

An Institute of Physics Report | **May 2018**

# The health of photonics

How light-based technologies are solving industry challenges,  
and how they can be harnessed to impact future economic growth



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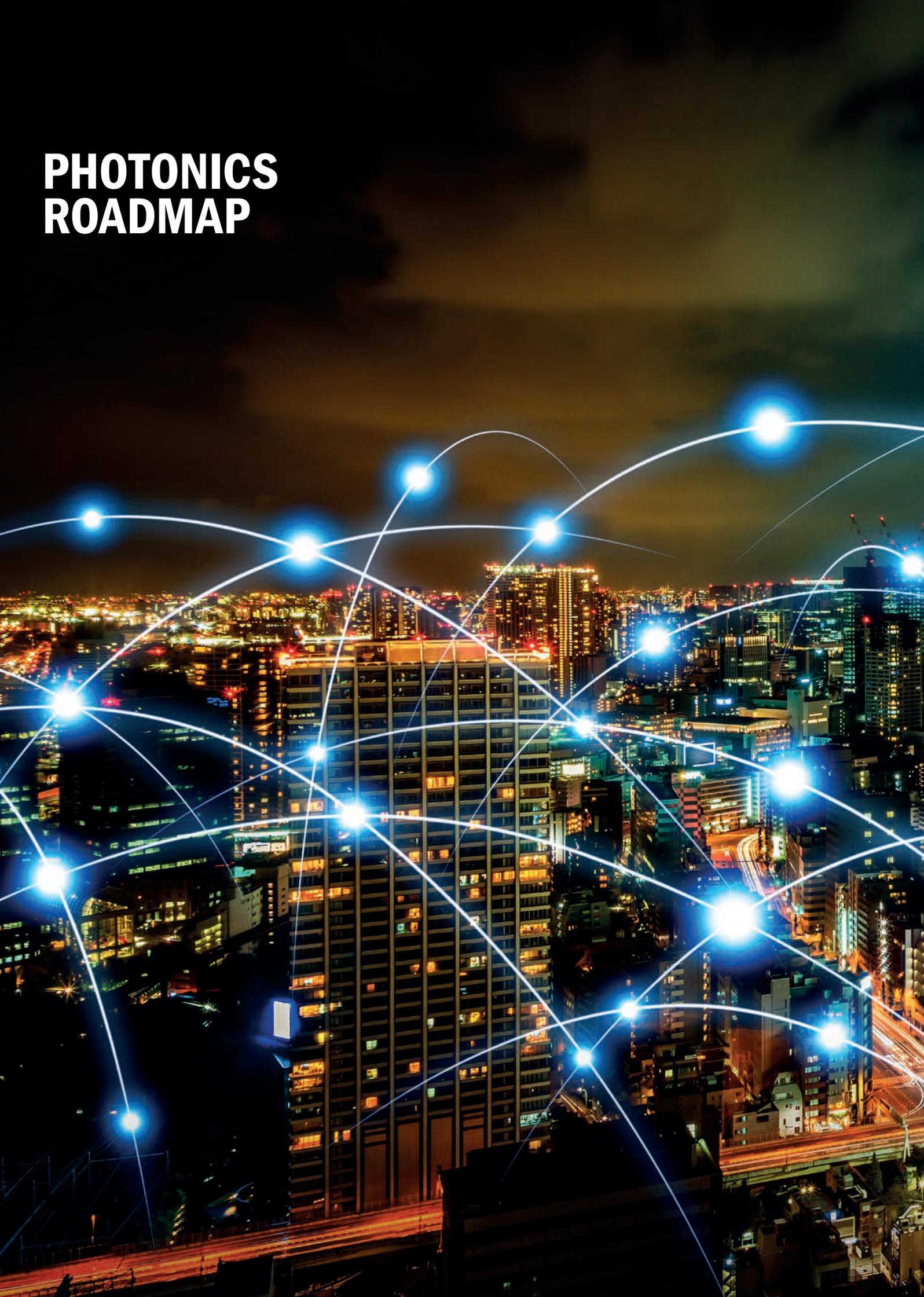
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# PHOTONICS ROADMAP



# Foreword

The Institute of Physics has long been an advocate for further research and innovation funding into photonics and light-based technologies. We were a founding partner for the International Year of Light in 2015, which took place across 148 different countries and significantly raised the profile of this hugely beneficial but often overlooked technology.

The photonics industry in the UK contributes almost £13 bn to the economy. Despite this and its status as an enabling technology, multiple uses across numerous sectors means that the industry lacks a singular figure to champion the importance of photonics.

This is a report by the photonics community, for the photonics community, but it also acts as a primer to the forthcoming photonics revolution. As the UK prepares to leave the EU, it's important to safeguard our economic prosperity going forward. Light-based technologies will be crucial in tackling the challenges laid out in the government's industrial strategy.

Our programme has brought together business leaders in different sectors, as well as innovators in academia, to articulate how photonics ties together their sectors and how physics can support further industrial growth.

This report recommends further research and investment in photonics. It also emphasises the role that physics will play in maintaining the UK's status as a global leader in light-based technologies.

The possible applications for light-based technologies are rapidly expanding. Investment, research and a clear industry profile will be central in positioning photonics-based advancements as important enabling technologies that underpin the government's industrial strategy. The age of light is dawning, and it's essential that the UK's commitment and contribution to photonics technology remains internationally renowned.

# Executive summary

<sup>1</sup> [www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/industrial-strategy-the-grand-challenges](http://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/industrial-strategy-the-grand-challenges)

In their *Industrial Strategy: the Grand Challenges*<sup>1</sup> the UK government has outlined four grand challenges and global trends facing the UK economy: artificial intelligence, clean growth, future mobility and an ageing society. Light-based technologies are vital if we are to meet these challenges and safeguard our economic prosperity.

## Artificial intelligence and the data economy

- New optical communications have the power to deliver more data in real-time.

## Clean growth

- Next-generation photovoltaic technologies and LED lighting that can be integrated into buildings.
- Wider adoption of highly efficient laser-cutting marking and welding in manufacturing.

## Future of mobility

- Dependable autonomous vehicles will need fail-safe camera and laser sensors to work in all weathers, in all locations, at all times of the day that can be built seamlessly into vehicles at low cost and huge volume.

## Ageing population

- Photonics is critical for non-intrusive predictive preclinical diagnosis enabling efficient healthcare delivery in the community.
- Laser surgery is being continuously improved to reduce the downtime of patients.<sup>2</sup>

<sup>2</sup> <https://photonicsuk.org/uk-industry-strategy-finalised-with-plenty-of-scope-for-photonics>

Decisive and timely action is required now to ensure our ongoing competitiveness in photonics, which cuts across all sectors of our economy.

IOP is in a unique position to harness the voice of UK physicists. We have reached out to our community across academia, industry and policy. Using the existing literature to guide our inquiry, we have explored the specific needs, barriers, resources and enablers that our community faces.

This report is the outcome of in-depth roadmapping sessions with our photonics community, interviews with sector leaders, specialised research into the underpinning physics and analysis of sector data. This report is not intended to be a complete guide to photonics, rather we aim to:

- Shine a light on the underpinning physics in photonics, giving informative examples that elucidate the value of photonics in key sectors.
- Identify some of the specific challenges that the photonics sector faces.
- Put forward recommendations for specific developments required to overcome these challenges.
- Bring together the photonics community across academia and industry.

We will show that:

- Light-based technologies are not only crucial in addressing the four grand challenges but also underpin much of the infrastructure, technology and manufacturing capabilities in every sector of our economy.
- Historically, the UK has been a leader in the fundamental research and innovation that underpins the light-based technologies now driving vital sectors including aerospace, manufacturing, healthcare, food, communications, energy and lighting.
- The full potential of light-based technologies has not been reached, and with specific action taken in targeted development areas, which we will outline, we can ensure that the UK continues to be a leader in this field.
- Fundamental and “blue sky” research leads to the major technological advancements of the future, investing now will drive the UK economy in the long term.
- Universities play a key role in providing training for the photonics industry through undergraduate courses, PhDs, DTCs, EngDs, and other programmes. Physics graduates are in particular demand due to a need for critical problem-solving skills.
- The photonics industry is facing both general and specific challenges, exacerbated by the fragmented nature of the sector. It is currently underfunded, underutilised and underdeveloped.
- The sector requires a higher profile and a more cohesive voice in government.
- With further investment into research, infrastructure and innovation, the photonics sector can continue to solve industry challenges and support economic growth.



### **Lighting enabled by photonics**

For light to be kind to humans and their activities, it must be dynamic and characterised by the desired spectral content. These requirements necessitate a level of control on the light sources that is now within reach. Further, from a market perspective, human-centric lighting is untapped – and LED technology seems the best candidate for this particular application. Related to human-centric lighting is the application of LED technology to horticulture and to hydroponics. Both require tunable light sources, and once again they represent valuable markets for private companies.

- *Read the full case study on p34*

### **Communications enabled by photonics**

We saw a good opportunity to keep our economy future-proof, say the founders of PureLiFi, which was founded in 2012 as a spinout company from the University of Edinburgh, where the research behind their pioneering technology had been going on since 2008. That solution is premised around using light rather than radio waves to transmit data – similar to that in a fibre-optic cable. Imagine you take away the fibre and have the data in the air, they explain. LiFi augments wireless with free-space optical communication.

- *Read the full case study on p24*



# What is photonics?

Photonics is the physics and technology of light. The applications of this field of knowledge are diverse and far reaching: from technologies that engage our fundamental sense of sight - such as displays and lighting systems, to less conspicuous technologies which harness light's exceptional capacity to work instantaneously and at a distance, such as sensors and lasers.

The electronic revolution, powered by our understanding of electrons, has allowed us to develop ever smaller and faster devices which have enabled step changes in almost every aspect of our lives; from how we communicate and store information, to the way we consume energy.

We are now in the middle of a photonics revolution. By harnessing the nature of light, there are opportunities to bring about new step changes in our society. As our current technologies are being pushed to the limits of speed, capacity and accuracy, light offers powerful new solutions.

Applications are ubiquitous and cut across almost every area of modern life: "Photonics provides the key functionality in a vast range of products eg fibre optics powering the internet, lasers welding safer more efficient cars, to microscopes and instrumentation essential to modern healthcare."<sup>3</sup>

<sup>3</sup> <https://photonicsuk.org/about>

The photonics industry in the UK contributes almost £13 bn to the economy and employs around 65,000 people in around 1,500 companies including small- and medium-sized businesses.<sup>4</sup>

<sup>4</sup> PLG, FPH, KTN report *Photonics – The Hidden Economy*

The sector consists predominantly of SMEs with a mix of sizeable subsidiaries of large international companies. Although this is a reflection of the nature of photonics as an enabler, it also means that the industry lacks one large sector champion able to successfully lobby on its behalf.

## Global context

Photonics is currently a strength of the UK, but one that needs to be maintained lest our position be usurped by nations more willing to invest and support the commercialisation of photonics-based technologies.

