dti

PHOTONICS: A UK STRATEGY FOR SUCCESS

Painting a Bright Future

FOREWORD

by the Minister of State for Industry and the Regions

There is good reason to believe that the impact of photonics in the 21st century will be as significant as electronics was in the 20th, or steam in the 19th.

The range of products using photonics continues to grow rapidly. It includes the displays on our mobile phones, cameras and televisions; safe and sensitive sensors that are used in research, health monitoring and security systems; bright and energy-efficient lighting and energy-generating solar cells; lasers in industry; plus all the advantages of high-bandwidth communications using fibre optics. These are just some of the early applications.

Many of the advances on which photonics is based were made in this country, and our research in the field is truly world-leading. Exploiting these advances in an increasingly competitive world is challenging, but the UK must be active in the application of the technology and the manufacture of its products. We cannot compete in all areas, but the markets in which we can succeed in can have a major impact and provide immense opportunities.

The photonics community is to be applauded for working together to produce this report, giving a practical and pragmatic analysis of the opportunities and challenges facing it.

The wide-ranging consultation exercise has identified the means to ensure the effective development of photonics within the UK, with all the benefits that go with that.

The mission of my department is 'Working to create the conditions for business success and help the UK respond to the challenge of globalisation'. It could have been the sub-title to this report. We will continue to work in partnership with you.

If you are involved in photonics, congratulations are due on all that has been achieved. If you have yet to consider its possibilities, this report will – I hope – open your eyes.

Margaret Hodge MBE MP

CONTENTS

INTRODUCTION

by Ian Vance, Chairman of the Photonics Strategy Group

Over the last few years photonics has become a topic of widespread discussion amongst researchers, the media, investment communities and the general public.

Photonics is a technology that includes light emission, transmission, deflection, amplification and detection by optical components, instruments, lasers, other light sources, fibre optics, electro-optical instrumentation and sophisticated nanophotonic systems. It promises smaller, cheaper, lighter and faster components and products, with greater functionality while often using less energy.

The UK has excellent research credentials in photonics, but it lacks a coherent and co-ordinated national strategy for developing and applying the technology. To address this, a Photonics Strategy Group (PSG) was set up and, in 2005, produced an interim report reviewing the industry in the UK. This highlighted the need to investigate the UK activity in further detail and to open the consultation process to include full academic and industry participation. Only by doing this did we feel that strategic recommendations could meaningfully be made.

We chose to focus on five key sectors where the UK has significant strengths and opportunities for industrial exploitation, viz:

- Information & Communication Technologies and Consumer Photonics
- Life Sciences and Healthcare
- Defence and Security
- Lighting and Energy
- Industrial Photonics

The consultation process included a series of workshops around the UK that brought together over 160 industrialists and academics with interests in photonics. The workshops concentrated on specific sector requirements with objectives to:

- Identify potential strengths, opportunities, weaknesses and threats within the sector
- Identify recommendations to support and expand the sector
- Challenge the interim sector report by highlighting current trends within industrial and academic communities.

Themes highlighted within each workshop were then substantiated through individual interviews with key industry leaders.

This report, then, is based on an extensive consultation process with the UK photonics industry and overseen by the PSG. It examines the growth of photonics and its potential implications for the UK industry. And it includes a series of recommendations to support the industrial application of photonic technologies.

I hope you will find this an interesting document, and a valuable one. The credit goes to all who contributed (see Appendix A at www.dti.gov.uk), and to the PSG members listed at right.

Ian Vance	Amazing Communications Ltd
John Bagshaw	BAE Systems plc
Leonard Fass	GE Healthcare
Malcolm Gower	Exitech Ltd
Julian Jones	Heriot-Watt University
Alan Knapp	Formerly Philips Research
Paul May	Occuity Ltd
Drew Nelson	IQE plc
Mike Scott	Formerly Bookham Technology
Wilson Sibbett	University of St Andrews
Will Stewart	Innos Ltd

For the Department of Trade and Industry

Geoff Archenhold
Peter Batchelor
Chris Carey
Rick Donnegan
Kevin Riordan
Ian Williams

EXECUTIVE SUMMARY

Not surprisingly, a consultation exercise attracting inputs from over 160 photonics and related professionals gave rise to a large number of views and recommendations. In this summary we have attempted to give a broad consensus.

INDUSTRY SNAPSHOT

The UK's photonics industry at June 2006 can be characterised as follows:

- There are very wide applications and a strong technical raison-d'être
- The UK has extensive and, in many cases, world-class research in these fields. This research is in both academic and industrial laboratories
- Consolidation has occurred in the component supply business as a result of the reduction in telecoms spending and this has resulted in a loss of UK capability
- The components and materials layers have responded by diversifying into other sectors such as defence, medical, industrial and consumer products
- Very significant growth is expected in several markets for photonic products over the next ten years – they include Lab-on-Chip, Security, Fibre to the Premises (FTTx) and Next Generation Broadband, Displays, and High Brightness LEDs
- Many of these markets are at an early stage that would not preclude UK companies from establishing a position, but many are also large-volume markets that would require significant capital investment
- Apart from these specific markets, there is a substantial opportunity for supplying a wide range of other photonic products, but the fragmentation of UK activity may inhibit this
- The majority of UK photonics companies employ fewer than 30 people although there is a reasonable representation of companies around the 100 mark
- A significant number of commercially-successful companies that rely on photonics technology do not associate themselves with the photonics industry
- Scotland and Wales appear to be most supportive of the industry, with significant investment supporting research and companies. At present few of the English Regional Development Agencies (RDAs) recognise the importance of photonics in their strategies
- There is a need to promote the importance of patenting to academic funding bodies and to encourage them to allow patent costs to be covered by grant money

- Current moves to third-stream funding will change the way universities interact with industry – it is not clear whether this will be positive
- There appears to be no organisation collecting data on the industry.

STRATEGIC RECOMMENDATIONS

1. Establish an industry/government strategic body to act as the UK voice for photonics and to provide strategic direction to all UK photonics stakeholders

The aim is to have a single UK voice for photonics, supported by all stakeholders, and ensure that photonics is central to the UK's innovation strategy. This could take the form of a Photonics Leadership Group (PLG) working in collaboration with relevant Knowledge Transfer Networks (KTN). The PLG should seek to influence policy development at a regional, national and international level, and to promote photonics to interest groups and the public.

2. Ensure the supply of highly-skilled photonics staff

Activities should be targeted widely, including work with the Sector Skills Council for electronics (SEMTA) and other relevant bodies. Photonics-related training should be extended to include leadership, global marketing/sales and intermediate technician skills, with a variety of means of access. Partnerships with industry could help with training generally, and in improving the skills and opportunities for photonics staff through employer-led development programmes.

3. Encourage newly-formed Knowledge Transfer Networks to map UK strengths against emerging market opportunities

The fragmented nature of photonics at present is a barrier to its promotion and development. A UK photonics capability database could facilitate training provisions and supply chain linkages as well as target resources on areas of greatest potential.

4. Raise the profile and promote the depth and breadth of UK photonics excellence

A co-ordinated communications plan using all media channels should be developed to address schools, government administrations, overseas posts, regional and devolved government, industry, the finance community and the general public. A network of industry 'experts'

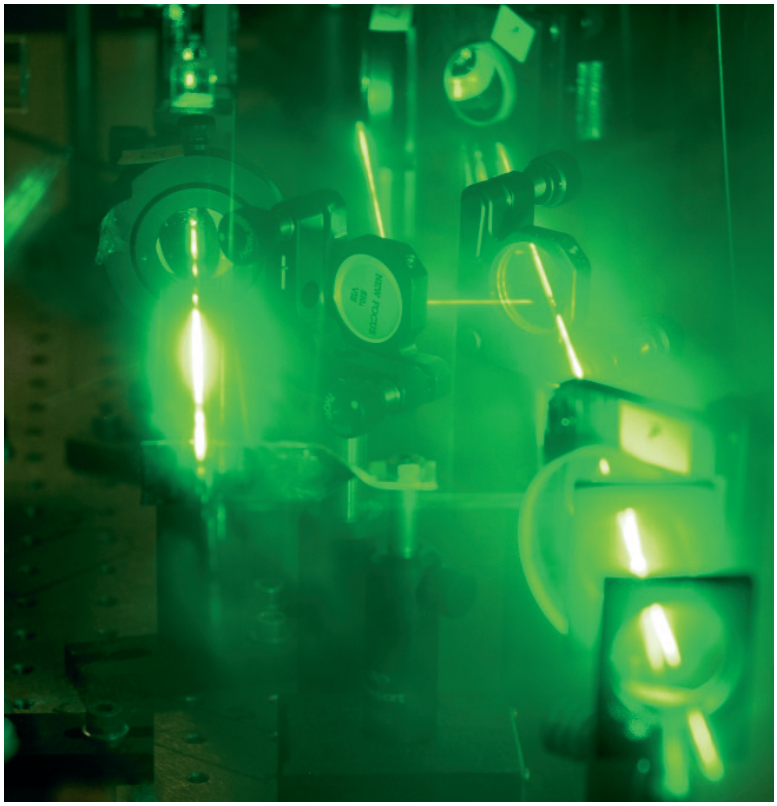
and showcase international trade and technology conferences could support the programme. This plan should address both domestic and international audiences.

5. Ensure that the UK remains an attractive location to support existing photonics activities and to attract global photonics organisations

DTI should work with UK Trade & Investment, Regional Development Agencies (RDAs) and Devolved Administrations (DAs) and other government departments to develop an attractive investment environment. These bodies will also be instrumental in harnessing public sector purchasing to drive innovation and business success, improving education and training, and reducing the taxation and bureaucratic burdens on Small and Medium sized Enterprises (SMEs) in particular.

6. Identify a series of aspirational photonic 'grand challenges' to develop innovative solutions based on future market requirements

Programmes similar to those of the US Defence Advanced Research Projects Agency should be considered, aligned to future public procurement needs in areas including healthcare, defence, public safety, environment, security and energy efficiency. The timing of these challenges could lead to suitable showcases at the London 2012 Olympics.



THE WORLD OF PHOTONICS

Photonics is about the generation, transmission, detection, manipulation and application of light and other forms of radiant energy. It is an enabling technology which extends across and impacts all industrial sectors, from healthcare to security, from manufacturing to telecommunications, from energy to the environment, and from aerospace to biotechnology.

If the 20th century was the age of the electron, many would argue that the 21st century will become dominated by the photon. Indeed, the analogy goes further with the argument that the photonics industry today is reminiscent of the fledgling microelectronics industry of the 1960s, where some of the base technologies are in place but the far-reaching impact of worldwide applications is only just beginning to be felt.

Given its pervasive nature, defining the photonics sector, like defining the electronics sector, is difficult and imprecise. This report, however, goes for the broadest definition which says it refers to 'those organisations for which the manufacture or use of photonic-enabled products is a key aspect of their business', and where photonic-enabled products are 'products that would not be possible without their photonic content'.

An example of a photonic-enabled product is the DVD player, which relies on a semiconductor laser, optical system and a photo detector as essential elements.

One of the most pervasive applications of photonics to date has been in telecommunications, where it can provide enormous traffic volumes within the Internet and other data networks coupled with high-speed switching. It is firmly established too in instruments and sensors – no interference or sparking problems - and consumer products. The US Optoelectronics Industry Development Association (OIDA) claims that over 35% of all consumer devices can be considered photonic-enabled, illustrating the extent to which the technology has already been embedded within large application-based markets[1]. The penetration of display and imaging-based products and technologies into consumer and computer markets - notably LCD TVs and camera phones – is self-evident.

Not surprisingly, the technology has spawned many new companies developing specialist applications ranging from laser components to software for managing and designing novel optical solutions.

CHARACTERISTICS – THE VALUE CHAIN

Unlike steel or coal, it isn't easy to appreciate the photonics industry. One way of representing it is as a value chain, as shown in Figure 1. As you move across and up the chain, the technologies, products and services encountered include materials and process equipment, components, modules, services, enabled products and finally end users. A full list of photonics product items is included in Appendix B at www.dti.gov.uk.

applications demand skills that cross the boundaries of many different departments in traditional universities and research institutes. For example, biophotonics is the combination of biology and photonics disciplines with areas of application covering life sciences, medicine, agriculture and the environment.

As well as being pervasive, it can also be seen that photonics is a disruptive technology. It displaces more conventional technologies and enables radically new generations of existing products and processes to

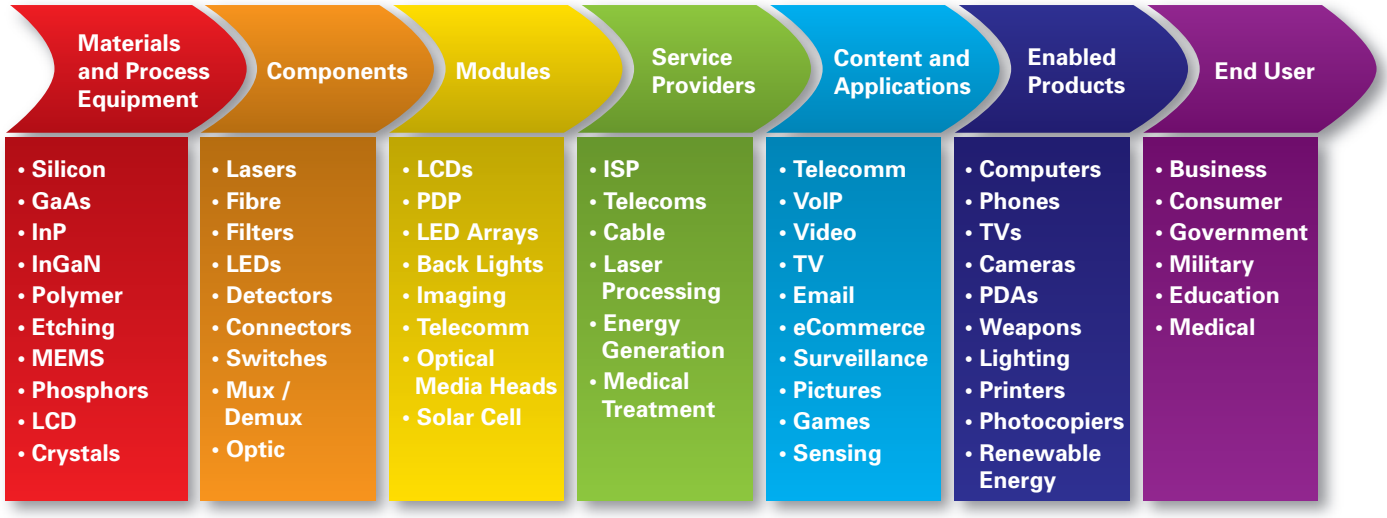


Figure 1: A detailed example of the photonics value chain

The figure illustrates that the pervasive nature of photonics depends on contributions from - amongst others - chemistry, materials science, life sciences, physics and many engineering disciplines. It is multi-disciplinary, and new

take over. For example, optical data storage, through devices such as the DVD, has changed the face of home entertainment and computing; digital cameras based on solid-state imaging sensors have all-but replaced those using photographic film.

