Department for
Business, Energy
& Industrial Strategy

South West England and South East Wales Science and Innovation Audit

Annex I: Next Generation Microelectronics Theme Report

A Science and Innovation Audit Report sponsored by
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Annex I Next Generation Microelectronics Theme Report

1. Introduction

Next generation microelectronics are key enabling technologies which underpin multiple industries such as aerospace, automotive and information technology. Their application is so widespread that the European Semiconductor Industry Association has estimated that the impact of micro- and nano-electronics on the whole economy is worth 10% of the worldwide GDP and the European Commission has reported that photonics is essential to keeping >10% of the EU economy competitive[1].

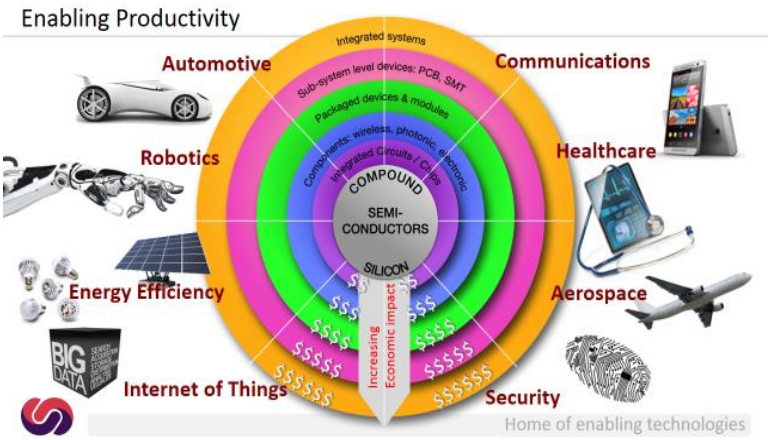

Figure NGM1 Industries underpinned by Next Generation Microelectronics

The South West England and South East Wales region has a long history of microelectronic, photonic and semiconductor companies as well as world-leading system integrators such as GE and BAE systems. The region is home to the largest silicon design cluster outside of the USA[2] and will shortly host the Compound Semiconductor Applications Catapult. The region's universities have a strong track record in relevant cutting edge research and have recently made significant investments in the areas of compound semiconductors and quantum technologies.

The economic importance of the sector is also widely acknowledged and forms a key component of the economic strategy of a number of the LEPs, including the West of England Skills Strategy and the Heart of the South West's Smart Specialisation Strategy. The latter emphasises that the electronics/photonics industry plays an important role both as a standalone sector and in supporting a number of other key sectors including Aerospace, Telecoms and Biomedical. Similarly, the Welsh Government is co-investing heavily in compound semiconductor R&D, supporting both commercial and higher education partners in our Audit region.

[1] The Leverage Effect of Photonics Technologies: The European Perspective, 2011, DG Information Society and Media SMART 2009/0066

[2] Silicon Southwest http://ubic.org.uk/siliconsouthwest/

2. Regional science and innovation assets

People and skills

Numerous studies[3][4] have identified the availability of a highly skilled workforce as being key to the development of the semiconductor industry in the South West England and South East Wales region. The region's involvement in this sector can be traced back to the beginning of the modern electronics industry in 1970s when companies such as Fairchild Semiconductor, Inmos, Nortel and Plessey Semiconductors established offices in Bristol, Swindon and Paignton. These large multinationals attracted highly skilled individuals to the area and created a local workforce with a broad range of technical and commercial skills. Some of these individuals then went on to create a new generation of innovative companies focussing on specialisations within the supply chain. This legacy of a highly trained workforce remains a key driver for attracting new companies such as Intel, Dolby and National Semiconductor to the area.

With the change of emphasis in the Microelectronic and Electronic Design sector away from fabrication towards fab-less design (due to the extreme high cost of building new deep-sub-micron foundries) the UK has become a centre for advanced design of electronic and optical circuits and systems, with the South-West being a particular hot-bed of this type of activity. The legacy of the large companies in the region has led to a significant numbers of smaller, design-oriented companies, with a vibrant and diverse range of applications from microprocessors, ASIC design to photonics, wireless and sensor integrated circuits. There are major opportunities for innovation in novel materials and advanced techniques outside the mainstream CMOS fabrication sector, in particular in wide band gap semiconductor (GaN and SiC) electronics as well as integration of MEMS and photonics with Si or SiGe electronic devices. These new methods are a key enabler of novel applications such as in integrated nano-photonics for the telecoms industry and for quantum technologies. Within the region there are well-developed plans to build a low cost, high throughput, open access compound semiconductor epitaxy foundry pilot line. The ambition is to create the foundations for Europe's 5th Semiconductor Cluster, and the World's first cluster dedicated to compound semiconductors. Simultaneously, multiple specialist manufactures continue to produce world leading products from the region leveraging knowledge intensive skills in fabrication as well as system and component integration for high value markets such as defence, aerospace and health.

Research facilities

The region has a large number of key assets for growing, processing and characterising electronic devices, see Appendix NGM2, including the following highlights:

- University of Bath's David Bullett Nanofabrication Laboratory which hosts the UK's Electron Beam Lithography Service[5].
- Cardiff University's Institute of Compound Semiconductor (£80M capital investment ongoing)
- Quantum Engineering Technology Labs - Bristol University
- University of Exeter's Savchenko Centre for Nanoscience

[3] Microelectronics and Photonics Cluster in the Heart of the South West Region, Harlin ltd, JR Lincoln, 2015

[4] Chips with Everything, NESTA, 2010, https://www.nesta.org.uk/sites/default/files/chips_with_everything.pdf

[5] http://www.bath.ac.uk/facilities/nanofab/electron/index.html

- University of West of England's Institute for Bio-Sensing Technology

Compound Semiconductor Applications Catapult
The UK Government recently announced that it would be investing £50M over 5 years[6] to establish the Compound Semiconductor Applications Catapult in South Wales. The Catapult will provide translational research facilities to accelerate the commercialisation of compound semiconductors in key applications such as: healthcare, the digital economy, energy, transport, defence and security, and space. The location of the Catapult in the region followed a thorough and detailed assessment by Innovate UK and reflects the scientific and innovation strengths within this area. The Catapult will be a cornerstone for establishing the compound semiconductor cluster.

Innovation assets
The region also has a number of key innovation assets:
- The Global #1 university business incubator - SETSquared Business Incubation Network.
- A regionally dispersed network of Science Parks and Innovation Centres - including Bristol and Bath Science Park (Emersons Green), Health & Wellbeing Innovation Centre (Truro), Poole Innovation Centre (Poole), Tremough Innovation Centre (Tremough), Winfrith Technology Centre (Winfrith), Tamar Science Park (Plymouth), Exeter Science Park (Exeter), Mendip Hub (Wells), Plymouth Science Park (Plymouth)
- Development of the £8M Electronics and Photonics Innovation Centre (EPIC) in Torbay[7]
- Compound Semiconductor Centre – a joint venture company between Cardiff University and IQE
- An active angel investors network (including South West Angel and Investor Network and Finance Wales)
- Innovation support for companies, Business West, Medilink SW, Academic Health Science Networks, Heath tech hub and IBST

3. Excellence in science and research
The science and engineering of next generation microelectronics and photonics spans a broad "stack" of activities that include theory, materials science, design and device architectures, manufacturing technologies and systems integration. The term microelectronics is a catch-all for many different approaches for acquiring, harnessing, controlling and manipulating information that is encoded digitally or quantum mechanically, however they all share in common a thread that is the miniaturisation of circuits and components to the micro and nano-scale on a substrate platform and subsequent integration into high value application specific systems – typically Silicon or Silica but increasingly Compound Semiconductor materials such as Gallium Nitride (GaN) and Silicon Carbide (SiC).