The global photonics industry was estimated at between £161 bn and £388 bn in 2015, and has seen an average compound annual growth rate (CAGR) of over 6.8%, a rate which is expected to continue to 2020.<sup>5</sup>

<sup>5</sup> [www.photonics21.org/ppp-services/photonics-downloads.php](http://www.photonics21.org/ppp-services/photonics-downloads.php)

The UK photonics industry is estimated to produce £13 bn worth of goods and services per year. When comparing this with global estimates we can deduce a UK share of the global photonics market upwards of 3%.<sup>6</sup>

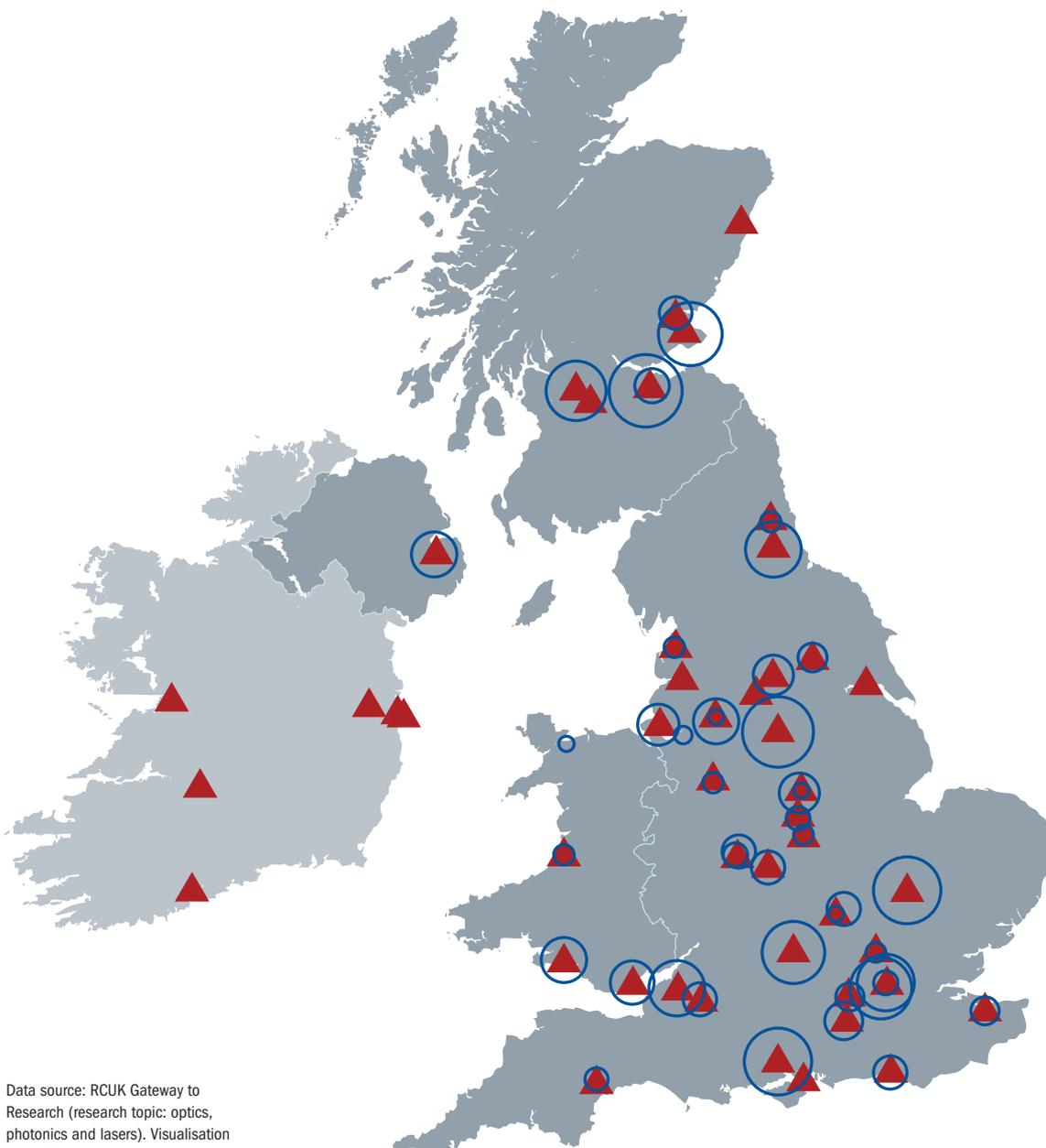
<sup>6</sup> PLG, FPH, KTN report *Photonics – The Hidden Economy*

Despite this significant share of the global market, the UK must ensure that it continues to grow its photonics industry. Between 2005-2015 the UK CAGR in photonics-based industry was one of the lowest in the EU at 2.3%, compared to 5.3% in Germany and 7.3% in the Netherlands. Despite a strong history in research and a burgeoning photonics industry, the UK needs to invest more in bringing novel technology to market if it is to compete globally in the future.<sup>7</sup>

<sup>7</sup> [www.photonics21.org/ppp-services/photonics-downloads.php](http://www.photonics21.org/ppp-services/photonics-downloads.php)

## UK Research Landscape

Photonics, including optics and laser research is a field that RCUK has invested in up and down the country, with a large proportion going to centres of excellence in Scotland, the South East and the Midlands over the past 10 years. Centres receiving high levels of funding in this field include Heriot Watt, the Glasgow universities, Sheffield, Cambridge and Southampton.



Data source: RCUK Gateway to Research (research topic: optics, photonics and lasers). Visualisation from IOP's Physics2020 dashboards.

# What is photonics?



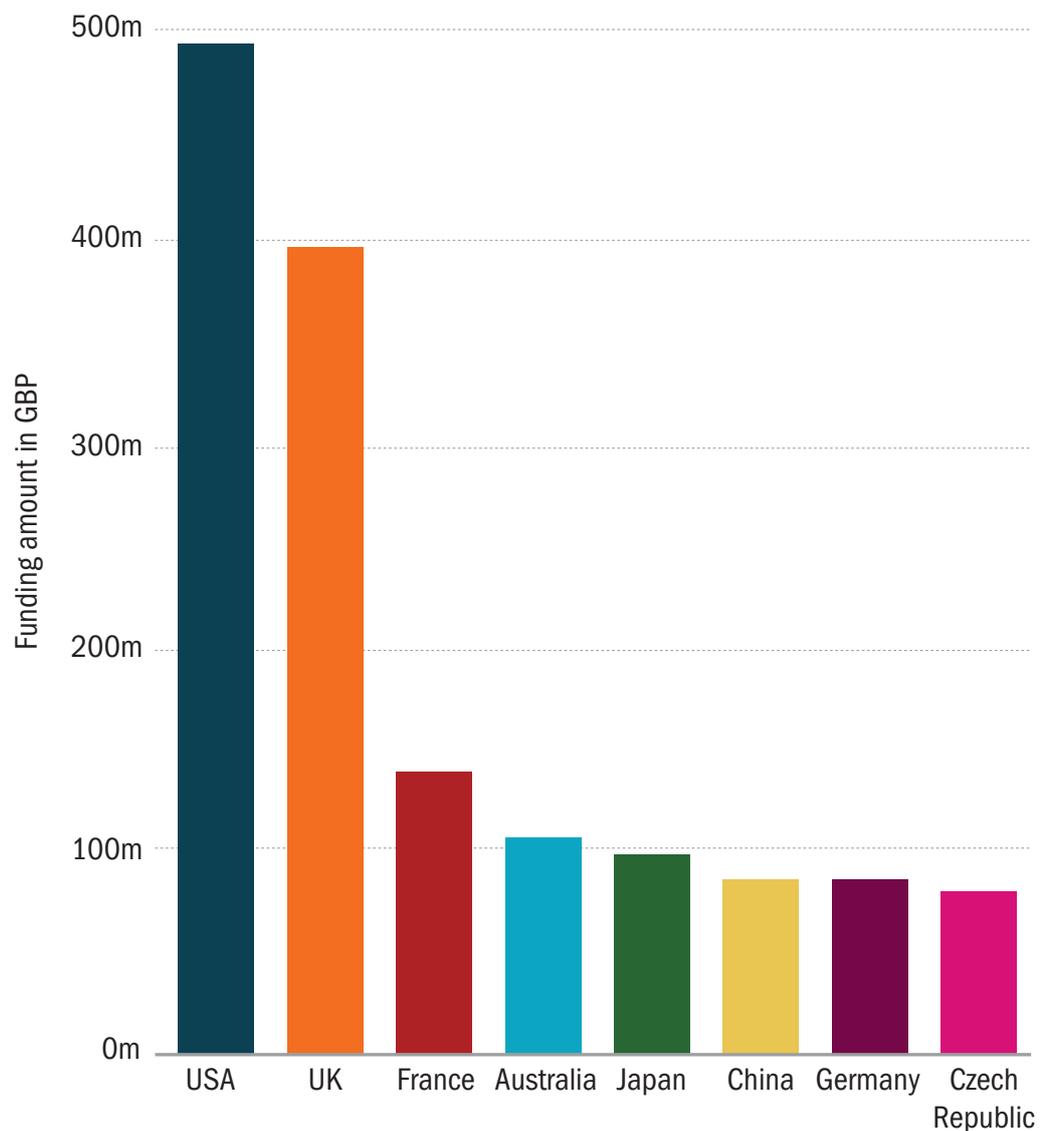
## Food enabled by photonics

Infrared sensors can detect moisture content in snack foods (such as potato chips), and can do so in-line for direct quality assurance and process control. A vision inspection system is responsible for the detection of colour defects in whole potatoes – an operation that will reduce costs and improve in-bag chip quality by rejecting unsuitable potatoes before they are even processed.

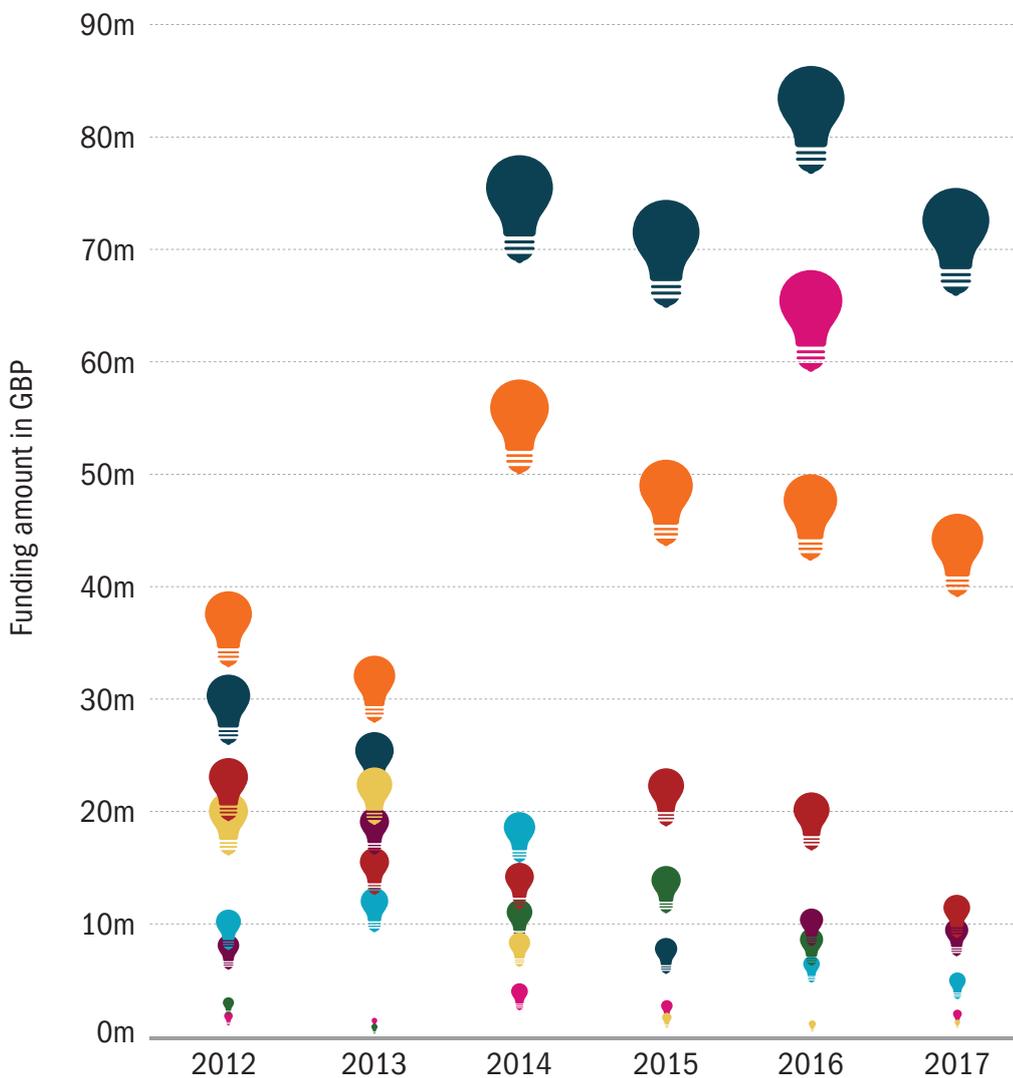
- [Read the full case study on p30](#)

The UK has been a world leader in Optical Physics over the past 10 years, investing close to £400 m since 2007, ahead of the rest of the EU nations. This funding was dominated by large investments in hubs such as the UK Quantum Technology Hubs and the Future Photonics Hub for advancing the manufacturing of next-generation light technologies.