Disruptive photonic technologies can also enable whole new classes of products and markets not previously feasible, such as portable computing, mobile phones or digital imaging. New industries and new companies grow, and existing companies can continue to compete if they take note of the new opportunities and adapt rapidly. Those companies that do not adapt, face rapid obsolescence and decline.

CHARACTERISTICS – BY APPLICATIONS

A second approach to an appreciation of photonics is to consider the applications to which it is put. These follow the five key market areas identified as being of most relevance to the UK.

1. ICT & Consumer Photonics

Displays

- Microdisplays
- Televisions 2D and 3D
- Holographic displays
- Advertising, indoor and outdoor messaging systems
- Low-power displays
- Projection and light shutters
- Low-resolution and High resolution displays

Optical Communications

- Internet: Voice over IP (VoIP), music, email, Web, eCommerce
- Fibre To The premises (FTTx): Video on Demand, VoIP, telemedicine

Optical Data Storage

- CD and DVD media recorders, and now Blu-ray
- Workstation and PC network data storage

Consumer Products

- Mobile phones: displays, cameras and LEDs
- Flat panel high definition LCD TVs: displays and backlights
- Portable music and video players: displays
- Digital camera: displays, image sensor and flash
- Entertainment: displays, data storage, communications

2. Life Sciences and Healthcare

Biophotonics

- Diagnostics: non invasive imaging
- Treatment: laser surgery (cutting, drilling), Photodynamic Therapy (PDT)
- Pathogen detection: Raman spectroscopy
- Drug development
- Biometrics

Instrumentation

- Microscopy (confocal, FLM etc)
- Endoscopy
- Genomics/proteomics
- Biosensors: Pulse Oximetry
- Cellular and Clinical imaging: OCT, 4D studies, Tomography

3. Defence and Security

Command, Control, Communications Computers and Intelligence

- Secure communications: Quantum computing and Quantum Cryptography
- Optical fibre: RF signal processing and transmission

Surveillance, Targeting Acquisition and Reconnaissance

- Visual sights, periscopes
- Displays
- Lasers: range finding, laser imaging, systems
- Remote sensing: typically employing multi-spectral techniques or passive IR sensors
- Forward Looking Infra-red Imaging (thermal)
- Perimeter security: IR sensors, image processing, optical sensors
- Checkpoint/Port/Airport security: Terahertz imaging, Raman spectroscopy and image processing
- Target imaging and identification
- Unmanned Aerial Vehicles (UAV)
- Electro-optical countermeasures
- Sensing: Chemical & biohazard, structural health monitoring, optical strain imaging, embedded NDE

4. Lighting and Energy

Solid State Lighting

- Architectural, amenity, egress, signage, messaging systems, signal, commercial and residential lighting: Organic Light Emitting Diodes, Inorganic Light Emitting Diodes

Photovoltaics

- Solar cells

Sensing for Process Optimisation

Fuel Analysis

Energy Infrastructure Security

5. Industrial Photonics

Lasers

- Cutting, welding, drilling and marking
- Micromachining
- Non-contact metrology and reverse engineering
- Material processing including surface hardening
- Scanning and positioning

Sensing

- Structural health monitoring
- Security and intrusion
- Chemical agents
- Biological agents
- Smart industrial and power utility monitoring
- Biophotonic/medical applications
- Positioning and control
- Traffic monitoring

Imaging

- Quality control and inspection
- Automated recognition
- Thermal imaging
- Security certification
- Document scanning

CHARACTERISTICS - BY COMPONENTS

A final overview of the photonics industry can be given by reference to its components. Broadly, all photonics enabled products are made from a combination of one or more basic components and the OIDA[2] has attempted to classify them as follows:

1. **Light Emitting Devices**
2. **Photodetectors**
3. **Subsystem Modules**
4. **Display Devices**
5. **Photovoltaic Cells**
6. **Optical Fibre and Cable**
7. **Connectors and Hardware**
8. **Passive Optical Devices**
9. **Storage Media**
10. **Other Optical Components, including sensor devices and lab-on-chip**

Putting together the two ways of categorising photonics above maps technologies to applications and gives rise to Figure 2.

Figure 2: Photonics is a pervasive discipline whose technologies enable new applications and markets

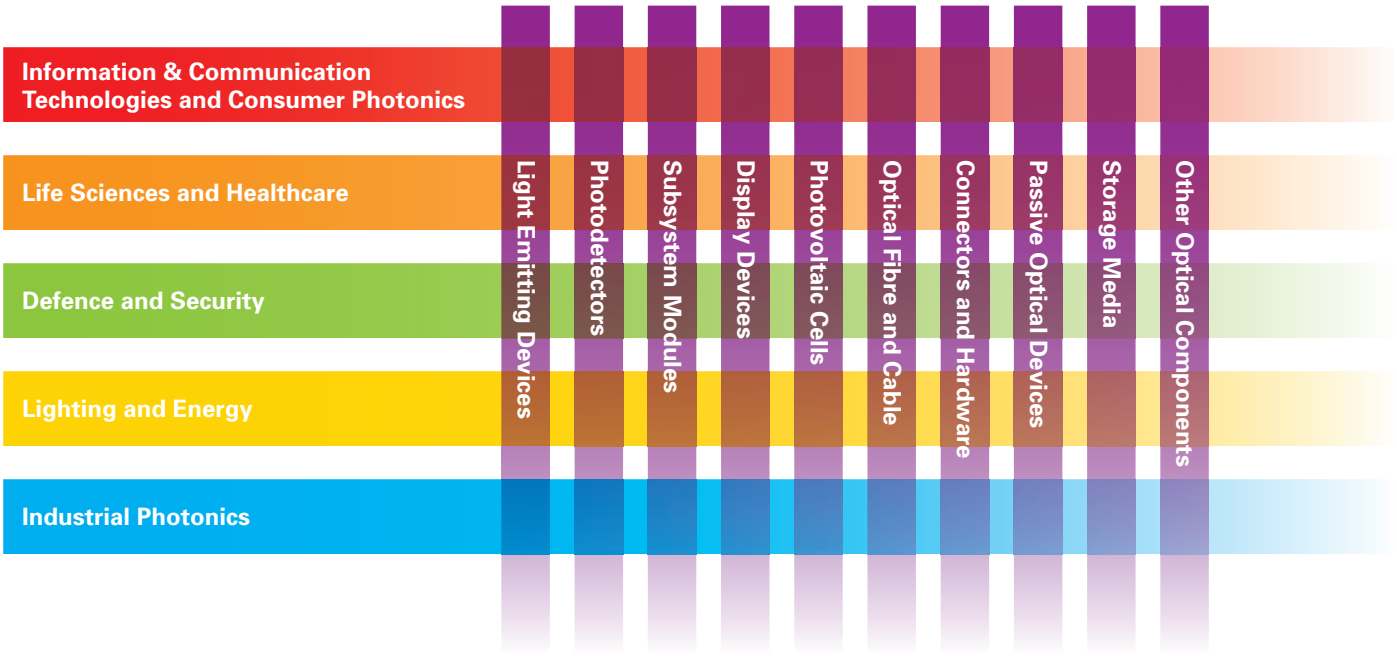
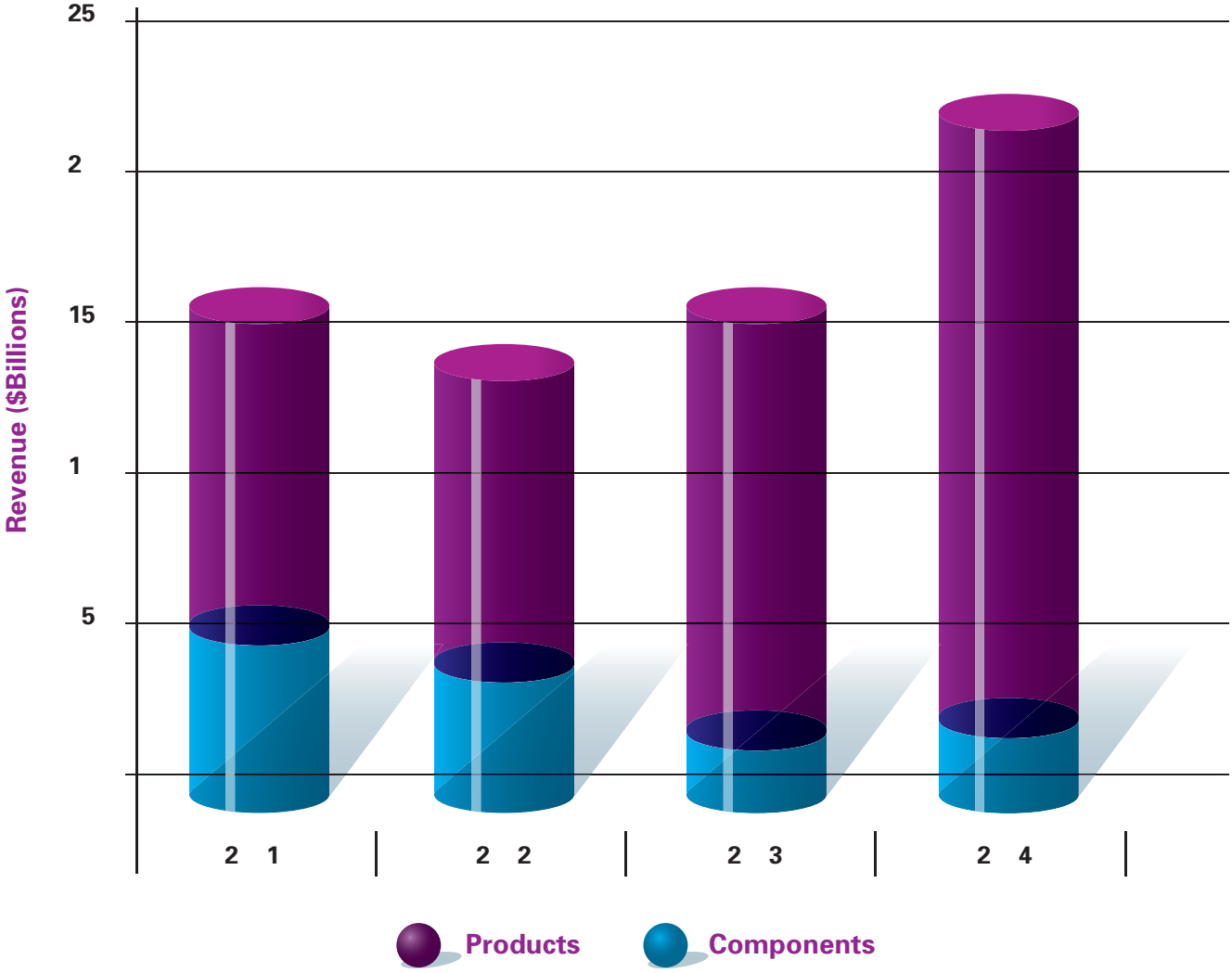


Figure 3: Worldwide Market Revenue for Photonic Components and Enabled Products
Source: OITDA[3]



A BIG BUSINESS

Photonics and photonic components lie at the heart of many modern products, where they typically represent between 5-20% of the cost of the product. For example, the massive growth in consumer products such as mobile phones is dependent upon photonics.

The world market for photonics grew by more than 39% in 2004 to $236 billion, as shown in Figure 3, with contributions from photonic components growth of 17% and photonic-enabled product growth of 42%. The pyramid of value shown in Figure 4 demonstrates that photonics enabled products now represent nearly 20% by value of the electronic equipment sector. It has been estimated by the Optoelectronics Industry Technology & Development Association (OITDA) of Japan that the photonics market will be worth close to 1 trillion US dollars by 2015[3].

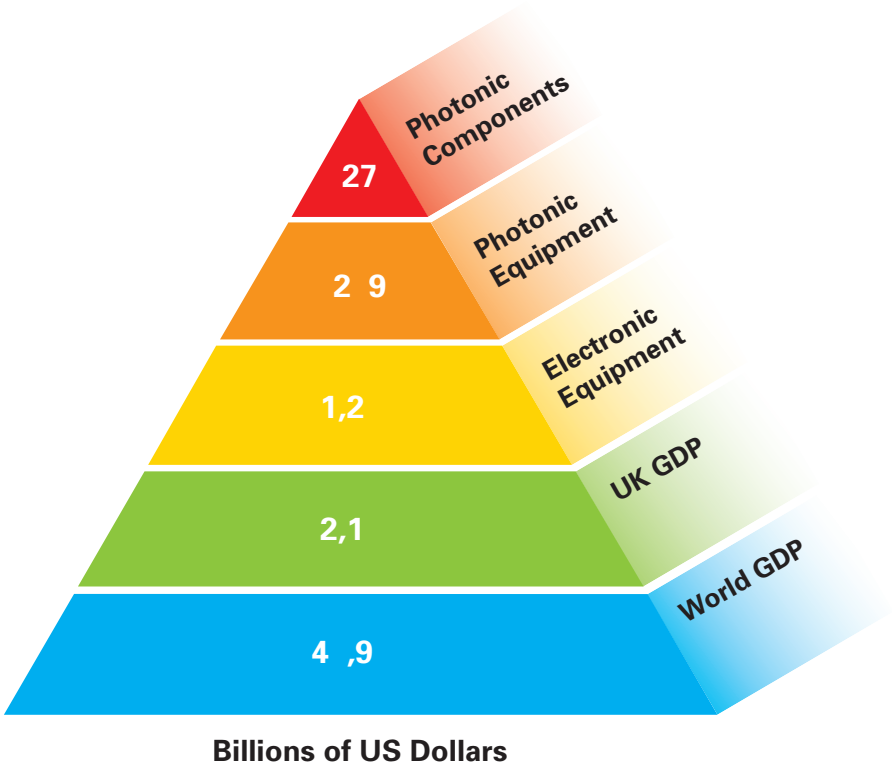


Figure 4: The Pyramid of Value, 2004 Figures
(Photonic Components Exclude Flat Panel Displays)

AN INTERNATIONAL BUSINESS

The potential for photonics is recognised around the world, with government support for R&D evident in many countries. For example, in 2004 the Ministry of Science and Technology in South Korea invested more than 30% of its annual R&D budget to electronics and photonics - around £4.5 billion[4]. The European Union allocated a significant proportion of the €3.6 billion under the Information Society Technologies topic to photonics in the Framework 6 Programme (FP6) over the period 2002 to 2006, and has, in December 2005, launched a technology platform dedicated to photonics, Photonics 21. This will help build consensus and drive forward a coherent European research and deployment strategy in the photonics sector.