The region has science and technological research activities that align with each component of the "stack" but has particular strength in material science, semiconductor growth and fabrication, chip architecture and design, integration and the development of next generation technologies such as quantum computing. Of key importance are the

[6] https://www.gov.uk/government/news/chancellor-pledges-50m-for-ground-breaking-new-innovation-centre-in-wales
[7] http://www.torbaydevelopmentagency.co.uk/projects/regeneration/epic

specialisation toward non-CMOS technologies (in particular III-V materials research from foundations through to application in semiconductor fabrication); photonics (including the light-matter interaction through to fabrication of photonic integrated circuits) and quantum technologies. These hardware research activities are complimented by research into applications such as device verification, validation and high-performance computing architectures, low energy device design and other novel integrated circuit designs for sensors and communications technologies.

Regional Strengths are:

- Photonics – together with the highly innovative Torbay Photonics Cluster[8], which includes Spirent, Gooch & Housego and BB Photonics, the region has research excellence across its academic institutions. Leading researchers at Bath, Bristol and Exeter Universities are opening up the potential for unprecedented broadband speeds via novel Photonic Crystal Fibre, Teraherz Plasmonics, Photonic Integrated Circuits, Metamaterials and Graphene technologies.
- Wireless – The region has pioneered research in wireless communications technologies for over 3 decades, with the underlying protocols for WI-FI being developed at Bristol University, advances in wireless spectrum analysis for the policing of critical national infrastructure at Bath University and the first practical demonstrations of waveform engineering at Cardiff University. These advances have given rise to the LTE communications technologies that are ubiquitous today. This research expertise has been pivotal in attracting Toshiba Research Labs and other communications technology companies to the region[9].
- Sensors – research at Plymouth University have worked on the development of magneto-resistive sensors and a specialist security thread in banknotes which has been adopted by De La Rue, the world's largest commercial currency printer and papermaker, and provided quality assurance for over five billion banknotes worldwide. Another major strength within the region is the development of new sensor technologies for health applications which is underpinned by the Institute of Bio-Sensing Technology (IBST) - a joint collaboration between University of the West of England and Bristol University. The region has one of only two Internet of Things NHS test beds which will be used to evaluate sensor technology in the health sector, in particular the evaluation of glucose sensors and the microelectronic support platforms for the sensors. In this context, we highlight Schneider Electric's base in Plymouth.
- Compound Semiconductors – Cardiff University is making an £80M investment to establish the Institute of Compound Semiconductors as a focal point for research into GaN, III-V on Silicon and other photonic and electronic technologies. Bristol and Bath also have proven and unique expertise, with accompanying high performance facilities for compound semiconductor materials and device research.
- Quantum – The region has world class expertise in the field of Quantum Information and Communications technologies. The Universities of Bath, Bristol and Exeter are partners in the UK Quantum Technologies Hub network and have demonstrated leading approaches in Quantum Computing, Quantum Communications, Quantum Sensing and Measurement as well as the developments in the foundations of Quantum Information Science. This strength has attracted four global businesses (Boeing,

[8] http://tda-business.com/events-and-workshops/hi-tech-forum/
[9] http://techspark.co/cluster-map/

Airbus Group, BAE Systems and Raytheon)[10] to establish Quantum activities in the region as well as catalysing the formation of a number of Quantum Technology start-ups.

- Industrial R&D facilities – The region is also home to a number of industrial R&D centres for companies such as Cambridge Silicon Radio, Huawei and Airbus Innovation Works.

With the increased focused on design and novel materials, companies are increasingly looking towards universities to produce the next generation of highly skilled staff with the necessary technical and entrepreneurial expertise to drive the industry forward. The industry recruits from a wide range of academic disciplines but is particularly interested in graduates and post-graduates with degrees in physics, electrical engineering and computer science backgrounds.[11]

In terms of supply, the region has 4 university Physics departments (Bath, Bristol, Cardiff and Exeter) which submitted a total of 127 academics to the recent REF 2014 exercise (average overall GPA of 3.17). In 2014/15, the region produced 335 physics graduates, 15 postgraduates and 65 PhD students with the University of Bristol hosting three EPSRC Centres for Doctoral Training in Condensed Matter Physics, Functional Nano-Materials and Quantum Engineering; and the University of Exeter hosting the Centre for Doctoral Training in Metamaterials. These physics departments have an annual combined research expenditure of £23M with approximately half of the research being directly relevant to microelectronics theme.

The region has 7 Electronic and Electrical Engineering (E&EE) departments (Bath, Bristol, Cardiff, Plymouth, Exeter, UWE and University of South Wales) which produce 435 graduates, 175 postgraduates and 55 PhD students each year. The University of Bristol also hosts the EPSRC Centre for Doctoral Training in Communications Technologies. These departments submitted 205 staff to REF 2014 (overall GPA of 3.01) and had an annual research expenditure of £18M. Approximately a fifth of this research is of direct relevance to the theme with a particular strong focus on mobile communications, high frequency engineering, new electronic materials like GaN, photonics and photonic integration.

Increasingly, the industry is recruiting more software engineers as much of the new device functionality can be achieved through software innovation[12]. The region is home to 9 computer science departments (Bath, Bristol, Cardiff, Cardiff Metropolitan, Gloucestershire, Plymouth, Exeter, the University of the West of England and University of South Wales) and produces 840 graduate, 300 postgrads and 55 PhD students per year. These departments have an annual combined research expenditure of £12M with approximately half of the academics undertaking research of direct relevance to microelectronics theme.

Overall, the region has 220 academics across the complement of universities whose research interests are directly aligned to the next generation microelectronics theme. A

[10] http://www.airbusgroup.com/int/en/news-media/corporate-magazine/Forum-87/quantum-computing.html

[11] West of England Local Enterprise Partnership Workshop - Workshop F, Sector Skills & Competitiveness Statement Microelectronics

[12] International Technology Roadmap for Semiconductors, Executive Report 2.0, 2015

key-word analysis of the SciVal publication database highlighted 2,029 papers in peer reviewed journals for the period 2011-16 which was directly relevant to the theme. This represented 8-10% of the UK total publications in this area and were of a particularly high quality, with a higher field-weighted citation impact (2.08 vs 1.69) and more citations per publication (10.7 vs 7.9) than the UK average. Of particular note, 591 of the region's publications fell within the top 10% most cited publications worldwide.

The shortage of suitable skills has also been recognised as a regional priority, particularly by the Heart of the South West LEP, which is supporting the development of a £16M Hi-tech Skills Training Centre based in South Devon College[13]. This Centre will provide tailored education and training to meet the needs of hi-tech industries, from design of components through developing firmware and computer coding to testing and verification of components, and the forms a key component of the emerging Torbay Photonics Cluster.

