HEMTs (high-electron-mobility transistors), packaged ICs (integrated circuits), HEMT base dies, packaged GaN-on-Si HEMT and ICs, packaged GaN-on-sapphire HEMT and ICs.

The consumer sector is the largest market for GaN power devices as they are used in fast chargers for mobile phones, laptops and other portable devices; GaN power devices are also expected to penetrate the automotive sector[43].

RF GaN

Owing to its unique properties, such as high power density, high efficiency, and ability to operate at higher frequencies, GaN has several applications in RF devices. GaN-based RF devices are utilised in various wireless communication systems including cellular networks, Wi-Fi and satellite communications. Longer battery life and fast data transfer can be achieved with the higher power density and efficiency of GaN-based power amplifiers. In satellite communication, GaN-based amplifiers offer higher efficiency and allow satellites to transmit signals over longer distances and at higher data rates. GaN is also used in military and defence radar equipment[44].

[42] GaN Systems, Gallium Nitride: The Fundamental Building Block for Power Electronics
[43] Analog Devices, Gallium Nitride (GaN)—Boosting PA Power and Efficiency
[44] University of Bristol, Gallium Oxide

Photonics GaN

GaN is used widely in photonics as a light source from LEDs to laser diodes. GaN components can also be used as pump lasers for solid state lasers or amplifiers. While mainly operating in the visible wavelength range, use in visible light communication systems is growing due to ease of use. Photonics devices using GaN are unlikely to be used in the backbone of major telecoms networks but have utility in edge use cases.

Gallium oxide (Ga_2O_3)

Ga_2O_3 is a promising compound semiconductor with a significantly higher band gap than Si, SiC and GaN, of about 4.9eV, which means that it can operate at even higher voltages and temperatures. It can be more cost-effective than GaN due to its ability to be grown in bulk. There are potential applications in power conversion, such as in EVs, traction locomotives, industrial drives, etc., and optoelectronics, for instance in sensors. While Ga_2O_3 shows potential it is still a material of the future as some challenges need to be addressed before it becomes mainstream; these challenges include low thermal conductivity[45].

Gallium arsenide (GaAs)

Gallium arsenide is a compound semiconductor with two elements: gallium and arsenic. It has high electron mobility, suitable for high-frequency transistors and diodes. With a direct band gap of 1.4eV and higher breakdown voltage than silicon it is a potential candidate for high-speed electronics, mobile phones, satellite communication and radar systems. GaAs has been explored for use in high-efficiency solar cells, light-emitting diodes (LEDs), lasers and other optoelectronic devices[46].

Aluminium gallium indium arsenide (AlGaInAs)

AlGaInAs is valued for its tunable band gap, which can be created by varying the relative amounts of aluminium, gallium and indium in the semiconductor alloy. This flexibility allows for precise control over the material’s electronic and optical properties, enabling the development of lasers operating at telecoms wavelengths (1310 and 1550nm). AlGaInAs is widely used in telecommunications networks as sources such as DFB (Distributed Feedback Grating) or FP (Fabry–Perot) lasers for generating wavelengths required for fibre optics networks.

[45] Eurofins, Advances in the Semiconductor Industry with Gallium Oxide
[46] Warwick University, Department of Physics, GaAs

Annex B

Applications of Semiconductors in Telecoms

Semiconductors, as the ubiquitous material for all electronics systems, are deeply embedded in telecommunications networks, both photonics applications for data transmission using lasers across the fibre optic networks, and the RF connectivity and signal broadcasting to devices. Both are volume markets with large industrial players manufacturing in this space. Due to the transmission properties of fibre networks across the world, the main transmission wavelengths for global fibre optic data transmission are 1310nm and 1550nm. These wavelengths primarily rely on compound semiconductor devices such as lasers and detectors as silicon cannot function effectively at these wavelengths.

Compound semiconductor devices for traditional telecommunications devices (transceivers and receivers) have matured, and future trends in R&D and direction are for higher data rates, which will require Photonics Integrated Circuits (PICs). RF devices, the ‘front-end’ of communications, have traditionally used silicon, but are transitioning to compound semiconductors due to their better power efficiency and output, as data rates increase. RF developments in communications will be more pronounced in the coming years; in photonics, data rates will be pushed upwards using PICs in future years as semiconductor device development matures.

Figure A2: RF semiconductor overview: various applications and their frequency and power requirements. Image credit: Yole[47]

[47] RF GaN Compound Semiconductor Market Monitor, Yole, 2024.

Annex B

Figure A2 provides an overview of various RF applications across different sectors. In the defence sector, military and civil radar systems operate with high power and frequency, ranging from a few watts to over a thousand watts and frequencies reaching up to 64GHz. The priority for companies in the defence industry is security and reliability, especially for critical high-frequency devices used in radar systems, electronic warfare and communications. Devices using compound semiconductors such as gallium nitride offer higher power density, enabling compact and lightweight defence systems.

In the consumer sector, RF applications include wired broadband and handsets. Wired broadband equipment typically involves low- to mid-power levels and operates at lower frequencies, while handsets require low power and utilise both sub-6GHz and high-frequency mmWave technology.

Satellite communications cover a broad spectrum of power levels and frequencies, as shown in the Figure A2. The use of materials such as gallium nitride allows companies to develop high-frequency communication devices, increasing satellite bandwidth and data transfer capabilities. GaN-based power amplifiers enable more efficient use of limited satellite power, optimising payload capacity and increasing satellite functionality.

High-frequency applications such as automotive radar, backhaul and mmWave base stations operate at around 100W. There are various use cases for semiconductors, such as gallium nitride components, within the automotive sector. As manufacturers embrace electrification and continue the development of autonomous vehicles, the need for secure and reliable sensing and connectivity becomes of critical importance.