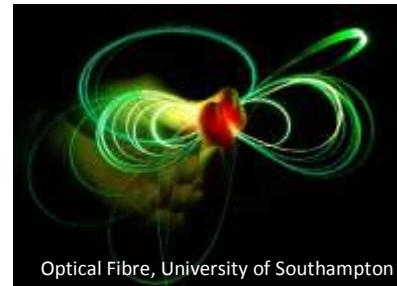


## UK Photonics

# Future Growth Opportunity Roadmap

### Introduction

The major opportunities for future growth within the UK photonics sector are identified within this report. Areas are highlighted where the UK can be an international leader in significant markets and what should be done to maximise these opportunities. This report acts as a guide for developing and reaffirming business and investment strategy, research direction and partnership development by providing guidance on the 3 key questions of:-



- 1. Where is UK photonics growth coming from?**
- 2. What strength have we got in the area to build on?**
- 3. What action essential to make growth happen?**

The initial basis for this analysis has been the European Multiannual Strategic Roadmap for Photonics “Towards 2020-Photonics Driving Economic Growth in Europe” compiled by Photonics21<sup>1</sup> from which opportunities of particular relevance to the UK are clarified and linked to core UK strengths.

UK photonics produces ~£10.5bn output from 15000 firms as such is already a significant international supplier and innovator of photonics solutions with unique strengths operating in a distinct business environment. Thus there are additional growth opportunities for the UK that do not appear in the broader European analysis that are also identified here. The Security and Defence domain, in particular, has been subject to bottom-up analysis based on interviews with UK suppliers, integrators and end users in this domain.

Actions to make the most of these key UK growth opportunities are identified. In some cases these are UK specific actions, others refer to maximising participation in EU programs. In all cases they require active and collaborative engagement by a combination of industry, investors, support and research organisations to create the critical momentum in the various supply chains. Just as the Photonics21 roadmap is informing investment by the European Commission via Horizon2020, this report aims to inform the direction of UK investment by organisations throughout the UK innovation chain.

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<sup>1</sup> [http://www.photonics21.org/download/Brochures/Photonics\\_Roadmap\\_final\\_lowres.pdf](http://www.photonics21.org/download/Brochures/Photonics_Roadmap_final_lowres.pdf)

As an underpinning technology, photonics enables advances in many end markets and applications in a highly globalised industry- most UK photonics companies export 75-95% of their output. The opportunities identified in this report therefore address significant global markets. Fully exploited, they will lead to significant growth both in the UK's £10bn photonics industry and to in the many industries enabled by photonics, leading to substantial manufacturing based employment, GDP and export growth.

Opportunities for UK Photonics are summarised in following 6 tables representing the major photonics sectors of:-

1. **Optical Communications**
2. **Manufacturing, materials processing and industrial photonics**
3. **Photonics for Health and Life sciences / Bio-photonics**
4. **Lighting excluding (Plastic electronics)<sup>2</sup>**
5. **Security, sensing and defence.**
6. **Research, training and education**



For each sector a priority area is identified likely to be the highest impact growth opportunity. This is subject to on-going biannual review by the PLG, whom recommend priority topics for the scoping of support actions. The key area of component development (treated separately by working group 6 at photoincs21 within Europe) is integrated within each of the 6 key domains above.

Examples of leading UK centres of excellence, including companies and research institutes have been identified with each opportunity. This is not an exclusive list of companies and research groups operating in an area, but intended as a sample only further organisation with particular expertise can be sourced at [www.ukphotonics.org](http://www.ukphotonics.org)

We are extremely grateful to the experts in the Photonics Leadership Group and elsewhere who have contributed their time to this analysis and its further development. In addition, we appreciate the support of the EU FP7 project "InnoPho21" through InnoPho21 partner ESP Central, EPSRC Centre for Innovative Manufacturing in Photonics and EPSRC Centre for Innovative Manufacturing in laser based production processes.