4. Innovation strengths and growth points

Business Environment

There has been considerable consolidation within the microelectronics industry in the past 15 years as volume production has shifted to Asia. This has been driven by the increasingly high cost of building new fabrication plants (e.g. 2015 $23bn estimated cost of Samsung's new plant[14]) and resulted in the development of a 'fabless' business model whereby the actual manufacturing of the chips is subcontracted to a 3rd party. This development has led to a much more fragmented industry and enabled companies and clusters to emerge which focus on a particular specialisation within the value chain such as chip design, device packaging and integration.

The region has a number of next generation microelectronics companies across the entire value chain. The industry is highly international with many regional companies fully integrated into global supply chains with high levels of export. The industry is particularly innovative and under constant pressure to deliver products which are 'smaller, faster and cheaper'. This reduced time to market and increasing pressure to qualify products and processes in advance of full scale manufacture (1st to Production) provides a major challenge for the UK microelectronics industry. The flip side is a major opportunity to extract more value from the supply chain maximising the market advantages realised by exploiting novel component technology within locally clustered system integrators.

The region's expertise can be clustered into three distinct but overlapping sectors.

Cluster	Scope	Key Companies
Microprocessor and Communications Chip Design	Microprocessor and signal processing chips, software, design tools and associated technologies.	Plessey, MIcrosemi, Intel Design Centre (formerly Picochip) Bath, CICO small cell R&D centre Swindon (formerly Ubiquisys), Imagination Technologies, XMOS, Blu Wireless

[13] http://www.southdevon.ac.uk/college-news/3064-college-announces-future-vision
[14] http://www.kitguru.net/components/memory/anton-shilov/samsung-to-use-worlds-largest-15-billion-fab-to-produce-dram-report/

Semiconductors	Design, fabrication, test / qualification & packaging of semiconductor devices.	Plessey. Infineon Fabrication Plant Newport, Plessey Fabrication Plant Plymouth, IQE Compound Semiconductor Facility Cardiff, Compound Semiconductor Applications Catapult (S Wales), Dialog Semiconductors, BAE Systems MEMS Fab Bristol
Photonics	Design, prototyping, fabrication, test / qualification & packaging of photonic devices	Specialist companies including Gooch and Housego, Oclaro, II-VI Laser Enterprise, Plessey Semiconductors, EFFECT Photonics, Bay Photonics, Venture Photonics.

The region is home to around 685[15] microelectronics companies with particular concentrations around Bath, Bristol, Cardiff, Exeter, Plymouth and Torbay see figure NGM2. These companies have a combined turnover in excess of £1.6Bn and employ 8400 people across the region[16]. Such employment is particularly important as the wages within the sector are substantially higher than the regional average.

Figure NGM2 Location of microelectronics companies (no data for Cornwall).

[15] Evidence based on iNET list of 425 companies + EstNet 260 companies
[16] http://techspark.co/cluster-map/

Systems integration
As well as individual components, the region is also home to a number of world-leading prime system integrators such as General Dynamics, Airbus, Rolls-Royce, Boeing Defence UK and BAE Systems. These systems integrators bring together various components and sub-systems to provide the technological solutions that drive advances in defence, aerospace, healthcare, Internet of Everything, robotics and many other areas.

Key clusters
The region has established a number of clusters which support the microelectronic industries including:

- Silicon South West
- Torbay High Tech Forum
- Electronic and Software Technologies Network for Wales

These clusters provide advice, innovation support, networking opportunities and seed funding to promising electronic companies. Such clusters provide direct support to the industry and have proven to be very successful - iNets South West (which was funded 2009-2015), for example, supported over 400 companies and resulted in 426 new jobs, 362 new products and £14.3m GVA[17]. However, many such clusters are dependent on external funding and have a very localised remit which hampers collaboration across the entire region.

Innovation support
The region has a strong track record of entrepreneurship which has been supported by dedicated university incubators such as the Set Squared Partnership which was recently ranked as the global number 1 university business incubator by UBI Global[18] having raised over £1bn investment into businesses[19].

The region has invested in a number of science parks including the development of a new £8m Electronics and Photonics Innovation Centre (EPIC) in Torbay which will focus on, collaboration between academia and industry, commercialising R&D, enabling knowledge transfer and accelerating innovation, prototyping and product development. This relatively small cluster is highly innovative and has been awarded 3 Queen's awards this year, including an innovation award for Gooch and Housego development of a new fibre optic control technology, and home to the fastest growing company on the Silicon Valley 150 index, Oclaro.

5. National and international engagement
The next generation microelectronics industry is highly international with supply chains spanning many different countries and companies. UK photonics companies, for example, will typically export >75% of their output.

The analysis showed that the region's academics are well connected as 59% of these publications included at least one international author. The countries that the region's scientists frequently collaborate with most frequently are the US followed by Germany, France, China and Italy. The region also collaborates with leading universities such as Cornell University, Massachusetts Institute of Technology and CERN.

[17] PACEC - Evaluation of Microelectronics iNet, July 2015
[18] http://ubi-global.com/research/ranking/rankings-2015/#globalubi2015
[19] http://www.setsquared.co.uk/global-1-university-business-incubator

In addition to academic collaboration, the region's universities also have a higher than average level of engagement with industrial partners (4.3% vs 2.9%). This includes joint publications with companies as diverse as Toshiba, IBM, Airbus and General Electric.

The region's universities are engaged with major UK science initiatives and are involved in 3 out of 4 of the EPSRC's recent £120M Quantum Hubs initiative. They are also involved in 2 of the 3 Quantum Technologies Training Hubs and host the UK's only dedicated quantum training centre for Post-Doctoral researchers - the Quantum Technologies Enterprise Centre. The University of Bristol also hosts the UK centre for Quantum Photonic Integrated Circuit Fabrication.

The region's universities are also very engaged with the skills agenda with 4 of the 18 UK Electronic Skills Foundation partner universities being based in the region.

6. Developments in science and technology – international markets and opportunities

Microelectronics are enabling technologies which drive innovation across a number of key market sectors such as automotive, aerospace, ICT etc. Within the microelectronics industry itself there are a number of key technological and commercial developments which present a major opportunity for the region.

Photonics

Photonics technologies are increasingly being used in smartphones, laptops, the Internet, lighting and medical devices. Their disruptive potential is becoming increasingly apparent given their ability to overcome a wide range of barriers inherent with present technologies. Some have even suggested that the 21st century will depend as much on photonic technologies as the 20th century depended on electronics. The overall global market for photonic technologies is huge (~ £250Bn) and is expected to continue to grow at an annual growth rate of 8-10%[20]. The economic importance of photonics has even been recognised by the EU which have identified them as one of their 6 key enabling technologies[21].

Photonic technologies are set to have a major impact in the areas of lighting, optical data communications, laser manufacturing and biophotonics. In future, further developments in nanophotonics, quantum information and extreme light sources are expected to be even more disruptive and lead to new application areas and markets.

