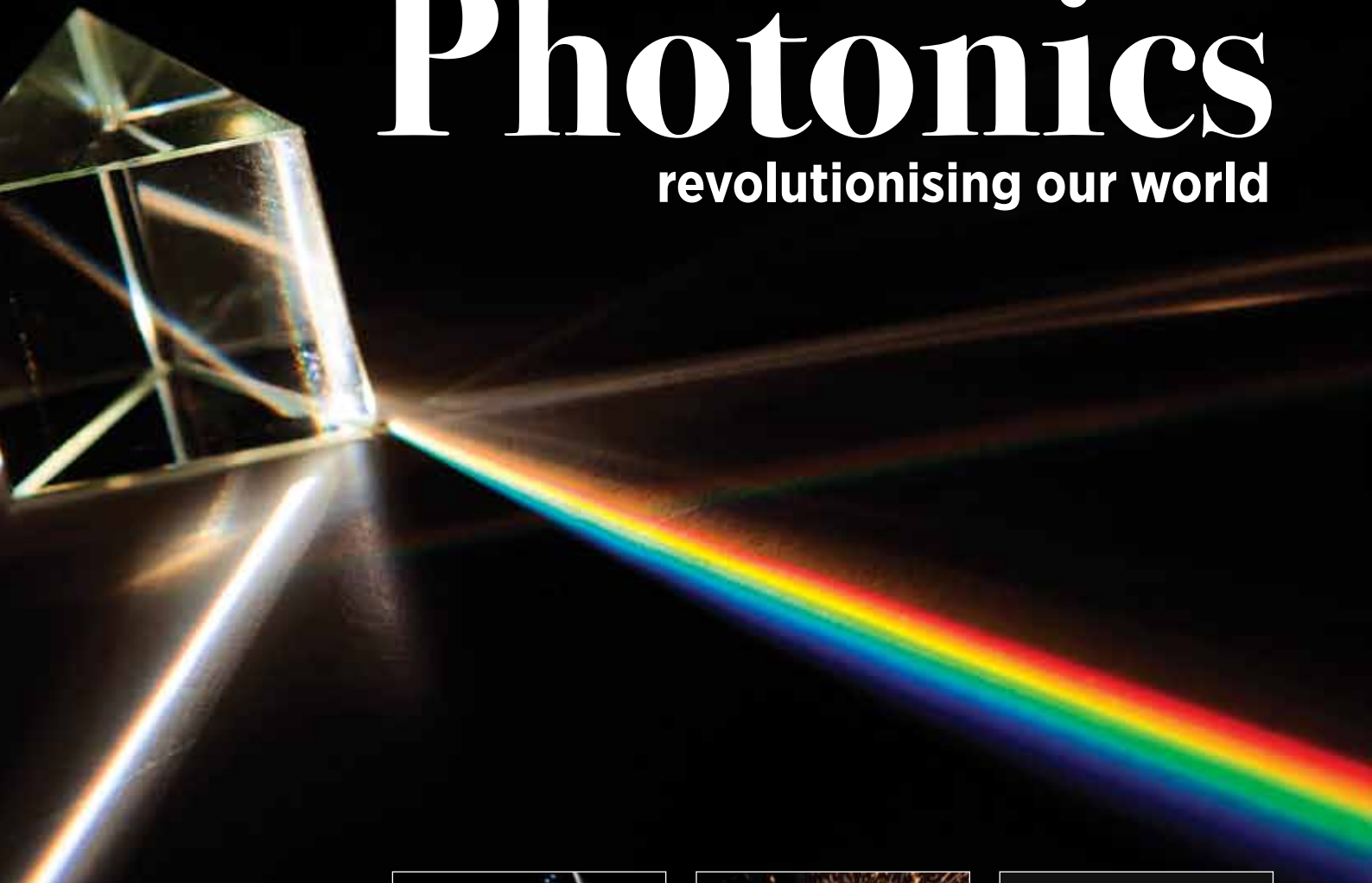


# Photonics

revolutionising our world



Transport

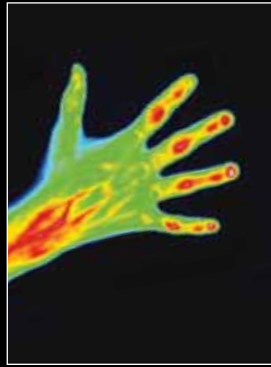


Manufacturing



Healthcare

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With a wealth of startup activity fuelled by a steady upward trend in investment, OCT is one of the most exciting and fast growing technologies in the life science sector.



### **Faster and leaner: laser car manufacturing**

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### **The UK's Robotcar challenge to Google**

Oxford University Robotics Professor Paul Newman firmly believes that the UK could have a major role in producing affordable autonomous vehicles.

## **Contributors**



### **Lead author: Adriana Hamacher**

Adriana Hamacher is an award-winning writer, seasoned web content editor and BBC trained broadcast journalist and producer. She has written, produced and presented reports on subjects from technology to techno, for outlets including the Discovery Channel, BBC World and IPC Magazines.

Exploiting a talent for making technology enjoyable as well as edifying, she's worked on a number of tech-inspired brochures for ESP KTN. Her regular blogs – on ICT, robotics, energy harvesting, human-computer interaction, design, energy efficient and high performance computing – can be found on the Technology Strategy Board's \_connect platform.



### **Author, Photonics in Healthcare: Grainne Jordan**

Grainne Jordan is a journalist who has written extensively about innovation and investment in healthcare and the construction industry. She has also

produced documentaries for the BBC, ITV and Channel Four on subjects as diverse as the pros and cons of the surveillance society and the music of Inspector Morse.



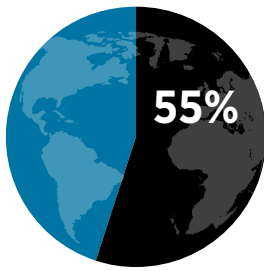
### **Design: Steven Randall**

Since establishing ocean-design.com in 1996, Steven has produced ground-breaking reports, magazines and brochures for a wide variety of clients in the public and private sectors – and

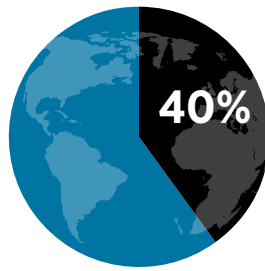
has won multiple industry awards for his signature creativity. His clients include British Gas, Engineering UK, Eli Lilly UK, BMW (GB), The Royal College of Midwives, the World Gold Council and PwC.

## Photonics manufacturing in Europe

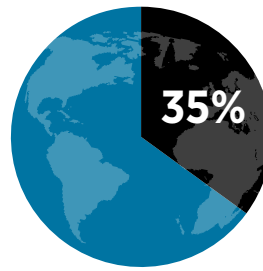
(Source: Photonics Industry Report 2013)



Europe's photonics industry holds about 55% of the world market in production technology, including laser material processing and lithography equipment.



Its world market share in optical components and systems is 40%.



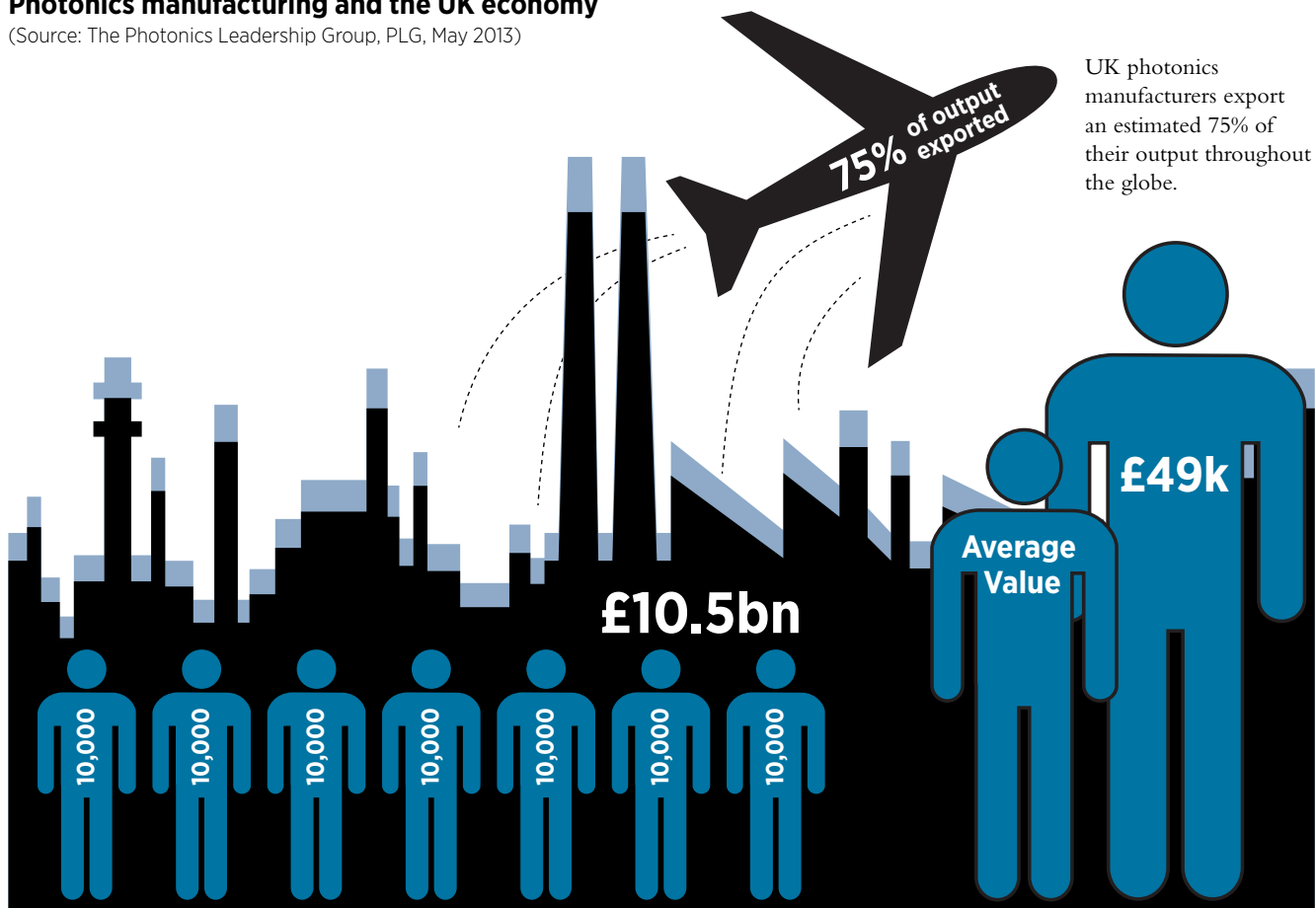
Europe's share of the image processing and measurement technology market is 35%.