The European Photonics21 platform categorises photonics into five broad subcategories as follows[5]:

- Information, Communication and Imaging
- Lighting and Displays
- Manufacturing and Quality
- Life Science and Healthcare
- Safety & Security

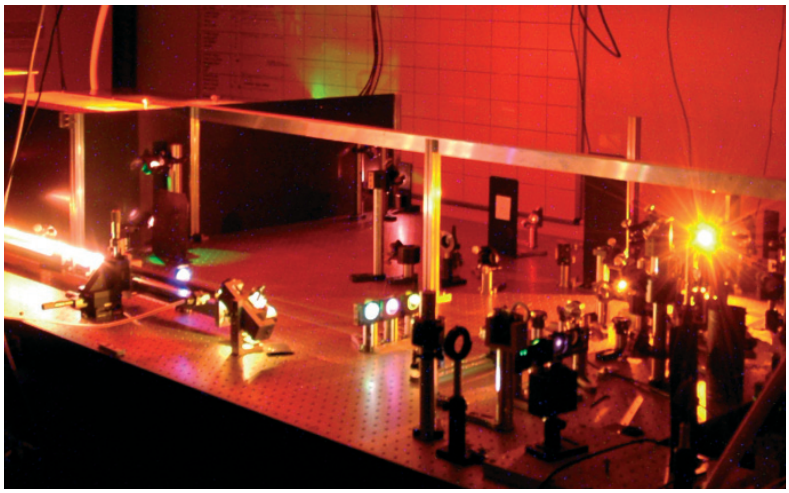
These compare closely with the areas identified as key for the UK in this report (ICT and Consumer Photonics, Lighting and Energy, Industrial Photonics, Life Sciences and Healthcare; Defence and Security).

PHOTONICS IN THE UK

For more than forty years the UK has been among the world's leaders in photonics. With innovations in fibre, lasers, materials, semiconductor growth technologies and optical amplifiers, and advances in manufacturing methods, equipment and complete systems, a widespread base of research, development and manufacture was developed. By the late 1990s this had reached critical mass, with most substantial international players having some presence in the UK and a large number of start-ups and smaller companies providing specialised services and products.

Today, the UK photonics industry can be characterised by a substantial level of activity spread across multiple research, application and manufacturing areas. The balance of activity has moved from having a large telecommunications component to something much broader. It should be noted that the UK has fared no worse than other western countries in this field since the start of the telecommunications down-turn in 2000. Indeed, the UK has continued to compete strongly in the global market. Specific examples of this are Bookham Technology which has been aggressively leading the consolidation in optical components, and IQE which has established itself as a global player in the supply of wafers. Several companies have also emerged as leaders in new fields, for example Micro Emissive Displays in microdisplays, and Teraview, in terahertz imaging. It is estimated that the turnover of photonics related businesses in the UK now exceeds £20 billion

A shake-out of the many start-ups that originated during the 'dot com' boom is still continuing, but academic activity within photonics appears to have increased during the same period. This largely represents the widening scope for applications of photonics in new fields such as biophotonics, laser processing and nanophotonics.



Factors such as the fragmented nature of the UK industry, the increasingly multidisciplinary nature of the subject and the difficulties in facilitating technology transfer from academia to business will continue to challenge the industrial awareness, support and exploitation of photonics.

A great concern is that the UK photonics industry is seen as a largely invisible asset – with no significant presence or recognition – by government, the public, general industry or other key movers.

COMPANY PROFILE

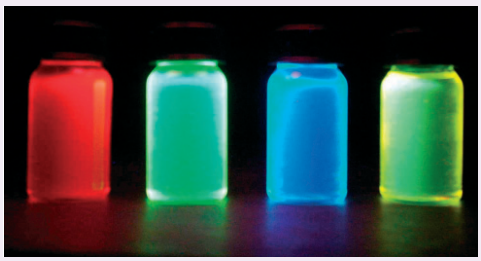
Cambridge Display Technology Ltd

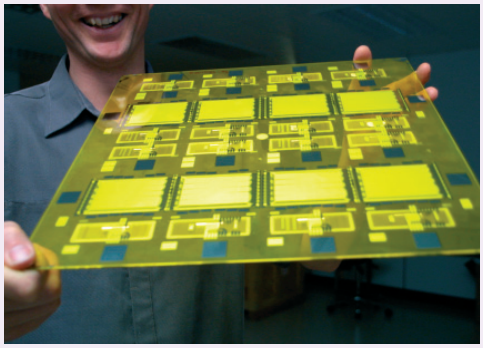
www.cdtltd.co.uk

Cambridge Display Technology (CDT) engages in the research, development, and commercialisation of polymer organic light emitting diodes (P-OLEDs) for use in flat panel displays, lighting and other applications. P-OLEDs have a number of advantages over other display types, including a very thin form factor, low power consumption, high contrast, very fast response and a wide viewing angle. P-OLED technology also has the potential to form displays on plastic substrates.

P-OLED devices are based on organic electroluminescence from certain polymers, a phenomenon discovered in 1989 by a team at Cambridge University. CDT was founded in 1992.

P-OLED technology is already used in various consumer and industrial applications such as mobile phones, electric shavers, MP3 players and medical devices. A number of printing technologies - notably inkjet printing - can be used to manufacture P-OLED display devices, and CDT offers Litrex printers, along with know-how in inkjet printing methodology. It has a joint venture to develop, manufacture, and sell polymer OLED materials. And it has co-operated in the development of roll printing for P-OLED displays.



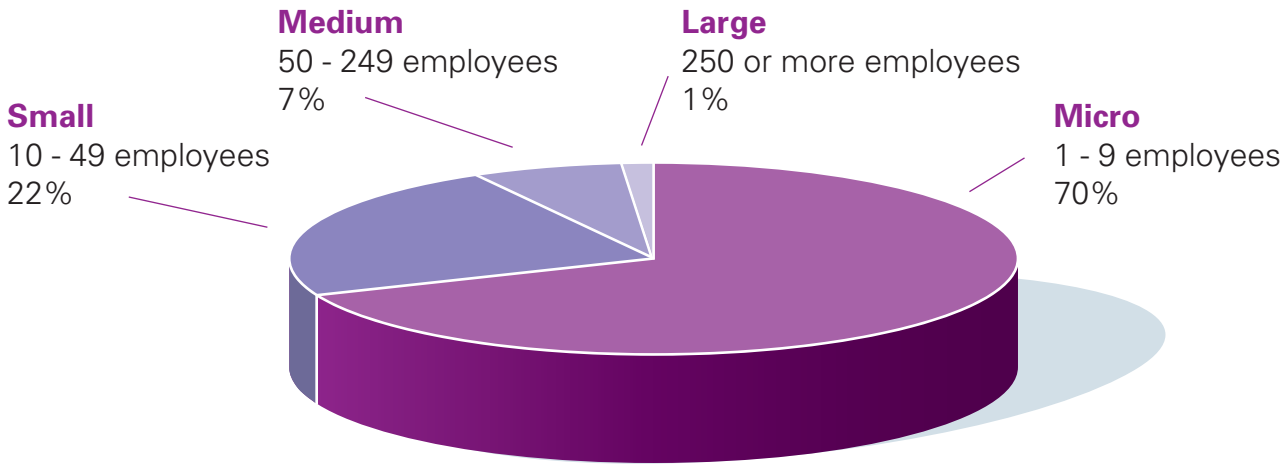


The industry is exceptionally proud of its world-class achievements and confident about its technical capabilities, but there is a lack of confidence about its ability to exploit that capability. As with any key technology, photonics is blessed with almost endless opportunities encompassing all high-growth sectors. Unfortunately, significant and wide-scale success has remained elusive - most notably due to the lack of a coherent UK strategy and a scattergun approach (too many opportunities without focussing on a selected few) to sub-sector technologies.

SMALLER BUSINESSES

The UK photonics industry has relatively few large companies and many small and micro-sized organisations. It is difficult to determine the number and nature of photonics companies within the UK, but analysis suggests that there are of the order of 1,500[6] to 3,400 companies, and that fewer than 1% have more than 250 employees, whilst 92% have fewer than 50. Although only 8% of the total are medium and large companies, they employ 76% of the workforce and generate 81% of the wealth. Firms with more than 1,000 employees are mostly non-UK owned.

Figure 5: The percentage of UK photonics companies by employee number



Due to the large number of small companies, photonic developments in the UK tend to be carried out in isolation with little evidence that companies collaborate on innovative product development. It has been

COMPANY PROFILE

Andor Technology plc

www.andor-tech.com

Andor Technology, a spin-out of Queen's University, Belfast, has been developing digital imaging solutions for the scientific research and instrumentation communities for almost 20 years. The sensitivity, speed and resolution of its camera solutions has made it possible to study structures at an atomic level across the spectrum of light from X-Ray to infrared, and to be able to detect signals in extremely light-starved conditions.

In 2001 Andor launched the first commercially-available Electron Multiplying Charged Coupled Device (EMCCD) camera, the Andor iXon. The iXon has detection limits as low as single photons, and allows applications such as single molecule detection, calcium flux microscopy, detection of weak expression in DNA chips, and weak luminescence detection. EMCCD technology combines sensitivity with speed. Upgraded in 2006 to the iXon+, the camera is a significant technology development in the scientific imaging market.

found historically that, where networking activities are higher (for example, more R&D with other businesses or universities), the potential for knowledge transfer tends to increase innovation and the exploitation of the technology base.

BEST-OF-BREED TECHNOLOGIES

In spite of the large number of SMEs, the majority of UK photonics companies operate across international markets, reflecting the quality of their products and relevance to their markets. Some examples are given in the company profiles throughout this section.

UK ACADEMIC RESEARCH

Research activity in UK universities has been a major source of innovation in photonics, even though there was a marked decrease in the number of full-time equivalent staff within Higher Education Institutions (HEI) during 2004. However, there are numerous groups across the UK engaged in photonics-related work. They are listed at C at www.dti.gov.uk

Data for actual photonics-related activity levels in universities is difficult to determine due to the extensive overlaps between disciplines. The sum of grants (typically 3 year) funded by the Engineering and Physical Sciences Research Council (EPSRC) is shown in Figure 6 for the classical photonics fields of:

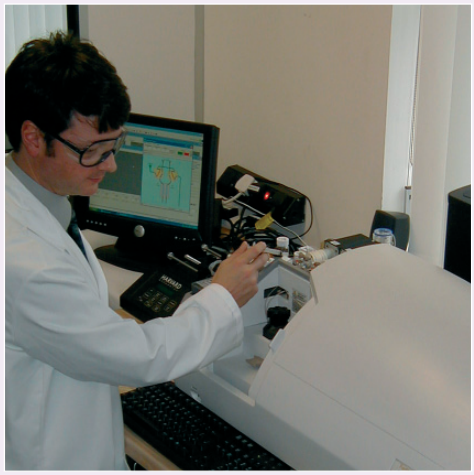
- Lasers and laser systems
- Optical communications
- Optical devices and optical subsystems
- Applied optics
- Biophotonics
- Optical storage
- Photovoltaics.

It should be noted that, while the Engineering & Physical Sciences Research Council (EPSRC) is historically the relevant research council, increasingly photonics is seen in other councils' work, eg the Biotechnology & Biological Reasearch Council (BBSRC) in medical and biological fields.

COMPANY PROFILE

Farfield Scientific Ltd

www.farfield-scientific.com



Farfield has developed a new range of biophotonic instruments to measure molecules on a glass surface with the nanometer-level precision only previously possible with big physics accelerators. Life scientists and pharmaceutical researchers can now 'visualise' molecules that change shape as they are stimulated by pH, ions or other molecules.

Farfield's nano-photonic technology is helping researchers understand diseases such as Alzheimer's, nvCJD, cancer, HIV, and a host of other cardiovascular or inflammatory disorders. Equally importantly, it is helping to search for their cures.

The company was a spin-out from the University of Durham.

The novel photonics technology employed has been adapted for other uses such as measuring the wavelength of light in the telecommunications sector, and the company has grown into an established group of subsidiaries selling leading edge scientific instrumentation. The company mission is to 'illuminate the molecular world'.

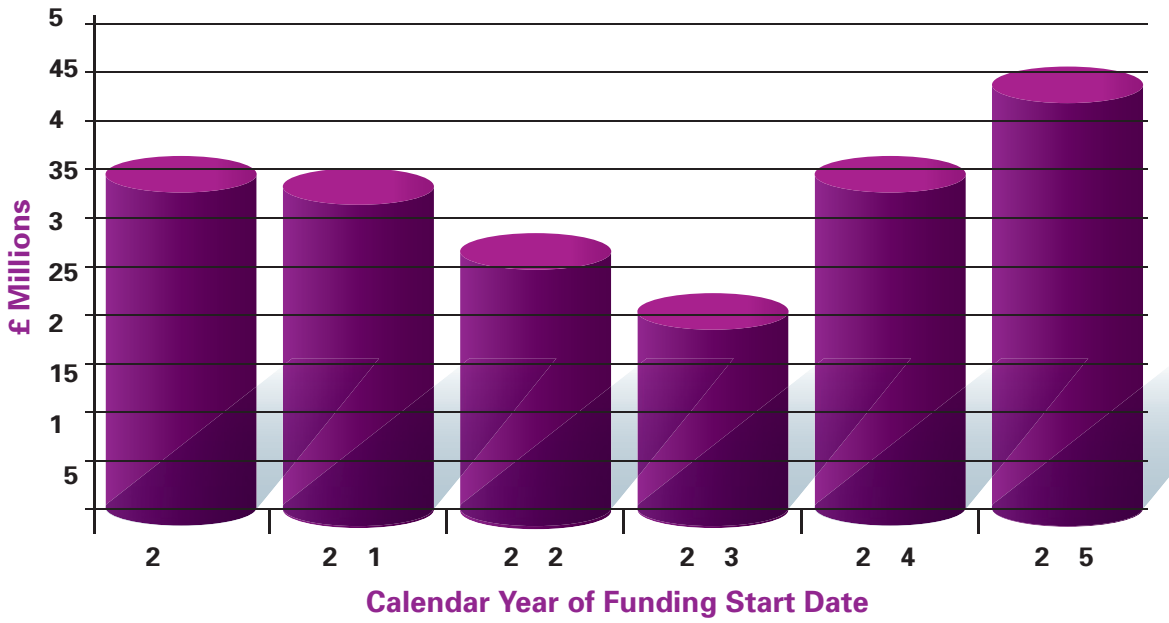


Figure 6: Total amount of EPSRC photonics related grants approved covering years 2000 to 2005. Source: EPSRC.

The increase in the level of funding during 2005 can be partly attributed to the EPSRC review of photonics in May 2005[7] which stated that there was an overwhelming case for increased expenditure on photonics research for the following reasons:

- The value of the photonics business is growing, hardware by 30 to 60% per annum
- There is strong consumer demand and industrial need for innovative developments, consequently there is great potential for 'UK Limited' to reap a very high commercial return from additional research investment
- The scientific quality of UK research is acknowledged, and the academic community is therefore able to give a good scientific return on research investment
- There is a need to encourage more fundamental research
- There is a strong industrial demand for trained manpower in the photonics area.

Recent activity in 2004 included the EPSRC BioPhotonics platform call where grants were made to three centres at Heriot-Watt, Aston and St Andrews. Also the Nano initiative has resulted in large awards, for example £11m over 5 years to Southampton for what are photonics related technologies. The University of Bath has also created a £2m nanofabrication facility. Further grants, such as the Ultrafast Photonics Consortium at St Andrews and the Innovative Manufacturing centres, contain significant photonics aspects.

COMPANY PROFILE

Enfis Ltd

www.enfis.com

The company - formed as a spin-out from Swansea University in 2001 - produces a range of multi-watt MW-LED light engines for medical, dental and illumination applications.