If you would like to input further into this analysis, provide suggestions for improvement and revision or would like further detail in any areas please contact the Photonics Leadership Group at [www.photonicsuk.org](http://www.photonicsuk.org)

## Contact

The Photonics Leadership group at [www/photonicsuk.org/contactplg/](http://www/photonicsuk.org/contactplg/) or [john.lincoln@photonicsuk.org](mailto:john.lincoln@photonicsuk.org)

## Revisions

- First Final version issued 26 February 2015.
- Second revision issued 1 June 2015.

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<sup>2</sup> The [UK Plastic Electronics Leadership Group](http://www.ukphotonics.org) Analysis conduct separate analysis of the Plastic electronics domain.

## 1. Information, Data and Optical Communications

	Future UK Opportunity	Supporting UK Core Strength/Justification	UK centres of excellence	Action(s) Required
Broadband	<p><b>Next Generation Broadband</b> giving Gigabit connectivity will require fibre to within 100m of the end user. Increasing merging of wireless and wired broadband provision based on 4G development and Future 5G</p> <p><b>Development of Radio on fibre</b></p>	<p>Smaller cell sizes for 4G and 5G will require closer integration of fibre and wireless infrastructure</p> <p>UK has well established mobile networks development centres..</p> <p>UK universities and specialist companies have world class skills in radio over fibre vital for future 4G and 5G for base station front-haul and back –haul</p>	<p>Huawei, Vodafone</p> <p>Bristol, Surrey Uni’s</p>	<p>Skills training in installation and maintenance of optical networks. Involvement in future standards generation and European collaborations on 5G.</p> <p>Support research programmes that investigate the cross-over of radio and fibre technologies</p> <p>Increase links to those developing models of future cities.</p>
	<p>Growth in Data Centres, Cloud storage, electronic trading and Financial services.</p> <p>Growth in Big data and data based services.</p>	<p>UK major centre for high speed financial services</p> <p>UK businesses are increasingly dependent on the large data centres and leverage big data. Will require Terabit interconnectivity and high performance optical networking.</p> <p>Key suppliers of cloud storage equipment with manufacturing and design centres in UK</p>	<p>City London trading, Colt telecom, Equinix, Seagate, Xyratex</p>	<p>UK led collaborative research programmes involving operators, service and technology providers to develop higher capacity and energy efficient optical interconnect architectures.</p> <p>Development of next generation of core network technology capable of supporting growth in Cloud services</p>
Data	<p>Quantum information. Major UK opportunity at all points in supply chain</p>	<p>Significant integrated photonics design and fabrication capability</p>	<p>Quantum hubs</p>	<p>Coordinate quantum technology and integrated photonics investment to ensure full system value can be captured in UK.</p>
Components	<p><b>On chip photonics integration for data centres, fibre to home, quantum computing and high capacity comms</b></p>	<p>Multiple world leading industrial and academic design centres in integrated photonics</p> <p>Significant wafer and chip level fabrication capacity especially in III-V semiconductors.</p> <p>Established export channels to network equipment suppliers globally</p>	<p>Oclaro, Optocap, Bristol, Glasgow, St Andrews, Southampton Uni</p>	<p>Support for collaborative R&amp;D in photonic integration (PICs) e.g. Integrated Silicon and/or III-V photonics.</p> <p>Development of foundry services to maximise use of fabrication assets</p> <p>Support commercial automated/high value packaging approaches compatible with UK manufacturing</p>
	<p>High reliability components &amp; systems for Satellite Aerospace and Undersea communications</p>	<p>UK has world leading capability in manufacture of high reliability components, including undersea, space and aerospace (civil &amp; defence).</p>	<p>Gooch &amp; Housego, ESA, API tech, BAE</p>	<p>Build capability to mission qualify components and systems for aerospace &amp; space</p> <p>Increase academic research into high reliability devices. Support for high reliability packaging R&amp;D</p>
	<p>Growth in use of valued added /Enabling Materials e.g. compound Semiconductors and Metamaterials Silicon / III-V hybridisation</p>	<p>UK major manufacturer of epitaxial wafers for global optoelectronic/ comms industry</p> <p>World leading research in integrated photonics &amp; metamaterials at multiple UK universities.</p>	<p>IQE, CST, Exeter Southampton, Imperial College, , Sheffield, Glasgow</p>	<p>Promote routes for the exploitation and commercialisation of novel materials that capture value in UK whilst fitting with complex global supply chains</p>