The study's long-term outlook for 2020 predicts that photonics will experience continuing nominal growth of 6.5%, out-growing the global average annual GDP growth by about 50%, and resulting in a Photonics market volume of 615bn Euro by 2020 contributing to wealth and job creation

## Photonics manufacturing and the UK economy

(Source: The Photonics Leadership Group, PLG, May 2013)



Over 70,000 people are directly employed in UK photonics manufacturing

An industry worth £10.5bn to the UK economy and growing at 8-10% annually

The Gross Value Add (a measure of output) was reported as £49k per employee, 40% above the UK manufacturing industry average.



# Photonics

## revolutionising our world



**T**echnology affects us all. Mostly it makes life easier, safer and more enjoyable. It allows us to explore unknown territory and to produce things that were impossible only a few years ago. And there is so much more to come. One technology driving many of these changes is photonics – evolving rapidly and soon to enjoy the same status as something like electronics, an older technology which impacts so many parts of our lives today.

### **But, what is photonics?**

Normally an introduction would begin with a definition of the subject matter. Not so here. The range and depth of the photonics field precludes definition. Instead, the objective here is to illustrate why this is becoming one of the key industries for the future, to encourage you to delve in and see for yourself how photonics effects your life and how it's on a path to making the 21st century that of the photon. And to shed some light on the matter.

It's impossible here to cover all the application areas for photonics technologies, so we've picked key areas important to individuals and society. With transport we show how this technology will reduce traffic jams and make car lights more efficient (and attractive). In manufacturing we demonstrate how it allows the fabrication of complex shapes – in car bodies or personalised medical implants. Finally, in healthcare, where photonics is already key to medical diagnostics, it is clear that this is a technology not only improving lives but also saving them. Let us take you on a journey. You'll be amazed at what photonics can do for you.

Anke Lohmann, editor



# Photonics and Transport

Photonics is a main innovation driver in many established application areas such as communications, safety and security, lighting and displays.

Communication technology is moving into the terabit era, with dramatically increased data capacity and transmission speeds. This has massive implications for transport, bringing smart city networks and solutions to the challenges of energy efficiency.

In the future, solid-state light (SSL) sources are expected to outperform almost all others in efficiency, offering potential energy savings of 50% or even more.

These, together with the next-generation in sensing technologies, bring improved efficiency and safety to the design and maintenance of our vehicles and transport systems, rooting them firmly in the 21st century.

# Sensing Technologies

Sensors form the fabric of intelligent transport and automotive systems. Applications include in-vehicle systems for efficiency and safety; traffic sensing, signalling, management and situation aware systems.

*The market  
for fibre optic  
sensors will hit  
\$4bn by 2017*



© John Cairns

## The Oxford team vying for Google's autonomous vehicle crown

Professor Paul Newman is on a mission to prove that Google's fleet of autonomous cars is not the only show in town. "The gene pool we pull from in the UK is the same as at Google," he told the Engineer. "Our team's got 30 people and the Google team is the same size." He firmly believes that, in the field of affordable autonomous vehicles, the UK could have a major role.

Newman leads a team of robotics specialists from Oxford University who are developing a low-cost autonomous navigation system that doesn't rely on existing infrastructure or communication with other intelligent vehicles.

Funded by the Engineering and Physical Sciences Research Council (EPSRC), the RobotCar team has modified a Nissan Leaf, with the aim of building a system that can

be integrated into a regular car. The robot car navigates using lasers and cameras linked to a computer. A horizontal laser on the number plate detects obstacles and halts the car to avoid collisions, and a vertical laser casts a curtain of light on its surroundings to make a 3D model of the environment. When the car takes the same route a second time, it 'recognises' where it is and can 'drive' accordingly.

### Affordable

Newman's team is working to make the technology more affordable by using less expensive equipment and not relying on expensive satellite navigation technology, "I don't need to communicate with every car on the road to be able to drive home safely, so must we ensure that machines do?" he asks.

His vision is shared by the UK government's Department for Transport (DfT), which, in its recently published

'Action for Roads' report, envisages a world where, by 2040, semi-autonomous vehicles are commonplace on our roads.

The fully autonomous car will not appear overnight but a number of associated technologies are closer than we think. Traffic-jam-assist technology, for instance, that will take control of the vehicle on congested highways. Newman believes this will be a welcome first step for the driverless car.

Another trend may be a 'roadtrain,' a convoy of closely-packed-together, autonomous vehicles. This would make better use of battery power and is more energy efficient. The concept was developed as part of the EU funded SARTRE project with Volvo.

### Challenging

The consensus is that automated driving will appear first on motorways, where it has already been tested and where traffic conditions are predictable. Moving the technology into a more complex urban traffic environment will be more challenging.

In road tests the technology is performing well, rapidly reestablishing a safe trajectory for instance, when the autonomous vehicle is poised to overtake, but the sensors register another vehicle pulling in from an outside lane – a potentially hazardous scenario familiar to anyone who's ever driven on a motorway.

There are undoubtedly some tough challenges ahead, not just in the technical sphere, but also regulations, consumer acceptance issues and cost. However, the forward trajectory of the technology is unstoppable.





## Cost is key

Using more sensors means more detail is captured and, generally produces a higher resolution image. However, this sort of system can be costly.

Now, cheap sensors to help cars avoid collisions could emerge from US research into a lens-less imaging system built using metamaterials (materials with properties purposefully designed rather than determined by their chemistry) and mathematics to generate an image of a scene.

## Ford develops a car to monitor your health as you drive

Engineers at Ford are developing a car that can measure temperature via infrared light sensor and monitor your health as you drive. If you become ill or fall asleep it can simply take over. The company has tested biometric sensors that use body temperature to tell when a driver is having

a seizure so the car can steer or park itself safely.

In India, Ford is also testing 'car ambulances' that contain medical sensors to measure heart rates and allow doctors to examine people remotely.

## Sensors to synchronise traffic lights and prevent gridlock

Every one of the 4,500 traffic lights in the US city of Los Angeles has been synchronised with a view to alleviating the gridlock which threatens to engulf the metropolis.

The system uses magnetic sensors in the road that measure the flow of traffic, hundreds of cameras and a centralised computer system that makes constant adjustments to keep cars moving as smoothly as possible.

However, experts believe even this may not be enough to manage the soaring car population. However, it has created the possibility, in theory at least, of driving through the city without stopping.



## Developing the next generation of microsensors

An accelerometer is a type of motion detector which uses a sensitive displacement detector to measure motion. Although the average person may not notice them, electronic microchip accelerometers are quite common in our daily lives. They are used in vehicle airbag deployment systems, in navigation systems, and in conjunction with other types of sensors in cameras and cell phones. They can be made very small and at low cost, however, up to now, a compact optical version has eluded researchers, although laser light is one of the most sensitive ways to measure position.

In the past, only large projects, such as the Laser Interferometer Gravitational-Wave Observatory (LIGO) could avail themselves of so-called optical interferometers, which use laser light reflecting off mirrors separated by kilometres of distance, to sensitively measure the relative motion of the end mirrors. There have been attempts to make miniature versions but it's much easier to detect accelerations with larger sensors and a challenge to integrate all the components (the lasers, detectors, and interferometer) into a small package.

However, last year, researchers at the California Institute of Technology (Caltech) and the University of Rochester achieved this feat.

"We made a very sensitive sensor that, can simultaneously also measure very large accelerations, which is valuable in many applications, making it capable of measuring both extremely small and extremely large accelerations," says Caltech professor of applied physics, Oskar Painter.

The applications in consumer electronics are attractive. The device could be used as a navigator, enabling targeted advertising for instance. But there are also applications in oil and gas exploration, improving the stabilisation systems of fighter jets, and even for use in some biomedical applications where more traditional sensors cannot operate.



New Measurement Train (NMT). Image courtesy of Network Rail

## Road and track inspection

Cheaper, safer and more efficient: modern methods of track and road inspection have little in common with their predecessors. Using lasers, sensors, ultra fast cameras and cutting-edge software programmes, they can even predict where future problems may occur.

### Laser track inspection at 125mph

Rail track maintenance is no longer an old-fashioned undertaking. Modern technology is replacing traditional track maintenance equipment with sophisticated automated inspection tools with massive benefits for rail personnel.

Network Rail has recently introduced a new virtual system of monitoring track condition on its New Measurement Train (NMT), from London to Bedford. Named 'Plain Line Pattern Recognition' (PLPR), the technology uses a system called OmniVision, designed by York-based Omnicom.

Four lasers, seven linescanners and a number of thermal imaging cameras are mounted on the underside of the train. The cameras are synchronised and capable of taking photographs at a rate of 70,000 pictures per second. At 125mph, this gives a picture of the rail every 0.8mm.

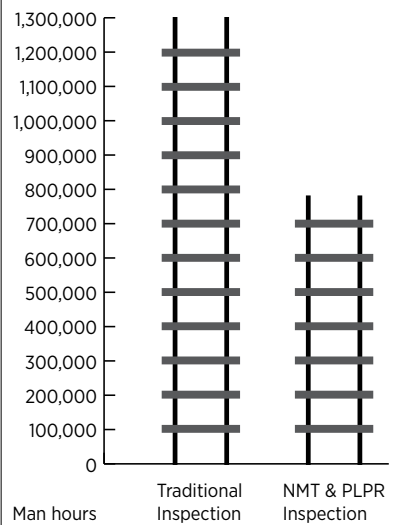
The laser-scanner monitoring equipment works to a route-setting map that uses structures such as stations, bridges, and tunnels as reference points to measure inter-track spacing and ballast shoulder heights. The movement of the

train is detected by gyros, accelerometers and transducers with cameras looking at the floor of the train and surrounding objects.

Removing the need for physical inspection will alleviate costs (each track maintenance delivery unit employs about 240 direct and 80 indirect staff), reduce the pressure on hightraffic areas and shorten the time needed for track access.