The commercial availability of high power, high efficiency LEDs has led to their rapid mass adoption for lighting applications and is driving demand for higher efficiencies through techniques such as nano-patterning, multi-level structures and thermal substrate matching. The market for LED lighting technologies is continuing to grow and is expected to reach £55Bn by 2020[22]. The region is particularly well placed to take advantage of this growth as Plessey (based in Plymouth) have developed a novel technology to exploit the cost benefit of using standard Silicon substrates on which the GaN layer is grown. By utilising the inherent advantages of a large wafer scale silicon based approach, Plessey is able to

[20] Photonics: A Key Enabling Technology for Europe, http://tinyurl.com/hyctqbb
[21] https://ec.europa.eu/growth/industry/key-enabling-technologies_en
[22] Towards 2020 – Photonics driving economic growth in Europe Multiannual Strategic Roadmap 2014 – 2020

exploit advanced packaging technology from the silicon industry and is bringing to the market novel LED products that will enable high performance cost effective solutions.

Photonics technologies will also be required to underpin the communications revolution and will find increasing use as low-cost high efficiency interconnects. In telecommunications, trends such as video consumption, cloud storage, network virtualisation have driven an exponential growth in data transfer. This places increased pressure on the “backbone network” and a drive towards the deployment of advanced all-optical switching (to avoid the inefficiencies and bottlenecks of conversion and switching back and forth to the electrical / copper connection domain.). Novel photonic technologies will be increasingly required to cope with the ever-increasing demands for capacity, especially in the backbone networks, for which a transmission capacity of several times 100 Tbps per fibre is predicted by 2020.

The data rate increase is also driving the need for inclusion of optical interface components and optical processing components together with traditional microelectronic components all on a single chip. E.g. 1Tbps software-defined transceivers (array transmitters and receivers with integrated RF electronics) achieving 3x throughput of conventional systems). The trend is driving research into multi-layer optical PCBs, 3D integrated devices, active optical cables and optical backplanes.[23]

Photonics will be used to solve the bandwidth limitation of data interconnects at rack, board and chip level. A major challenge for the coming years will be the development of high-bandwidth, low energy consumption optical interconnects at low cost. The demand for more energy efficient ways of computing and moving data is particularly important for data centres which already use a significant fraction of the UK’s total electricity consumption in 2015. New services such as cloud computing continue to drive this trend and will require significant improvements in the network architecture and high-speed (fibre-based) access to meet customer demand.

Another important use of photonic technologies is the transfer of high powered light along Hollow Core Photonic Crystal Fibres which allows energy to be transferred along a flexible connection from a laser to a cutting head. This technology is increasingly revolutionising many manufacturing process and has applications in cutting, shaping and sintered metal powder based additive manufacturing. Such developments are driving research into high brilliance / high power lasers, tunable lasers, novel laser array and beam steering techniques.

Wireless

The wireless market covers electronic devices that communicate wirelessly such as mobile phones, smartphones, mobile networks, WiFi, smart metering, satellite navigation, and a plethora of other connected devices. The wireless communications market has grown rapidly in recent years reflecting the increased adoption of wireless technology, coupled with the need for an increased compound semiconductor content to support greater sophistication of mobile devices.

The ever increasing flow of information across the internet and increased use of internet enabled devices across the globe will drive the demand for the next generation of wireless technologies. The trend for all devices to become connected and the near exponential

[23] Towards 2020 – Photonics driving economic growth in Europe Multiannual Strategic Roadmap 2014 – 2020

rate in mobile data consumption driven by increasing direct video content, improved formats such as 4K and 8K video, new services and content are driving the wireless sector research in multiple fields including emerging technologies such as Software Defined Networking (SDN), Network Functions Virtualization (NFV), Mobile Edge Computing (MEC) and Fog Computing (FC) to achieve the required performance, scalability and agility[24].

New technologies will require supporting higher operating frequencies, increased spectral efficiency, latency reduction, higher energy efficiency, complex legacy co-existence scenarios, increased data rate, spectrum aggregation, interference cancellation and new modes of communication. New techniques such as Massive MIMO, new waveforms, Joint cell processing, beam steering and increased frequencies operation from VHF (~100 MHz) to Millimetric Microwave (~30 GHz) are being developed as part of the Long Term Evolution (LTE) / 4G, LTE- Advanced and 5G programmes.

Supporting the diverse services envisaged for LTE/LTE-A/5G and the Internet of Things is proving to be challenging for all aspects of mobile devices, network topologies and core network elements. It requires techniques to be developed to ensure user experience continuity in challenging situations such as high mobility (e.g. in trains), very dense or sparsely populated areas (e.g. satellite access), and journeys covered by heterogeneous technologies. In addition, wireless will be a key enabler for the Internet of Things by providing a platform to connect a massive number of sensors, rendering devices and actuators with stringent energy and transmission constraints. It has been predicted that the Internet of Everything will see 50 billion connected devices by 2020 and this will place unprecedented demand on the LTE, 4G, 5G and the evolution of WiFi.

Sensors

The global market for sensors is expected to reach $154.4bn by 2020, and is demonstrating a compound annual growth rate of 10.1% over the five-year period from 2015 through 2020*[25].

The development of smaller more energy efficient sensors which can monitor external factors (such as temperature, air flow, speed, exhaust gas content sensing within an internal combustion engine) are enabling electronic systems to interact with the real world. The development of such “smart” systems are becoming increasingly important for IoT, Smart Building, Smart City wide area applications and digital manufacturing. Microelectronics companies are increasingly incorporating micro-scale sensors onto microchips to drastically reduce the costs and power requirements thus enabling electronic devices to better engage with the outside world. For example, Renishaw (based within the region) has integrated a Laser interferometry onto a micro-chip to provide a low-cost device which was capable of measuring dimensions to the accuracy of a few parts per million in a non-contact manner.

Sensor technologies are already widely used in smartphones with the number of sensors per mobile expected to rise from 15 today to 22 by 2029[26]. Such sensors will include

[24] 3GPP Work Items for 5G , https://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf

[25] http://www.bccresearch.com/market-research/instrumentation-and-sensors/sensors-ias006f.html)

[26] International Technology Roadmap for Semiconductors, Executive Report 2.0, 2015

MEMS accelerometers for tilt, movement, inertial positioning; acoustic transducers for voice and audio applications; pressure sensors for barometric altitude; finger print sensors; touch screens, light level sensors; and camera components. The development of low cost, reliable sensors includes research into wide bandgap semiconductors, devices for medical applications, wearable/ implantable systems, novel materials, nanotechnology, biosensing and chemical sensing techniques.

Sensors are also increasingly been used in manufactured items with the number of sensor on cars expected to increase from 100 to 200. Sensor technologies will also play an increasingly important role in the aviation industry with Airbus planning to equip future aircraft with over 10,000 sensors per wing producing over 7.5Tb of data per day. Such technologies will also drive new applications such as wearables (for fitness and health monitoring purposes) or smart building monitoring and will require the integration of multiple low power sensors into miniature packages capable of being powered for long periods with small batteries, super-capacitors or through energy harvesting.