## 2. Industrial manufacturing with lasers

	Focus of future UK growth	Supporting UK core strength	UK centres excellence	Action (s) required
<b>Adoption</b>	<p><u>Increased Use of laser based processing by UK industry</u></p> <p><b>Forecasts for significant increase in utilisation of laser processes in manufacturing (e.g. automotive 5-30%)</b></p>	<p>Catapult centre in High Value Manufacturing and EPSRC Centre for Innovative Manufacturing in Laser-based Production Processes</p> <p>Well established national trade association (AILU) for industrial laser users/developers</p> <p>Vibrant engineering subcontract sector, in laser cutting but also welding, marking etc</p>	<p>TWI, Cambridge, Cranfield, Liverpool, Liverpool John Moores, Manchester, Heriot-Watt Unis</p> <p>M-Solv,</p>	<p>Raise awareness of laser process with UK manufacturing community via Manufacturing advisory services (MAS) etc</p> <p>New method for funding the adoption of laser processes that substantially increase efficiency of established manufacturers</p>
<b>Manufacturing efficiency</b>	<b>Laser based additive manufacturing</b>	<p>UK suppliers of laser based additive processing equipment. Early adoption by UK aerospace, Funding for additive processing for aerospace at High Value Manufacturing catapult.</p>	<p>Renishaw, BAE, Airbus, Liverpool, Birmingham, Cranfield, Heriot-Watt Unis</p>	<p>Support for additive processing developers to develop systems jointly with UK lasers manufacturer.</p> <p>Laser post-processing (machining, polishing)</p>
	<b>Joining of dissimilar materials</b>	<p>Strong and growing aerospace industry with requirement for joining dissimilar materials</p> <p>UK is major automotive manufacturing location and this industry requires expertise in joining of dissimilar materials</p>	<p>BAE, Airbus, TWI, Cranfield, Heriot Watt Unis</p>	<p>Simplification of the technology transfer of laser welding processes</p> <p>Research into joining dissimilar materials e.g. dissimilar metals, metal to glass.</p>
	<b>Short pulse materials processing</b>	<p>Long established knowledge base in short pulse laser material interactions</p>	<p>Oxford Lasers, PowerLase, M-Solv, Oxford Lasers, TWI/ Cambridge, Liverpool, Heriot Watt Uni</p>	<p>Increased support for developing and characterising <u>industrial</u> processes using short pulses e.g. surface modification</p>
	Surface processing /modification	<p>Extensive metrology expertise</p> <p>Machining of optical surfaces</p> <p>Modification of surface properties – friction, wetting</p> <p>Marking and engraving</p>	<p>HVM Catapult, Powerphonic, SPI Lasers, M-Solv</p> <p>Heriot-Watt, Liverpool Unis</p>	<p>Integrated systems development</p> <p>Applications-specific research</p>
	<b>Laser processing of composite materials e.g carbon fibre</b>	<p>Vital for next generation of automotive and aerospace manufacturing</p>	<p>Liverpool John Moores Uni</p>	<p>Identify key processing challenge with user groups.</p>
	<u>Laser welding</u>	<p>Long established UK knowledge base</p> <p>Applications in aerospace, automotive, nuclear, ship-building</p>	<p>MTC, TWI, Rolls-Royce, Airbus, Cranfield, Manchester Unis</p>	<p>Development of new applications</p> <p>Removal of 'black art'</p>