Traditional inspection techniques consume 1.3 million man hours of work each year. Using the NMT and the other trains for PLPR will remove 520,000 hours of this, which, above all else, will be a significant safety benefit for track workers, as the work is fairly hazardous.

**Comparison of traditional and NMT/PLMR inspection methods, in man hours used**



## Keeping Germany's roads in prime condition

A non-obtrusive, fast and efficient monitoring system to maintain optimum road conditions is being developed by researchers at the Laser Scanning group at the Fraunhofer Institute for Physical Measurement Techniques (IPM) in Freiburg, Germany.

The aim is to identify damage and wear, before they become a problem, with the aid of a laser scanner which is smaller, cheaper, faster and more precise than any others currently in operation. Up to now much of this time-consuming work has been carried out using cameras.

Germany is famed for its autobahn system – which accounts for over 60% of the capital assets of many municipalities – but the budget for maintaining it is set to reach a historic high of 3.5bn euros in 2016. The new system is sure to ease the burden and has already scanned a total of 15,000 kilometres of roads across the country, since last summer.





## A look at LiDAR

LiDAR (Light Detection And Ranging) sensors work on the same principle as RADAR (RADio Detection And Ranging), firing a laser light at an object and timing the delay in its return to the source to measure the distance between the two points. Because laser light has a much shorter wavelength than the radar it's possible to accurately measure much smaller objects, such as aerosols and cloud particles, which makes it especially suitable for airborne terrain mapping.

The oldest known variation of modern LiDAR systems evolved in nature millions of years ago. Bats use a guidance system now known as SONAR (Sound Navigation And Ranging) emitting short 'chirps' from their noses and receiving an echo by using their ears as antennae. This provides the animal with a three-dimensional view of the surrounding area, allowing them to avoid obstacles and to find their prey.

Human science started to develop similar systems in the beginning of the 20th century and today, airborne and ground-based LiDAR systems have applications from forestry management to pollution modelling and military surveillance.

- LiDAR is particularly suited to aircraft and can provide traffic controllers and pilots with concise information on wind shear – strong gusts typically caused by stormy weather that can hit aircraft during take-off or landing.
- Ground based LiDAR is also increasingly being used for navigation, as a guidance system for autonomous vehicles. The speed and accuracy of a scanner means that data can be passed to the system almost in real-time. This allows the device controlling the vehicle to detect obstacles and to update its route extremely quickly.

The ZephIR 300, deployed for wind measurements as part of wind farm development campaign.



Image courtesy of ZephIR LiDAR



Image courtesy of Audi UK

- Adaptive Cruise Control (ACC) systems for cars hold further applications. Systems, such as those by Siemens and Audi, use a LiDAR device mounted in the front of the vehicle to monitor the distance between the vehicle and any vehicle in front of it.
- Used with the simulation platform, Pre-Scan, LiDAR can enable scanning of a road surface so that the information can instantly adjust the car's suspension to achieve the smoothest and safest ride possible.
- As an alternative to radar guns, LiDAR can be used for vehicle speed measurement. It's able to pick out one vehicle out of many, however there are currently limitations imposed by range and beam divergence.





By 2020 more  
than 95% of lighting  
turnover will be  
based on SSL  
technology

# Lighting Technologies

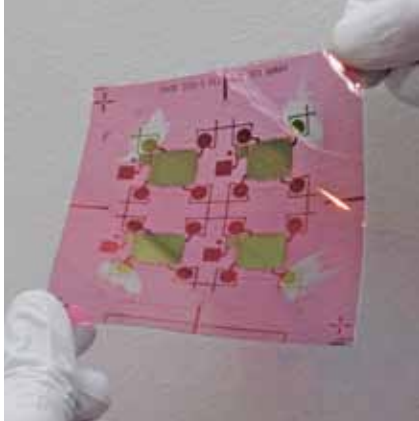
Displays are one of the most visible expressions of photonics as a key enabling technology. Whether it's a 40 inch TV, a smartphone, a 3D or flexible interface, a revolution in display lighting is underway.

As efficient and robust light emitting diode (LED) based 'solid state lighting' (SSL) progressively replaces traditional incandescent and fluorescent bulbs, it's finding its way into new areas including signage, illumination, consumer electronics, displays, clothing, avionic and automotive applications.

LED technology is projected to become the dominant lighting technology before the end of the decade and by 2020 more than 95% of lighting turnover will be based on SSL technology (source: European Lighting Industry (ELC-CELMA)).

## FAST FACTS: DISPLAYS

- Despite the display market being dominated by the Asia Pacific, Europe has maintained its position of strength in material supply, production equipment and visualisation systems.
- The display industry is currently shifting its focus: From LCD (Liquid Crystal Display) towards OLED technology for direct-view displays; from lamps towards LEDs for microdisplays and towards high brightness LEDs or solid-state lasers for projection displays.
- 3D displays that do not require special viewing glasses will be the next step in televisual experience, ultimately enabling remote collaboration. This will require systems with a resolution exceeding that of current HDTVs by at least a factor of 100. However, speed of development will be dependent on the rollout of access infrastructure.
- Direct-view AMOLED (active matrix OLED), e-paper, projection displays and near-to-eye displays are areas with definite potential
- Current research topics include: improvement of the metal oxide TFTs and organic TFTs, new OLED and film materials for longer lifetime, increases in wall plug efficiency and curved, flexible and rollable displays.



## Game-changing OLEDs?

Short for organic light-emitting diode, an OLED is a display device that sandwiches carbon-based films between two charged electrodes. Unlike LCDs, which require backlighting, OLED displays are emissive devices – they emit light rather than modulate transmitted or reflected light.

OLED technology was invented by Eastman Kodak in the early 1980s and is beginning to replace LCD technology in handheld devices. The attractions are obvious: OLEDs are brighter, thinner, faster and lighter, use less power, offer higher contrast and are cheaper to manufacture.

### UK advantage

Although 15 years have passed since UK-based Cambridge Display Technology (CDT) embarked on its quest to develop flexible displays using OLEDs, it's only since last year that the technology has really taken off for use in mobile phones, car dashboard displays, navigation systems and digital cameras.

But now it appears there's no stopping the rise of the OLED: Apple is reportedly testing iWatch designs with flexible OLED displays, and use in large-size applications, such as information displays and TVs is not far off.

This puts CDT (acquired by Japan's Sumitomo Chemical Co in 2007) and another UK company, Plastic Logic, at the vanguard of an industry which a recent report from technology information specialists, IHS, claims is at tipping point: demand for flexible OLEDs is expected to grow by more than 300% in 2014, with sales reaching nearly \$100m, it states.

With this in mind, it's unsurprising that this is a popular area for R&D investment and, in 2013, Plastic Logic became the recipient of Technology Strategy Board (TSB) funding for a project titled ROBust OLED or ROBOLED which promises to pave the way for OLEDs into a wide range of applications such as tablets, smartphones, game consoles, smart displays and notebook PCs.

## Vehicle lighting

LEDs are now being used both inside cars and out: in interior lighting, to illuminate the dashboard console and, most importantly as exterior lights.

The common goal of car manufacturers is to reduce weight, energy consumption, and the cost of materials, so LEDs will undoubtedly become the norm, which is why the LED headlamp market was estimated to be worth \$1bn in 2012 and is set to double to \$2bn by 2014.

Since cars were first produced, in the late 1800s, driving at night has been an issue. The invention of electric headlights in 1915 was a major advance but LED headlamps may be an even bigger one.

The clean, clear, intense light given off by LEDs is prized by many for being more 'natural'. It's also longer lasting, as much as 200 times more than conventional lights, and the distinctive blue light given out is a distinguishing feature which immediately puts a vehicle in a higher price bracket. In headlights, LEDs also eliminate the need for a bulb and minimise the surrounding metal reflector. They provide a sharp beam, rather than the broad spread of light produced by a bulb, and reduce eyestrain.

But although LEDs have been used in brake lights (they can help prevent accidents, as they come on a split second

earlier than ordinary brake lights) – and also reverse lights, signal indicators, and interior lighting for years, headlights are another matter, largely due to expense.

This means that they're currently only available in top of the range models from Audi, Mercedes-Benz and Jaguar, although they're slowly filtering down through a range of vehicles.

And retrofitting them is tricky, requiring modifications to the existing wiring system, such as installing heat sinks.

But the precise nature of the point of light from the LED has led to their increased adoption for exterior applications such as daytime running lights (DRLs) — the front lights on a vehicle that automatically switch on when the vehicle is moving forward – and the decision by the European Commission for all new passenger cars to be fitted with DRLs (in February 2011) has seen the use of LEDs increase. Their low energy budget makes them the obvious choice for a light source that is on all the time.

LEDs can also be combined with other systems, such as satellite navigation, so that the car knows, for instance, when it's about to enter a crossroad and can change the light intensity and direction accordingly.

LED headlights can also provide added driver safety by adapting beam brightness based on the proximity of other vehicles, so



Image courtesy of Audi UK



**The LED  
headlamp market  
is estimated to  
be worth \$2bn  
by 2014**

that an oncoming driver isn't blinded by high beams.

But the desirability of intelligent dimming of headlights varies depending on whether you're in Europe, where it's seen as a valuable safety feature, to Japan and South Korea, where they remain dubious about the benefits. In fact, in the US, it's a legal requirement for a vehicle's beams to be able to switch manually from high to low.

Although the development of automated headlights, such as Audi's recently announced Matrix headlamp, could be stopped in its tracks unless it has support outside Europe, other developments are seen more favourably.

Research is also in progress to bring OLEDs onto the exterior of a car, potentially revolutionising the look of a vehicle, with futuristic panels visible in the curve of the car exterior for seamless lighting design.

The OLED 3D research consortium, funded by the German Federal Ministry of Education and Research, has recently introduced large-area, 3D OLEDs in the rear lighting of a vehicle for the first time, although the project is still at conceptual stage.

Audi has also shown an OLED concept, the Swarm, where OLEDs coat the back of a vehicle in a graceful arc, acting as brake lights or indicators. They can also light up when the car approaches another in the dark or illuminate handles and other features.



Image courtesy of Audi UK



## Visible light communication

What if light could do more than just illuminate? What if it could also send streams of data and we could receive maps from a street light, news alerts from a lamp and download music from an electronic poster?

Visible Light Communications (VLC), as it's known, may seem a futuristic concept but it may not be so far off.