LEDs have become widespread in bright large area displays, mobile phone keypads and backlighting and traffic signals. The emergence of the next generation MW-LEDs is leading to their use for medical and dental applications as well as other areas.

For example, Enfis has developed a patented method for the treatment of acne by killing the bacteria present in the skin: this has been proven to work in clinical trials as a safe and effective treatment.

The company is currently developing MW-LEDs for medical lighting, dental lighting and curing, endoscopic illumination, phototherapy and photo-dynamic therapy and fluorescence diagnostics.

DTI SUPPORT FOR PHOTONICS

Government spending in the UK on photonics R&D is difficult to quantify precisely because it is spread across different departments, research councils and research programmes. However, the Technology Programme has allocated in excess of £55 million of funding for photonic-related R&D during 2004-6.

Photonics is also supported indirectly by several other government departments, but the extent of this support is difficult to quantify.

INDUSTRIAL R&D

The UK has historically had a large industrial R&D activity in photonics, based on major laboratories both UK-owned and those funded by inward investment. These also formed the base for much industrial collaboration with the universities.

However, the last five years have seen many of these corporate R&D laboratories greatly diminished. For example, Nortel has closed almost all R&D activities at Harlow, a site that once boasted several hundred people working on photonic systems and hardware. Some of this, and the former Marconi optical component laboratories, have been absorbed into Bookham Technology. Similarly the former BT laboratories at Martlesham are much reduced.

There are examples where corporate R&D is increasing, such as at Oxford-based Sharp Laboratories of Europe. Also, a number of smaller companies are expanding rapidly.

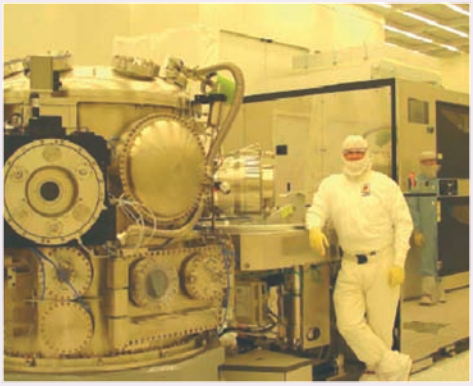
Worldwide, companies focussed on telecommunications have reduced their activities. At the same time the buoyant sectors of consumer and computer products (together with such items as displays for mobile phones and similar products) have seen an increase in R&D. Some countries, particularly in Asia, are better placed in these other applications and have therefore sustained more activity.

By studying the DTI 2005 R&D scorecard, which covers the top 750 UK companies by R&D investment, it is possible to estimate the minimum contribution made by UK-based photonics companies to business enterprise R&D during 2003. This analysis revealed approximately 68 companies (see Appendix D at www.dti.gov.uk) that are critically dependant on photonics. They employed more than 220,000 people with a combined R&D expenditure in excess of £1.4 billion.

COMPANY PROFILE

Exitech Ltd

www.exitech.co.uk



Exitech specialises in the use of lasers for micro and nanofabrication applications in industry. It is the world's leading supplier of pulsed laser processing systems that integrate the laser source, beam delivery, diagnostics, parts handling, alignment and machine control. The tools are used for production and R&D in areas such as photolithography, micromachining, microdrilling, annealing, surface treatment, component marking, and wire stripping; and in industries as diverse as microelectronics, telecoms, aerospace, automotive and biomedicine.

Exitech is also the world's leading supplier of deep-UV (DUV) and extreme-UV (EUV) microstepper tools used by the semiconductor industry to qualify new technology nodes in the manufacture of future generations of silicon chips.

Exitech has recently developed a range of laser tools for patterning nanometre precision surface structures on thin films for flat panel displays and projection TVs.

UK ORGANISATIONS

As well as industrial and academic activity, the photonics industry has numerous bodies that represent groups and that bring together interested parties. Given the widespread nature of much of the work, these present an opportunity for greater interaction between (relatively) specialised interests and also (potentially) a vehicle for delivering government support.

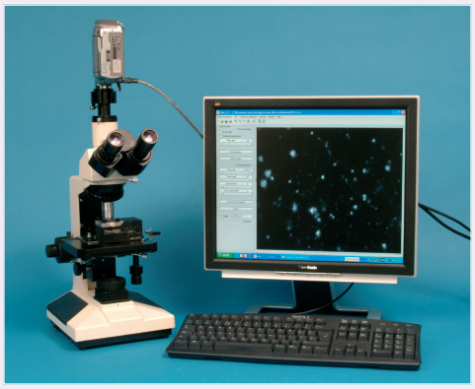
There are, however, more than 40 UK organisations concerned with different aspects of photonics and this presents a significant co-ordination problem. Figure 7 and Appendix E at www.dti.gov.uk provide details of the associations and groups operating.

Figure 7: UK Photonics Related Sector Associations and Institutes

COMPANY PROFILE

Nanosight Ltd

www.nanosight.co.uk



Nanosight was formed in 2003 to develop nanotechnology instrumentation for nanoparticle tracking analysis. The unique instrumentation, based on experience gained at the Centre for Applied Microbiology and Research, Porton Down, enables real-time detection of particles as small as 20nm.

The instrumentation utilises a low-power laser and patented technology to scatter and detect light from nanoparticles. By attaching it to a conventional microscope, particles appear as bright spots of light whose motion is characteristic of their size. Intelligent image processing software allows particle size analysis to be rapidly accumulated.

The applications for viewing small particles are limitless and include the detection and identification of viruses for security, defence and medical applications, as well as for process control and investigations in the manufacture of pharmaceutical drugs.

STRENGTHS, WEAKNESSES, OPPORTUNITIES AND THREATS

For the five sectors examined for this report, and described in the next section, analyses of Strengths, Weaknesses, Opportunities and Threats (SWOT) were undertaken. A summary of those analyses is given below.

STRENGTHS

- International reputation of UK photonics research
- Some best of breed technologies (eg; Organic Light Emitting Diodes [OLED], Terahertz)
- UK scientific research base has been sustained during market downturn
- Flexible & strong labour market
- Diverse photonics products range
- Niche product excellence
- Innovative culture

WEAKNESSES

- High proportion of small photonics companies
- No benchmark data or agreed roadmaps for the UK photonics sector
- Fragmented industry
- Inadequate interface between science base and industry
- Ineffective marketing as an industry
- Finance investors still disillusioned
- Manufacturing costs too high

OPPORTUNITIES

- Many growth markets overseas
- New technologies, materials
- UK trading and exports, prevalence of English
- Early stage markets and applications
- Niche markets
- Energy regulation and general public eco-awareness

THREATS

- Emerging, high growth foreign competition (eg; China)
- Competition for Government funds from other strong sectors (eg; pharmaceutical, aerospace)
- Traditional photonics segments maturing quickly (eg; optical communications – UK role in niche markets)
- Recent downturn has led to many skilled photonics workers leaving the sector.
- Loss of manufacturing base could undermine design and development cycle

SECTOR FOCUS

Information & Communication Technologies and Consumer Photonics

This account gives an overview of the consultation. It is an edited version of the full consultation report which is available from www.dti.gov.uk

Consultation in this sector looked at two main areas – Displays and consumer photonics, and Communications and networks. Each is covered separately here.

DISPLAYS AND CONSUMER PHOTONICS

Photonics plays a significant role in the development of displays and consumer applications including TVs, projection systems, computer monitors, DVD recorders/players, digital cameras, mobile phones, etc. It is the advent of new and light-weight display technologies that has enabled many of the new consumer applications, especially within the portable devices market.

The innovation and development skills of UK scientists and engineers have been supporting the global flat screen display markets since the 1970s, when the first stable liquid crystals for displays were synthesised at the University of Hull, and the first thin film transistor (TFT) displays were fabricated at Dundee University. The replacement of Cathode Ray Tube (CRT) televisions with electronic flat panel displays is just the first step towards fully-immersive display technologies which will combine flexible electronics to create an 'intelligent environment' that will enable electronic systems to be available everywhere and to anyone. Although there are many FPD display technologies available commercially, the highest by volume and value is that of Liquid Crystal Displays (LCDs) which exist in a variety of different types and have benefited from UK materials technology expertise.

The FPD has changed the modern working and social environments with highly-advanced feature-rich notebooks, PDAs and mobile phones. Future technologies will have a similar influence, allowing full access to all forms of visual information, whether for reading, viewing video, game-playing or watching TV.

A substantial photonic display and consumer manufacturing presence has left the UK and Europe, however, and is now firmly established within Asian countries, particularly Taiwan, Japan, Korea and increasingly China. The short-term strategy of Asian countries differs to the UK in that there are considerable amounts of research activities focused on the further development and refinement of production-process technologies in order to reduce costs and increase manufacturing yields.

In the UK, research is focused on advanced displays driven by the creation of novel applications, consequently proving the feasibility of new display technologies.

The UK, through a variety of companies and institutions, is well-placed to develop and manufacture flexible displays using additive printing processes, or a combination of coating/patterning and additive printing processes to build display devices. These innovative materials and processes will be suited to both low- and high-volume production at costs significantly lower that those used in conventional glass substrate-based manufacturing employed in Asia. The UK is a global leader in all aspects of flexible display technologies, including substrates, solution processable electro-optic effect and other functional materials, organic semiconductors and transparent conductive polymers and metals, new device architectures, and also material delivery and post-printing processing equipment.

THE MARKET

The worldwide sales of displays and related products increased in revenue terms to approximately $85 billion during 2005. Revenues were dominated by LCDs which experienced strong growth in 2004 to $62 billion. Plasma-based displays also exhibited strong growth with an approximate increase of 43% to $6 billion in 2004. CRTs are maintaining a steady decline with a market reduction from 26% in 2003 down to an anticipated 4% by 2009.

The PSG consultation examined a number of areas in depth, and accounts are available at www.dti.gov.uk. They include:

- *The displays value chain*
- *What are flat panel displays?*
- *Drivers for future display technologies*
- *Developing the technologies and processes for next generation displays.*

ANALYSIS OF THE UK DISPLAYS AND CONSUMER PHOTONICS ECO-SYSTEM

The UK displays eco-system is well-established due to significant government support during the past two decades. However, there are indications that volume manufacturing of display systems in the UK will continue to diminish as CRT technology is displaced by flat panel displays, thus weakening the strength of the supply chain. This has been demonstrated recently by the closure of a large CRT TV manufacturing plant in South Wales.

Today, the supply chain is remarkably intact despite high volume manufacturing taking place in Asia. The UK is seen as a strategic base for material suppliers, academic

research groups, electronic designers, processing and equipment companies, distributors and large end-users. Indeed, a number of international companies have research teams based in the UK, but almost none consider this a stepping-stone to manufacturing display products here.

Large-area printable organic electronics is emerging as a new area with a market potential even beyond displays. The UK is recognised as a world-leader in this emerging and disruptive area of photonics, and offers a relatively complete embryonic eco-system of its own.

The pressure on the UK eco-system is increasing as R&D for materials and components, once led by the UK, begins to move towards the manufacturing bases in Asia. There is a need to develop a next generation manufacturing facility that is based on organic electronics for specialised and niche display products. This UK facility would need to be supported and utilised by the display community to create and prototype new materials, processes, systems and manufacturing equipment.

There is little activity in other photonics enabled consumer products (excluding displays) such as optical storage devices due to the strongly cost-competitive nature of Asian countries. The UK has an excellent opportunity to design new consumer devices and to develop novel methods of human-to-machine interfaces. However, large-scale manufacturing will inevitably be offshore.

SWOT ANALYSIS OF UK DISPLAYS AND CONSUMER PHOTONICS

The consultation process identified the key strengths, weaknesses, opportunities and threats to the UK display and consumer photonics sector. This is a huge market segment but the UK situation is that, whilst there is a plethora of research and some development activity, there are effectively no volume production facilities and, probably more significantly, no large-scale customers for the components layer.

As the segment continues to change and new technologies emerge, it seems likely that there will be opportunities for the UK to re-engage this market. Support for new start-ups from the research base would seem the most useful way forward and the establishment of assembly plants for equipment would also create a local market.

Since Korea and Japan have a very strong research base, with about 100 university groups as well as large corporate R&D divisions, regaining leadership in making commodity LCDs and plasma display panels (PDP) in the short term is nearly impossible. However, the standard manufacturing approaches of LCDs and PDPs today depend highly on glass processing, offering an opportunity for the UK to concentrate on flexible displays: large-area printable is an emerging area with a market potential of over a hundred billion dollars.

STRENGTHS	WEAKNESSES
• World class R&D base in both academia and industry • Numerous small companies in disruptive display technologies like OLED and microdisplays • Materials • Printing R&D and equipment manufacturing • Electronic design innovation • Strong IP portfolio • Very active UK retail, consumer and mobile telecomms markets	• Lack of large indigenous display manufacturers • No mainstream display panel production • Lack of display systems approach in academic programmes and display technology start-ups
OPPORTUNITIES	**THREATS**
• Changing and expanding market • Flexible displays • Exploitation of UK materials strength • Niche medium-scale manufacturing with new technologies • Add value by vertical integration and developing equipment for next generation displays • Low-energy displays for retail and signage applications • Systems aspects of displays, eg signal processing and electronics • LCD and plasma TV assembly (attracted by EU tariffs)	• US and Far East treating displays as strategic • Flat displays market levels off by 2010 • Development of next generation displays, ie; OLED, 3D, lacks critical mass • Whole display industry (inc R&D) moves to Far East - UK loses all contact with manufacturing. • Far East developing IPR in all areas of display sector from materials to manufacturing • TV assembly could end when tariffs disappear

Combining its strength in display technology, large area processing, signal processing, organic systems, and customised electronics, the UK could fully enter the stage of display and large-area electronics manufacturing.

Future opportunities include focussing on newly-emerging niche applications such as projection or 3D TV or high-resolution and high-dynamic range monitors for medical imaging.

COMMUNICATIONS AND NETWORKS

The UK has been at the forefront of optical communications since engineers at Standard Telecommunication Laboratories pioneered fibre optics in 1966. But it was the creation of the world-wide web in 1993 that opened up mass-market applications.

Uses of photonics in optical communications include long-haul (between centres) and metro telecoms (within centres), as well as the emerging possibility of Fibre To The premises (FTTx) giving next-generation broadband access to all. Optical switching, optical packet routing, wavelength switches and all-optical regenerators are just a few of the emerging photonic components that will differentiate future network products. Other applications of photonics in telecommunications include the use of free space light transmission to provide information transfer over fixed paths. Optical fibre including specialist products such as photonic crystal fibre may also provide innovative solutions, but are at an early stage of development.

THE MARKET

The world-wide photonic communications market reached $14.7 billion in 2004, a growth of 25% on 2003[8]. Importantly, photonic components underpin a global telecommunications market projected to reach $2 trillion by 2008, according to the Telecommunications Industry Association (TIA).

The photonic components share of the market in 2004 was approximately 15% or $2.2 billion, with equipment accounting for 59% of this, fibre and cable representing 26% and components 15%.