	Focus of future UK growth	Supporting UK core strength	UK centres excellence	Action (s) required
Lasers and laser components	<p><u>Ultra-short pulsed, high power high repetition rate lasers</u></p> <p>Flexible lasers (e.g multi-colour, pulse / colour tuneable)</p>	<p>Large number of UK laser manufactures with strong exports. Strong laser research in multiple institutions Significant UK capacity in laser components from coatings to specialist optical fibre to modulators</p>	<p>Coherent, Fianium, Gooch Housego, Litron, Powerlase, Rofin-Sinar, SPI Lasers, TWI</p> <p>Bath, Cambridge, Heriot- Watt, Liverpool JM, Southampton Unis</p>	<p>Long term backing for Centres developing industrial lasers and laser industrial processes.</p> <p>Research into ps/fs &gt;1kW laser and new approaches for ultrahigh power lasers</p> <p>Develop new volume processes for manufacturing laser systems themselves (laser industrial working group?)</p>
	<p>Coatings and components for high power / high intensity laser beam.</p> <p>Laser arrays, multiple fibre arrays</p>	<p>Globally leading suppliers of laser components. Multiple specialist optical coating suppliers.</p> <p>World leading fibre laser research</p>	<p>Artemis, Gooch and Housego, Qioptiq, Bath, Southampton Uni</p>	<p>Research into alternative approaches for beam combination and steering.</p> <p>Development multifunctional coatings</p>
Beam Delivery	<p>Beam patterning using spatial light modulators</p> <p>High speed scanning systems</p> <p>Fibre delivery for high power and/or IR / UV ultra-short pulses</p>	<p>Several UK companies specialising in integration of robotics and beam delivery. Gooch &amp; Housego are global leading supplier of acousto-optic modules.</p> <p>World leading research in speciality optical fibres and spatial light modulators</p>	<p>Gooch &amp; Housego, Isomet ULO optics, Edinburgh, Heriot Watt, Bath, Southampton Uni</p>	<p>Research into alternative approaches for beam combination and steering.</p> <p>Development of new fibres for beam delivery</p> <p>Development of acousto-optic deflectors and spatial light modulators.</p>
Quality control & automation	<p>Precision measurement to increase manuf. efficiency</p> <p>Multimodal sensors combining sensing techniques &amp; multi/hyperspectral imaging.</p> <p>Combination of laser technology with online non-destructive testing</p>	<p>Strong UK machine vision capability integrating imaging chips into control and monitoring systems</p> <p>Photonics hardware development combines well with UK strength in embedded systems and automated image processing</p>		