It also promises to help address the 'looming spectral crisis' in Radio Frequency (RF) wireless communications and can be deployed in situations where RF is either not applicable (e.g. in underwater applications) or is undesirable (e.g. aircraft, ships, hospital surgeries).

The technology, also known as LiFi, is still in an introductory phase, having so far only penetrated the indoor networking and location based services market. However products for other applications, such as intelligent traffic management systems, in-flight entertainment, and underwater communication, are expected to hit the market by the end of 2013.

Ultimately, VLC is expected to impact Machine to Machine (M2M) communication, smart cities, power over Ethernet (PoE), wireless sensor networks, ubiquitous networks and augmented reality in around 2018.

### VLC ADVANTAGES

- Provides ubiquitous high-speed wireless access offering greater data density than Wi-Fi.
- More secure because light will not pass through walls and can be turned off.
- Integrating light and data reduces both infrastructure complexity and energy consumption.
- VLC doesn't interfere with radio-frequency (RF) electronics, making it suitable for use in hospitals and aircraft.

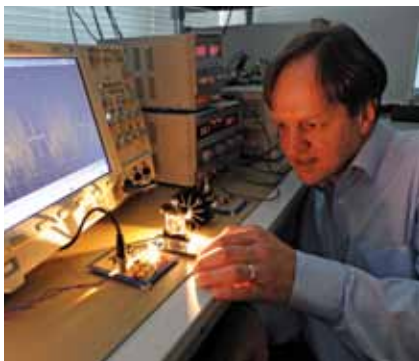
### VLC PITFALLS

- Reliability and network coverage are major issues. Interferences from external light sources like sun light, normal bulbs and opaque materials in the path of transmission will cause interruption in the communication.
- VLC has to prove itself against the competing technologies of LiDAR, radar and RF, as well as to overcome some of its own technical challenges.
- Atmospheric conditions outdoors, such as fog, smoke and temperature variation are major difficulties. The answers lie in efficient modulation and coding schemes to push the beam through fog, for instance, without increasing power to the light source.

*“Visible light exists along with radio waves in the electromagnetic spectrum, but has ten thousand times more capacity than radio waves.”*

### UK company in the spotlight: pureVLC

The global leader in visible light communication, pureVLC was established in 2012, as a spin-out from the University of Edinburgh, where pioneering research into VLC has been ongoing since 2008. Its Chief Scientific Officer, Professor Harald Haas, first demonstrated Li-Fi technology to the world, live on stage at TED Global in July 2011.



“Five billion mobile devices exist in the world, serviced by 1.4 million radio towers,” he informed the audience. “More than 600 terabytes of data are transmitted every month. Radio waves are scarce and expensive, and current capacity and wavelength will not keep up with the demand for data.”

Visible light exists along with radio waves in the electromagnetic spectrum, he continued, but has ten thousand times more capacity than radio waves.

Haas’s solution, appears obvious: to transform the 14 billion light bulbs currently in use to transmit wireless data along with light. Initially, this entails replacing light bulbs with LEDs, which can transmit thousands of signals at once through a process called spatial modulation. By flickering an LED light on and off in a specific pattern, data can be sent at speeds that are undetectable to the human eye.

The combination of lighting and data or ‘data through illumination’ and ‘data through displays’ is a powerful one which Haas and his company are also helping a major funded project to explore.

Running from October 2012 to September 2016, Ultra-parallel visible light communications (UP-VLC) is an ambitious EPSRC-funded £4.6m programme grant which will explore this transformative technology of communications through a partnership between 6 research groups at 5 institutions and guided by Haas.

They will examine novel communications systems which combine display functions and video with multiple, high-bandwidth communications channels.

In August 2013 the group produced the world’s fastest bi-directional VLC system and the following month pureVLC was able to boast another breakthrough: showing that the technology does not require a line-of-sight connection.

The engineers at pureVLC showed that Li-Fi can operate by using incident light (which includes reflections) and demonstrated that Li-Fi can achieve the same high speed performance from reflections.

This breakthrough, in what was thought by many to be the Achilles heel of Li-Fi, opens a world of possibilities when considering its commercial applications. By relying on incident light rather than just direct line-of-sight, Li-Fi can penetrate in diverse market segments, from aircraft cabins, to museums, everyday offices and more.

So, although we’re still waiting for the first commercial Li-Fi LED bulbs to come to market, with so many possible uses, from street lamp-to-car communications through to ultra-fast short-range communications, and the growing maturity of LED lighting, it’s really just a matter of time until VLC or Li-Fi becomes a reality.

### VLC in car-to-car communication

One of the most promising applications is in car-to-car communication. VLC-aided collision-avoidance technology would work by the headlights on a car communicating with the tail lights of the car ahead. In the same way, traffic lights could send detailed information of congestion up ahead directly to a vehicle.

In military operations, where RF-based communications are restricted during troop movements, VLC could be used to securely pass information down a convoy of vehicles.

### Not such a new technology



The first attempt at harnessing visible light to carry data was made in 1880 by Alexander Graham Bell with a device known as the Photophone, which could transmit data on rays of sunlight.

Although Bell believed that the Photophone was an extremely important invention (he even wanted to name his second daughter after the device!), it ultimately failed to protect transmissions from interferences such as clouds and it was many years before its significance became apparent.

#### OTHER VLC RESEARCH PIONEERS

- Work has been pioneered in Japan by the Visible Light Communications Consortium (VLCC).
- The US has invested \$18.5m
- The Chinese government is also thought to have put aside large sums to integrate it into aircraft.
- In Europe, Oxford and Edinburgh universities are involved in research, along with firms such as France Telecom and Siemens.

*“FSO is still considered relatively new. But the market is expected to nearly double in the next five years.”*

### Free Space Optics

Free Space Optics (FSO) is based on the same principle as VLC but is not constrained to visible light, so ultraviolet (UV) and infrared (IR) also fall into the FSO category.

A FSO system is designed to connect two points which have a direct line-of-sight and operates by taking a standard data or telecommunications signal, converting it into a digital format and transmitting it through free space.

Another distinguishing feature is that laser diodes rather than LEDs are often used for the transmission.

Originally developed by the military and NASA, FSO has been used for more than three decades in various forms to provide fast communication links in remote outdoor locations.

Only in recent times are indoor

applications, where FSO is used to connect end-users with internet service providers or other networks, increasing.

So, while fibre-optic communications have gained worldwide acceptance in the telecommunications industry, FSO is still considered relatively new. But the market is expected to nearly double in the next five years, according to Electronicast.

But the consultancy also warns that the technology still has a niche appeal so that, outside of military use, the total market will still be worth less than \$60m by the end of the forecast period.

However, several research projects such as the VICS (Vehicle Information and Communication System) in Japan and European funded research projects like CVIS and COOPERS are working on potential applications in communication between vehicles.

### UK co in the spotlight: PAV Data Systems

PAV Data Systems prides itself on providing connectivity where other technologies simply cannot reach. A further advantage to FSO technology is limited disturbance to existing infrastructure which means no traffic-clogging roadworks are needed.

With a global presence of over 7,000 installed FSO systems, in all types of terrain and environment, the company is now a market leader in the process and has installed high-speed links for public bodies and private companies both in the UK and overseas.

For the Zurich Opera House, which wanted to link up its theatre with offices and rehearsal rooms located on different sites within the city centre, FSO proved an obvious solution.

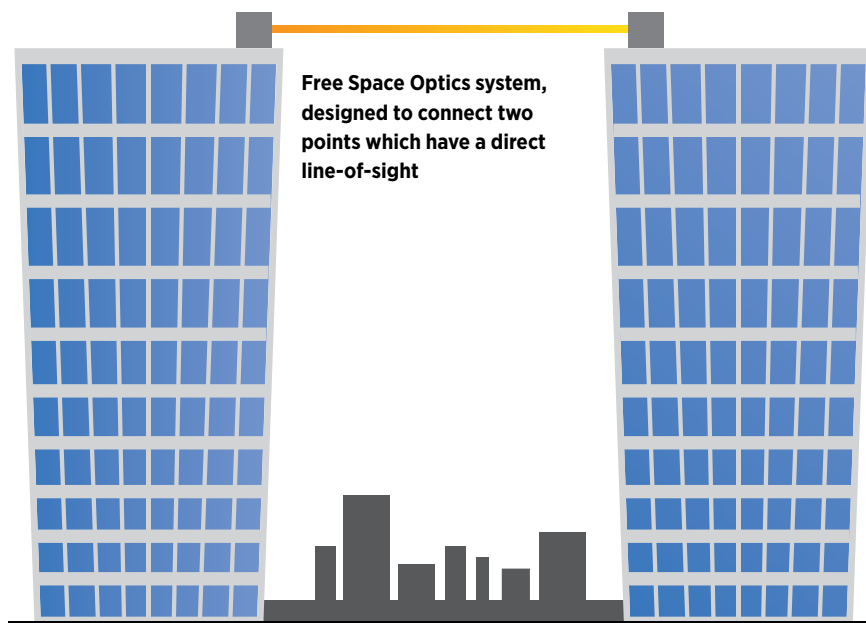
Due to the location, in the old and historic part of the city, digging up the cobbles to lay cable was out of the question.

Customers also report that the systems are very quick and cheap to install. Typically, freespace systems require less than a fifth of the capital outlay of comparable ground-based fibre-optic technologies.

“The total cost of purchasing the PAV FSO system outright and the first year’s maintenance was less than the annual rental price of a BT leased line,” commented PAV Data Systems customer, Jason Barrett, Network Manager at East Staffordshire Borough Council.

Moreover, the systems can be up and running in a matter of days and even faster if equipment can be placed in offices behind windows instead of on rooftops.

Impressively, PAV Systems boast that “With FSO, a service provider can be generating revenue while a fibre-based competitor is still seeking municipal approval to dig up a street to lay its cable”.







*“Lasers can send six times more data with 25% less power than RF systems.”*

### **NASA attempts laser transmission to the Moon**

NASA is testing two-way laser communication beyond Earth. Its Lunar Laser Communication Demonstration (LLCD) mission in September 2013 sent 3D HD video into space and could be the future of man's communication with Earth.

Radio frequency (RF) communication has been the platform used in space thus far but is reaching its limit as demand for more data capacity continues.

Lasers can send six times more data with 25% less power than RF systems, a capacity equivalent to transmitting more than 100 HD television channels simultaneously. They're more secure and less susceptible to interference and jamming.