As the optical communications market returns to solid growth, there is the opportunity for telecommunication companies to begin to invest in new network technologies. For example, BT is leading the way in the UK with the launch of the 21st Century network programme. When this network is completed in 2009, BT will have converted its entire core backbone network to Internet Protocol (IP), making the networked environment a far more flexible option.

The PSG consultation examined a number of areas in depth, and accounts are available at www.dti.gov.uk. They include:

- *Network topology*
- *Drivers for future optical communication networks*
- *Low-speed and next generation high-speed broadband access*
- *How the UK compares in the adoption of FTTx broadband*
- *Developing the technologies for next generation networks.*

ANALYSIS OF THE UK OPTICAL COMMUNICATIONS ECO-SYSTEM

The UK optical communications eco-system is well-established and among the most mature of the photonics sectors in the UK. However, optical communications has suffered over the last five years from overcapacity, and this has meant that many activities have been scaled back with consolidation leading to some global organisations withdrawing from the UK. But the supply chain remains intact – from academic research and material suppliers through to component manufacturers and service providers – and this offers great potential as market growth returns. UK industry and research must firmly focus on the requirements for next generation networks and FTTx deployment.

STRENGTHS

- Well-established business in all layers
- World leaders present in some layers
- UK university research is excellent and has been sustained during market downturn
- Supply chain and standards are well defined
- UK has the capability to develop communications infrastructure
- Clear recognition that communications is critical to the economy and service sectors
- Many SMEs with high growth potential

WEAKNESSES

- Sector has seen decline and cut-backs (but solid market growth seen in 2005)
- Over-capacity exists in fabrication
- Only one UK company to act as cluster centre in OEM layer
- UK network is fragmented
- UK unbundling regulations can deter new FTTx
- Other regions/countries pushing ahead with FTTx etc
- UK lacks support for IP costs

OPPORTUNITIES

- FTTx +next generation broadband in greenfield sites
- Fibre in the metro and access area
- Upgrades of installed base
- Breakthrough low-cost techniques
- New services, digital rights/content management
- Data storage networks, video on demand, VoIP, IPTV and other applications
- Spin-out culture in telecoms and exploitation of IPR
- Automated manufacture and test

THREATS

- Negative perception of sector still exists
- Continued market flat growth
- Diversification by companies leading to less activity in communications
- Growth of competition (eg; China)
- No support for developing next generation components and network infrastructure
- Asian 'loss-leading' long-term investment policy
- Loss of manufacturing base could undermine design and development cycle

SWOT ANALYSIS OF UK OPTICAL COMMUNICATIONS

The consultation process identified the key strengths, weaknesses, opportunities and threats to the UK optical communications sector.

The future growth areas of metropolitan networks using optical technologies and FTTx are being held back as there is currently almost no UK activity at the service provider level. This undermines the UK's ability to strive for increased levels of competitiveness and productivity. Other countries, both in Europe and elsewhere, are taking strategic decisions to develop next generation networks and provide FTTx facilities to the user: this encourages R&D activities within their industries.

The promotion of next generation broadband, as advocated by the Broadband Stakeholder Group, is an opportunity which will lead to a large increase in traffic on networks and so to a resumption of capital spending by telecommunications operators. Links between companies and academia are well-established in this segment, and the main activity required is an aggregation of demand at the higher levels of the eco-system.

In terms of photonic components and systems, the situation remains that optimal performance of each and every component is still required. Despite incremental improvements in the specification of many parts, there is little to be traded off in link budgets, and amplification remains expensive and is a cause of other degradations to signals traversing the network. Many apparently promising new technologies that might create significant reductions in cost are not finding their way into use as rapidly as had been predicted.

SECTOR FOCUS
Life Sciences and Healthcare

This account gives an overview of the consultation. It is an edited version of the full consultation report which is available from www.dti.gov.uk.

The widespread use of photonics has created a paradigm shift in life science and healthcare applications, with countless new photonic-related technologies, instruments and systems being used to create a new science known as biophotonics. The breakthrough came with the fluorescent tagging of proteins and molecules that revolutionised genetics. Not only could these tags be activated and then imaged, but researchers also realised that they could use light to move and interact with these molecules.

Biophotonics is more than a combination of biology and photonics: it is a field that operates at the interface of physical sciences, engineering, biology and medicine. It refers to the emission, detection, absorption, reflection, modification and creation of photonic radiation from living organisms and organic material.

Areas of biophotonic application include:

- Life science
- Microbiology (viral and bacterial analysis)
- Pharmaceutical and drug analysis
- Medicine and clinical diagnosis
- Agriculture
- Environmental science
- Food and drink processing and analysis.

The future role of biophotonics as a key enabler in healthcare and life sciences will expand tremendously due to:

- The capability of light to monitor biomaterial in real-time and in a non-contact way without affecting the life processes of a subject
- The use of light as a probe to image a variety of features simultaneously and to observe very complex processes such as protein reactions in living cells
- The ability to image biomaterial from the molecular level right through tissue samples and living organs to whole bodies of animals or humans
- The use of light as a tool to manipulate or modify cells. Such properties are essential for new tools in cell biological research and minimally invasive treatment.

No other 3D-imaging and manipulation technology for life sciences and healthcare offers similar capabilities in resolution, simultaneous probing, cell manipulation and sensitivity.

New photonic devices and procedures will identify, prepare and treat living cells in a fast, three-dimensional way to cure significant diseases such as cancer and degenerative conditions. The advances in biophotonics will have

a huge impact on health services by making them more effective, cheaper and accessible to all.

In the future it is feasible that a mass-produced, small optical device could monitor health parameters and help to regulate automatic drug delivery for individuals. It would also be possible to perform environmental monitoring using sensitive biosensors to warn of impending infections and allergens with early identification systems.

THE MARKETS

The embryonic state of the sector makes it difficult to assess current markets, but small cross sections of healthcare markets that utilise photonic technologies include:

- Emerging bio-health technologies estimated at $260 billion in 2005[9]
- Medical diagnostics estimated at $27.5 billion in 2005
- Medical biosensors estimated at $8.5 billion in 2005
- Breast cancer biopsy market estimated at $2.3 billion in 2005
- Cervical cancer diagnostics estimated at $1.6 billion in 2005.

The prognosis for photonic technologies in medical devices expects to grow from $5.95 billion in 2002 to $20.4 billion in 2010, and could reach $38 billion by 2015. This relates to a global medical devices market valued at over £124 billion in 2005[10] with the UK having a 3% share.

The PSG consultation examined a number of areas in depth, and accounts are available at www.dti.gov.uk. They include:

- *Market drivers for life science and healthcare applications*
- *Biophotonic applications and technologies*
- *Cell and molecular biology*
- *Advanced and early diagnosis*
- *Preventive medicine*
- *Minimally invasive and personalised therapies*
- *Photonic tools for cell and tissue manipulation*
- *Optical coherence tomography*
- *Functional microscopy and spectroscopy*
- *Optical biosensors*
- *Near-infrared (NIR) spectroscopy and imaging.*

ANALYSIS OF THE UK LIFE SCIENCES AND HEALTHCARE PHOTONICS ECO-SYSTEM

The UK is very strong in medical and pharmaceutical-related research and production and, in 2003, the UK world trade in pharmaceuticals was valued at £11.9 billion for exports and £8.4 billion for imports to create a trade balance surplus of £3.5 billion.

The NHS R&D budget for 2004-05 was £612 million which will rise by £100 million a year to 2008, providing a strong main funding stream for research. By 2004/5 the NHS had created nine innovation hubs throughout England with a budget of £7 million dedicated to the technology transfer and commercialisation of innovative ideas and intellectual property from within the NHS to industry.

Such UK-based activity has established the potential for a strong medical and healthcare photonics eco-system with large potential customers such as the National Health Service and global pharmaceutical companies including GlaxoSmithKline and AstraZeneca.

There is considerable photonics activity amongst academia, and among large and small companies with strong evidence of rapid growth. Many companies are working on components and the application of optical reading of analysis results, fluorescence, optical manipulation, etc. Application areas include flow cytometry, various fluorescence techniques, optical coherence tomography (OCT), genomic and proteomic analysis, Raman spectroscopy, and a variety of extensions to microscopy techniques. Further R&D is needed into procedures including laser ablation, photodynamic therapy, eye surgery and cosmetic skin treatments.

The markets for medical devices and healthcare services are growing and, in turn, there will be demand for new photonic-based components, devices and equipment. The eco-system shows the great potential for exploitation at all levels within the supply chain from academic research through to equipment and device manufacturers.

The most significant gap within the eco-system is in the equipment layer (the users of photonic components) where the largest players are predominantly located in North America. There needs to be a concerted effort to generate an environment that encourages the growth of UK organisations to compete at world-class levels. The potential rewards are great with, for example, DNA sequencing equipment alone being a multi-billion dollar business. Most equipment companies have some UK presence, but this is often only a sales and support office.

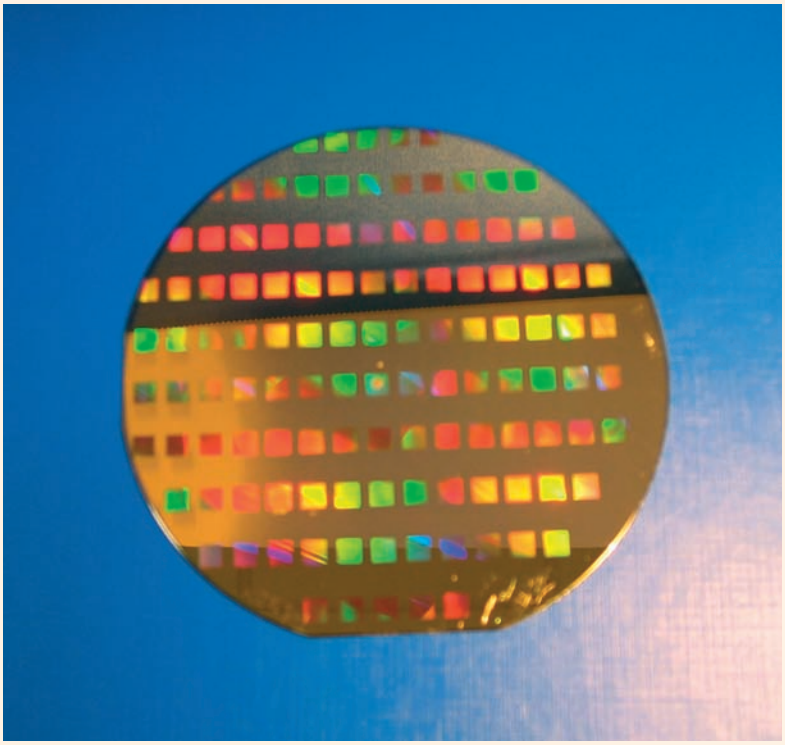
STRENGTHS	WEAKNESSES
• Wide and deep research base in academia • Sector noted by Research Councils and being promoted • Very strong potential customer base • Very strong Pharma presence in UK • Most required technologies are present in UK (including those outside photonics) • Large number of small biophotonics companies with several leaders • NHS has acknowledged innovation is key to service improvements	• Fragmented activity in industry - many small players and parts of larger groups • Lack of large instrument manufacturers • Academic funding falling between research council remits • Diverse skills required across physics, chemistry, bio, medical, etc. • Fragmentation of funding resources • Product acceptance can take to10 years
OPPORTUNITIES	**THREATS**
• New techniques emerging • Develop smaller-scale devices/machines • Industry growing & at an early stage world-wide in many sub-sectors • Markets in multi-billion pound range available by 2007 • Suitable for venture capital funding • To link research council funding to increase biophotonic activity • NHS Institute for Innovation and Improvement	• Strong US, European and Japanese programmes • Timescales of clinical trials • Ethics issues with some applications • Approvals difficulties • Disconnect between different disciplines and parts of the biophotonic value chain • IPR disputes between eg; NHS, academia, industry • Projected downsizing of the UK pharmaceutical industry

SWOT ANALYSIS OF UK LIFE SCIENCES AND HEALTHCARE PHOTONICS

The consultation process identified the key strengths, weaknesses, opportunities and threats to the UK life sciences and healthcare photonics sector. The biophotonics sector offers a tremendous opportunity to shape the future delivery of healthcare services around the world. The UK presents an excellent opportunity for R&D of new medical devices, surgical techniques and personalised therapy development due to its close proximity to a huge local market demand from intermediaries such as the NHS and the wealthy end-user population within the UK and Europe. Currently, the sector is embryonic and inherently multi-disciplinary, which requires the excellent communication and integration of skills between photonics, life sciences, pharmaceutical and medical communities. The UK has to develop a strong networking organisation that is able to bridge the gap between all the specialists and create significant cross-disciplinary R&D collaborations to develop the next generation of market-led photonic tools.

The UK academic community is very strong and biophotonics has been recognised by the research councils as a growth area with newly-launched platform grants announced. The UK also provides a very strong potential customer base with the NHS in healthcare and the large pharmaceutical research presence. There is some evidence that UK companies already active in adjacent technologies or applications are interested in evolving into the biophotonics area and are looking for technical inputs with photonics.

The NHS procurement procedure will become a strong influence in the UK market place, especially when there is a wider context placed upon medical devices. However, the lengthy product acceptance cycles need to be integrated alongside product development and patient trials. The key for exploitation will be to link new technologies with the priorities outlined within NHS Institute for Innovation and Improvement strategic plan.



SECTOR FOCUS
Defence and Security

This account gives an overview of the consultation. It is an edited version of the full consultation report which is available from www.dti.gov.uk.

The defence and security requirements cover numerous end-users from the government through its military defence requirements and emergency services to the private sector - including para-military operators, industry and the general public. The defence and security sectors are increasingly being underpinned by sophisticated technologies, including photonics.

Generally, the markets for defence and security segments have different eco-systems and end-use applications, but many of the underpinning technologies required are applicable to both.

THE DEFENCE AND SECURITY MARKET

The total world-wide market revenue for the defence segment was estimated at $950 billion in 2004, with the USA having a significant lead with a defence budget of $466 billion. Significantly, less than 2% of the US defence budget is spent outside its home market, and of this around one per cent goes to UK contractors[11]. It is increasingly vital for UK industry to develop a closer association with the US market.

In 2004/5 the total UK budget for defence was £38.4 billion and is the third highest area of government expenditure behind health and local government[12]. Although it is difficult to determine how much of the total budget is related to photonic-enabled expenditure, analysis shows that in 2003/4 £1.33 billion was dedicated to electronics and optical technologies.

In addition, the total UK defence expenditure on R&D activity totalled £2.7 billion. It has been estimated that MOD expenditure and defence-related exports support 305,000 employees within the UK, with over 140,000 indirectly-supplied through the supply chain.

Importantly, two of the prime contractors to the MOD – BAE systems and QinetiQ – have significant interests in photonic-based technologies covering materials development through component design and manufacture to full systems integration.

During the 2006-2015 forecast period, the worldwide 'total defence' outlay (military, intelligence community, and homeland security/homeland defence) is forecast to grow by approximately 50%, from $1,400 billion in 2006 to $2,054 billion by 2015[12]. The world-wide homeland security (including the private sector) outlay is forecast to grow by nearly 100%, from $231 billion in 2006 to $518 billion by 2015. Where the homeland security outlay was 12% of

the world's total defence outlay in 2003, it is expected to become 25% of the total defence by 2015.