### 3. Photonics for Health and Life Sciences

	Focus of future UK growth	Supporting UK core strength	UK centres excellence	Action (s) required
Health	<p><b>User friendly mobile point-of-care equipment using light to detect and/or monitor disease / patient condition with, high sensitivity, accuracy, reliability and speed</b></p> <p>Improved, safer and personalised treatment (therapy and monitoring) and <b>highly targeted therapies</b> e.g target photo dynamic therapy</p> <p>Non-invasive people centric solutions</p>	<p>Depth of expertise in techniques</p> <p>Major academic and industrial strength in Raman and other spectroscopic techniques applied to diagnostics</p> <p>Strength of medical device design industry with numerous hand held point of care device designs</p>	<p>Zilico, Renishaw Diagnostics, Uni Exeter, Strathclyde, St Andrews, Southampton, Swansea, Heriot Watt</p>	<p>Involvement of NHS, bringing clinical, life science and/or medical physics and photonics communities together</p> <p>Lab on a chip not chip in a lab.</p> <p>Improved links to chemical sensing</p> <p>Better integration of the development of life science solutions with high value manufacturing (see HVM in healthcare roadmap, HealthKTN)</p> <p>Improved connectivity to design consultancies developing instruments for healthcare.</p>
	<p>Development of multiband photonic <u>imaging</u> methods to analyse age and life-style related diseases<sup>3</sup> allowing clinician/patient to make informed decisions. Must be either label-free or use already safety- approved labels</p>	<p>Biological imaging research</p> <p>Major academic and industrial strength in optical coherence tomography and biological imaging research</p>	<p>Michelson Diagnostics, Aurox, Zilico</p>	
Life Science	<p><b>Next generation of Biophotonic tools to understand the origin of diseases.</b></p> <p>Solution to efficiently developing and supplying photonics technology to the large number of subtly different (niche) life science applications, e.g. one light source for multiple instruments</p> <p>Photonics tools for online process control of drug manufacture</p> <p>Photonics instruments for quality control and counterfeit drug protection</p>	<p>Extensive track record in supplying bioinstrumentation</p> <p>Very strong pharmaceutical and biotechnology presence in the UK</p> <p>UK research groups have pioneering numerous photonics techniques to understanding of biological systems.<sup>4</sup></p> <p>Extensive supply of lasers into life science instrumentation</p>	<p>UK Pharmaceutical research sector</p> <p>Coherent Scotland, Fianium, Laser Quantum, M Squared lasers</p> <p>Swansea, St Andrews, Strathclyde</p> <p>Southampton, Imperial, UCL Uni</p>	<p>Greater collaboration with big pharma research, therapy and manufacture, to match photonics capability with need e.g.</p> <ul style="list-style-type: none"> <li>• New process analytical techniques for improving drug manufacture</li> <li>• New techniques for rapid screening drug candidates</li> </ul>
Food	<p>Lower-cost and faster methods to control water and food safety/ quality. E.g spectroscopic techniques.</p>	<p>Experience in hand held device development</p>		<p>Involvement of medical device manufacturers, pharmaceutical industry can clinicians</p>

<sup>3</sup> Age and life-style diseases refer to conditions that increase in prevalence with age or life style choices, e.g, diabetes, many cancers, coronary conditions, eye disease etc.

<sup>4</sup> Examples include Fluorescence Lifetime Imaging Microscopy (FLIM), confocal and multi-photon microscopy, Fluorescence Resonance Energy Transfer (FRET) and Stimulated Emission Depletion (STED) techniques

#### 4. Lighting including solid state LED lighting (also see analysis from PELG)

Future UK opportunity		Supporting UK core strength / justification	UK centres excellence	Action (s) required
LED and OLED's	III-V nitride materials and devices: Lower cost manufacturing processes and materials - substrates, epitaxy, devices Improved high power, high efficiency LED device structures	Substantial UK cluster of institutes and companies specialising in GaN materials, fabrication, design, characterisation, & manufacture Growing market for GaN in RF power electronics & laser diodes	IQE, Plessey, Bath, Cambridge Uni	Access to affordable finance required, to grow capital-intensive volume manufacture opportunity. Leverage strong UK defence industry applications for low defect, high-power devices. Increase awareness of LED properties, strengths and limitations within UK lighting industry.
	Test and Measure Instrumentation for: LED wafer/ device manufacture and luminaires / lighting systems Certification / standards enforcement	Existing UK base of instrumentation manufacturers and test and measurement services companies. New standards for solid state lighting		Representation on relevant standards bodies. Support for development of novel test and measurement equipment and services. Improved standards enforcement
	Enhanced Organic light-emitting materials with better efficiency, colour, stability, reproducibility, Materials and manufacturing processes enabling OLEDs to be price-competitively	UK and EU has invested substantially in OLED materials and manufacture processes. Globally recognised strength in architectural creativity	Cambridge Display Tech, Plasma Quest,	Identify and support leading core research particularly in materials chemistry and hybrid systems. Close monitoring of potential OLED lighting market Support from UKTI, BIS, SDI, etc to promote UK IP to overseas stakeholders in existing markets.
Light fixtures	<b>Innovative designs of LED luminaires based on replaceable fixtures</b> Thermal management of packaged LEDs in luminaires Materials for effective light extraction and control from luminaires	UK lighting industry includes several large, multi-national companies and SMEs leading in solid state lighting. UK has a global reputation for lighting design to be leveraged by luminaire and lighting systems manufacturers.	Photon Star, Zeta	Grow market by raising awareness of the benefits of SSL. Support and facilitate cross-supply chain engagement. Support education and training in engineering and manufacturing skills Seed fund technical problem solving activities in SME sector. Encourage collaboration with academic research institutes.
Systems and control	Intelligent control of lighting systems including self-learning and integration with building control systems Integration with PV, renewable energy sources & DC networks Integration with city wide networks <b>Human Centric Lighting: health benefits of controlling the lit environment</b>	Strong UK base of companies and research in photonic sensors and electronic drivers UK has a global reputation in structural engineering, architecture and commercial building design and construction.	Photonstar, Zeta,	Higher up-front costs will require access to investment capital. closer involvement of several industries across the value chain, e.g. architecture, construction, building management, power generation. Leverage state-owned infrastructure (government buildings, NHS, schools, etc), validation and drive market uptake. Increase understanding of human response to LED lighting
Visible light comms	Fast-switching LEDs, sensors, components, systems and systems integration	UK photonics research in Li-Fi components and systems is currently world-leading.	PureLiFi, Edinburgh Oxford, Strathclyde Uni, Fraunhofer CAP	Develop roadmap for this emerging market and identify priority applications and stakeholders Support from UKTI, BIS, SDI, etc to engage global stakeholders