The European Space Agency already has successfully demonstrated laser communication between satellites in Earth orbit. However, LLCD's laser link from the moon will be ten times farther away.

### **Wavelength Division Multiplexer (WDM)**

With the ability to combine several different types of signals over the same medium, a modern Wavelength Division Multiplexer (WDM) can handle up to 160 of them on a single optical fibre, effectively multiplying capacity. This is achieved by using different wavelengths (i.e. colours)



of laser light, enabling bidirectional communications over one strand of fibre.

The WDM market is exploding. The technology is of particular interest to the aviation industry. Optical fibre has many advantages over the traditional copper coaxial cable used in aircraft to transport radio frequency (RF) signals between antennas and electronic equipment. It's more compact, with lower power loss, larger bandwidth, and immunity to corrosion.

The US military is already trialling WDM within a prototype photonics technology for standard use in its aircraft and, in the next 20 years, it's estimated there will be 25,000 potential new aircraft sales worth over £2 trillion worldwide.

With the UK well placed as the second-largest aerospace manufacturing nation in the world (the industry employs over 100,000 people and contributes almost £30bn a year to the economy), the opportunities for applying WDM technology are considerable.



# Security

The worldwide security equipment market is worth in the region of €76bn



Image courtesy of Thales Group

The world's largest airports are the size of small cities, covering tens of square kilometres and handling up to 200,000 people daily.

In this domain, security refers to anything from the detection of explosives through 'fingerprint' gas analysis, the improved recognition of individuals through EIR signatures (distribution of veins in face and hands) to more effective identification of prohibited or dangerous goods through large-scale cargo screening and improved surveillance in public spaces. It's an ever more lucrative area, with studies estimating the worldwide security equipment market worth in the region of €76bn (World Security Equipment to 2014 – Demand and Sales Forecasts, Market Share, Market Size, Market Leaders, The Freedonia Group, Cleveland, USA, December 2010)

## Thales: security in infrastructure

Thales is a global technology leader for the Defence and Security and the Aerospace and Transport markets. In 2012, the company generated revenues of £11.5bn and boasts 67,000 employees in 56 countries.

Thales UK is now Britain's second-largest defence contractor. It employs more signalling and telecom engineers than any other UK company.

In August 2013, its Intelligent Infrastructure Management (IIM) system for remote conditioning monitoring won both the innovation and Project of the Year Awards at the Real IT Awards. The IIM system allows Network Rail to reduce delays caused by asset failure and so improve the efficiency and reliability of the infrastructure. The system monitors the performance of key assets then raises alerts when these are in danger of failure, enabling corrective action to be taken to avoid disruption.



## Kromek's Identifier captures market needs

Anglo-American technology innovator, Kromek, has achieved the highest European standard for its Identifier bottle scanner and Liquid Explosive Detection Systems (LEDS).

The company's timing is spot on, with restrictions on carry-on liquids due to be relaxed with the implementation of new screening measures at EU airports in January 2014.

The Identifier is unique in its ability to scan metal cans and foil pouches, in addition to all types of glass and plastic containers.

The company is now planning to raise £15m from a stock market flotation to fuel future expansion.



Image courtesy of Kromek

## A biometrics system for the masses

Ever increasing security measures mean that the time it takes officials to process a passport has more than tripled in just two years. Biometric systems are the only way to speed up the process and many airports and entry points are experimenting with different methods. However this technology is not without its problems, as the costly scrapping of iris recognition scanners at two UK airports last year demonstrates.

To get it right, any biometric technology needs to consider potential human impact. Race, gender, occupation, age, or colour of eyes may all affect the error and success rates of certain systems.

Currently, conventional iris recognition systems have been limited to effective capture ranges of around 25 to 40 centimetres, requiring a high degree of user interaction and cooperation. However according to the International Biometrics



Group, vendors have now begun to develop long-distance and mid-motion processing capabilities, to enable target subjects to be acquired from as far away as 20 metres, and even while walking.

Palm recognition has been slower in developing only because of restraints in computing capabilities and live-scan technology. A UK based survey of 500 people found fingerprint recognition to be the most reliable biometric but least socially acceptable measure, due to the intimate contact necessary.

However, in recent years, there have been efforts to develop contactless biometric systems removing many of the problems with this technology.

The most promising recent development, however, is the new iPhone 5s with its fingerprint Touch ID authentication system which uses a laser-cut sapphire crystal combined with a image sensor. There's a good chance that it may help usher biometric technology adoption into the mainstream.

## Cobalt Light Systems: a pedigree in innovation

UK based Cobalt Light Systems is developing unique products for analysing chemical materials through translucent layers, such as bottles, bags, clothes and skin, using a technology called Spatially Offset Raman Spectroscopy (SORS).

Initially developed to probe human tissues for non-invasive cancer and bone disease diagnosis, SORS also has applications in airport security – screening bottles for liquid explosives – and in quality control of pharmaceutical products and the scanning of incoming raw materials in pharmaceutical manufacturing.

The company is a spinout from Rutherford Appleton Labs, part of the Science & Technology Facilities Council (STFC) funded Central Laser Facility, which has a rich history of innovation and technology development.



Image courtesy of Cobalt Light



Smart Kiosk biometric concept ©uavniargus-global.co.uk





# Photonics and Manufacturing

In manufacturing, research in optics and photonics has contributed to accurate measurement, micro-fabrication and cutting techniques as well as laser welding and process control.

Photonics holds out the opportunity not only to improve existing manufacturing methods, but to develop entirely new ways to make things.

With UK photonics manufacturers exporting an estimated 75% of their output throughout the globe, this is a highly lucrative industry worth £10.5bn to the UK economy and growing at 8-10% annually.



# Laser Manufacturing

Lasers have revolutionised manufacturing and are now used to make anything from the latest BMW i3 to tiny parts like the integrated circuit (IC) in your smartphone. In the past fifty years, the laser has become the most versatile tool in modern manufacturing.

Automotive manufacturing contributes some £9.8bn value-added to the UK economy

## Laser use in car manufacturing

### The drive toward ultralight cars

The automotive industry is slimming down. Take the most recent incarnation of the Golf – it weighs in at a full 100 kg less than its predecessor, with the main loss (8.6%) being in body weight, the result of innovative materials and production processes. At the fore of these processes lies the laser. The proof of the maturity of laser processing in car bodies was perhaps first apparent with Volvo's 2008 XC60 model, which was designed for laser welding and contains more than 10 million laser welds. It's also a weight saving of 1.5 kg in comparison to an earlier model.

BMW's new i3 electric city car is also taking this drive towards efficiency to the extreme. The German manufacturer has come up with an ultra-lightweight platform that combines carbon-fibre-reinforced plastic with an aluminium drive module that holds the battery, powertrain and structural crash protection. Even the instrument panel supports are made of magnesium, another very light material. "Every step in the development of the i3 has been shaped by the demands of weight optimisation," according to BMW literature.

But this use of innovative materials comes at price; it requires the very latest in laser welding technology.

Accordingly, laser applications at BMW plants worldwide are growing and the company is investing heavily in this

technology's innovation, as well as internal education and training specialists to use it. The company recently spent around £30m on welding equipment at its Swindon plant alone. This is BMW's UK base and produces 90% of the body components for the Mini.

### Evolution of laser techniques

But all these developments aren't just about being faster and meaner. The constraints of the stricter global fuel economy and emission mandates play a large part. And, as car makers race towards this new, leaner world, they need to use the very latest in innovation which quite often comes with paying some homage to research of the past.

From as early as 1973, when Ford introduced an underbody laser welding system for an assembly line, the automotive manufacturing industry has been a pioneer in adopting the lasers.

In the 1980s, the use of lasers expanded into gear parts welding, the production of air-bag components and the welding of engine parts such as injection valves.

Then, in 1991, BMW became the first European car manufacturer to put roof laser welding in production on its 3 Series touring model, and Volvo, recognising its advantages, introduced it a few months later on the 850.

As laser power increased, design and manufacturing engineers saw that it offered superior joint strength, a narrower tolerance range (due to less heat input), a better overall finish and single-sided processing

that made new design solutions possible.

From the customer's perspective, laser technology produces a car with better handling due to the stiffer body and with reduced fuel consumption as a result of the vehicle's lower weight.

Now, the development of new materials, like light-weight, high-strength Boron steels, offers new applications for lasers.

But often more than one type of material needs to be used, and this is one of the challenges the industry faces. The major issue with joining two lightweight structures together is the brittle inter-metallic compounds that are formed when a material such as aluminium is joined not only to steel, but also to other lightweight metals such as magnesium or titanium.

Temperature is key, as carbon steel liquefies at a much higher temperature than aluminium so the two don't connect well. With a version of friction stir welding (see processes on page 25), Honda now believe they've found the answer. Their solution is to join steel and aluminium through mechanical pressure, using a rotating tool. The new technique has already been used in the 2013 Accord.

A further solution from Brigham Young University and Oak Ridge National Laboratory is friction bit joining which works by inserting a thin layer of steel between the two metals being joined. It's thought to yield a tough connection between ultra-high-strength steel and lightweight aluminium and is likely to be used in practical applications very soon.



The new i3 electric city car. Image courtesy of BMW

### The future

New materials which have not only different structural characteristics but also differing sensory and electrical ones, are becoming a trend in the automotive industry: a bumper, for instance, with parking sensors and electrical wiring integrated with the structural material. New materials are also developed to further reduce weight and improve efficiency.

Diode lasers are likely to become popular, with the increased use of plastic and are almost ready to be substituted for more traditional methods.

The future is also likely to bring non-gasoline-powered engines and the likelihood that gearboxes, drivetrains, transaxles, injection valves and steering columns may all be history. But if, as some believe, cars end up being powered by fuel cells, their thin foil composition makes it almost certain that car manufacturers will continue to rely on precision high-speed welding, cutting and drilling to mass-produce these too.



*“The development of new materials, like light-weight, high-strength Boron steels, offers new applications for lasers.”*

### Car manufacturing: the UK position

As the most diverse and productive vehicle manufacturing location and as a global centre of excellence for engine development and production, Britain leads Europe.