**Figure 1:** Optical physics research investment over the last 10 years by nation



**Figure 2:** Optical physics research investment over time by nation



In recent years countries such as the US and the Czech Republic have significantly increased their investment in contrast to the UK; including the Czech ELI programme which aims to develop the world's most intense laser system enabling groundbreaking research into physics, material science, biomedical research and laboratory astrophysics. The US is also investing heavily in lasers and novel optical materials in recent years. It's vital that the UK remains competitive in this kind of core research which underpins so many enabling technologies and research techniques, as we will show.<sup>8</sup>

<sup>8</sup> [www.eli-beams.eu/en/about](http://www.eli-beams.eu/en/about)

### Energy enabled by photonics

In this evolving landscape, materials such as perovskites have only been known as useful for photovoltaics for about five years – a rather short time... further understanding and improvement will be gained through basic research in materials science and chemistry, for instance. The headroom for further innovation to drive up the efficiency of modules based on new materials is massive.

• *Read the full case study on p28*



# What is photonics?

## Business Landscape

By looking at a break-down of the photonics based companies in the UK it becomes clear how diverse the sector is. While the majority of companies in the UK fall primarily into laser sources and systems as their main focus, this is clearly a wide and varied sector with applications reaching from defence and security to manufacturing and agrifood.

**Figure 3:** Photonics companies broken down by category



## Category

- Aerospace/transportation (16)
- Agrifood (16)
- Automotive (3)
- Bio/medical/health (38)
- Communications and storage (115)
- Consultancy (27)
- Consumer and entertainment (7)
- Defence and security (62)
- Displays (65)
- Fabrication/packaging/assembly (20)
- Laser cutting (45)
- Laser sources and systems (140)
- LED sources and systems (39)
- Lighting (77)
- Manufacture (35)
- Oil and gas (11)
- Optics/lenses/coatings (108)
- Process manufacturing (2)
- Renewables (13)
- Sensing and imaging (44)
- Test and measurement (72)

Data source: <http://photonics.ktnlandscapes.com>.

## Aerospace enabled by photonics

Optical fibres are a simple example of a photonic technology with promising applications to the aerospace industry. At the moment, Anzalchi's attention is directed to integrated photonics: if a laser source, a modulator and other crucial parts within a satellite could all fit within an area of 6 mm by 2 mm (as opposed to the current footprint, which has the area of an A5 paper sheet), payload constraints would cease to be an issue. In this view, a radio-frequency signal sent to a satellite in space would be transmitted to a low-noise amplifier via an antenna and subsequently converted into the optical frequency domain for further processing.

- [Read the full case study on p22](#)



Breaking down these companies by category shows the impressive breadth of photonics-based business.

## Major obstacles

The UK photonics industry, though thriving, faces some overarching challenges that impact industry, academia and the flow of knowledge between them. These include:

- Fragmentation due to a highly diverse industry working across multiple applications.
- A low profile compared to other sectors, partially because many of the enabling photonics technologies, though vital, are not visible in final products.
- Uncertainty due to our changing relationship with the EU.
- Regional skills shortages in key skills and expertise.
- Insufficient funding for blue sky research.
- High variation in links between academia and industry, with too little funding for national programmes which spread best practice.
- Difficulty in scaling powerful new technologies to meet high volume market pull.

# Roadmap outputs

## Challenges and solutions

The photonics community and sector leaders involved in IOP's roadmapping work identified specific photonics challenges that drive the sector, many of these relate directly to the grand challenges set out in the UK Government's Industrial Strategy: aging society, future mobility, AI and data-driven economy and clean growth. The delegates also identified challenges relating to food security. While this is related to clean growth they do represent a distinct challenge that threatens to become a growing issue in a changing climate and global economy. The remaining photonics challenges could be categorised under improving productivity and efficiency. These demonstrate the value of photonics in supporting all areas of UK manufacturing and technology, from life sciences to 3D printing.

The challenges were expanded upon to give details of specific opportunities for photonics development.



### Defence enabled by photonics

A peculiarity of the defence sector is the need for a precise definition of the system under consideration. “There is the need for ‘systems thinking’,” summarises Colquhoun. He considers drones as a telling example: “drone” may only describe the flying device for some, but it actually includes many more components – such as the satellite that ensures the data exchange. In this view, a crucial challenge in defence is system-level integration. “Systems can be so complex that it becomes all too easy to end up with unreliable devices, even though each sub-system works as it should.

- *Read the full case study on p26*

### Manufacturing enabled by photonics

Manufacturing is already dominated by photonic processes to a great extent. This is certainly the case in modern manufacturing, and in all sectors where miniaturisation imposes the use of tools that can operate precisely within a small area without risks of damage to the immediate vicinity. It is thus not a surprise to find out that the semiconductor industry is now highly dependent on ultrafast laser systems, which are capable of delivering highly confined energies where they are needed for cutting or drilling.

- *Read the full case study on p36*

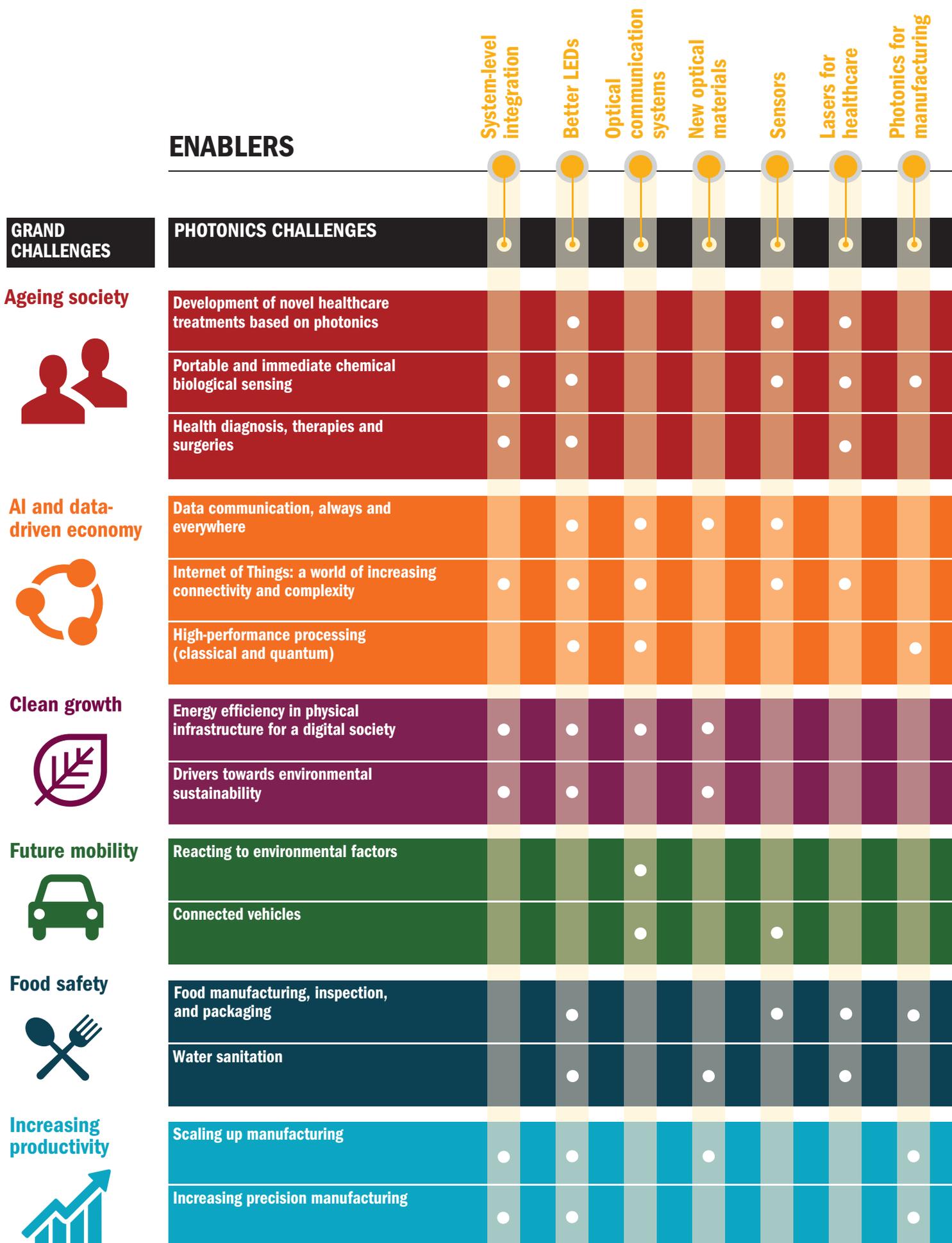


## Photonics enablers

While specific solutions can be varied and complex, specific photonics enablers were identified by an IOP roadmapping workshop attended by representatives across the community:

Enabler	Description of challenges
System-level integration	<ul style="list-style-type: none"> <li>• Integration of light-based technologies with conventional systems, electronics, protocols, standards and other photonics systems.</li> <li>• Every time we convert an electrical signal to a light signal or <i>vice versa</i> we lose energy.</li> <li>• Systems involving photonics elements need to be integrated at a system level, the processes for doing this need to be standardised and optimised in order to improve efficiencies across all market sectors and societal challenges. Example: Lidar.</li> </ul>
Better LEDs	<ul style="list-style-type: none"> <li>• Improved specifications for LEDs, particularly power, intensity, wavelength tunability, MW-UV, reduction in size, cost, turnkey, robustness, efficiency.</li> <li>• Lighting with minimum energy use. LEDs can be used to increase bandwidth for the Internet of Things – particularly by enabling LiFi.</li> <li>• Additionally, higher-efficiency UV LEDs can improve printing technology and manufacturing processes.</li> </ul>
Optical communication systems	<ul style="list-style-type: none"> <li>• High-capacity, low-power consumption, and low latency optical communication systems, including fibre optics and free-space technologies.</li> <li>• Further developments in optical communications, such as multi-channel LiFi, higher performance semiconductor lasers and quantum-secure communications.</li> </ul>
New optical/photonic materials	<ul style="list-style-type: none"> <li>• Better photonic materials for fibre-optic communication.</li> <li>• Improved materials to enable efficient light emissions.</li> <li>• Optical quality polymers and new glass types.</li> <li>• Novel photovoltaic materials for energy generation including hybrid materials, organic/inorganic, and artificially structured materials.</li> </ul>
Better sensors	<ul style="list-style-type: none"> <li>• High-efficiency single-photon detectors that can be used in optical circuits.</li> <li>• Better photonic materials for efficient detectors that can be used in more places and for wider applications.</li> </ul>
Lasers and imaging (focus on healthcare)	<ul style="list-style-type: none"> <li>• Treating cancers, smoothing skin, diagnosing bone disease and making precise incisions (eg in eye surgery).</li> <li>• Photodynamic therapy using light-activated medicines to destroy cancer cells.</li> </ul>
Photonics for manufacturing efficiency	<ul style="list-style-type: none"> <li>• Precision measurement to increase manufacturing efficiency.</li> <li>• Laser-based additive manufacturing.</li> <li>• Short pulse materials processing.</li> <li>• Surface processing/modification. Laser processing of carbon-fibre composites.</li> </ul>