## 5. Security, Sensing and Defence

	Future UK Opportunity	Supporting UK core strength/ Justification	UK centres excellence	Action (s) required
Imaging	3D ground mapping and obstacle avoidance. Depth profiling for long range target interrogation. Active 2D and 3D <b>LIDAR</b> imaging using high repetition rate, low pulse energy lasers Synthetic aperture LIDAR techniques for high resolution at extreme ranges	Leading UK defence manufacturers of laser imaging, range finding and designation. Large number of UK laser suppliers including expertise in tuneable systems. Expertise in single photon detectors and imaging systems for depth and range profiling Established Quantum Enhanced Imaging Hub Exploitation route for low-light level, Geiger mode arrays across visible, NIR and SWIR and MWIR.	Coherent Scotland, GSS, Laser Quantum, M squared lasers, Optasens, QinetiQ, Selex ES, Thales. CENSIS, Cranfield, Glasgow Sheffield, Heriot-Watt Unis	Focus on solutions with improved size, weight, power consumption and cost (SWaPC) Dual waveband lasers for imaging and designation, improved low cost eyesafe lasers, Beam and sight-line steering/ stabilisation. Improvement in data acquisition rates to support identification of threats Precision timing and range measurement for coherent signal combining. Chip-scale atomic clocks.
	Larger format thermal imaging <b>cameras</b> operating at > 200K with reduced SWaPC Thermal imagers with minimal cooling requirements.	Manufacturing capability in IR detectors especially high operating temperature (HOT) arrays for the MIR.	Selex ES, Thales, Qinetiq Malvern, III-V National Centre, Glasgow Sheffield Unis	Research in detectors at 200 Kelvin. Address trade-offs between pixel counts and need for real time comms for autonomous systems. Greater engagement with III-V National Centre to transfer detector research to development.
	<b>Detectors</b> for discriminative imaging with wide band spectral response and functionality (polarisation, avalanche gain and spectral response)	Established research community for III-V semiconductors. UK capability in “imaging chips”, ranging from advanced CCD/CMOS technology to comprehensive IR detector activity for both passive and active imaging systems.	E2V, EWS Simulation, III-V National Centre, Glasgow Sheffield Unis.	On chip polarisation for visible NIR. Avalanche diode inc. SPAD arrays. For VIS, NIR and SWIR. Need to be cost effective and a suitable size. High power, high sensitivity wide bandwidth detectors for RF applications. Extend fabrication capabilities to enable manufacture of sensor arrays to allow exploitation by camera manufacturers.
	<b>Lens-less</b> or compact imaging approaches for improved identification	Coded aperture imaging for improved depth of field, non-mechanical focusing and lensless, compact imaging	QinetiQ, Quantum enhanced Imaging Hub, Glasgow Uni	Enhance availability of bespoke optical components eg spatial light modulators.
	Low light <b>CMOS imaging arrays</b> ( Vis and NIR)		E2V	Develop low light imaging arrays inc. RGB
	Hyperspectral Imaging	Multiple demonstration developments but technology has yet to be fully established in defence systems	BAE Systems, Thales and QinetiQ G&H	compact approaches that do not degrade resolution and sensitivity performance.