More than 40 companies manufacture vehicles in the UK – ranging from global volume car makers, van, truck and bus builders, to specialist niche players. The list includes BMW (Mini), Ford light commercial vehicles and engines (together with its Premier Automotive Group marques: Jaguar, Land Rover and Aston Martin), GM (Vauxhall), Honda, Nissan, Peugeot and Toyota.

The industry is supported by a dynamic supply chain including many of the world's major component manufacturers, technology providers, design and engineering consultancies; and it benefits from a world-renowned knowledge base.

Automotive manufacturing provides 221,000 jobs in some 3,300 firms and contributes some £9.8bn value-added to the UK economy.





## Laser manufacturing processes

### Friction stir welding

Friction Stir Welding (FSW) was invented and patented by The Welding Institute (TWI) in the UK. It produces welds of high quality of dissimilar and difficult to weld materials, such as aluminium and steel, and is fast becoming the process of choice for manufacturing light weight transport structures such as boats, trains and aeroplanes.

UK automation specialist, Meta, is currently developing new applications for FSW and working to help automate the process and simplify machine operation. The research comes under the EU Framework 7 Programme.

### Remote laser welding

Remote laser welding (RLW) is rapidly emerging as a powerful replacement for spot-welding technology in vehicle manufacturing.

With laser optics embedded into a robot and a scanning mirror head, RLW can easily create joints in different locations through simple repositioning and beam redirection from a remote distance.

The process also differs from spot welding as the latter joins parts using the heat generated by resistance to the flow of electric current, and is therefore

known as a contact technology. This means that access is required to both sides of the part to make a joint. By contrast, RLW is a non-contact technology and only requires access to one side, with a single high-power laser beam used to create the joint.

RLW is able to create a joint in a fraction of a second, and the process may even be as much as five times faster than spot welding. And, because it's faster, a single robot is all that's necessary, which means that floor space could be reduced by as much as 50%. With corresponding knock on advantages for maintenance costs and energy usage, RLW could reduce assembly costs by 10%.

Leading the fray in advancing this technology is the UK-based Warwick Manufacturing Group (WMG), the recent recipient of £3.3m in EU funding. A challenge is the accuracy required for high volume production so, to date, RLW has been limited to fairly niche components. To address this, the WMG project is developing a simulation tool to replace guesswork with precise mathematical modelling.

Ultimately it's hoped that the technology can be used in the oil and gas industry, where rapid, high-precision pipeline welding is vital.

### The wobble method/laser stir welding

Although riding high in popularity, RLW has always had one drawback: it cannot weld across gaps in butt joint seams, as there is no way of adding filler material.

The answer to this comes from the wobble method, also known as laser stir welding. It has the advantages of remote welding but also bridges gaps between the surfaces being joined. The laser beam doesn't just move along the gap in a straight line, it oscillates from side to side. Moving the beam in a spiral motion melts material to the left and right of the gap, broadening the melt pool. As the liquid metal removes the need for additional filler materials, weight is reduced.

### Disk lasers and fibre lasers

A drawback to existing robotic-arm systems is the laser's rather low utilisation rate; the machine spends more time moving the robotic arm than it does welding.

The improved beam quality in disk lasers means that the robotic arm can operate farther from the workpiece – perhaps as far as 500mm. Thus, the time spent moving from one weld to the next can be reduced from seconds to milliseconds.

A disk laser was recently used to produce the rear shelf of the new Volkswagen Passat. The technology is also behind a number of other recent advances in automotive manufacturing.

## A short history of lasers

In 1960, Theodore Maiman (below) and colleagues at Hughes Research Laboratories in the US demonstrated the first laser. However, it was not until the 1980s that laser applications really took off.

After the discovery of the laser diode in the 1970s, the next key development was the use of glass fibres to guide the internal reflection of light beams. Combined with laser amplifiers, fibre optics revolutionised global telecommunications and ultimately made the internet possible.

At the same time, the development of semiconductor-chip technology brought lasers into the everyday world. Tiny, robust, semiconductor lasers are now ubiquitous – in anything from supermarket barcode readers to CD players and computer printers.

One of the most dynamic areas for lasers is now manufacturing, where welding, drilling, cutting, and various methods of surface modification are bringing about an ever wider range of products.

It's the high intensity of laser light that has allowed researchers to study extreme optical responses. Exploring and harnessing this behaviour continues to be a major goal in photonics research as established applications continue to broaden and new ones open up.



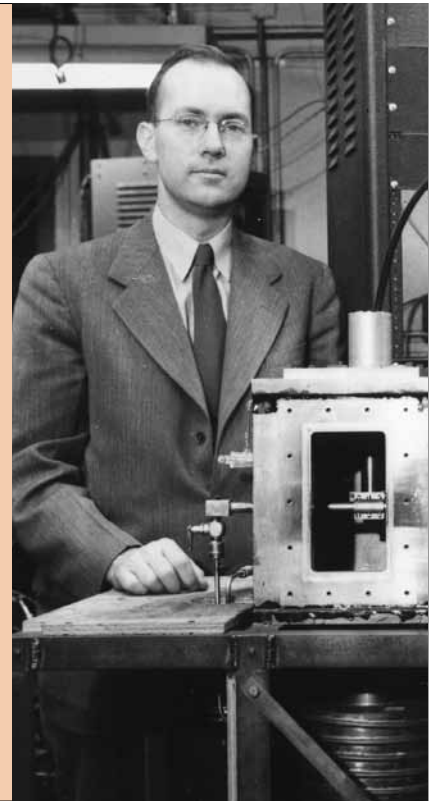
### LASER ADVANTAGES

- Increased process speed, leading to higher productivity
- Enhanced strength
- Reduced vehicle weight
- The same laser can weld, braze and cut.
- Reduced maintenance.

## Opinion: President of the European Physical Society Professor John Dudley highlights the impact of research in laser physics.

The early pioneer of the laser, Charles Townes (right), said very eloquently, "Which doctor looking for a surgical instrument, or which industrialist looking for a way to cut metal, would have started out by trying to study molecules with microwaves?"

It just goes to show that it's very difficult to identify in advance where results will come from and highlights the difficulty in the search for some kind of prioritisation. All areas of science, not only physics, need to have a critical mass of personnel and resources assigned to them so that they can continue with the possibility of new discoveries in all fields. This should include a focus on the fundamentals, rather than always looking for applied research directed towards specific goals, to encourage pure curiosity-driven research with no short-term goal in mind.



## Advantage UK

The UK is a world-leader in novel fabrication techniques, often at the nanoscale. This, combined with excellent theoretical understanding of the underlying physics, gives the UK a leading edge in optics and photonics research.

The country also has a wealth of laser processing scientific knowledge, new materials processing technologies and a strong industry base. There's been much recent progress in laser materials processing technology innovations and industrial applications.

Laser welding has been applied by UK industry for over 40 years and continues to open up new applications. Key developments include fibre and diode laser sources for materials processing and recent breakthroughs in lasers for ultra-high speed cold machining, engraving and large area micro-texturing.

### FAST FACTS

- European laser welding equipment market revenues have increased from \$542m in 2004 to an estimated \$802m in 2011
- The emergence of new end user sectors, innovative products and novel application areas (as well as the increasing penetration of existing technologies among current end users) are the main drivers behind the success of laser technologies.
- The automotive sector contributes to over half of the total demand for laser welding equipment in Europe and is set to remain the largest sector over the long term.
- The electronics and medical end-user sector is predicted to be the fastest growing demand generator over the long term.
- Remote welding holds great promise and will further increase productivity and support additional savings.

(Source: Frost and Sullivan)



# A tiny revolution

For mobile devices such as smart phones and tablets, laser processing is used to manufacture key components such as displays, integrated circuits, and printed circuit boards, as well as for marking, cutting and welding of often minute mechanical components.

*The global market for lasers is expected to grow at a compound annual growth rate of 9% through to 2014*

## FAST FACTS: LASERS

- The global market for lasers is expected to grow at a compound annual growth rate of 9% through to 2014, when the total market is expected to be \$8.8bn (source: Strategies Unlimited).
- The number of laser materials processing systems in the UK is estimated to be 2,500, spread around 850 sites. Many of these are in the process of replacing old carbon dioxide reliant cutting machines with new higher power ones, leading to increased productivity
- Germany is the current world leader in the use of lasers in manufacturing, with an output three times that of the UK. According to analysis, at least part of the explanation for this is that, in Germany, lasers are used to increase productivity and add value to the product, rather than the process being exported to Asia, as in the UK. An additional factor is the relatively low level of capital investment in the UK manufacturing industry, which discriminates against high capital cost purchases.

## Writing on stones

Moore's Law dictates that the number of transistors that can be put on an integrated circuit (IC) will double every couple of years; it's largely through the continuous refining of lithographic equipment technology that this has, up to now, been possible.

The word lithography comes from the Greek lithos, meaning stones, and graphia, meaning to write. In the case of semiconductor lithography, the stones are silicon wafers and the patterns are written with a light sensitive polymer called a photoresist.

Lithography typically accounts for about 30% of the cost of IC manufacturing and, as mobile devices become ever more sophisticated, so do their components.

Automated lithographic machines, such as those from leading UK manufacturer OpTek Systems, are used

to handle increasing consumer demands. The company manufactures multiple machine installations which operate 24/7 with minimal scheduled downtime, addressing the necessity for complex circuitry in conducting metal layers.

However, lithography also tends to be the technical limiter for further advances in feature size reduction and, historically, advances in lithography have gated advances in IC cost and performance. The so-called next-generation lithography tools, which will keep us ahead of Moore's Law, are complex and costly, which has delayed development.

That's why a new process, developed by American company, MonolithIC 3D™ Inc., has excited the industry. It involves integrating several active layers and then incorporating a common set of global wiring. Many believe it has the potential to re-invigorate Moore's Law.

## Ultrafast glass cutting

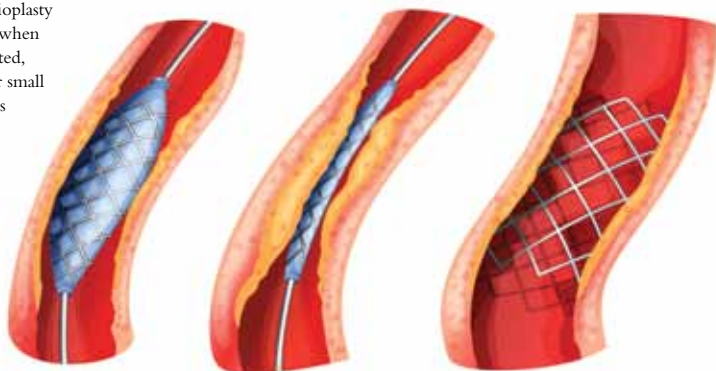
The UK subsidiary of industrial laser specialist Rofin-Sinar is developing a high-power ultrafast laser for applications including cutting the specialist glass used in smart phone and tablet computer touch screens.