One of the fastest growing applications for sensors are as medical diagnostics and this market is expected to reach $22.68Bn by 2020. In particular, photonic and sensor technologies are increasingly being used to provide low cost point of care screening methods. Novel biosensors, including devices with nano-crystalline semiconductor substrates, optically active nano-materials and Micro-Engineered Mechanical Systems (MEMS) will also be required to address the expanding markets for environmental and health monitoring.

Semiconductors

The overall global market for semiconductors is £230Bn and expected to grow by 4% over the next two years. Within this, the market for compound semiconductors is currently worth around £23Bn but has an anticipated growth rate of 17.3%[27].

The development of lower power, higher performance and an increasing number of transistors has dominated semiconductor technology over the past few decades. Semiconductor development have been characterised by “Moore’s law” where the number of transistors on a microprocessor chip will double every two years. As top-of-the-line microprocessors currently have circuit features that are around 14 nanometres across, smaller than most viruses, the industry is running out of later space. Although there may be still be potential to extend in 3D and increased the integration of memory and micro processing chips, the increased use of mobile devices and more embedded devices in placing a new emphasis on low power.

Another key challenge for the industry is the increased integration of micro-scale elements such as power transistors and electo-mechanical switches directly onto the chip (see previous Sensors section). These so called “More than Moore” technologies will substantial reduce the cost and power requirements of integrated circuits thus enabling developments such as the Internet of Things[28].

Another key development is the increase use of the remarkable capabilities (light emission, speed etc.) of compound semiconductors. To date, the compound

[27] http://www.bccresearch.com/

[28] EC Strategy micro and nano electronic components and systems, http://tinyurl.com/h5cs634

semiconductors have been grown on small area native substrates using bespoke device fabrication purposes. By contract the success of Si electronics have been due to a foundry approach, where devices are created using common fabrication processes on large area substrates. The growth of compound semiconductors on Si substrates and the subsequent use of standardise foundry process on 200mm+ wafers will substantially reduce cost and enable development such as the “Internet of Everything”

7. Conclusions

The microelectronics sector is of vital importance to the region but will only prosper if there is a continual flow of highly qualified individuals with the right blend of technical and commercial skills. In particular, there is a shortage of graduates and PhD students in those emerging key technologies, such as quantum technologies and compound semiconductors, which will underpin the next generation microelectronic devices. Such continued investment in people and skills will be essential to ensure that the region remains competitive in such a global industry. A key focus for future sustainability of the sector will be to ensure that there is a supply of postgraduate qualified R&D staff via PhD level training initiatives.

The microelectronic industry is particularly innovative and continues to develop technologies that will transform established market sectors such as automotive, health and the Internet of Things. Such rapid technological achievements can only be sustained if there is continued investment in the underlying research base and enhanced incentives for private sector investment. The region’s universities already have a strong track record of world leading research and working closely with industry partners. The private sector also requires increased support to compete on a global scale such as additional incentives to undertake the necessary product and process qualification and verification prior to large scale production. Such late stage developments are often unsupported by funding bodies but are a critical stage in translating promising research to manufactured product. The recent announcement of the Compound Semiconductor Applications Catapult is very much welcome and addresses both the regional strength in this area but also the global opportunity for this market for UK plc.

Finally, microelectronics is a highly globalised industry but still benefits from local interactions. The region has previously benefited from establishing clusters such as iNets and Silicon South West but both were dependant on external funding and were unable to continue the scale of activity required without external funding. Our Audit has clearly identified a need for a sustained funding model which can support effective networking across the region.

Appendices

Appendix NGM1 Underpinning of other SIA Themes by Next Generation Microelectronics

	Aerospace and Advanced Engineering	New Energy Systems	Digital Living	Digital Living – Digital Health
Photonics	Lighting, high speed inter component comms, 3D scanning, metrology, laser powered manufacturing (additive and subtractive), photonic integrated circuits, sensors, Non destructive testing.	Efficient LED lighting, optical power transfer, efficient Solar cells.	Internet Petabit communications backbone, All optical switching, optical short range communications, RF over fibre, virtualisation, fibre to the premises, optical backplane connectivity, OLED display technology	Minimally invasive sensing (biophotonic sensing, fibre raman spectroscopy), enabler for additive/subtractive custom implants and orthotics
Wireless	Communications capability, situational awareness,	Intelligent built environments, responsive load balancing, dynamic tariffs, dynamic energy market.	Higher bandwidth support through LTE evolution, 5G, Integrated IoT connectivity, software defined radios	Wellness monitoring, fitness tracking and pervasive diagnostics. Electronic patient records.
Sensors	Engine optimisation, navigation, autonomous operation (collision avoidance, obstruction detection)	Intelligent grid, smart environment (Occupancy, predictive environment control.)	Integrated IoT sensors, context sensitive services, improved interaction methods	Diagnostics, implantable devices, smart home care / telecare environments. Wearable sensors.

Semiconductors	Size, cost and power reduction, processing power increase for autonomous operation, machine vision, machine learning, high efficiency motors and switching components.	Efficient LED lighting and power controllers, high efficiency solar cell inverters, low power IT equipment,	Size, cost and power reduction, processing power increase to enable advanced applications VR, 360 degree video, natural language recognition, smaller and lighter portable devices, inference deduction, large data, processing power and algorithms for network virtualisation and signal processing to support 5G data rates,	Low cost / disposable medical sensors, lab on a chip diagnostics devices, low power devices for medical implants, pervasive monitoring.

Appendix NGM2 List of Assets

Asset	Location	Host/Lead	Descriptor
Centre for Quantum Photonics	Bristol	University of Bristol	The Centre encompasses over 100 staff and undertakes research into Quantum Communication and Networks, Quantum Sensing and Metrology, Quantum Information and computation.
Quantum Sensing and Imaging Hub	UK	University of Bristol	Aims to build ultrasensitive light detectors for a range of applications including medical imaging, security monitoring and manufacturing, led by the University of Glasgow
Quantum Communications Hub	UK	University of Bristol	Aims to create quantum-encryption systems for secure communications that can be widely and cheaply deployed, led by the University of York
Communication Systems & Networks Research Group	Bristol	University of Bristol	The Communication Systems & Networks Research Group aims to address the research demands of the fixed and wireless communication sectors. It performs fundamental academic research with strong levels of industrial application.
Centre for Doctoral Training in Communications	Bristol	University of Bristol	The Centre for Doctoral Training in Communications offers an integrated, cohort-driven environment in which to undertake world-leading research and provides a coherent advanced training network for the communications community nationally, and develops the skilled and entrepreneurial engineers needed to underpin the future of the industry.
Microelectronics Research Group	Bristol	University of Bristol	The Bristol Microelectronics Research Group is a team of world-leading academic experts in computer architecture, design verification, fault tolerance, reconfigurable technologies and high performance computing.
Quantum Engineering Technology Labs	Bristol	University of Bristol	QET Labs is a global centre for research, development and entrepreneurship in the emerging quantum technology industry and is an international node for collaboration with industrial and academic world leaders, and the EPSRC UK Quantum Technology Hub Network. It hosts the EPSRC funded CDT in Quantum Engineering, Quantum