	Future UK Opportunity	Supporting UK core strength/ Justification	UK centres excellence	Action (s) required
<b>Multi-functional systems</b>	Broadband optical systems combining multiple sensors and laser wavebands for operation in complex environments.	Defence and non-defence companies with capabilities in integration of sensors and lasers across wide range of wavelengths. Reduction of free space optics with waveguides and optical routing and spectral beam combining for SWaP advantages.	Qioptiq, Selex ES, Thales	Dev. of multi waveband detectors, optical materials / coatings. Understand benefits of sensor integration (including advanced processing algorithms) to enhance capability whilst reducing No. of apertures and cost
	Multi-band Infrared and laser countermeasures	Leading UK defence manufacturers of laser range finding, designation and counter measures. Large number of UK laser suppliers with expertise in tuneable systems.	Qioptiq, Selex ES, Thales, QinetiQ, Laser Quantum, M squared lasers. CENSIS, Cranfield, Glasgow Uni	Needs market pull by defence agencies. Improvements in SWaPC required to increase deployment. Fibre lasers may enable more applications cost effectively with suitable integration.
	Remote gas, liquid, solid & perimeter sensing / characterisation. Laser vibrometry for discrimination of decoys	Several manufacturers of gas/liquid/perimeter detection equipment using photonics for identification and quantitative assessment of target material. UK equipment in front line deployment at boarder locations	Cobalt Light, GSS, M squared lasers, Optasens	Improvement of coherent laser technologies required for vibrometry to increase capability.
	Exploitation of metamaterials	International leading research in metamaterials	De La Rue, Southampton, Imperial College, Liverpool John Moores, Exeter	Identify benefits for defence and security community.
<b>Materials</b>	Laser materials, optical fibre and components at eye safe wavelengths (>1.5um)	Broad strength in glass material research in UK	Thales UK, Gooch & Housego, Glass Technology Services Leeds, Nottingham & Southampton Unis	Development UK Capability in doped phosphate glasses for eye-safe laser operation. Focus on taking research capability to industrial production
<b>Lasers &amp; Sources</b>	Development of indigenous high power multi-band IR / MIR lasers/ band shifting	Several users of cascade lasers but no UK Quantum Cascade Lasers QCL manufacturer. Multiple fibre laser manufactures and extensive IR laser and fibre laser research	CST, IQE, GSS, Cascade Technologies, M <sup>2</sup> Lasers, Selex ES National Centre for III-V, Southampton, Sheffield Glasgow, Heriot-Watt Unis	Develop UK source of quantum cascade lasers. development of greater range of high efficiency eye safe laser sources (power, rep rate, wavelength, pulse width)
	Microwave / TeraHertz frequency generation and detection techniques	UK has internationally leading strengths in terahertz (THz) science and technology,	e2v, TeraView, QinetiQ , QMC Instruments.	Ensure exploitation of UK leading strengths in this area. Innovate UK and CDE joint support to move technology to higher TRL levels.
<b>Other</b>	Integrated Photonic components for high speed communications & sensing Optical arbitrary waveform generation	Wide applications in defence, security and comms market	API Tech, EWS simulation, Gooch and Housego, Oclaro, Fujitsu UK Southampton Uni, National Centre for III-V	Partnership with companies developing integrated components for the telecom data market.