The project has won £5m in government backing and is hoped to lead to over 50 new jobs. Ultrafast lasers are now seen as an important growth area, particularly in applications requiring high precision and involving materials that are sensitive to heat. The estimated market for ultrafast lasers is between \$200m and \$300m and growing at double-digit rates (source: Longbow research).



## Micromachining: From engines and aerosols to angioplasty

The angioplasty balloon, when it is inflated, will clear small blockages



**The current drive for speed, efficiency and precise, micro size, features, is perfectly suited to laser technology and specifically micromachining.**

### Engines

Micromachining is a form of laser drilling now commonplace in the component manufacturing sector. It's used for fabricating mass-produced parts, as well as intricately designed components for specialised applications commonly used by industries that demand very high precision – such as aerospace, automotive, biomedical, and electronics.

A good example of its applications is laser drilling equipment for the holes in fuel injectors used by the automotive industry, in which UK company Oxford Lasers specialises. These must be extremely precise, as any inaccuracies will ultimately result in poor performance, reduced fuel economy, greater engine wear, and ultimately, shortened engine life.

### Aerosols

Often, as with aerosol valves, a single type component may need to be produced in a range of sizes for different applications. UK-based laser micro-processing specialists OpTek Systems address this by producing blank components for stock and then laser-drilling the required orifice in response to the customer's needs. The company is a world-leader in production-line laser-systems for precision measurement and machining. Over 80% of sales are outside the UK.

This type of 'just-in-time' manufacturing reduces the number of parts and components manufacturers need to stock and allows the manufacturer to respond rapidly to customer demands.

### Angioplasty

Traditional methods of moulding or machining components for medical disposables – such as stents (illust), embolic filters, precision drug delivery devices such as micro needles, catheters and angioplasty balloons – can no longer cope with the small dimensions of today's devices.

Many of these devices are plastic-based with unusual shapes and small dimensions, which makes them ideally suited for production by UV laser micromachining.

Another plus is that any material can be processed with lasers. This means that complex multi material devices can be manufactured.

### And the rest!

Lasers are also used for producing moulds for plastic components and dyes for metal pieces. These are often used for manufacturing high volume, low cost components such as razors, electrical connectors and even toy trains.

### New horizons

Japanese company Lasertec has recently pioneered a laser micromachining technique called 3D ablation. This will allow a greater variety of shapes, spheres and cavities to be created, as a workstation can control the beam in three dimensions.

Other companies are working on generating valuable process feedback and metrology data. OpTek Systems, for instance, manufactures machines which also laser mark each component with a unique product code and make key geometric measurements, while operating at a rate of 1200 parts/minute.

And speed is crucial because many believe that effective automation is key to unlocking the full potential of laser micro-machining on a commercial scale.

## Laser Scotland

The presence of a number of major multinationals as well as an outstanding research base has enabled Scotland to become a world leader in the design, development and manufacture of high-value lasers and systems. With laser sales in excess of £204m in 2009, 90% of which were exported, this output brings significant wealth to the region. Scottish companies in the laser sector currently provide employment for around 3,000 people.

Founded in 1987, the Lasers and Photonics Application Group at Heriot-Watt University is responsible for a radical design that significantly enhanced the performance of the high-power carbon dioxide lasers used in materials processing. The Group has collaborated with major carbon dioxide laser manufacturers and estimates that the total sales of lasers and systems relying on this one design exceed \$900m.

The largest industrial Scottish players are currently Thales, based in Glasgow, and SELEX Galileo, in Edinburgh. Both specialise in products for the military market; SELEX has a reputation as a leading global supplier of airborne targeting lasers.

Another world renowned company, Coherent Scotland, has gone from strength to strength in the last decade. The company manufactures lasers for industrial environments such as the semiconductor capital equipment market, as well as focussing on microscopy and micromachining.

Also of note is M Squared Lasers, which is pioneering new laser technologies such as sources emitting in the mid-infrared and terahertz regions. Applications for these include homeland security and remote sensing.



*Image courtesy of Jennie Hills/Science Museum*

# Prototyping & Additive Manufacturing

## The importance of rapid prototyping

In the fast-moving sectors of micro and nanotechnology, it's crucial for a product designer to be able to access a prototype quickly. One of the reasons lasers have become so popular for product development and prototyping is because the path from the initial idea to the first proof of concept can be short, often a matter of days. The path to batch production can also be quick, as well as cost-effective.

UK company PowerPhotonics has recently launched the world's first low cost micro-optics rapid fabrication service. Named LightForge, it allows optical designers to create a wide range of optical elements and have the fabricated part shipped in under 2 weeks, without the expense incurred in non-recurring engineering (NRE) – the onetime cost to research, develop, design and test a new product.

## 3D printing

### Entering the manufacturing mainstream?

This revolutionary production process is entering the manufacturing mainstream; 3D printing has recently been taken up by some of the world's biggest manufacturers, such as Airbus, Boeing, GE, Ford and Siemens.

The market is growing fast. Last year it was worth \$2.2bn worldwide, up 29% from 2011, according to consultancy, Wohlers Associates.

But can what is still essentially a niche technology expand to become the key to the factory of the future? While 3D printing for consumers and engineers has received a great deal of publicity, it's in manufacturing where the technology could have its most significant commercial impact.

The answer appears to lie in the fact that 3D printing is not competing with conventional manufacturing techniques per se, but is instead complementing them to make new things possible.

### How it works

3D printers make things by building them up, a layer at a time, rather than the traditional method of removing material by cutting, drilling or machining. This explains the term often used to describe the process, additive manufacturing.

The first type of 3D printing was known as stereolithography and variations of this process are still used. Like all 3D printing, it begins with Computer Aided Design (CAD) and requires software that takes a series of digital slices through a computer model. Each of these slices is used to harden a layer of light-sensitive liquid, usually with ultraviolet light, to form the required shape until the object is complete.

Laser-sintering is a 3D printing method which involves zapping layers of powdered plastic or metal with a laser to harden the powder in some places, but not others. Because laser-sintering is capable of printing things in plastic, metal and ceramics to high levels of detail, it's often used to make finished products rather than mere prototypes.

One of the most popular techniques is fused deposition modelling (FDM), which can be described as a computer-controlled glue gun and involves multiple heads that can extrude different colours.

Many FDM printers now cost less than \$1,000. However industrial systems, like laser-sintering machines, can cost as much as \$1m.

### Significant milestone

The recent decision by GE – the world's largest supplier of jet engines – to produce a fuel nozzle for a new aircraft engine through 3D printing, is a significant milestone for the technology. It shows that, although the aerospace industry currently only uses 3D printing for non-critical items, that's likely to change soon. Already, many of today's planes have a surprisingly large number of printed parts: the F-35, a new strike aircraft, has around 900 parts that have been identified as suitable for additive manufacturing (source: 3D Systems).

GE chose the additive process to manufacture its nozzles because it uses less material than conventional techniques. This reduces production costs and, because it makes the parts lighter, yields significant fuel savings for airlines. The process is also

a faster way to make complex shapes because the machines can run around the clock. And additive manufacturing in general conserves material because the printer can handle shapes that eliminate unnecessary bulk and create them without the typical waste.

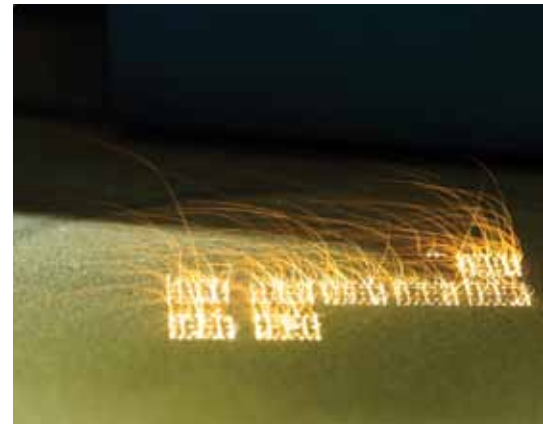
GE Power & Water, which makes large gas and wind turbines, has already identified parts it can make with additive printing, so it's likely it won't be long before it's introduced into other significant areas of GE's manufacturing base.

### Moving onto the factory floor

Slowly but surely 3D manufacturing is beginning to enter the factory floor to enhance mass-production. BMW, for instance, designs and prints custom tools to act as temporary replacements for broken ones or to make it easier to hold and position parts.

Hard-to-find spare parts are also being 3D printed by other manufacturers. In one case, an American airline used it to print plumbing for its ageing McDonnell Douglas MD-80, as production of these craft ceased many years ago.

The printers and the materials they use are also improving, which means better quality products.



Selective laser melting. Image courtesy of Additive Manufacturing & 3D Printing Research Group/University of Nottingham, 2014

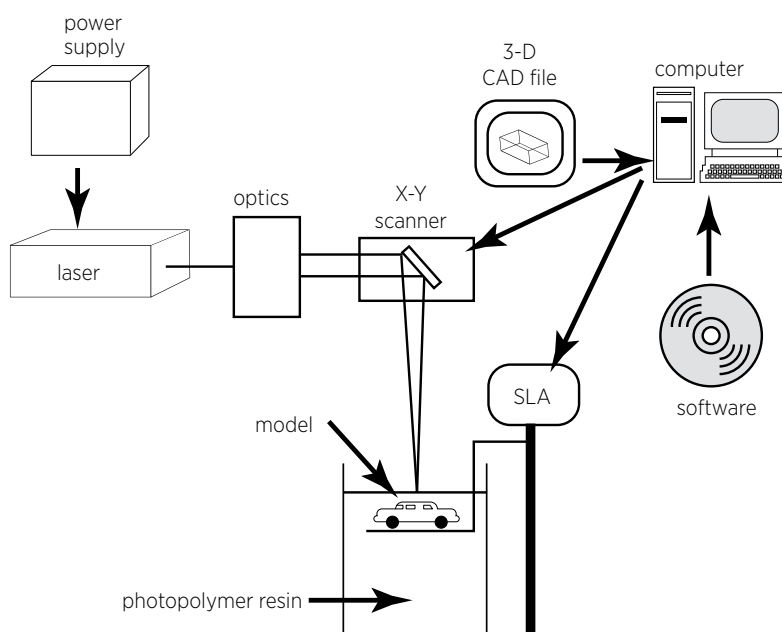
### ADVANTAGES

- A fast, efficient and inexpensive prototyping tool, 3D printing is also a popular way to make one-off items.
- 3D printing takes weeks or months off the design process;
- It can repair or manufacture anything from turbine blades to teeth.
- It can blend multiple materials seamlessly in one part. A single part, for an engine for instance, could be made with different materials so that one end is optimised for strength and the other for heat resistance.
- Development has been ameliorated by the expiry of a number of patents, which has led the price of some printers to fall below \$1,000. Another phase of innovation may begin in 2014 when some of the patents on laser-sintering expire.