			Technologies Enterprise Centre and QuPIC quantum fabrication service.
Centre for Device Thermography and Reliability	Bristol	University of Bristol	The CDTR is a world-leading center focused on improving the reliability of novel semiconductor devices, circuits and packaging. Since 2001 the group have been applying key technologies developed in Bristol for thermal and reliability research of semiconductor devices, in particular for microwave and power electronic devices.
Electron Microscopy Group	Bristol	University of Bristol	Analytical facilities include energy dispersive X-ray microanalysis (EDX), electron energy loss spectroscopy (EELS) and cathodoluminescence (CL). Much of our current work is on semiconductors, including the wide band gap semiconductors gallium nitride (GaN), silicon carbide (SiC) and diamond.
High Performance Networks	Bristol	University of Bristol	High Performance Networks group (HPN) led by Professor Dimitra Simeonidou specialises in the application of advanced hardware and software technologies, targeting future optical communication networks for data centers, cloud based applications and distributed technologies etc.
Bristol Centre for Functional Nano Materials	Bristol	University of Bristol	BCFN Centre for Doctoral Training is a World-leading interdisciplinary training centre for PhD and MSc in Functional Nanomaterials funded by EPSRC.
Photonics Group			The Photonics group is pursuing world leading research topics for affordable and faster information and communication technologies and sensors to revolutionise healthcare and new methods of harvesting renewable energy.
Biomedical Physics research group	Exeter	University of Exeter	The group has extensive expertise in magnetic and photonics imaging for medical applications including next generation based diagnostic techniques
Electromagnetic and Acoustic Materials group	Exeter	University of Exeter	This group explores the fundamental interaction of light (from X-ray to microwave) with matter and how this can be manipulated with synthetic metamaterials and at nanometre scales

			with plasmonic materials.
Quantum Systems and Nanomaterials	Exeter	University of Exeter	The Quantum Systems and Nanomaterials Group has a wide range of cutting edge nanofabrication facilities used to research the physical properties of materials at the nano-scale including quantum effects.
EPSRC Centre for Doctoral Training in Metamaterials	Exeter	University of Exeter	The CDT is a key UK investment in training for this cutting edge new technology.
Centre for Graphene Science	Exeter / Bath	Universities of Exeter and Bath	The Centre for Graphene Science brings together the Universities of Exeter and Bath in internationally leading research in graphene and aims to bridge gap between science and industrial applications.
Semiconductor Physics Group	Exeter	University of Exeter	This group is concerned with both the experimental and theoretical properties of semiconductors.
Savchenko Centre for Nanoscience	Exeter	University of Exeter	
Centre for Photonics and Photonic Material	Bath	University of Bath	The Centre for Photonics and Photonic Materials perform research across a range of topics to extend a deeper understanding of photonics, photonic materials and photonic devices into applications
Centre for Advanced Sensor Technologies	Bath	University of Bath	The Centre for Advanced Sensor Technologies brings together expertise in microelectronics, optoelectronics and novel materials. The Centre's interdisciplinary research focuses on highly accurate sensors, devices and related technologies
David Bullett Nanofabrication Facility	Bath	University of Bath	The Nanofabrication Facility comprises a range of equipment within a suite of cleanrooms of ISO Class 6. Photo- and nano- lithography is combined with etching and deposition to create structures for the fundamental studies of the electronic, magnetic and optical properties of materials, as well as devices such as Hall sensors or Light Emitting Diodes (LEDs). £1.5m planned upgrades to infrastructure will provide additional capability in

			Electron Beam Lithography, Focused Ion Beam, and electron microscopy, underpinning many of the technologies described in this report and increasing the facility's industrial engagement.
Centre for Advanced Engineering Systems and Interactions	Plymouth	University of Plymouth	The research Centre for Advanced Engineering Systems and Interactions conducts research across a wide range of engineering subject areas and has expertise relevant to those developing electronic and photonic systems for the marine environment and with in-depth understanding of requirements of the marine sector e.g. in structural monitoring where photonics is increasingly being deployed
Centre for High Frequency Engineering	Cardiff	Cardiff University	The Centre for High Frequency Engineering is internationally renowned in the fields of non-linear measurement systems, device characterisation, and circuit design.
Institute for Compound Semiconductors	Cardiff	Cardiff University	The Institute for Compound Semiconductors is a major £80M investment aimed at positioning Cardiff as the European leader in compound semiconductors. The Institute has cutting-edge facilities and works closely with industry to develop academic research to a point where it can be introduced reliably and quickly into the production environment.
Compound Semiconductor Centre	Cardiff	Cardiff University	The Compound Semiconductor Centre (CSC) is Europe's new home for product, services and skills development in compound semiconductor technologies. Providing cutting-edge facilities that help researchers and industry work together CSC, based in Wales, will position Cardiff as the UK and European leader in compound semiconductors. CSC is a joint venture between compound semiconductor specialists IQE and Cardiff University.
Bio-Photonics & Quantum Optoelectronics Group	Cardiff	Cardiff University	The Bio-Photonics & Quantum Optoelectronics Group undertake research at the interface between life and physical sciences. The group has developed novel microscopy methods for studying biological systems.

Institute of Bio sensing	Bristol	University of West of England	The Institute of Bio-Sensing Technology is a collaborative venture with research groups from universities across the south west and elsewhere and aims to develop novel technologies for the detection and measurement of biological systems as well as the integration of biological systems into novel sensing technologies

Appendix NGM3 Research Excellence Framework 2014 (REF) data

The main units of assessment for the Next Generation Microelectronics theme are shown below. Not all institutions within relevant departments submitted a return to the relevant UoA.

UoA		Submitted staff associated with theme	No of Institutions	UoA overall profile (% 3 or 4*)
9.	Physics	59	4	91.3%
11.	Computer Science	49	6	69.5%
13	Electrical and Electronic Engineering	14	2	78%
15.	General Engineering	55	6	79.8%

Appendix NGM4 Publication data

The region has identified 220 academics whose research interests are directly aligned to the next generation microelectronics theme. To capture the academic output of the region, a key word analysis was performed of the SciVal database using the following keywords: photonics, semiconductors, microelectronics, optoelectronics, gallium nitride and sensors.