The PSG consultation examined a number of areas in depth, and accounts are available at www.dti.gov.uk. They include:

- *The defence and security drivers*
- *Key technologies*
- *Photonic sensor technologies*
- *Identification and authentication technologies*
- *Screening technologies*
- *Surveillance technologies*
- *Tracking and verification technologies*
- *Cyber and network security technologies.*

AN ANALYSIS OF THE UK SECURITY AND DEFENCE ECO-SYSTEM

The UK defence and security eco-system is well-established due to significant government support over the past few decades within military and security-based technologies, and demand has been boosted by recent international terrorist activities and foreign conflicts.

For defence, the UK supply chain is also very well-established, with several key primary contractors located within the UK acting as systems integrators and technology providers at the head of an efficient supply chain. The drive towards globalisation, however, has meant that industry consolidation has taken place with many companies becoming part of a European or global organisation. This has resulted in the reduction of UK-owned tier 2 and 3 suppliers representing mainly medium-sized companies, thus reducing the degree of self-sufficiency. The eco-system supports many small companies that are able to offer world-class technology solutions, and it is vital that continued support is provided to encourage their rapid and sustainable growth.

The key issue highlighted within the eco-system analysis is the lack of any significant photonics-related material suppliers and research, resulting in a reliance on overseas material suppliers. The analysis also revealed that, although there are some global component suppliers within the UK, they provide very selective or niche products resulting in the need to source other components from outside the UK.

The defence sector generally requires cutting-edge technology solutions in low volumes and it is essential that - to maintain a complete eco-system - small defence companies be encouraged to diversify their technology toward security applications which offer a potentially larger volume market. Many advanced photonic systems for military applications provide opportunities for commercial products. For example, technologies used for night vision goggles and

thermal imaging systems are now used for measuring the performance of combustion engines or as quality control systems for food and drink production.

A significant amount of vertical integration has taken place at sub-assembly, equipment and system integrator levels, so these are not entirely distinct. This may assist players in the lower 'tier' layers of the eco-system in finding markets.

The security sector eco-system has several large companies that act as security solution integrators, supported by a significant UK supply chain providing an opportunity to adopt appropriate military-derived technologies into next generation security solutions.

SWOT ANALYSIS OF THE UK DEFENCE AND SECURITY ECO-SYSTEM

The consultation process outlined the key strengths, weaknesses, opportunities and threats to the UK defence and security sector.

The UK defence and security sector has an excellent research base which includes a broad range of activities from night sights to laser infrared countermeasures, photonic sensors, communications and specialist displays. The industry is strong in niche areas - such as lasers, precision optical lenses and the thin-film coating solutions required within all photonic-enabled solutions. The sector has a few strong prime contractors with optical systems experience and there is a UK history of exploiting photonic technologies in niche applications that require a high degree of complex system design and implementation.

Particular weaknesses include the shrinkage in the industrial R&D base, most probably due to the consolidation happening within the supply chain. As there is a small market volume for photonic components, the defence and security industry represents a high risk of entry for SMEs and requires significant funding to develop large-scale innovation without much government support. There is a need to support highly-innovative small companies that have the potential technology tools to develop demonstrator and prototype models.

One such support mechanism is the Small Business Research Initiative (SBRI), but the consultation noted a lack of engagement between the SBRI and SME community, most probably due to the undeveloped SBRI profile within industry.

Another weakness is the risk associated with defence contracts which tend to have long product development cycles and often have a lack of early commitment from the purchaser. The USA has significant funding in this area in both defence and security applications.

The consultation process highlighted many significant opportunities in terms of technology research and commercial

opportunities for the sector. The increase in terrorist activities around the world has increased the need for both corporate and community-based security equipment and systems, leading to rapidly increasing market opportunities for photonics. There is an opportunity to capitalise on UK innovation by exporting technologies through the UK/US international technology alliance and, more recently, with European partners through the establishment of the European Defence Agency (EDA).

Present opportunities for the photonics sector include the civilian chemical, biological, radiological and nuclear (CBRN) Science and Technology programme led by the Home Office to ensure protection of the UK from a terrorism incident.

STRENGTHS	WEAKNESSES
• The UK research base is strong and covers a broad range of activities. • Strong in key niche areas of military hardware, (eg; lasers) • UK has a few strong prime contractors to act as technology integrators • Early and growing use of photonics in avionics applications • Safety and security markets in UK growing fast • Wide range of UK specialist SMEs • Defence Technology Centres, in particular Electro Magnetic Remote Sensing (EMRS)	• Established culture in defence contracts is adversarial • High risk, relatively small market for photonic components. Therefore lack of company-funded investment • Little funding for some underpinning science and technology (eg; atmospheric propagation and long-term materials & speculative work) • Shrinkage in industrial defence R&D base • Defence sector is demanding for SMEs to develop large-scale innovation • Defence culture is either bureaucratic (UK) or difficult (USA) to engage
OPPORTUNITIES	**THREATS**
• MoD CRP open to competition • UK/US International Technology Alliance • European Initiatives: Formation of European Defence Agency: Framework 7 • US Initiatives; Homeland Security; DARPA • Large number of potential technologies and applications • Spin out technologies for the civilian markets such as imaging and recognition • Increased demand for physical security • SBRI could help SMEs to deliver prototypes	• Changing military threats and strategic defence environment • Need for strong leverage/exploitation of civil developments • Changes in defence companies; becoming globalised or multinational joint ventures • Lack of open access to US markets • Low level of government funding compared to US and France

SECTOR FOCUS
Lighting and Energy

This account gives an overview of the consultation. It is an edited version of the full consultation report which is available from www.dti.gov.uk.

Consultation in this area looked at the two main areas separately – Solid State Lighting and Energy generation by photovoltaic solar cells, and each is reported separately here.

SOLID STATE LIGHTING

Solid-State Lighting (SSL) is perhaps the most significant advance in illumination since the invention of the light bulb more than a century ago. Based on inorganic compound semiconductors known as Light Emitting Diodes (LEDs) or organic LEDs (OLEDs), it is a serious alternative to conventional lamp technologies in many applications, and consequently provides considerable challenges to traditional lighting companies.

Since 2000, when the first high-powered LED components became readily available, significant numbers of niche applications have developed from architectural lighting products that can produce more than 16 million digitally controlled colours to high-efficiency traffic signals.

General trends suggest that LED outputs increase by more than 20 times every decade while costs reduce by a factor of 10, although there are signs that this underestimates the advances being made. Over the next five years solid-state lighting could be comparable in cost to fluorescent technologies.

The PSG consultation examined a number of areas in depth, and accounts are available at www.dti.gov.uk. They include:

- *The solid-state lighting market*
- *The lighting equipment market*
- *What are LEDs?*
- *What are OLEDs?*
- *Market drivers*
- *UK benefits of adopting SSL*
- *Regulations and policies driving SSL forward in the UK*
- *Challenges for solid-state lighting technologies.*

ANALYSIS OF THE UK LIGHTING (INCLUDING SSL) ECO-SYSTEM

The UK lighting eco-system is well-established at various layers within the supply chain due to the maturity of the lighting market. But there are indications that the volume manufacturing of conventional lighting systems in the UK will diminish rapidly as conventional lamp technologies are moved offshore due to lower

manufacturing margins. The challenge will be to ensure that the UK lighting sector transfers development and production to new, high-margin SSL technologies without incurring significant industrial decline in the sector. Here, government can show leadership by developing policies that support the adoption of SSL lighting within the UK market.

High-brightness LED activity for general illumination is embryonic in the UK, although niche markets are beginning to expand where SSL benefits outweigh the high entry costs of HB-LED fixtures. This opportunity has created many new start-up lighting manufacturers specialising in solid-state lighting fixtures and has resulted in an increase in the number of UK manufacturers to greater than 700. The number of companies involved in SSL technologies such as plastic optics, drivers and heat-sinks would make the number of companies associated with the UK SSL sector much larger, but the true number is difficult to quantify.

The UK has a wide base in nitride research but only a small fraction of this is directed toward the realisation of high-brightness LEDs. However, there are organisations such as IQE with excellent knowledge, capacity and die manufacturing capabilities based in the UK, along with organisations such as Mesophotonics that develop novel light extraction techniques such as Photonic Quasi-crystals.

The potential markets are very large and international, and also include many niches such as backlights for displays where efficiency can be very important in mobile applications.

One way forward is to encourage the development of highly-efficient LED products to enable SSL adoption to be accelerated. This could be achieved through increased funding on HB-LED projects similar to initiatives from other countries with alignment to UK strengths at the design and systems rather than the components level.

SWOT ANALYSIS OF UK LIGHTING (INCLUDING SSL)

The consultation process identified the key strengths, weaknesses, opportunities and threats to the UK solid-state lighting sector. Lighting represents a huge market segment but the situation is that, whilst there is a plethora of UK research and some development activity on solid-state lighting, there are effectively no volume production facilities for LED emitters or OLED lighting systems. Interestingly, this may not be a major issue as it is perceived that LED die, or LEDs themselves may become commodity items that will attract relatively little in the way of added value. More positively, the UK has a very strong position in producing the basic materials and IP for LED and OLED devices.

The UK is strong in the design and manufacture of secondary optics, electronic drivers, packaging and thermal management which enables LEDs to be built effectively into fixtures and luminaries. This establishes the UK firmly at the higher end of the value chain developing complex and intelligent lighting systems.

Further opportunities exist in materials for phosphor and wavelength converters required to generate white light SSL devices.

The UK has considerable knowledge, expertise and experience in organic LED materials, printing processes and manufacturing equipment which can be used as an opportunity to establish the future of the UK lighting manufacturing industry within the next two decades.

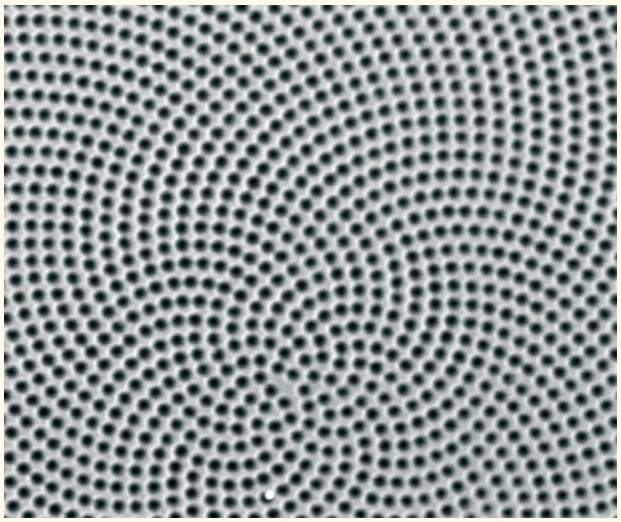
The UK government has an opportunity to demonstrate leadership in the adoption of SSL and to reduce carbon emissions through energy efficiency policies.

STRENGTHS	WEAKNESSES
• Strong materials characterisation base • Potential volume supply of RGB epi-wafers • Large UK general lighting market and knowledgeable OEM market • Strong OLED R&D and infrastructure for printing and volume production • Some large and many small OEM lighting companies in UK • Electronics integration experience • Lighting supply and value chains well defined • Regulations well-defined	• No indigenous HB-LED chip manufacturer • No UK initiatives on SSL comparable to those in USA and Far East • Device manufacture hindered by IPR strength of USA and Japan • Little visibility of SSL benefits to government or general public • Lack of standards • OLED technology vulnerable to environmental conditions • No organisation dedicated to networking along the supply chain
OPPORTUNITIES	**THREATS**
• Niche markets for SMEs with specialist lighting products • Improved efficiencies from nano structures • Conversion of low margin fixture manufacturing to high margin SSL products • Urgent need to reduce carbon emissions and future energy requirements: • Materials expertise - OLED, phosphors • SSL measurement services, regulation	• HB-LEDs for SSL might not be produced in UK • OLED might not diversify to incorporate SSL applications • Other governments support a coherent and& strategic SSL development programme • SSL is not adopted as a special case in building regulations to enable UK adoption • Government/Carbon Trust support is not provided on capital installation costs of SSL, leaving UK supply chain weak

There is a serious threat that the UK will lag behind the rest of the world in developing its own SSL eco-system and the economic benefits it would deliver. Government intervention in countries such as the USA, Japan, China and Taiwan is helping to create an SSL infrastructure by supporting programmes to develop new technologies and install SSL in early-adopter applications.

Future opportunities include focussing on newly emerging applications such as indoor commercial lighting applications for OLED devices and high-intensity multi-watt power LEDs for projection-based display and lighting systems.

European collaboration in new SSL technologies will be developed through the Framework 6 and 7 programmes to establish a counterbalance to Asian dominance. Switching to new manufacturing techniques - eg printing versus batch manufacture - could also present an opportunity.



ENERGY GENERATION BY PHOTOVOLTAIC SOLAR CELLS

The photovoltaic (PV) solar cells market is often viewed as mature as it is over 30 years old and dominated by silicon wafer technology. But the dominance of silicon-based PV is now being challenged with a wide variety of new approaches that use amorphous silicon or GaAs-based technologies. In addition, there are innovations that could affect the various types of thin-film structures used by all PVs, including the development of organic compounds and other nanotechnology-based materials such as titania nanoparticles, carbon and silicon nano-crystals.

In the UK, solar power has long suffered from prejudice caused by our 'temperate climate' and 'variable' weather conditions. The reality is that UK buildings annually receive over 1,600 TWh from solar irradiation, which exceeds the UK annual oil production (1,100 TWh in 2004).

In comparison to other countries such as USA, Japan and Germany, the UK has fallen behind in both the adoption and development of PV technologies. It has been suggested, however, that this could be reversed if we were to concentrate on thin film technologies. These have greater economic potential than conventional crystalline silicon technology, and are well suited to building-integrated PV (BIPV). BIPV is capable of providing an estimated 30% of the UK's current energy demands.

THE PHOTOVOLTAIC MARKET

PVs have a very wide range of potential (and actual) applications covering medium-scale power generation, domestic power production, integration into buildings, professional remote power systems (telecommunications), remote power systems for the developing world, remote/distributed applications and consumer products. Worldwide photovoltaic cells achieved market revenues of $2 billion in 2004, with revenues expected to increase rapidly to over $6 billion in 2009.

According to the International Energy Agency (IEA), the cumulative global installed PV capacity total grew by over 770 MW to just under 2.6 GW by the end of 2004, with the vast majority (94%) of this growth in capacity installed in Germany, Japan and the USA[14].

The Japanese producers Sharp and Kyocera maintain their lead whilst Germany remains the second largest producer of cells and modules. Globally, beside well-established companies such as Mitsubishi Electric, Shell Solar, RWE Schott and BP Solar, there has been an emergence of specific cell or module companies like Q-Cells in Germany.

In the UK the installed PV generation capacity is increasing rapidly, albeit from a low base. A total of 2.3MW was installed in 2004 with the cumulative installed PV generation capacity increased by 38% to 8.2MW.