# Mapping the grand challenges to photonics enablers



## PHOTONICS SOLUTIONS

Prosthetics to augment human capabilities: light sensors to sense muscle contractions, developing optical polymers and biocompatible materials, artificial retinas	Light-triggered drug release, phototherapy and laser therapy are all novel techniques that use light to directly treat or aid in the treatment of a range of conditions
Development of novel healthcare treatments based on photonics	Instant, high-sensitivity chemical and biological analysis can be achieved by mounting tiny sensors to specialist optical fibres. Drug pharmacology and pharmacokinetics (how molecules behave in the body) can also be enhanced by photonics techniques that visualise real-time behaviours of drug molecules in the body
Rapid, early, non-invasive clinical diagnosis and treatment using <i>in vivo</i> techniques, which don't require samples to be extracted from the body. Greater exploitation of spectrometry for diagnosis, eg fluorescent emission from tissue irradiated with UV light can be used to locate tumours	Lasers in surgery (eg eyesight corrections) can be developed to target organs with minimal down time. Radiotherapy for cancer treatment can be made more available with the development of laser accelerators, resulting in much smaller equipment compared to traditional synchrotron techniques
Cheap mobile devices depend on developments in photonic materials and sensors that can replace expensive materials, eg copper, and reduce breakages and power consumption	Free-space optics communication (using the infrared spectrum), and LIFI (visible spectrum) allows wireless communication at a higher rate and with very low error rates
Internet of Things increases competition for bandwidth; Wi-Fi has a limited bandwidth and so alternatives are required. Developments in faster and more accurate communications depend on developments in fibre optics as well as free space optical communication and LIFI	Photonics sensors are paramount in the Internet of Things. New technologies, from driverless cars to smart cities, will depend on cheap, reliable, low-power solutions to measure light, heat, biometrics and more
Optical computing opens massive capabilities in deep learning, an AI process that requires huge amounts of processing power – similar to that of a supercomputer	Optical chips take advantage of quantum behaviour of photons to complete calculations much faster than traditional transistor chips, meaning that more calculations can be done in a shorter time and allowing AI technologies to become more ubiquitous and responsive
Communications via optical fibres is more energy efficient than traditional methods, further developments are allowing further reductions in energy losses	
Development of advanced photovoltaic materials, eg III-V semiconductors, to harness energy from the Sun, thereby reducing carbon emissions	Concentrator technology (harnessing optical techniques such as lenses) can be used to focus sunlight and thereby reduce the required surface area of a solar panel, allowing solar power to be used in a wider range of applications
Multimodal sensors combining sensing techniques and multi/hyperspectral imaging required for autonomous vehicles. Rain and Sun sensors using photodiodes to detect and respond to changing conditions	LIDAR (or laser scanning) systems that allow automated vehicles to generate pictures of their surroundings that are much more accurate than radar, and more reliable than cameras in poor light
Connected vehicles require high data transfer to enhance navigation, eg using realtime data to avoid traffic jams	Harnessing ambient Wi-Fi signals to improve responsiveness, eg finding free parking spaces
UV-LEDs for printing and manufacturing improvements, eg using UV inks that contain photoinitiators (chemicals that react with certain wavelengths of UV light), resulting in practically instant curing	Safety and quality assurance in a globalised food-supply chain can be supported by advanced imaging techniques and spectral analysis techniques
Effective usage of UV-LEDs to purify water by using strong short-wavelength (250–280 nm) radiation to destroy micro-organisms in water	Moving away from UV mercury lamps towards UV-LEDs allows better point of use water-purification systems that could be made widely available in the developing world
Circadian lighting harnesses LED lighting to replicate the natural daylight patterns in indoor environments; this can help reduce mistakes and increase productivity	Advances in laser photochemistry would allow further access to new synthetic chemicals, and is less wasteful than traditional methods. 3D printing also requires further development of lasers for heating and precision machining
Optical and atomic clocks, optical metrology and high-precision spectroscopy can be used to greatly reduce waste and contamination	New and portable generation of frequency combs (eg crystal fibre frequency combs), which allow development of optical clocks and precision measurement techniques

# Quick wins and long-term gains

## ENABLERS

## PRIORITIES

### Short-term

System-level integration



Improving system performance: smaller, cheaper, lighter, and energy efficient

Dealing with rare materials: how to reduce, re-use and recycle

Better LEDs



Material innovation and device development

Business funding for LED systems innovation

Optical communication systems



New methods for amplification

Novel data-transmission medium

New optical materials



Polymers and biocompatible materials

Sensors



Fundamental research: increase the speed with which the sensor collects signal and delivers it to computer

Bio-imaging: Increase efficiency of data storage and processing for volume of data collected

Lasers and imaging (focus on health care)



Approval of existing technologies and methods

Photonics for manufacturing



Review of how photonics pilot lines have improved efficiencies

Research into processing of novel materials for manufacturing

**PRIORITIES**

**Medium-term**

Overcoming limitations such as switching speeds, bulk optics and coatings, and wavelength constraints

Reducing losses in energy when converting electrons to photons or *vice versa*

Improving performance and system standards

Further materials characterisation and development of new substrates

Non-linear physics harnessed in optical communications

Multicore/few-mode fibres

Materials for energy generation and photovoltaics

High throughput and computer-assisted materials discovery

Broader wavelength sensitivity eg 0.4 x 5 micrometres in one array

Low-cost reliability and "plug and use" devices

Improved laser proton acceleration: higher energy, better beam profile and focussing, sufficient flux

Industrial development of laser accelerator to improve reliability and safety

Better understanding of failure mechanisms and failure analysis

Developing machine-defined processes: research into how AI can be harnessed to build self-optimising machines

**PRIORITIES**

**Long-term**

Universal integration frameworks and best practice adopted internationally

Intelligent lighting systems and advanced data applications

Single-photon communications components. Ultra-low-loss hollow-core fibres, and quantum networks

Scalable, advanced (eg nano) manufacturing. Multimode amplifiers, and multi-channel transceivers

Research into theory and simulation techniques to create virtual prototypes. Imaging sensors on flexible substrates

Better understanding of biological cells and molecules using photonic technologies

Agreed strategy for photonics in manufacturing. Adoption of lasers in production line becomes the standard

## Closing remarks

The roadmapping outputs show that photonics is a highly diverse sector, with technologies and enablers that cut across all of the grand challenges set out in the UK Government's Industrial Strategy. Furthermore, these outputs represent the tip of the iceberg.

We have explored examples of specific solutions that could lead to major developments in our health, communication, mobility, safety, growth and productivity – but these are not a complete or definitive list. Detailed roadmaps could be produced for each of the enabling technologies shown here, such that the full value of the photonics industry, as well as the specific requirements and challenges for each enabler, can be understood within the photonics community and beyond.

This bird's-eye view demonstrates that if we are to find solutions to the grand challenges we face, we are no doubt reliant on the continued advancement of photonics research and innovation in the UK.



### Healthcare enabled by photonics

Ophthalmic surgery as it is known today would be unthinkable without existing laser sources. Lasers are used for treating skin conditions, including some forms of skin cancer; another promising application is *in vitro* diagnostics, where a laser may be used to illuminate blood, urine or tissue samples to provide early diagnoses. Suitably designed 3D printers could find a large market for a growing human population in search of bespoke devices and prosthetics, such as teeth replacements and hearing aids.

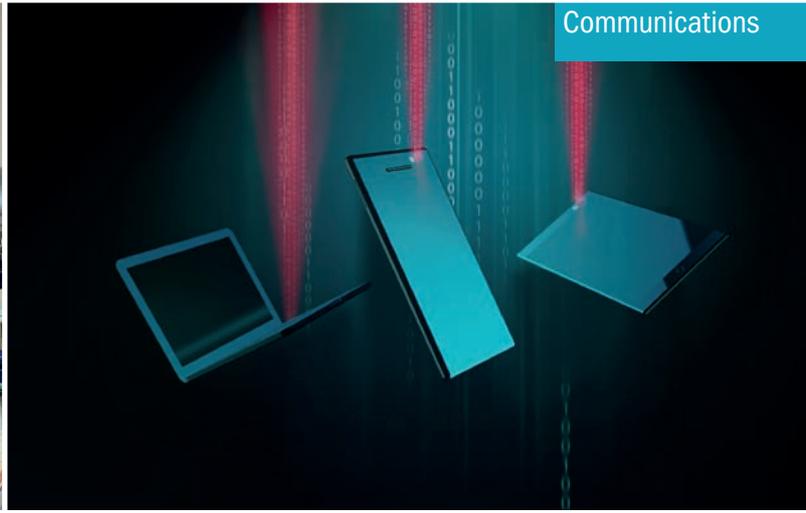
- *Read the full case study on p32*

# INDUSTRY CASE STUDIES

Aerospace



Communications



Defence



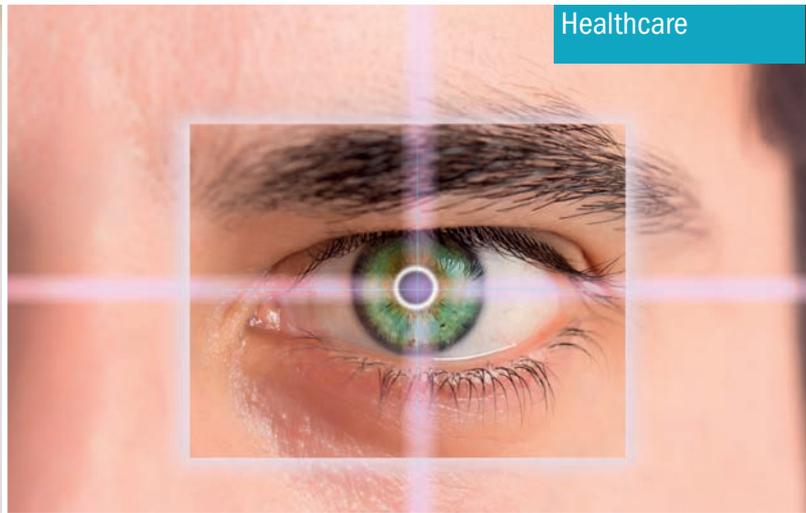
Energy



Food



Healthcare



Lighting



Manufacturing





## CASE STUDY AEROSPACE

Conversation with **Javad Anzalchi**, Advanced Payloads Product Manager (Space Systems), Airbus

In the aerospace sector, photonics is yet to show its full potential. In the case of satellites for communications, for example, the current technology is based on a portion of the electromagnetic spectrum restricted to microwave and radio frequencies. “At the moment, not many components have been used in space,” comments Javad Anzalchi. However, the sector must now face a significant challenge: if the total channel capacity for a spacecraft used in communications is around 100 Gbit/s, this value will need to increase by one order of magnitude, that is, to about 1 Tbit/s, in the early 2020s. Even if microwave and radio-frequency technology could meet this target, it would most probably fail to satisfy the requirements in terms of footprint and payload. Anzalchi supports this argument with numbers: 1 m of coaxial cable weighs 100 g, whereas the same length of fibre optic cable weighs only 2 g. Mass is a crucial parameter in this sector, as each kilogram sent to space costs about \$25,000 (approximately £18,500).