	Keyword dataset
Scholarly Output (publications)	2029
Field-Weighted Citation Impact	2.08
Citations per publication	10.7
Outputs in Top Percentiles (Publications in top 10% most cited worldwide) %	29
International Collaboration % (Publications co-authored with researchers in other countries)	59
Academic-Corporate Collaboration % (Publications with both academic and corporate affiliations)	4.3

Academic-Corporate collaborations

In terms of collaboration with corporate partners, the following companies and organisations had the most publications:

Company	Number of publications
Toshiba	16
IBM	13
Airbus Group	7
General Electric	5
Nokia	5
U.S. Army Research Laboratory	5
Hitachi	4
IBM Zurich Research Laboratory	4
Intel	3
Nippon Telegraph & Telephone	3
QinetiQ	3

Appendix NGM5 Income data

HESA funder type		Total research income as related to theme (£k)						
		2008/09	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**2014/15**
BIS Research Councils, Royal Society, British Academy and Royal Society of Edinburgh	1	8,330	10,021	10,184	11,278	10,615	13,566	18,311
UK-based charities (open competitive process)	2	398	212	332	302	689	1,041	1,372
UK-based charities (other)	3	36	30	1	37	54	15	6
UK central government bodies, local authorities, health and hospital authorities	4	1,322	1,074	894	1,082	2,146	1,983	1,859
UK industry, commerce and public corporations	5	1,065	1,136	1,456	1,338	1,303	1,372	1,417
EU government bodies	6	1,427	2,370	2,651	4,483	4,618	5,988	6,723
EU-based charities (open competitive process)	7	58	20	66	166	3	73	33
EU industry, commerce and public corporations	8	332	232	648	30	32	149	45
EU other	9	1,143	1,396	1,114	1,462	1,366	1,561	1,932
Non-EU based charities (open competitive process)	10	99	126	128	132	78	136	198
Non-EU industry, commerce and public corporations	11	263	303	404	312	336	617	659
Non-EU other	12	11	46	267	329	272	249	260
Other sources	13	9	60	118	404	137	104	177
		14,494	**17,027**	**18,264**	**21,356**	**21,648**	**26,855**	**32,990**

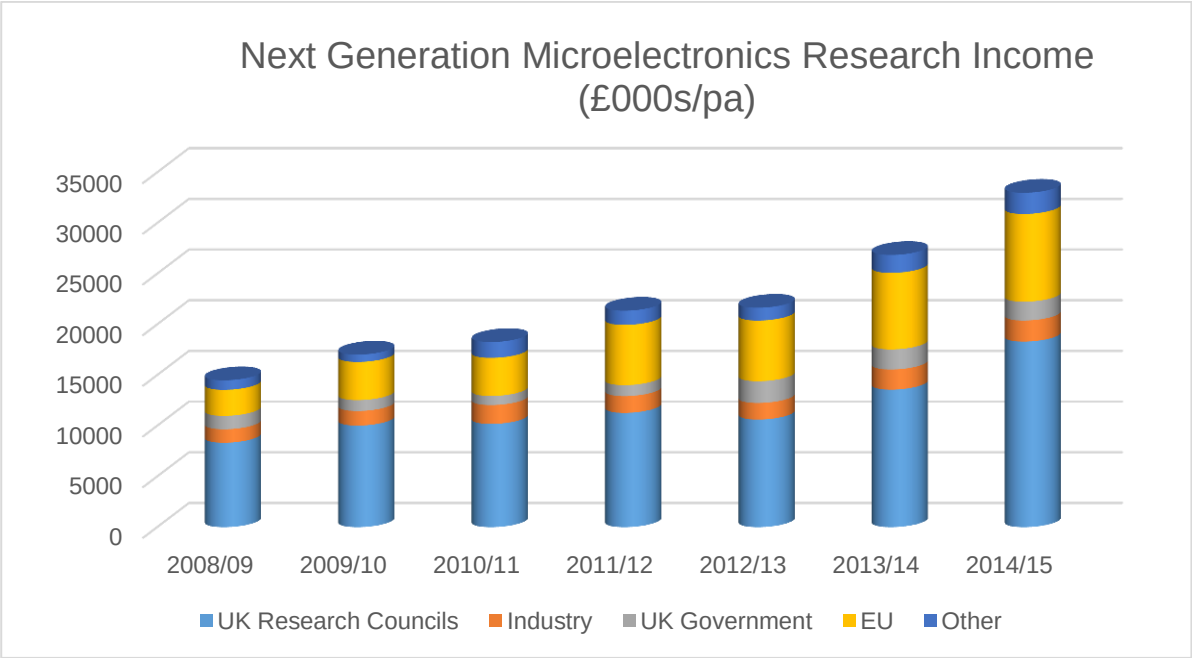

Figure NGM3 Research Income 2008-2015

Appendix NGM6 Major Companies in Theme

Company: II-VI Laser Enterprises
Location: Paignton
Description: VI Laser Enterprise is an industry-leading manufacturer of high-power semiconductor laser components enabling fibre and direct diode laser systems for material processing, medical, consumer and printing applications. In addition, II-VI Laser Enterprise manufactures pump lasers for optical amplifiers for both terrestrial and submarine applications and vertical cavity surface emitting lasers (VCSELs) for optical navigation, optical interconnects and optical sensing applications.

Company: Airbus Defence & Space Ltd., Location: Bristol, Newport
Description: Europe's No. 1 defence and space supplier with business sectors spanning Military Aircraft, Space Systems, Communications, Intelligence and Security. Annual revenues for the group exceed €14Bn. The Newport site specialises in secure information services, cyber solutions and the security of critical infrastructure in the UK, which includes cyber security for Parliament and for 90% of Ministry of Defence networks

Company: Cisco; Location: Swindon
Description: Cisco (NASDAQ:CSCO) the San Francisco based multinational IT company with 71,000 employees and $49Bn turnover acquired the small cell/femtocell experts Ubiquisys in 2013 and undertake small cell development in their Swindon location.

Company: DELTA Microelectronics Ltd., Location: Hengoed
Description: DELTA Microelectronics is part of the DELTA (Danish Electronics, Light and Acoustics) group with €42M turn-over earned from activities in development, test, certification, and advice to all phases of product development including electronics, microelectronics, software technology, optics and light technology, acoustic and vibration technology, and sensor systems

Company: General Dynamics UK Ltd., Location
Description: General Dynamics UK, part of the global defence and aerospace company General Dynamics Group (NYSE:GD) whose turn over exceeds $30Bn. General Dynamics UK is a defence contractor employing 550 people at its South Wales site into which it has invested £12M to become the UK Armoured Fighting Vehicle Centre of Excellence and a unique capability for the integration and digitisation of MoD's 16,000 vehicle fleet. The group also specialises in avionics equipment for fixed and rotary wing aircraft, mission and video management systems, communications and systems integration. It has contributed >£4.5Bn to UK economy since 2001.

Company: Gooch and Housego, Torquay and Ilminster
Description (FTSE AIM: GHH) Gooch & Housego is a UK based global leader in photonics technology with expertise from R&D to volume manufacturing with £78M turnover. It supplies innovation and manufacturing in the aerospace & defence, industrial, life sciences and scientific research sectors from 8 manufacturing sites worldwide, 2 of which are in the SIA region.

Company: Huawei; Location: Bristol
Description: Huawei is a major global ICT company headquartered in China. Its global turnover exceeds $60Bn US and employs 170,000 people. Of these 1,100 people are employed at 15 offices across the UK from where it has contributed £950M to UK GDP since 2012. In 2014 it opened a new £125M R&D centre in Bristol. The group is planning to invest £650M in the UK by 2017.

Company: Imagination Technologies Ltd., Location: Bristol, Chepstow
Description: The group employs 1,700 people in 15 countries and creates processor solutions for graphics, video and vision processing, general purpose and embedded processing and communications chip designs for consumer electronics. It has design centres in Chepstow and Bristol where they develop graphics processor technology. The group ships over £1Bn units a year and had revenues of £177M in 2015.