The PSG consultation examined a number of areas in depth, and accounts are available at www.dti.gov.uk. They include:

- *The photovoltaic value chain*
- *What are photovoltaic cells?*
- *Drivers for future PV technology*
- *Photovoltaics in the UK*
- *PV research and development activities.*

ANALYSIS OF THE UK PV ECO-SYSTEM

The UK photovoltaic eco-system is well-established due to significant government support over the past decade. However, there are indications that volume manufacturing of PV cell systems in the UK could diminish as most production is directed to export markets, weakening the strength of the UK supply chain.

Today, the supply chain is intact despite high-volume cell manufacturing taking place in Germany and Japan. The UK is seen as a strategic base for material suppliers, academic research groups, processing and equipment companies and distributors. Indeed, a number of international companies have research or production teams based in the UK, including Sharp and Romag.

The key issue within the eco-system is the lack of significant end-users, due to the high initial cost of PV systems. The lack of a sufficient home market (beyond that stimulated by UK

government programmes) means the UK PV industry might find it difficult to compete against those in larger markets such as Germany and Japan.

Throughout the consultation process it was highlighted that, in order for the UK PV industry to thrive, a feed-in tariff should be established along the lines of the model used in Germany. Implementing such a model would provide a platform for future generations of PV technology and help create a dynamic and complete UK eco-system.

SWOT ANALYSIS OF THE UK PHOTOVOLTAIC ECO-SYSTEM

The consultation process outlined the key strengths, weaknesses, opportunities and threats to the UK photovoltaic sector.

The UK has an excellent academic research base with strengths in the development of new PV materials and processes including the PV Supergen projects supported by EPSRC. The UK also has expertise in PV manufacturing processes such as depositing thin-film coatings using laser and vacuum deposition techniques. The UK has an international reputation for modern architecture design and expertise in construction and building integrated systems.

However, the UK lacks a global-scale PV industry either in the demand-side or supply-side.

As photovoltaic technology will have little impact on meeting the 2010 climate change targets, it is not prioritised by energy analysts and opinion leaders. But with no significant investment today, PV will not be commercially viable beyond 2025. It is important that PV is included in an integrated long-term UK energy policy.

There are significant opportunities for PV technologies including the university spin-outs researching third generation PV materials that will occur from the current investment cycle in university research. Also, there is a strong commercial case for off-grid PV applications, especially when combined with energy-efficient lighting products such as LEDs. These off-grid applications already show fast returns on investment and will provide niche, early-adopter markets. The opportunity to adopt a feed-in-tariff will significantly spur on the UK PV market and has the possibility of creating a global scale industry as it has done in Germany.

Significant threats include the lack of investment and grant support mechanisms to the PV sector. Furthermore, the material costs for conventional PV cells are increasing, with silicon rising by more than 300% in 2004/5: it is essential that new PV materials are brought to market.

The UK has considerable knowledge and experience in organic materials, printing processes and manufacturing equipment which can be used as an opportunity to establish the future PV manufacturing industry.

STRENGTHS	WEAKNESSES
• Academic research base – materials (PV SuperGen) • Modelling • Quantum well solar cell expertise • Innovative concepts for high efficiency and low cost • Expertise in construction and building integrated systems • Expertise in manufacturing techniques • Global market leader in the UK – Sharp	• Limited scale of industry and supply chain • No future planning for large-scale manufacturing of PV technologies • No strong links between PV academia and industry demand • PV will not meet 2010 climate change targets and is therefore not on the priority technology list • No major UK government support compared to competitors
OPPORTUNITIES	**THREATS**
• University spin-out of new technological approaches and designs for second and third generation PVs • Urgent need to improve eco-friendly electricity supply • Feed-in-tariff adopted across EU for growth • Invest in new and potentially disruptive 3rd generation PV materials (eg; thin film and organics) • Off grid applications (eg; LED lighting in remote applications) • Electronics systems for intelligent controls	• Lack of investment and grants to PV sector • Growth of competition (Japan and China) • Material costs are increasing (silicon 3x in the last 9 months) and being tied into lengthy contracts • Market for established technologies are mature and industry consolidation taking place

SECTOR FOCUS
Industrial Photonics

This account gives an overview of the consultation. It is an edited version of the full consultation report which is available from www.dti.gov.uk.

Industrial applications of photonics are many and varied, including imaging, sensors, laser machining, laser processing, instrumentation, metrology and process control. A significant advance has taken place in the last decade with the introduction of photonic technologies in production processes on the macro-, micro- and nano-scale. The wide application of lasers within industry extends from laser welding in automotive manufacturing through to lithography for creating the very latest microprocessors.

The development of lasers for material processing illustrates the importance of photonics for production and manufacturing, which has seen the market develop from small beginnings 25 years ago to a market worth more than $5 billion in 2005[15]. The UK has a strong laser and laser processing industry covering academic research into high-speed femtosecond lasers through to laser diode design for optical communication and consumer equipment.

Optical fibre sensors also have widespread applications and have stimulated photonic technologies to a considerable extent. The technology of in-fibre refractive index gratings has provided a near-ideal optical fibre component for sensor applications, principally in the guise of a strain-gauge. Most applications at present are in structural monitoring – notably in aerospace composites or in civil engineering infrastructure – but emerging applications within security, medical and healthcare areas are increasingly commonplace.

Conventional imaging and mainstream camera technology are an important area for industrial systems based on machine vision and image processing to provide novel, innovative processes for quality control and automation. The use of cameras to detect photons enables machines to generate digital pictures of objects (parts, features or products) and to derive information to verify processes, perform diagnostic tasks and take automated intelligent decisions. The advantage of machine vision is that it can provide absolute reliability at extremely high speeds. Image processing extends beyond simple machine vision, digital photogrammetry, and feature recognition to techniques that overlap with full-field optical instrumentation, covering structured-light shape measurement, particle image velocimetry and various forms of interferometry - and notably speckle interferometry.

Advanced imaging techniques are applied in very diverse sectors: defence and aerospace, environmental and earth observation, life-sciences, manufacturing, security, and generally in scientific research. A particularly exciting new area is terahertz technology, for example for medical imaging where the generation of the THz radiation is dependent on optical techniques.

The PSG consultation examined a number of areas in depth, and accounts are available at www.dti.gov.uk. They include:

- *Lasers*
- *Non-Laser Diode lasers for industrial applications*
- *Laser Diode lasers for consumer applications*
- *Applications including material processing, medical and instrumentation.*

ANALYSIS OF THE UK INDUSTRIAL AND CONSUMER LASER ECO-SYSTEM

The UK industrial and consumer laser eco-system is well-established with a vibrant academic community involved with both laser development and material processing. The UK academic community is particularly strong in both micromachining and modern macro-machining areas (eg; rapid prototyping, drilling and surface engineering). Academic laser-based research activities have been strongly supported by EPSRC and, since 2000, more than £15m of research grants have been provided to develop novel laser systems.

There is also a strong UK presence of laser equipment manufacturers, predominantly within the non-diode and industrial material processing sector, which is growing. The UK is very well-placed in fibre and diode pumped solid-state (DPSS) lasers which offer a tremendous growth opportunity in the near future.

The laser eco-system analysis indicated there is no significant UK presence of users, but this was based upon the understanding that the majority of UK manufacturers' revenues are from export sales. However, the UK industrial manufacturing user base has great growth potential, though the trend is towards niche high-value, low-volume components. This trend reflects that seen by general UK manufacturing whereby low-value, high-volume manufacturing is sent offshore. Large UK users of lasers - specifically diode types - exist within the telecommunications sector. The telecommunications sector also supports a fairly robust components supply chain within the UK. However; the non-diode laser components supply chain is weak as the majority of components are purchased from outside the UK for cost and/or availability reasons. Overall, the laser eco-system is relatively complete. But future attention should be focused

on supporting initiatives to encourage the widespread use of lasers within UK industry and to provide technology and knowledge transfer mechanisms between the many industry sectors that utilise laser material processing.

SWOT ANALYSIS OF INDUSTRIAL LASER PHOTONICS

The consultation processes identified the key strength, weaknesses, opportunities and threats to the UK industrial and consumer laser photonics sector. This is a large market sector worth nearly $6 billion worldwide each year. The UK has pockets of world-class activities throughout the supply chain from companies such as Bookham Technology, that supplies diode lasers for a variety of sectors including the telecommunications industry; Intense Photonics, which provides laser array modules for the digital printing industry; and TWI, a world-class laser and material processing research technology organisation.

The UK can boast that it maintains significant activity in industrial lasers used for material processing. There are a few well-established international industrial laser companies - GSI Lumonics; Rofin Sinar UK, Oxford Lasers, Exitech; and a number of smaller companies including Litron Lasers, Advanced Optical Technology, and Powerlase.

The number of potential end-users is growing as lasers begin to enable modern manufacturing and material processing within general industry. This can be demonstrated by the increase in laser 'job shops' providing laser processing services to industry. They include Micrometric Techniques and Precision Micro (it is estimated by the Association of Industrial Laser Users, AILU, that there are 320 job shops providing laser services in the UK). Large international manufacturing organisations that use lasers as part of their manufacturing processes are also present throughout the UK including Rolls-Royce, BAE Systems, Corus, BMW and Ford.

There are also companies which specialise in laser processing systems, such as Exitech, Optek and Oxford Lasers, with industrial-based research carried out across a number of universities and at TWI. Attention is turning to higher-precision applications, often generically called 'micro-technology' and incorporating micromachining.

An interesting modern development is the enthusiasm for high-power fibre lasers with their excellent beam quality, reduced size and low maintenance. Southampton Photonics (SPI) is a leader working in this area.

European collaborations in new laser technologies and applications knowledge could be developed through Framework 6 and 7 programmes to establish a lead over North American and Asian-based competitors.

STRENGTHS	WEAKNESSES
• University research base • Diversity of technologies and markets • Highly innovative laser community • Significant laser job shop activity – enables smaller UK manufacturers to make use of the technology • Some leading UK businesses in fast-growing areas such as DPSS, fibre lasers	• Fragmented commercial sector • Only a fraction of relevant research is exploited • Limited presence of major corporate players in the UK • Relatively small sector of high power laser market supplied by UK-based companies
OPPORTUNITIES	**THREATS**
• Instrumentation: biomedical; environmental (compliance and earth observation); security; infrastructure monitoring • Laser material processing: move to higher precision; growing need for clean, accurate, flexible, techniques • Flexibility of laser manufacturing processes ideally suited to 'mass customisation' trend in modern manufacturing • Increased micro-machining applications, (eg; electronics, telecoms, medical) • Growth potential of UK manufactured solid state lasers system • Developing European laser platforms in FP7	• Many non-UK competitors in a better position to exploit • Relative weakness of UK manufacturing industry overall • Shifting priorities for DTI/research council support. • Growth of competition (China and Taiwan)

THE WAY FORWARD
A Discussion Document

This final section of the report covers observations made in the consultation exercise that underpin the six strategic recommendations described earlier.

Effective government and industry stakeholder engagement is essential to ensure the right climate for the photonics industry to grow and prosper. But photonics industry representation currently is very fragmented, resulting in a lack of clear leadership and the critical mass to ensure visibility and influence. Networking in the UK is often poor between government and business, business to business, and between business and the academic community. Consequently there is a lack of effective influence on key policy areas, and a failure to engage effectively with the Regional Development Agencies.

Given the scale of the opportunity before us, this needs to be remedied.

The challenge is to create strategic leadership and management within the UK photonics industry, and an industry-wide alliance with high-quality analytical and leadership skills. We set out below more details of the way forward for each recommendation.

1. Establish an industry/government strategic body to act as the UK voice for photonics and to provide strategic direction to all UK photonics stakeholders

A key recommendation of this report is to establish an industry/government strategic body, the Photonics Leadership Group (PLG), to act as the UK voice for photonics and to provide strategic direction to Knowledge Transfer Networks and other delivery organisations.

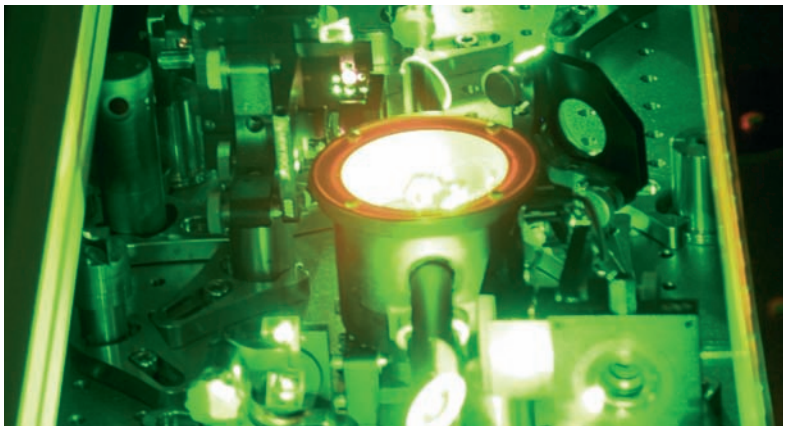
The PLG should be a relatively small but influential body that is business-led on behalf of the whole industry and key stakeholders, with appropriate senior government and RDA involvement. It would set the strategic direction for photonics within the UK, and monitor the implementation of the recommendations of this report. It would initiate work streams for tackling some of the strategic problems identified by the consultation process, and provide the glue to give critical mass to existing activities.

The challenge is to create strategic leadership and management within the UK photonics industry

This group would not displace existing bodies that represent the numerous sections of the photonics community, but bring them together in a co-ordinated and effective manner. The PLG aims need to be agreed at its outset, but could be to:

- Act as the UK voice of photonics through a comprehensive regional, national and international promotional programme
- Develop photonics priorities within the government technology programmes
- Provide strategic direction to UK photonics stakeholders
- Ensure photonics is core to the UK innovation strategy
- Liaise with RDAs to identify and develop a UK-wide policy to support the photonics industry
- Ensure that the photonics industry has influence on policy development.

The PLG would act in a strategic capacity, working with an industry-wide alliance and through existing, and possible future, photonic-related KTNs.



2. Ensure the supply of highly skilled photonics staff

The consultation process highlighted several specific skills challenges . This is a rapidly-changing technology requiring new and updated skills, and attention needs to be given to maintaining employees' proficiency. The advent of organic LED technologies, for example, could bring about more distributed and local manufacturing, making the maintenance of small-scale printing equipment a priority.

Currently, the most pressing gaps are in:

- Top level commercial leadership
- Global marketing and sales
- Intermediate technician skills.

Interestingly, we found that skills requirements varied significantly between regions and this is a challenge that needs to be addressed by the leadership group and the KTNs, working with SEMTA. For example, it is much easier to locate skilled intermediate technicians in the northern regions of the UK than in the south and east.