Optical fibres are a simple example of a photonic technology with promising applications to the aerospace industry. At the moment, Anzalchi’s attention is directed to integrated photonics: if a laser source, a modulator and other crucial parts within a satellite could all fit within an area of  $6 \times 2$  mm (as opposed to the current footprint, which has the area of an A5 paper sheet), payload constraints would cease to be an issue. In this view, a radio-frequency signal sent to a satellite in space would

be transmitted to a low-noise amplifier via an antenna and subsequently converted into the optical frequency domain for further processing.

Integrated photonics would not be limited in its application to satellite communications. Another example could be synthetic-aperture radar technology for the observation of our planet’s landscapes. The signals are already processed optically on board the satellite, but the problem is that optical signals do not fare well in the transmission through the clouds. If this issue was resolved, the whole system would then be optical, making it faster and potentially more accurate – as in the case of global position systems, to cite yet another potential area of application for photonics.

Once the toolbox of integrated photonics steps out of the research laboratory, the main priority for companies such as Airbus is to contribute actively to raising the technology readiness level for applications to a space environment. This step will then be followed by vibration testing, thermal-vacuum testing and radiation testing by Airbus. In the same way as the collaborations with research centres and individual scientists are of paramount importance, in Anzalchi’s view, it is also necessary to build up a reliable network of suppliers for photonic technology with applications to the aerospace industry – the latter being an aspect on which he is currently working.

When asked about the challenges faced by his sector,

Anzalchi does point out that their end customers tend to be “very conservative”. They are so for a very good reason: a telecommunication satellite must work for 15 years flawlessly, which is a long time in a harsh environment. Nevertheless, he now finds that his customers start to embrace change and new technologies, as the limit with the current solutions and the need for higher channel capacity are all too evident.

Companies such as Airbus do not exclusively collaborate with research centres and universities. They also value the knowledge exchange that takes place with intermediaries such as Innovate UK and Catapult Centres. Anzalchi finds it helpful to share their roadmaps

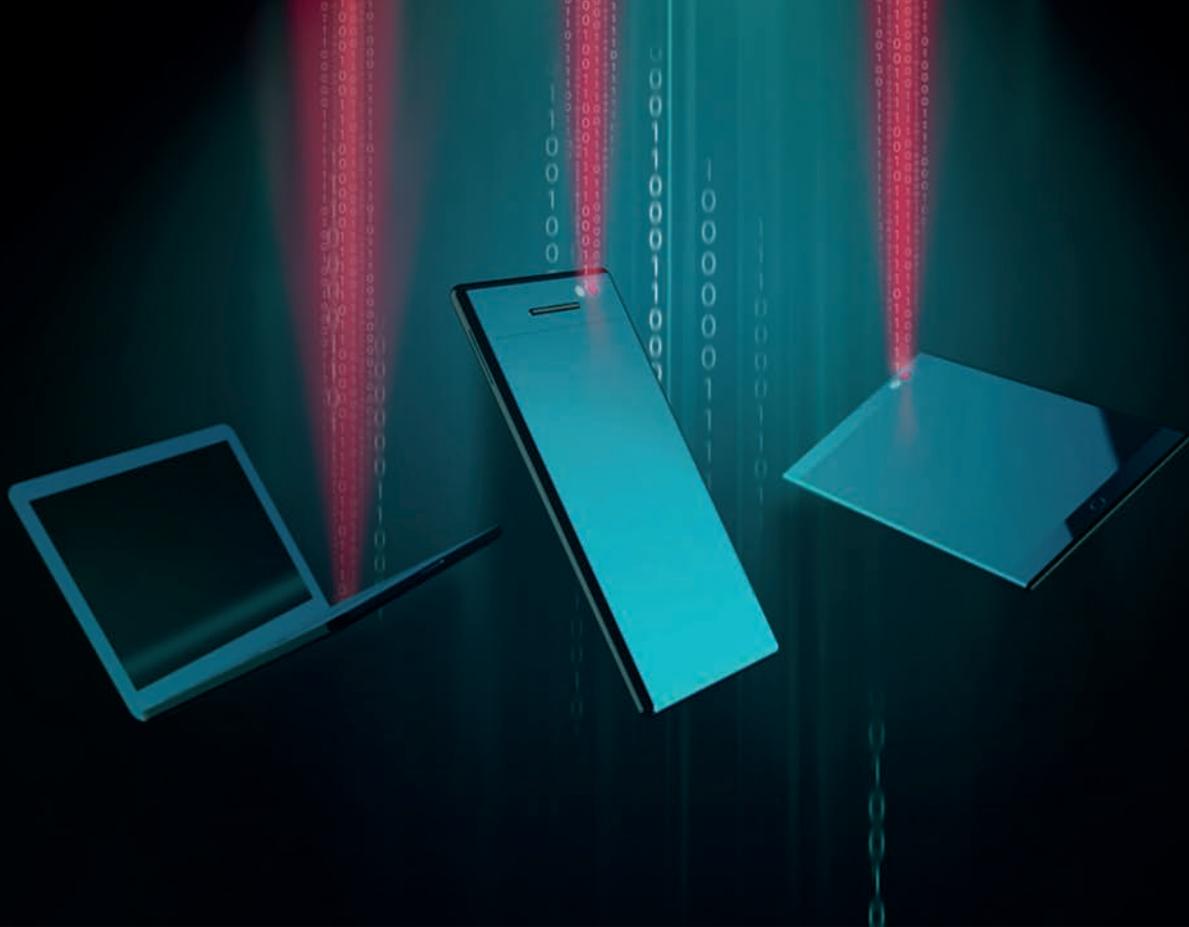
with these organisations, as these can help companies identify their priorities over time.

While the importance of physicists is indisputable, it is Anzalchi’s view that the methods of teaching – particularly in higher education – could change in order to encourage broader views and foster more cross-disciplinary exchanges, for example by informing physics students of the scientific and technological challenges present in several industry sectors – challenges that they might one day find themselves tackling.

Anzalchi believes in the importance and reach of photonic technologies, and for this reason he hopes that this area will receive continued support in the UK.



**Javad Anzalchi** is a senior manager within the Advanced Payloads Development Department at Airbus Defence and Space. He is involved in the systems engineering and development of new technologies and techniques for fixed, broadcast and broadband satellite communications. He has worked on a number of European Space Agency and European Commission studies related to future advanced high-capacity and reconfigurable telecommunication satellites. In recent years, he has been working on the introduction of photonics technology in telecommunication satellites and other space applications.



## CASE STUDY COMMUNICATIONS

Conversations with **Alistair Banham**, Chief Executive Officer, and **Professor Harald Haas**, Chief Scientific Officer and Co-Founder, pureLiFi

Our world is increasingly interconnected digitally. Not only has there been a proliferation of mobile devices, but our TVs, headphones and even fridges are now making use of wireless connections.

This level of connectivity provides us with greater convenience, efficiency, or entertainment, but comes at a cost – spectrum crunch.

Consider places such as airports or stadiums, with potentially thousands of people trying to make calls, send messages, or post video to their social media profiles – all at the same time. It becomes very difficult, sometimes impossible, to simultaneously transmit all of that data over the narrow radio frequency (RF) spectrum currently used for wireless communications – a digital bottleneck.

And this will only get worse. As more and more devices are wirelessly connected, and more and more traffic is multimedia or augmented reality, and the number of users of such devices goes up, the demand for bandwidth increases exponentially. Traffic increases at around 60% per year – meaning that by the year 2025 RF will be unable to support the demand for wireless data.

“We see a good opportunity for LiFi to future-proof our digital economy”, says Alistair Banham of pureLiFi, which was founded in 2012 as a spinout company from the University of Edinburgh, where the research behind their pioneering technology had been going on since 2008.

“The solution to that problem is light.”

That solution is premised around using light rather than radio waves to transmit data – similarly to in a fibre-optic cable. “Imagine you take away the fibre and have the data in the air,” Prof. Harald Haas, explains. “LiFi augments wireless with Light communication.”

LiFi has been made possible by what Haas described as the “blue LED revolution” – the invention and commercialisation over the past couple of decades of blue LEDs, which enabled the creation of white LED light.

Three Japanese physicists, Isamu Akasaki, Hiroshi Amano and Shuji Nakamura were awarded the 2014 Nobel Prize in Physics for inventing blue LEDs, but the strength of the photonics industry in the UK has provided “great opportunities” for commercialising this kind of technology. pureLiFi’s aim is to allow every LED light source to send and receive data.

As well as helping to avoid spectrum crunch, LiFi has several further advantages over traditional wireless communications. Where WiFi has security vulnerabilities, LiFi inherits the security of fibre optics, making it “by miles more secure and provides greater data density than existing radio technology”. Access points can be placed much closer together – if they’re under different lamps, they’re not stealing data from one another. And the rate of data transfer that is achievable is unprecedented.

“This could unlock the Internet of Things quite easily,” say Banham and Haas, envisioning the smart home, city and environment. “Because we have this bandwidth we can build this infrastructure.” Haas sees LiFi as paving the way for a “fourth industrial revolution” of a data-centred economy. “A whole new industry will be born from the lighting industry looking for new revenue streams.”

Central to this will be collaboration and applying new discoveries made from blue-sky research. “We’re always looking for the next technology that will drive us towards these unprecedented speeds. We always want to work with

new ideas – bridging that into the commercial world is what we’ve been doing for the past 20 years.”

For now, pureLiFi are working towards miniaturisation, and envisage that their innovation will be integrated into everyday devices and become a commonplace complement to existing WiFi technology. “We’re not here to replace RF technology. We’re here to be complementary and additive.”

This would come at little cost to the consumer – but be of huge value to the economy. “Without it, the whole communications sector would be in trouble. This is the light at the end of the tunnel.”