Company: Infineon Technologies, Location: Newport, Bristol
Description: Infineon designs and manufactures semiconductor devices for consumer, industrial and automotive use. The global business with a €6Bn turnover employs over 35,000 staff. Production is undertaken at 19 locations including its Newport fabrication plant and R&D is undertaken across 34 locations including Bristol.

Company: Intel, Location: Swindon, Bath and Bristol
Description: Intel corporation employs more than 100,000 people worldwide and generates > $50Bn revenues annually. Intel acquired the Bath based wireless silicon and software company (formerly Picochip) in 2013 and between its Swindon and Bath offices undertakes development of wireless communications systems and software for mobile devices and small wireless basestations. The Bristol R&D lab develops algorithms and software for Intel's processor graphics hardware for low-power devices such as tablets and smartphones.Swindon is home to Intel's main UK site and is one of the headquarters for the EMEA sales region as well as carrying out R&D on High Performance Computing, Wearable Technology and Memory Devices.

Company: Microsemi Semiconductor Ltd., Location: Caldicott
Description Microsemi Corporation (Nasdaq: MSCC) design and supply semiconductors and systems for aerospace and defence and industrial markets. The company is headquartered in the US has sales of $1.25Bn and employs 4,800 people globally. The Caldicot R&D centre specialises on medical technology packing and miniaturisation for implantable communications and energy harvesting devices.

Company: Mitel Networks Ltd., Location: Caldicot
Description: (NASDAQ:MITL). Mitel is a business communication technology and service company with a $1.2Bn turnover and 60 million users in 100 countries. It employs 1,300 people globally conducting R&D at multiple sites including Caldicot.

Company: Oclaro, Location: Paignton
Description: (NASDAQ: OCLR) An optical components and technology company (turnover >$500M) specialising in laser technology, photonic integration, and transceiver/subsystem design. Their products are components of fast optical networks and high-speed

interconnects within streaming video, cloud computing, voice over IP and other high-speed and bandwidth-intensive data communication applications. Oclaro has R&D production sites across the world including its facility in Paignton Oclaro Paignton where it develops components and subsystems for use in Gbit /s optical telecommunications systems.

Company: Plessey, Location: Swindon, Plymouth
Description: Plessey is a privately held UK company and is a leading manufacturer of semiconductor products used in lighting, sensing, measurement and control applications. Plessey has design and technology centres in Swindon and Cambridge, and a state of the art Gallium Nitride LED semiconductor manufacturing facility in Plymouth.

Company: Renishaw PLC, Location: Wotton-under-Edge,
Description: Renishaw is a global company advanced engineering company manufacturing products for measurement, motion control, healthcare, spectroscopy and manufacturing. Its turnover was £490M in 2015 and it operates from 70 locations in 33 countries. The majority of its R&D is carried out in Gloucestershire with production on many sites including Miskin, Cardiff. 95% of Renishaw's sales are from export markets.

Company: Spirent Communications PLC
Location: Paignton
Description: a global leader in networks and applications, wireless and service experience across the entire technology lifecycles from proof of concept to subscriber experience. It specialises in test and measurement services along with innovation and development services across communications networks and IT organisations. The company is leading in Global Navigation Satellite Systems (GNSS) venerability and has supported NASA and the European Space Agency.

Appendix NGM7 Project Portfolios

The table shows current and proposed initiatives in Next Generation Microelectronics related areas across the region. This includes funded programmes and those looking to access funding through a variety of routes including Research Councils, Local Growth Fund LEP round 3 submissions, City deals and other Government programmes.

Project/Scheme	Funding Source	Description
QTIC - Bristol	LGF – business case under development	Quantum Technologies Innovation Centre – offering facilities to support early stage companies developing products and services utilizing emerging quantum technologies. Aligned with the Quantum Technologies Lab at the University of Bristol
UEZ - Bristol	BIS UEZ pilot/LGF	Opens 2016 - ….
Open Programmable City Region (OPCR)	West of England LEP Local Growth Fund	Description: A distributed Software Defined Network (SDN), Research and Development test-bed using existing but upgraded fibre infrastructure in Bristol and across the West of England as a research and development test bed for companies to be able to test their technologies, systems and services on a unique open and programmable communication service platform. The test bed will work across Bristol, the Temple Quarter Enterprise Zone and the five Enterprise Areas at Avonmouth/Severnside, Filton, Emersons Green, Bath City Riverside and Weston's J21. (In phased deployment Summer 2016)
Advanced Engineering Campus (Bristol and Bath Science Park extension)	West of England Devolution Deal	Description: Building on existing infrastructure of the National Composites Centre, Centre for Modelling and Simulation + facilities of the Bristol and Bath Science Park the Advanced Engineering Campus will use local & regional assets and further & higher expertise to deliver the training of the engineers of the future, as well as the next generation of teachers and tutors in STEM subjects. Its mission is to offer further education from apprenticeship to postgraduate level including Doctoral Training Entities in manufacturing and Industry 4.0. Stage of development: Funded as part of Devolution Plan, Commencing Summer 2016
Developing a globally relevant Compound Semiconductor Pilot Line in the South West and	£20M Various	Project EFFICACY will help enable the European CS industry to build and regain global market share in competitive application segments that are of high strategic importance, fiscally attractive, and technologically rich. In doing so, EFFICACY will also help underpin many of the major UK and

East Wales Innovation Region		European initiatives under Horizon 2020, embracing Excellence in Science, Industrial Leadership and will help tackle the major Societal challenges. Within the overall project there are powerful links to the existing PPPs of 5G, Big Data, Robotics, Photonics and Factories of the Future. The vision is a creation of globally competitive, low cost, high throughput, open access CS Epitaxy Foundry pilot line in the UK, forming a key pillar in the creation of Europe's 5th Semiconductor Cluster and the World's first cluster dedicated to Compound Semiconductors. To date, the Cluster has already been successful in establishing both a CS Institute (TRL 1-3), and a Prototyping RTO (TRL 4-6), and an CS Applications Catapult with over £200M funding already committed from both public and private sources. The European Advanced Semiconductor Epi Foundry (EASEF) pilot line, which would be created within EFFICACY at TRL 6-8, would provide the third pillar to building the CS Cluster, and provide the bedrock for establishing globally competitive CS Anchor companies within Europe at TRL 9.
EPIC - Torbay (HotSW LEP)	£8M - Growth Deal, CCF, TBC & ESIF	Electronics and Photonics Innovation Centre (EPIC), building on existing hi-tech cluster. £8M project for a 3,700 Sqm Centre of Excellence - providing laboratories, clean rooms and specialist equipment for R&D, enabling collaboration, start-ups and new underpinning technologies to market, plus bespoke business support. Completing April 2018, EPIC will catalyse collaboration and growth of the photonics sector in HotSW.
EPSRC Future Compound Semiconductor Manufacturing Research Hub - Cardiff	£10M - EPSRC	Starting in late 2016, this project will establish a centre of excellence in manufacturing technologies related to compound semiconductors. This collaborative Hub will be based in Cardiff but will also involve Manchester, UCL and Sheffield universities
Compound Semiconductor Centre for Doctoral Training	£10M - EPSRC	Cardiff University is currently preparing a proposal to establish a CDT in compound semiconductor technologies, addressing a number of the higher level skills issues highlighted in this report.