It is recommended that an education and skills work stream is created within the PLG that can engage and promote the needs of the photonics industry. There is also scope for photonics activities to be incorporated within the electronics skills activities of SEMTA (the Sector Skills Council that covers the electronics industry). Similarly, promoting photonics in the education

sector could initially be linked with existing electronics, physics and engineering curricula. The workstream should consider the following as initial challenges to address:

- The development of a priority outreach programme for promoting photonics as a career, targeted to the next generation workforce via schools, colleges and the general public
- Increasing the number of teachers qualified to teach photonic-related technologies within the 11-16 and 16-19 age groups
- Facilitating student access by aiming to make aspects of photonics a part of the National Curriculum
- Broadening photonic-related training to include intermediate skills, distance learning, short courses and interdisciplinary master courses
- Increasing the awareness of current programmes and opportunities such as Knowledge Transfer Partnerships (KTPs) to stimulate links between academia and industry.

There is also a need to co-ordinate new courses for undergraduate and master level degrees that meet the needs of businesses in the UK for photonics knowledge. For example, there should be foundation degrees that allow specialisation to happen later. There should also be options available to graduates to access 'conversion' courses to enable them to move into photonics from other careers.

It was also noted that, in the UK at present, there are very few university-based degree programmes dedicated to photonics, in contrast to the USA where several very strong programmes are thriving. University-based educational activities in photonics in the UK tend to be focussed in host departments, typically physics or engineering. It has been shown that there is a need for enhanced UK activities to integrate photonics in educational programmes at the university level. The development of multidisciplinary courses that cater for high-growth sectors could be given priority, enabling the rapid exploitation of emerging technologies such as biophotonics.

There is also a need to co-ordinate new courses for undergraduate and master level degrees that meet the needs of businesses in the UK for photonics knowledge.

One of the key issues is to get the right balance between technical skills and business skills at board level. It was found that recruitment into the sector comes largely from other photonics companies and, therefore, experience from other business areas tends to be limited. This contributes to a proliferation of traditional management practices and excludes much learning from outside the industry.

There should also be a co-ordinated approach to providing up-to-date information for young people on the many rewarding careers available to them within photonics. The awareness of photonics should take the form of interactive websites, experimental kits (perhaps provided by industry), CDs and DVDs that all feed into a distribution chain of information. The industry-wide co-ordination should lie within the KTNs.

The fragmentation of the UK photonics industry hinders any focus on the most important areas of the market.

There is also a case for developing mechanisms for a more effective 'skills market' for people seeking jobs or with vacancies to fill. This would facilitate recruitment from other EU countries in specialist areas.

3. Encourage newly formed Knowledge Transfer Networks to map UK strengths against emerging market opportunities

The fragmentation of the UK photonics industry hinders any focus on the most important areas of the market. The PLG, with appropriate KTNs or other bodies, should review the evolution of the market for photonic products and work to steer the development of infrastructure, academic programmes and available skills so as to optimise the opportunities. Whilst this will require decisions about likely 'winners', the indications are that it is broadly clear where high growth is most likely to occur.

The information from this exercise will be distributed to industry and academia, with workshops held to address the opportunities presented, for example, by teaming between companies and academic groups.

4. Raise the profile and promote the depth and breadth of UK photonics excellence

Photonic products are everywhere today, and photonics understanding and expertise is likely to be required in an increasing range of industries within the next decade. However, the relevance of photonics in the UK is considered marginal by many of the important stakeholders.

The lack of perception of photonics is not only a constraint to the recruitment of qualified young people, but also obscures the advantages that photonics brings to the general public. It is important to develop initiatives to promote the importance of photonics to areas including quality of life and the protection of the environment. There are many excellent examples of how this could be developed – explaining how the use of photovoltaic solar panels, for example, reduces dependency on fossil fuels.

There are also opportunities for the UK to work with photonics users and producers in other countries, and it is

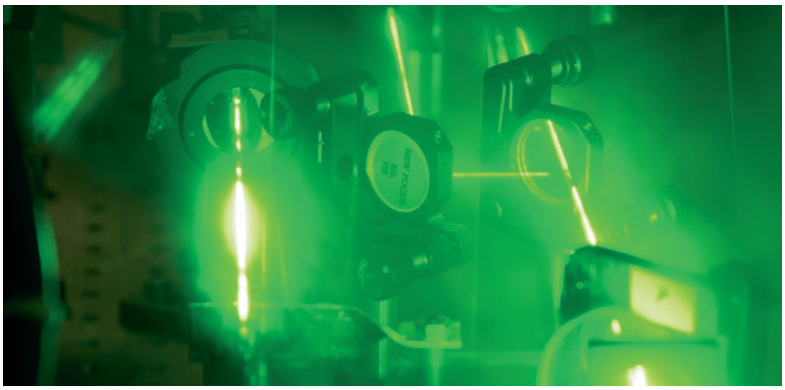
recommended that the UK should build upon its strength in photonics R&D, design and finance to develop strategic alliances with groups overseas. The KTN should also work with government to ensure that routes to international markets are optimised so that UK photonic innovations are designed into new products.

Raising the awareness of photonics within the finance community is another priority. Capital investment is an important driver of productivity and competitive advantage, and also helps provide supply chain opportunities. The UK saw large investments in consumer electronics in the 1980s, semiconductors in the 1990s, and IT hardware in the run-up to the millennium. Photonics is possibly THE opportunity of the current century.

5. Ensure that the UK remains an attractive location to support existing photonics activities and to attract global photonics organisations

The PLG will engage with government to address issues of taxation, planning, support and infrastructure. The UK is considered less attractive than it was by investors. The main deterrents are higher employment costs and fewer fiscal incentives than in some economies in the Far East and Eastern Europe. Conversely, UK R&D is highly valued by the foreign inward investors and many intimated they would still invest in UK R&D.

To address these and other concerns, it is recommended that the KTN should engage with public-funded Regional Venture Capital Funds and other finance investors to establish the needs of the financial investor community. It should develop a programme of activities to connect them with suitable investment-ready photonics companies throughout the UK.



The trend to devolve government support to the regions is a significant opportunity for the industry, but many photonics companies claim they are not gaining benefit. The majority of the industry representative associations do not have the resources to engage effectively with all the RDAs, and so photonics is excluded from regional innovation strategies. Advantage West Midlands and the devolved administrations in Scotland and Wales are more effectively engaged with the industry through specific clusters, however. But these clusters have suffered in recent years as a consequence of the telecommunications downturn and the transfer of manufacturing overseas.

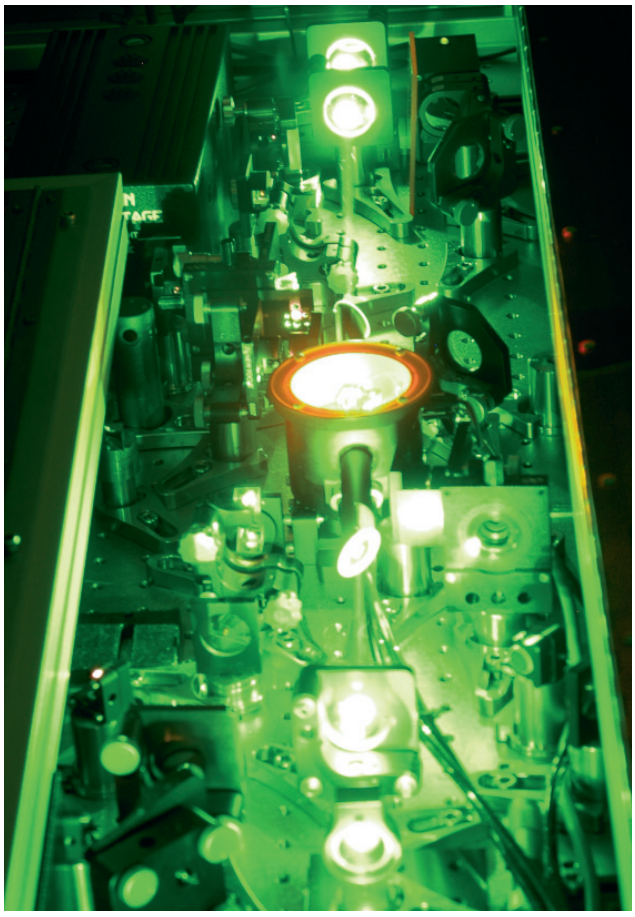
The photonics community welcomed the Technology Programme initiative, and many companies commented favourably on the reduced paperwork required and reduced time for successful funding to be announced.

The situation was in marked contrast to views on EU programmes which were seen as having high levels of bureaucracy and administration, and low success rates. It was also felt that European funding was prejudiced towards large companies to the detriment of small, innovative photonics companies. Worryingly, it was reported that UK academic establishments are engaging in EU programmes much more than UK industry, which results in net technology transfer out of the UK.

The KTNs should therefore provide a 'connect Europe' service for UK SMEs wishing to find network partners in European programmes, and it should encourage government to provide more support to enable UK companies to access EU Framework programmes as well as work to persuade the EU to simplify and streamline it's application process.

There was broad support for the formation of the European Photonics21 technology platform that aims to address future research requirements from a European perspective. It is recommended that the KTNs should be actively engaged with the programme to represent the interests of the UK photonics community.

R&D tax credits were strongly supported by the photonics industry in general. They encouraged companies to increase investment in more basic and applied research and experimental development, and they provided the



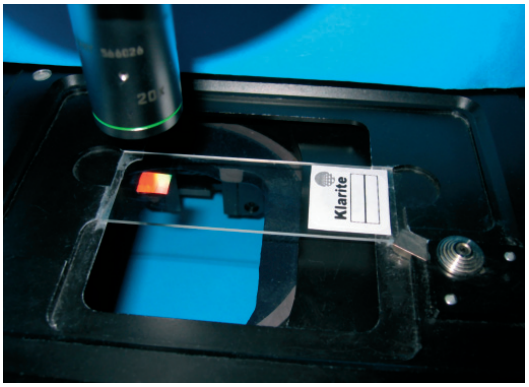
motivation to pursue riskier R&D projects. There were concerns, however, about the lack of awareness of the scheme, of the difficulty of getting advice on submitting claims, and on the limits of what could be claimed – no expenses for patenting or intellectual property rights, for example.

6. Identify a series of aspirational photonic 'grand challenges' to develop innovative solutions based on future market requirements

Some mechanisms are required to avoid the 'chicken and egg' syndrome whereby markets are not considered attractive until they have emerged, by which time it is too late to enter them. One mechanism that has been used, for example by the US Defence Advanced Research Projects Agency (DARPA) is to issue a 'Grand Challenge'. This comprises a target performance specification and a substantial prize for groups that can demonstrate their achievement of it. The result has been multiple R&D activities which, in aggregate, deliver far better value-for-money for the public purse than traditional support schemes. Photonics is ideal for this approach, with possible challenges in high-efficiency lighting, solar cells, security and bio applications. The PLG should suggest suitable targets.

More generally, public procurement is a significant market opportunity for photonics companies, particularly in health, defence and security, transport, public administration and education. Public policy relating to terrorism, sustainability, crime, identity theft and sustainable communities also offers significant potential.

The consultation exercise revealed that nearly all of the companies engaged had little or no experience of dealing with government procurement departments and other public bodies. However, many companies reported a significant negative perception of public procurement, seeing it acting as a barrier rather than a catalyst to innovation. Public procurement should be one of the future work streams of the PLG which would lead to an engagement with the main procuring departments for photonics. Procurement and technical strategy road maps should be created by all government departments, and pilot task forces developed for new procurement opportunities. This should lead to improved understanding of the potential of new technologies for the public sector and support for developers. The government should allocate a percentage (say 2 – 4%) of its procurement budget for technology development.



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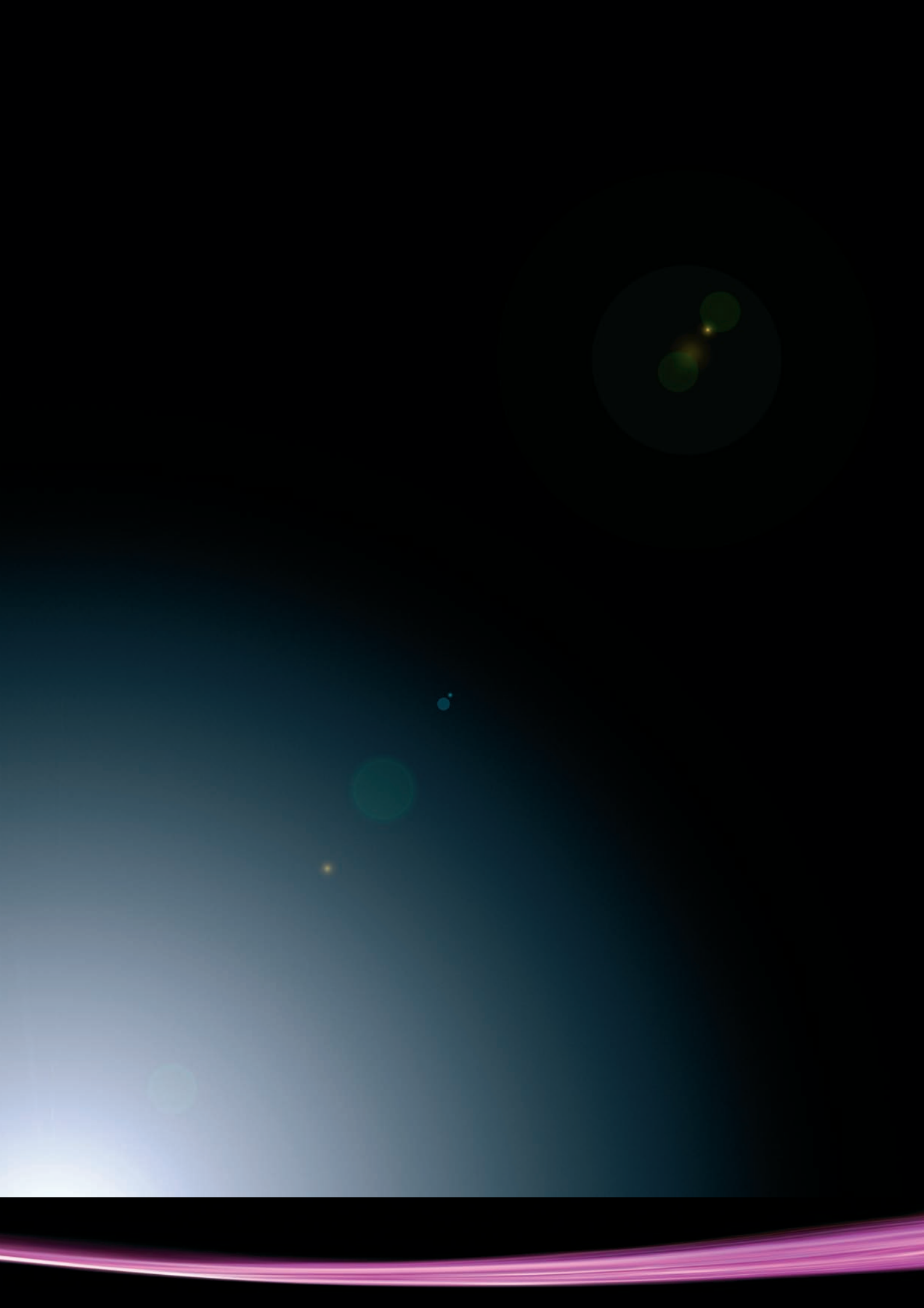

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