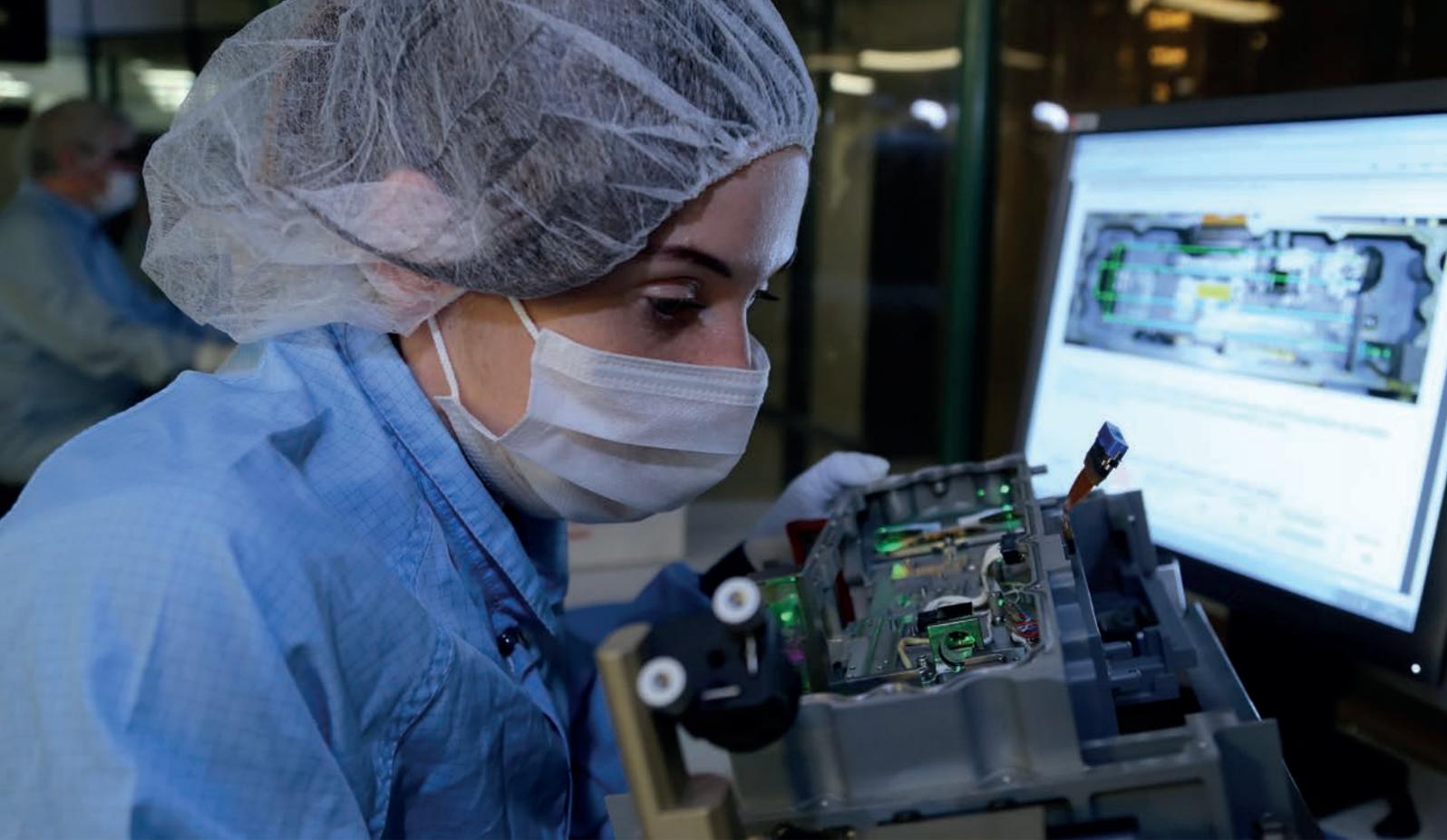


**Alistair Banham** CEO of pureLiFi, has more than 30 years leading international business units in the semiconductor industry. He has previously held senior VP roles at Wolfson Microelectronics where he was responsible for product innovation and focussed on engaging with tier 1 global accounts and at Philips Semiconductors. He has worked around the world driving innovation in semiconductor industries from California to Asia.



**Harald Haas** received his doctorate from the University of Edinburgh in 2001. His main research interests are in optical wireless communications, hybrid optical wireless and RF communications, spatial modulation, and interference coordination in wireless networks. His work has been cited more than 21,000 times. He has published more than 400 conference and journal papers including a paper in *Science*. He has won numerous prestigious awards and accolades, including LiFi being listed among the 50 best inventions in *TIME Magazine* 2011. Most recently, he was elected as a

Fellow of the Royal Society and a Fellow of the IEEE in 2017.



## CASE STUDY DEFENCE

Conversation with **Allan Colquhoun**, University Liaison and Emerging Technologies Manager (Airborne & Space Systems Division), Leonardo

In the defence sector, a technological shift that could be compared to the migration from incandescent bulbs towards light-emitting diodes (commonly known as LEDs) is the one that led from lamp-pumped laser systems to diode-pumped devices. In the former case, lasing is achieved by pumping a suitable active medium with a gas discharge lamp (or, more rarely, a tungsten-halogen lamp) – as in the first experimental demonstration of a laser by T H Maiman. Lamp-pumped laser sources are advantageous in terms of achievable pump power and price (per Watt) of generated pump power, but notable drawbacks are the difficulty to reduce their size (because of the powerful cooling systems) and the impossibility to use some solid-state active media for lasing.

Allan Colquhoun explains that diode-pumped lasers came with a whole suite of benefits such as reduced size and weight, reliability and lifetime of the system. These aspects are particularly relevant when one considers that laser sources find defence applications such as range finding and designation, sometimes aboard military aircraft.

In Colquhoun's view, the mid-infrared operating wavelength range is an aspect that would benefit from further photonics research. As an example, he cites infrared-based countermeasure systems that protect aircrafts from heat-seeking missiles. A suitable infrared laser source can produce a signal that confuses the

missile, but this application necessitates high powers and efficient systems. Colquhoun also wonders whether novel engineered materials might prove helpful in this area. At the moment, Leonardo uses periodically poled lithium niobate – described as a rude metamaterial – as an efficient medium for wavelength conversion. Materials with suitably designed sub-wavelength features could be very interesting for reducing the number and the size of optical elements in a given photonic system.

Another area of importance to the defence sector is that of sensing devices, either active (in the case of laser-based measurements) or passive (that is, relying on uncontrolled illumination). Once again, the portability of a sensor is key: Colquhoun refers to detectors that operate at the single-photon level as a promising avenue, yet he also stresses that the challenge with these systems is to design them in a way that makes them practical – avoiding the need for operation at cryogenic temperatures, notably.

Variable-light sensing, which includes sensing at the single-photon level, is an example of a photonic quantum technology; atomic clocks are another research area with a potentially high impact on defence. Nevertheless, Colquhoun notes that it does not always seem an appropriate choice of terminology to refer to quantum technologies as entirely new and disruptive solutions – especially given that quantum devices have existed

for some time now, as in the case of superconducting quantum interference devices.

Colquhoun is equally cautious about the impact that photonic computing might have on his sector. He indicates the fundamental issue is not with the optical fibre in the ground, but rather at the two ends: in a communication scenario, the nodes are likely to be more vulnerable (and, consequently, less secure) than the channel. Eventually, he expects protocols such as quantum key distribution to be more relevant to the finance sector.

A peculiarity of the defence sector is the need for a precise definition of the system under consideration. There is the need for “systems thinking”, of which drones are an interesting example. “Drone” may only describe the

flying device for some, but it actually includes many more components – such as the satellite that ensures the data exchange. In this view, a crucial challenge in defence is system-level integration. It is Colquhoun’s view that the complexity of systems can result in unreliable devices overall, even if each sub-system works as it should.

In the same way as a system will often be composed of many elements, which all need to be successfully integrated, a project in the defence sector typically requires physicists as well as mechanical and electronic engineers. Colquhoun explains that physicists make up 10–20% of a team. But they represent a crucial element of the sector and one that can be difficult to find in the light of an increased demand and a limited supply.



After nine years at the University of Strathclyde as an undergraduate, postgraduate and postdoctoral fellow focussing on precision measurement using superconducting devices, **Allan Colquhoun** joined what was Ferranti in Edinburgh in 1985 where he worked in design engineering, project management, marketing and strategy roles in fields as diverse as laser scanning, inertial navigation systems and electro-optic targeting systems, before becoming the University Liaison and Emerging Technologies Manager in 2007.

Over the last 20 years, he has contributed to the wider community in many roles. He has been involved with the Scottish Optoelectronics Association (SOA) as chair and council member since its creation. He is currently the Chair of Technology Scotland, the representative body for the high-tech sector in Scotland. He recognised the skills gap many years ago and has worked with many organisations to increase the quantity and quality of the STEM workforce. Previously, he has sat on the Institute of Physics Business and Innovation Board and IOP Scotland Committee, and is currently a member of the IOP Business and Innovation Group. He is a member of the Royal Society of Edinburgh Business and Innovation Forum. He is also an IOP Fellow.



## CASE STUDY ENERGY

Conversation with **Henry Snaith**, co-founder and Chief Scientific Officer, Oxford Photovoltaic

In the energy sector, photovoltaics (PV) is an area that successfully combines materials science, chemistry and physics – the latter including photonic aspects such as the study of ways to ensure optimal coupling of the incident light to a solar cell. It is Henry Snaith's observation that the PV industry is 90–95% dominated by silicon. About 10 years ago, thin-film solar cells based on cadmium telluride or on copper indium gallium diselenide (CIGS) generated considerable interest as they promised to be less expensive solutions at the manufacturing stage. However, two main factors slowed down the progress of thin-film technology. Snaith explains that one was the continuous drive down in the costs of silicon through scaled manufacturing, which outpaced the development of CIGS. Moreover, the efficiency of solar cells based on multi-crystalline silicon improved from 10–15% to 21% within the last 10 years, in part also to improve light coupling with the silicon. Indeed, a textured optical structure at the front face of the silicon layer and an additional anti-reflection coating can effectively contribute to minimising the amount of light reflected off the solar cell.

Snaith was one of the first scientists to put forward perovskites – which, broadly speaking, identify materials with a specific crystal structure – as valid candidates for solar technology. Consequently, he advocates for the replacement of all silicon PV with perovskite and thin-film solar cells (or a combination of these approaches), which may boost even further the achievable efficiencies

as well as offer more lightweight, cheaper solutions. Nevertheless, Snaith is aware that there are approximately 15–20 significant cell manufacturers in the world and only a fifth of those have significant R&D effort with the others focusing on manufacturing reliable products. Snaith's company, a startup that has recently made plans for starting a pilot production facility in Germany, is interested in setting up partnerships with established companies willing to take on the challenge, and the potential reward of developing new technology. At the same time, Snaith admits that a more realistic way into the market of PV is improving the current existing silicon-based industry – which leads to tandem solar cells where a perovskite layer is added to the traditional silicon layer, for example.

Tandem cells are promising because they make it possible to extract more energy from the incident sunlight: high-energy photons are absorbed in the perovskite layer at the front, whereas infrared photons go through to the silicon. A tandem cell is also referred to as a two-junction cell, and this logic may be scaled up further to three or more junctions. Photonics is expected to play a crucial role in the design of these junctions, as the materials between the cells and on either side of the tandem structure must have the right electronic properties – for extracting charge from incident photons – together with the perfect optical behaviour in order to ensure light transmission. Snaith believes that there is at least a decade of further

improvements required on the relatively simple perovskite-on-silicon tandem cells, indicating that there are many aspects in need of further basic research. While this observation might seem discouraging, Snaith also believes that there is a whole range of markets that could be enabled by perovskite and thin-film technology, and which will be more difficult to access with crystalline silicon.

A challenge that must be taken seriously by those who work on new solar technology competing with all-silicon systems is that of stability and making sure that modules can last 25 years in the field. This critical aspect might by itself slow down the rate of adoption much more than the capability of alternatives such as tandem cells. This is because those manufacturing and deploying solar technology will ask for a significant amount of real-world data before venturing away from silicon modules; that said, stakeholders might be more inclined to take on risk if new PV materials enabled electricity production at significantly reduced costs. The industry is very competitive, and Snaith thinks that in this case, it would be difficult for silicon to compete with cheaper alternative solutions.

In this evolving landscape, Snaith stresses that materials such as perovskites have only been known as useful for PV for about five years – a rather short time. He thus believes that further understanding and improvement will be gained through basic research in materials science and chemistry, for instance. He believes that the headroom for further innovation to drive up the efficiency of modules based on new materials is massive. Similarly, Snaith is somewhat optimistic about the environmental impact of solar cells based on perovskites. His company has been evaluating the issue of using lead in perovskite. Even though the amount used is very small, soldering the metallic contacts on the modules introduces larger amounts of lead, which

is nonetheless still required to get the best adhesion. In his view, a sensible goal may not be to avoid dangerous materials altogether, but rather to make sure that these are used responsibly and that appropriate recycling policies exist ensuring that such substances do not go into landfill.

When asked about actions in support of the energy sector, Snaith points out that research funding is absolutely critical – and will be even more so now that the UK is leaving the European Union. He believes that it will be at an increased cost for the government to keep the same level of R&D and that “the loss for research, technology and innovation in the UK will be much greater if national funding initiatives prove unable to match the considerable research income received through European grants today. Snaith believes that eventually, PV will be the main power source throughout the world, whether it takes 10 or 30 years. For this reason, Snaith believes that the importance of governmental investments into R&D should not be underestimated.

Drawing from his experience with Oxford PV, Snaith also recalls the difficulties encountered when the company was looking for a facility to begin their pilot-scale development. He feels that the speed “from the people that we interacted with in terms of the possibility of either setting up a new facility or adapting current facilities was very slow in the UK – eventually leading the company to set up their pilot production in Germany. He thinks there is an apathy from those who are directly responsible for trying to grow new technology companies and manufacturing in the UK. From an industrial perspective, Snaith further observes that the UK still seems to perceive PV as a technology mostly aimed at domestic use, whereas it is a large export industry.” In this sense, he believes that governmental support to the growth of PV throughout the full supply chain will pay back multiple times.