## 6. Research and Education

	Focus of future UK growth	Supporting UK core strength	Action (s) required
<b>Science and Research</b>	<p>UK has a world class science and research base in at least three disruptive research fields that offer step change improvements in a range of applications:</p> <ul style="list-style-type: none"> <li>- Nanophotonics (sensing, imaging, energy generation)</li> <li>- Quantum optics and quantum information (computing, secure communications, imaging)</li> <li>- Extreme light (sensing, imaging, material characterisation and processing, advanced manufacturing)</li> </ul>	<p>EPSRC has made large scale investments in photonics including the three disruptive research themes</p> <p>UK investment of £270m in quantum technologies.</p> <p>Multiple UK companies have active interest/investment in disruptive research topics.</p> <p>Often requires skilled intermediary (Catapult, Fraunhofer,</p>	<ul style="list-style-type: none"> <li>• Continue to <b>Generate awareness of collaborative research opportunities including EU and UK support mechanisms, to academia, large and small industry scale industrial players.</b></li> <li>• <b>UK Symposia/ roadshows in target research areas to focus UK communities and help UK industry identify the opportunities.</b></li> <li>• UK engagement with EU Extreme Light Infrastructure development (ELI)</li> </ul> <p>Increase UK industry investment commercialisation of low TRL research into products. Focused support for SMEs e.g removing barriers to start-up and increase access to risk capital.</p> <p>New collaboration models and better use existing models for SMEs to engage with academia (Catapults, Hubs, CDTs, Fruanhofer, innovation vouchers etc)</p> <p>Increase flexibility in commercialisation/license arrangements from Universities, particularly toward the needs of SME's ('Kite mark' for the best?)</p>
<b>Education and training</b>	<p>Growing demand for photonics skills at all levels from management to assembly to R&amp;D. Significant demand for photonics training for none technical staff, e.g. operations, legal manufacturing,</p> <p>More integrated approach linking training provision to market/industry demand for skills e.g vocational training in hi-tech 'clean' manufacturing.</p>	<p>Large number of UK universities offering undergraduate and postgraduate courses in photonics.</p> <p>Centres for Doctoral Training incorporating photonics</p>	<p>Increase awareness of the role photonics plays in our lives.</p> <ul style="list-style-type: none"> <li>• Accessible stories into press</li> <li>• Outreach to undergraduates and schools highlighting career opportunities in photonics in collaboration with IET/IOP/IEEE/OSA, ILU &amp; STFC</li> <li>• <b>UK industry to provide examples of career opportunities /role models</b></li> </ul> <p>Develop a UK industrial perspective on training needs</p> <p>Increase the photonics content in non-photonics specific courses</p> <p>Ease restrictions on employing none EU nationals with specialist Engineering skills and/or increase number of UK/EU Engineering graduates.</p>
<b>Infrastructure and facilities</b>	<p>Increase access for companies to University and publically funded facilities</p> <p>Further increased open access to large scale facilities hosted in the UK and Europe.</p>	<p>A number of large scale facilities are hosted and or operated from the UK and scheduled for further development e.g. Diamond light source, km square array</p>	<p>Increase awareness within vertical application markets of opportunities for working with large photonic facilities.</p> <p><b>Develop a UK "map" of photonics facilities and expertise extending recently launched National Photonics portal <a href="http://ukphotonics.org">ukphotonics.org</a></b></p> <p>Reach into specialist Engineering firms, consultancies and catapults so they know where to source for photonics knowledge / facilities</p> <p>Fully leverage large scale European facilities e.g Silicon foundries</p>
	<p>Large format optics and imaging systems for satellite imagery, science and space</p>	<p>Track record in supplying large scale scientific projects, e.g. EELT. Expertise in polishing / metrology of large optics through EPSRC IKC Ultra Precision and Structured Surfaces.</p> <p>Established commercial expertise in satellite imagery</p>	<p>Capability for processing optics &gt;1m diameter vital for the UK for applications in satellite communications, space and science.</p>