**Henry Snaith** leads the Photovoltaics and Optoelectronics Device Group at the University of Oxford and is the co-founder and Chief Scientific Officer of Oxford PV Ltd, found in 2010, to commercialise the photovoltaic research from his Oxford research group. He undertook his PhD in organic photovoltaics at the University of Cambridge. Following his PhD, Snaith spent two years at the École Polytechnique Fédérale de Lausanne (EPFL) as a post-doc, where his research focused on developing the technology behind and understanding of the operation of solid-state dye-sensitised solar cells. In 2012, Snaith was awarded the Paterson Medal and Prize by the Institute of Physics for his important contributions to the field of excitonic solar cells. The following year, his discovery of high-efficiency metal halide perovskite photovoltaics was recognised as one of the top breakthroughs of 2013 by *Science*. In 2013, *Nature* named Snaith for its list of 10 people who mattered, in recognition of his work on next-generation solar-power technology and was one of the youngest ever elected Fellow of The Royal Society in 2015. In 2017, he was named as a Clarivate Citation Laureate, for the “discovery and application of perovskite materials to achieve efficient energy conversion”. Recently, he has received the UK Blavatnik Awards Laureate in physical sciences.



## CASE STUDY FOOD

Conversation with **John Bows**, R&D Director, PepsiCo

Many packaged foods and snacks are studied through techniques such as infrared tomography and X-ray imaging before reaching the supermarket. John Bows considers infrared tomography to be a consistent research tool to quantify the surface temperature of a product heated in a microwave field. This surface temperature distribution often indicates how uniform the internal temperature distribution is, particularly to identify where the coldest regions may be located, which is typically not the geometric centre as in conduction-limited heating. Similarly, infrared sensors can detect moisture content in snack foods (such as potato chips), and can do so in-line for direct quality assurance and process control. Thinking of the visible portion of the electromagnetic spectrum, Bows notes that his company has recently installed a vision-inspection system responsible for the detection of colour defects in whole potatoes – an operation that will reduce costs and improve in-bag chip quality by rejecting unsuitable potatoes before they are even processed. Independently of the steps that precede processing and packaging, X-ray imaging of the finished food portions follows for metal detection.

While he does not think that traditional food safety systems (which are currently in place for the detection of food allergens and other potentially dangerous substances) will be replaced with photonic-based techniques in the near future, Bows observes that there

is ample room for innovation in non-traditional food processing such as microwave heating and for microwave packaging. At the moment, it is considered best practice for any product that is ready for the home microwave that contains meat to have already received a heat preservation treatment: this is because it would not be safe to rely on the thermal kill achieved by a standard microwave oven due to their inherently non-uniform heating and considerable oven-to-oven variability. The quality of these foods could change significantly if they were closer to fresh, explains Bows. For this to happen, there would need to be a way to confirm that a minimum temperature was reached inside a packaged food when heat preserved by non-conduction limited heating technology, thanks to a non-invasive, remote sensor operating in-line. If the minimum temperature is known, then it is possible to prove to regulators that a validated thermal process can be achieved on packaged food that is close to fresh. Unfortunately, this technology is not available at the moment. For this reason, he thinks that temperature validation in non-traditional food preservation systems is an area that would benefit from further research, including inputs from the photonics sector.

In the food industry, physics is quite possibly the least represented of all the sciences, according to Bows. Indeed, he is the only physicist in PepsiCo's R&D in Europe. However, the role of physics in the food industry should not

be underestimated. Partnering with physics departments is critical for the type of exploratory R&D work that big food organisations can afford to undertake, observes Bows. In fact, PepsiCo is presently collaborating with the Lawrence Berkeley National Laboratory in the US to perform three-dimensional real-time imaging of the microstructure evolution of a snack food portion in a microwave field thanks to the facility's X-ray source.

Equally important is the role of intermediary organisations: R&D departments can be relatively small compared to a company's size in this sector, and the company may not wish to incorporate much expertise internally. Consequently, being able to collaborate with centres of excellence, universities and intermediaries becomes crucial.

Bows is committed to reaching out to the physics

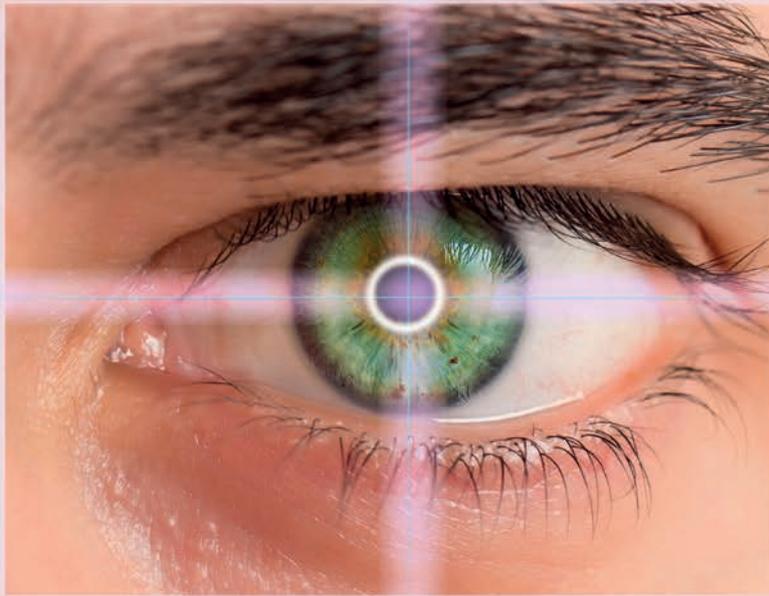
community, making physicists more aware of the great challenges found in the food sector. For this reason, he co-created the Physics in Food Manufacturing special interest group at the IOP, which was inaugurated in May 2017. He hopes to succeed in engaging the physics community and discussing the industry's pre-competitive innovation challenges. Specifically, Bows stresses how photonics underpins much of the equipment used in the food sector. It would then seem reasonable to expect further innovations to stem from this research area, yet progress might be hampered in the absence of a robust connection with the photonics research community. Bows sees the key to increasing the visibility of the photonics sector in food manufacturing challenges to be encouraging more cross-sector discussions and ultimately more engagement.



**John Bows** is an R&D Director within PepsiCo's Global R&D Snacks, investigating new process technologies to innovate new and healthy snacks.

John was elected to the PepsiCo Global R&D Fellow programme in 2016, with a research focus on coupling soft-matter physics to field physics to unlock new insights for snacks innovation.

John received a BSc (Hons) physics from the University of Exeter, and was elected a Fellow of the IOP in 2002. Prior to joining PepsiCo in 2005, John was a Research Scientist at Unilever R&D in the UK and the Netherlands, working on process, technology and packaging innovation across food categories.



## CASE STUDY HEALTHCARE

Conversation with **Simon Andrews**, Executive Director, Fraunhofer UK Research

The impact of photonic technologies on the health sector seems difficult to foresee, in some cases. Simon Andrews notes that there have been some false steps. This is partly because equipment that people predicted would be replaced by lasers, such as scalpels, simply weren't. This is essentially because there is nothing wrong with scalpels and there isn't the demand amongst the labour force to change the tools. Conversely, there exist areas where photonics research makes a significant difference: eye surgery – treating tears in the retina, for instance – is one such example that Andrews would consider to be groundbreaking. Indeed, ophthalmic surgery as it is known today would be unthinkable without existing laser sources. Lasers are used for treating skin conditions, including some forms of skin cancer; another promising application is *in vitro* diagnostics, where a laser may be used to illuminate blood, urine or tissue samples to provide early diagnoses. Andrews also mentions 3D printing, which is also based on laser systems, suggesting that suitably designed 3D printers could find a large market for a growing human population in search of bespoke devices and prosthetics, such as teeth replacements and hearing aids.

Andrews suspects that an inefficient approach to innovation in the world of medical devices and lasers has hampered results. He feels a more tailored approach to a specific problem would have been more beneficial.

A distinct trend in the area of photonics for medical

diagnostics is the increased interest in the ability to perform a selection of tests and monitoring activities autonomously – putting patients in charge of their own health, in some ways. As Andrews notes, it is already possible to buy a range of tests from high-street chemists – glucose-monitoring devices being one example. In this context, smartphones could represent a versatile platform for non-invasive diagnostics. Smartphones have very powerful computer processors, illumination sources and a camera. Andrews believes that with additional optics and test kits, it may become possible to perform a variety of colorimetric tests, for instance. As additional supporting evidence, Andrews remarks that basic ophthalmoscopes based on smartphones already exist.

The transition from using a smartphone to measure a physiological parameter to relying on an under-the-skin device communicating with a smart watch (the latter being an example of so-called “wearables”) is less far-fetched than it might seem at first sight. From adapted smartphones to wearable devices, Andrews stresses that these markets are large and some of the photonic challenges are moderate, not radical. The specifications would need to be altered, not designed from scratch.

Applications such as wearables and prosthetics hinge on optical sensing and imaging capabilities. Therefore, research progress in these areas might generate further capabilities to be later transferred to the health-industry

sector. Artificial retinæ are presently studied by research groups worldwide; optogenetics, which uses lasers or light-emitting diodes to stimulate or suppress the firing of neurons, could lead to a better understanding of the brain and, perhaps, facilitate the development of brain interfaces. Optical sensing counts an additional application to pharmacology, where it has an edge with respect to other technologies given that its mode of operation is both non-destructive and remote. Being able to analyse the content of pharmaceutical products optically, for example, could prove very useful in fighting counterfeits.

While he recognises that his view is inevitably biased, Andrews notes that the importance of research and

technology organisations such as Fraunhofer is to help the “jump” that some ideas and innovations must achieve to leave universities and reach out to industry. Specific to the healthcare sector is the need for funding at the interface between the physical and life sciences, according to Andrews. There are multiple different funding bodies such as the Engineering and Physical Sciences Research Council and the Biotechnology and Biological Sciences Research Council. Some topics would fall within the purview of several of these bodies and would require significant cross discipline collaboration. In this landscape, cross-disciplinary approaches should be granted opportunities for funding.



**Simon Andrews** is a graduate in laser physics and optoelectronics from the University of Strathclyde. Over 13 years, he built a career in industrial R&D with a range of roles from design and production engineering to R&D, operations and product management, often in start-up, spin-out and high-growth companies.

He has taken a wide range of medical devices from concept to market, through design, production, clinical trials, regulatory approval, marketing and user-training (including cervical cancer screening, heart valves, blood flow monitoring, medical laser and microwave devices). Having enjoyed working with universities while in industry, he moved to the Institute of Photonics to a varied business role for the next seven years. He brings experience in financial, marketing, commercial, legal and intellectual property matters to Fraunhofer. He holds three patents and is a chartered engineer, EUR ING, chartered physicist and Fellow of the IOP.

Simon has been employed by Fraunhofer UK since the company formed in 2012 and in January 2014 was appointed Executive Director. He is also a non-executive director of AIRTO (Association for Innovation, Research and Technology Organisations) Ltd and Technology Scotland Ltd.



## CASE STUDY LIGHTING

Conversation with **James McKenzie**, Chief Executive Officer, PhotonStar LED group plc

Today, light-emitting diodes (LEDs) are the preferred choice in most situations where lighting is concerned – whether in an office space or for a portable torch. As James McKenzie explains, a huge leap for this lighting technology was the invention of the blue LED by I Akasaki, H Amano and S Nakamura (who were later awarded the Nobel Prize in Physics for their research). Red and green LEDs had been available for decades; when the blue LED completed the triad at the end of the 1980s, it made the generation of white light possible – opening the way to LED lighting solutions. Another important step in support of this technology was made later by the US Department of Energy, which committed to an ambitious roadmap for the development of better diodes between 2000 and 2020. The goal was to improve the efficiency of LEDs from around 30 lm/W (lm stands for lumen, the unit of luminous flux that determines the efficiency of a light source) to about 200 lm/W, while also cutting down on the costs (from \$5 to 10 cents for one LED). Amid initial scepticism over such ambitious projections, the US Department of Energy funded the development of LED technology for general lighting and in so doing, sparked the attention and, more importantly, the establishment of similar support schemes in other countries, eventually allowing LEDs to become the prominent technology that they are at the moment.

Light-emitting diodes are not only cheap and efficient – they are essentially electronic components, which is

notable because, as McKenzie observes, historically electronics and lighting couldn't be joined together. This makes them a very versatile component, and one that is rather environmentally friendly, as there are well established techniques for recycling electronics. As an additional feature, they are free of dangerous elements such as mercury. Regarding one of the most important metrics in the lighting sector, namely the efficiency of LEDs, McKenzie is of the opinion that with continuous investments and all major companies involved, it will be possible to improve this metric.

If efficiency is of paramount importance to reduce the costs of individual devices, an entirely new application is of special interest to McKenzie. He explains that developments in LED lighting allows for lighting to be better for people. LightingEurope, the industry association that represents the lighting industry in Europe, is now an active promoter of the idea of human-centric lighting, sometimes referred to as circadian lighting. According to McKenzie, for light to be kind to humans and their activities, it must be dynamic and characterised by the desired spectral content. These requirements necessitate a level of control on the light sources that is now within reach. Further, from a market perspective human centric lighting is untapped – and LED technology seems the best candidate for this particular application. Scientific studies are far from having reached full agreement on the benefits and applicability of circadian

lighting, however, and it would thus seem wise to maintain some degree of caution together with an equally justified interest. Related to human-centric lighting is the application of LED technology to horticulture and to hydroponics. Both require tunable light sources, and once again they represent valuable markets for private companies.

Thinking of a more fundamental challenge, namely that of ultraviolet (UV) LEDs, McKenzie notes that while they have huge potential, they are expensive and difficult to package because of their poor efficiency. He thinks that UV LEDs are now where blue LEDs were 10 years ago, and believes that further work on the semiconducting materials at the core of all light-emitting diodes will eventually lead to competitive devices in this region of the electromagnetic spectrum.

As in other industry sectors, the crucial role of physicists is undeniable for McKenzie. In rising areas such as that of human-centric lighting, he adds that it will become more and more important to be good communicators, as physicists will find themselves collaborating with clinicians, biologists and plant scientists.

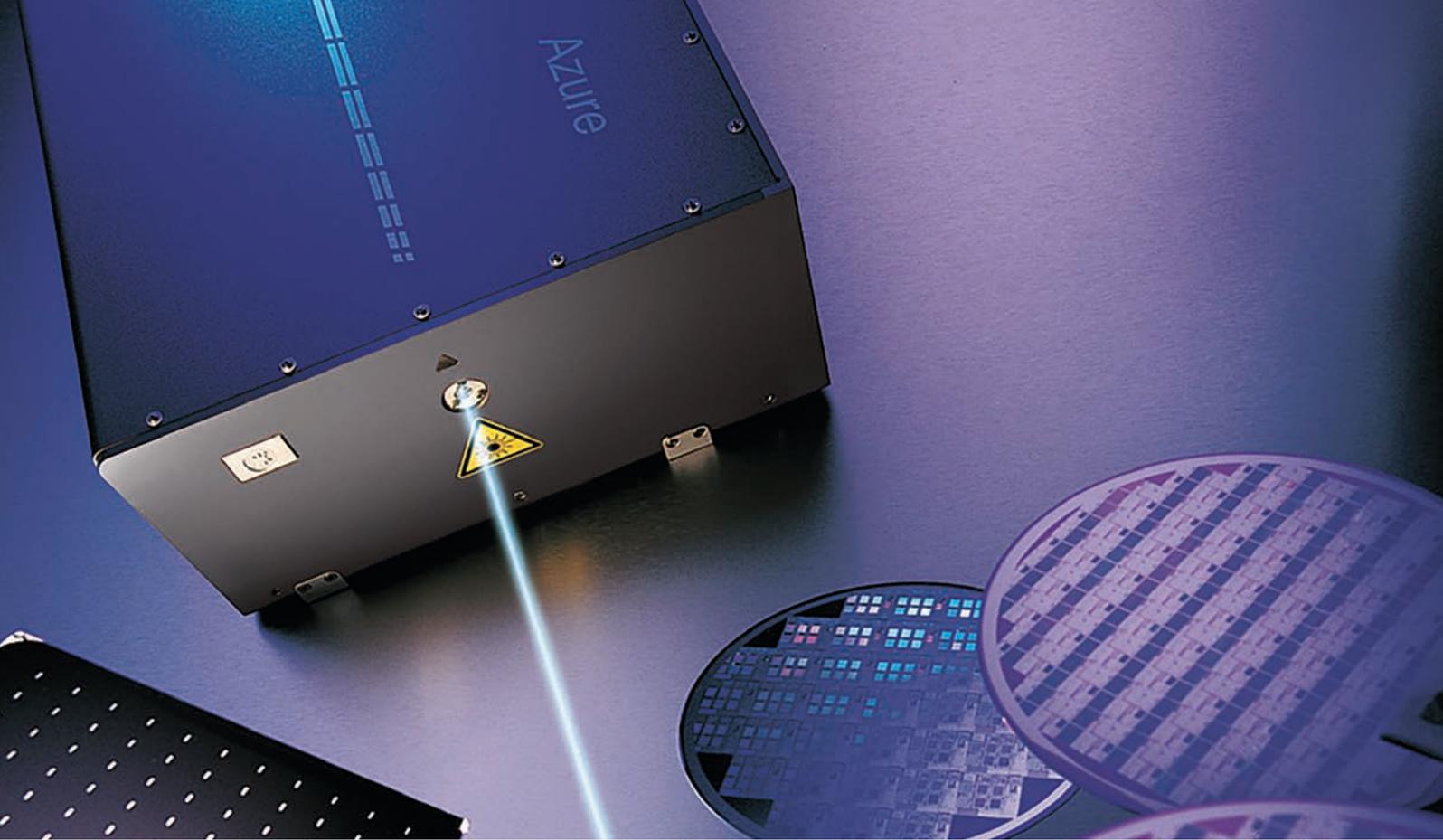
At the funding level, McKenzie would encourage practical thinking – understanding where to invest more resources and energies and where to accept that it may not be worth the effort anymore. He believes that the UK can excel at developing cross-field solutions, whereas it may be difficult to catch up with other countries on more fundamental aspects (such as the fabrication of semiconductors, for instance).



**James McKenzie** is Chief Executive of PhotonStar LED group plc – a business that he co-founded in 2007 to commercialise LED technology in LED lighting. He has been involved in bringing new technology and products to market over the last 25 years, and has held several senior management positions and leadership roles.

After studying physics at Cardiff University he went on to study control systems at the University of Sheffield and McGill University, then completed a PhD in 1993.

He was briefly a research fellow at Brunel University then joined Bookham Technology and was involved in the fast growth of the company. He became Chief Executive of Mesophonics Ltd in 2003, a venture-capital backed spin-out of the University of Southampton, where he developed two business units that were later sold. James is currently Vice-President for Business at IOP, and chairs IOP's Business, Innovation and Growth Group. He is also Fellow of the IOP.



## CASE STUDY MANUFACTURING

Conversation with **Chris Dorman**, Vice-President and General Manager, Coherent

The connection between the manufacturing sector and photonics may be analysed from two different standpoints: the first focuses on the manufacturing process that delivers cutting-edge laser technology, as is the case for the Scotland-based factory of the company Coherent. The second looks at how laser systems contribute to improving the manufacturing process in sectors including the automobile and electronics industry.

Over the past 50 years, the laser industry has grown from a “garage-based” enterprise led by a few laser physicists, to a mature professional industry with high volumes and profits. Chris Dorman notes that the photonics industry is following the same kind of trajectory as the electronics industry. To illustrate the transition witnessed in his sector, Dorman refers to the example of a particular type of laser system used for multiphoton microscopy. The latter differs from conventional confocal microscopy, which relies on a continuous-wave laser beam hitting a sample to produce two-dimensional images, because its use of pulsed light beams allows for the creation of three-dimensional images. This scheme was revolutionary for life scientists, yet the first laser sources of this kind required the presence of an expert capable of ensuring that the laser system could operate without problems. About 15 years ago, what Dorman terms “industrial laser philosophy” made it possible to build hands-free multiphoton lasers. This outcome turned these laser systems into devices that did not require expert

intervention to ensure their correct daily operation, and this enabled life scientists to carry out their research without worrying about the source’s performance. According to Dorman, his company has now sold several thousand laser systems for multiphoton microscopy – a sizeable business figure. This example highlights an aspect too often misjudged, namely that of the crucial difference between an invention and a product. In Dorman’s view, acknowledging this difference was paramount to the successful industrialisation of laser systems over the past decades.

As for the way in which laser sources contribute to manufacturing processes in various industry sectors, Dorman believes that a significant evolution in modern manufacturing was given by the adoption of ultrafast laser systems. There has been a dramatic rise in the number of ultrafast processes in modern manufacturing, especially in electronics. Most importantly, he stresses that in these sectors the critical parameters are not completely dominated by the technical specifications. Rather that these lasers are delivered quickly, in large volumes, and on time, together with the guarantee that these systems will work for a long time without the need for any maintenance or realignment.

Following the latter perspective, Dorman thinks that manufacturing is already dominated by photonic processes to a great extent. This is certainly the case in modern manufacturing, and in all sectors where miniaturisation

imposes the use of tools that can operate precisely within a small area without risks of damage to the immediate vicinity. It is thus not a surprise to find out that the semiconductor industry is now highly dependent on ultrafast laser systems, which are capable of delivering highly confined energies where they are needed for cutting or drilling, for instance.

Dorman acknowledges the paramount role of solid-state lasers, and explains that improving these systems over the years meant achieving shorter pulse durations, shorter wavelengths and higher powers. However, he believes that the performance of these systems is now such that it

can be fully exploited in the manufacturing sector, shifting the competition between companies in the laser industry to a new level – that of industrial design, reliability of the products and quick response to customers' needs.

To Dorman, a stable and continued investment in photonics teaching and research at the university level is critically important; as he notes, his business cannot thrive in the absence of knowledgeable experts. As long as he can hire well-rounded physicists, the photonics industry will follow its growth trajectory as the electronics sector did before it.



**Chris Dorman** is Vice President and General Manager at Coherent Inc a global leader in lasers and photonics components. He joined Coherent in 2002 as a Product Line Manager and has held various Business Management positions. He has an MA in Physics from Oxford University and a PhD in Lasers and Quantum Physics from Imperial College, London. He is currently Chairman of the UK Photonics Leadership Group and serves on the Technology Advisory Group of Scottish Enterprise and is a visiting professor at the Institute of Photonics, University of Strathclyde and he is a Fellow of the IOP.

# Acknowledgements

The Institute of Physics would like to thank the following people for their invaluable work on this report:

- David Binks
- Mat Wasley
- John Lincoln
- James McKenzie
- Javad Anzalchi
- Alistair Banham
- Harald Haas
- Allan Colquhoun
- Henry Snaith,
- John Bows
- Simon Andrews
- Chris Dorman

We're grateful for support from UKCPO (the UK Consortium for Photonics and Optics) and Rank Foundation, as well as the photonics community, and our members for their contributions to this report.



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