### LIMITATIONS

- Additive manufacturing is not about to replace the traditional methods: the finish and durability of printed items can still fall short of requirements and 3D printers can't produce large numbers of identical parts at low cost, like production lines.
- It can be slow. A body panel for a car, for instance, could take several hours.
- Currently, material costs are high. The most common material, ABS, costs a minimum of \$2 a kilo, and a bespoke powder can cost up to \$80. However, some manufacturers, like GE, are developing their own systems which are not dependent on a single supplier or material.

### The stereolithography 3D printing process





## 3D printed electronics

Many manufacturers – including Disney, Xerox and British-owned GKN Aerospace – are experimenting with systems capable of printing electrical circuits directly onto or into components.

Working with the University of Warwick, GKN has developed a printing material called ‘carbomorph’ which changes its electrical resistance when it’s squeezed and can be used to print functioning switches, buttons and sensors.

An American firm, Optomec, has been exploring printing LED lighting onto wallpaper and control circuits for the wings of drones. The company is also working with mobile-phone manufacturers to print circuits directly into handsets. The goal is to eventually print electrical components directly into a product.

## Retail revolution?

Meanwhile, 3D printing outlets are beginning to spring up on the high street. Shapeways in New York, Sculpteo in France and Materialise in Belgium, offer the printing of medical implants for surgeons, models of buildings for architects, lightweight parts for industrial robots and all manner of prototypes for designers.

In October 2013, London department store Selfridges was hosting a 3D pop-up shop manned by iMakr, UK specialists in the technology. Customers could not only use 3D software to print designs of their choice and buy 3D printers for their homes, but also have a bust or full length 3D model printed of themselves.

## Additive design

Design students at the School of Jewellery in Birmingham, UK, are using laser additive manufacturing to produce complex new pieces rapidly.



The flexibility of the additive process has given designers both a new freedom of expression and the ability to produce multiple pieces extremely quickly.

Because they are created layer-by-layer, their pieces feature none of the usual ‘joins’ that are traditionally required, and may detail fine, intricate patterns.

A patented process, from German company Concept Lasers, is popular for this kind of manufacturing. It’s particularly suited to intricate work, as the segments of each individual layer are built up sequentially.

## 3D printers in space?

“On Earth and potentially in space, additive manufacturing can be game-changing for new mission opportunities, significantly reducing production time and cost by printing tools, engine parts or even entire spacecraft,” comments Michael Gazarik, NASA’s associate administrator for space technology.

The possibilities for additive manufacturing in the space industry are interesting. A rocket injector, which NASA recently created through the process, took one third of the time it would have taken using traditional methods, along with a 70% reduction in cost. The part passed tests with flying colours, indicating that it’s only a matter of time before this is a mainstream process.

*“98% of hearing aids (more than 10 million) are 3D printed today.”*

### LEADING MEDICAL APPLICATIONS FOR 3D PRINTING

It’s in the medical field that 3D printing may, in the long run, have the most impact, as the extrusion of living cells instead of plastic material in a 3D printer leads us to bioprinting.

1. Hearing aids – 98% of hearing aids (more than 10 million) are 3D printed today.
2. Digital dentistry – dentists have been using the technology for 10 years, making anything from braces to implants.
3. Body parts and bone – an American patient recently had 75% of his skull replaced with a 3D printed implant.
4. Faces and childrens hands – prosthetics have become easier to customise and produce.
5. Stem cells are treated with a laser to get the right shape and are then linked – paving the way to artificial organs.

(source: CGTrader)



3D printed hearing aid components

Image courtesy of Sonova AG

# Quality Control and Inspection

Light as an instrument of precision opens up many possibilities for measurement, sensors and analytics. It can be used for many purposes from integrated quality assurance to tracking and tracing systems, and 3D shape measurement to terahertz spectroscopy and computer tomography.

## Versatility in machine vision

Machine vision is a multi-disciplinary technology, encompassing computer science, optics, mechanical engineering and industrial automation. As quality demands from manufacturers and customers increase, it's become key to process control and inspection.

Systems for (non-destructive) production control mean a higher efficiency rate; replacing traditional visual inspections also offers the possibility of 100% accuracy in quality control, even in rapid, mass production processes.

And with advances in optical technology, inspection to the submillimeter has become possible, even in barely accessible sites.

Machine vision uses industrial image processing, with cameras mounted over production lines inspecting products and manufacturing equipment, such as robots, in real time, without operator intervention.



Image courtesy of [santechpackaging.co.uk](http://santechpackaging.co.uk)

The cameras interact with a control system which is programmed for individual requirements, providing high-speed, high-magnification, 24-hour operation.

A typical system will consist of one or more digital cameras; a synchronizing sensor, for part detection to trigger image acquisition and processing; actuators to sort, route or reject defective parts; a computer programme to process images, detect, measure and confirm a quality criteria has been met and hardware, such as Industrial Ethernet for communication links. Smart cameras can now combine all the above into single unit.

The system typically checks compliance with certain requirements, such as prescribed dimensions, serial numbers and presence of components. The task can be also subdivided into independent stages.

The machine vision industry market has continually grown over the last 20 years due to the ever increasing capability of processors allowing the technology to be employed in increasingly complex applications. After moderate 1% growth in 2012, an upturn is expected in the future thanks to the automation trend in Asian factories, new capital expenditure in the semiconductor industry and the emergence of new low-end applications.

“Versatile detection and inspection, and compact 3D inspection, will fuel most of the machine vision industrial market’s growth over the coming five years, driven by new low-end applications,” according to analysts Yole Développement.

*“Versatile detection and inspection, and compact 3D inspection, will fuel most of the machine vision industrial market’s growth over the coming five years.”*

# Metrology: to be precise, a booming sector

Increased focus on precision and accuracy in manufacturing processes means that the global metrology services market is expected to reach \$720m in 2018.

Products in this sector are broadly grouped into either coordinated measuring machines (CMM) or optical digitisers and scanners (ODS), with the latter forming the largest and fastest growing segment. Most demand is for 3D laser scanners, as their touch probe technology offers precise measurement for difficult geometries. 3D laser scanners accounted for a 35.1% share of the total ODS market in 2012.

The automotive, aerospace, and power generation sectors are particularly reliant on this

technology and vehicle manufacturing is expected to be the fastest growing end user segment, with a compound annual growth rate (CAGR) of 8.7% from 2012 to 2018. Behind this lies the huge technological advancement in the automotive sector, which has increased the level of precision necessary in parts and components.

Due to an increased demand for metrology services in industrial and aerospace applications, Europe was the leading market in 2012 and accounted for around 31% of the global share. However growth in Asia Pacific is expected to surpass both Europe and North America fuelled mainly by the automotive industry (source: Transparency Market Research).

## GM: red, white and blue to keep ahead of the competition

GM's competitive benchmarking is a patriotic affair. The 3D laser scanners they use to deconstruct the competition's vehicles come in red, white and blue.

In addition to traditional white light scanning, technicians use red light scanners to document fine details of interior design, and to scan smaller parts, and blue light on reflective and transparent surfaces.

The end result is a complete set of reverse-engineered computer models of the competitor vehicles, which are shared with GM's designers and engineers who can then compare their company's designs to those of competitors. It's as good as having direct access to the competitors' original engineering data.

## A metrology clinic for the UK's manufacturing heartland

In a drive to help manufacturers improve the consistent quality of their products and to encourage innovation in inspection processes, businesses in the proximity of



Huddersfield are being offered free weekly metrology clinics and advice on the use of measurement technology and processes.

The clinics are run by the UK's primary measurement institute, the National Physical Laboratory (NPL), from its new inspection facility in Huddersfield. The facility, which opened in June 2013, operates alongside a new multi-million pound research centre promising major breakthroughs in metrology for precision engineering.

A recent customer survey estimated that NPL has directly helped organisations achieve benefits of more than £100m per annum through the introduction and application of good measurement practice.



Images courtesy of Hexagon Metrology

## The Light Controlled Factory

The Light Controlled Factory, a project led by the University of Bath, is looking to foster the use of lasers and optical methods for measurement and control of machines in industry. It's the recipient of a £2.5m Engineering and Physical Sciences Research Council (EPSRC) grant, as well as match funding in excess of £1.25m from 10 industrial partners, including Airbus, Astrium Satellites, Rolls-Royce, Renishaw and the NPL.



Europe was the leading market in metrology services in 2012 and accounted for around 31% of the global share

#### The BLOODHOUND SSC Land Speed Record

The Bloodhound SSC (supersonic car) aims to break the 1,000mph barrier in South Africa in 2015. The project team are using equipment by leading measurement specialist UK-based Hexagon Metrology, to inspect individual components and sub-assemblies and ultimately to ensure the car is built as designed and so has the best possible chance of success. The company is also number one metrology supplier to the UK aerospace industry.



Image courtesy of Siemens NX

### Tracking and tracing

Many goods or components have a distinct surface structure that can be recognised at microscopic level with a camera during production. Distinctive characteristics can be stored along with data such as measurements or production details.

### Computerised tomography

Tomography refers to imaging by sections or sectioning, through the use of any kind of penetrating wave. Computerised tomography (CT) enables us to detect deviations in density and defects, and their position in an object, using reconstructed volume data and a spatial representation contained in software. Even concealed inner structures can be measured.

The process works by rotating the part 360 degrees along its axis inside a CT machine, while up to 720 images are taken using a high physical resolution x-ray detector of around 3 million pixels.

CT can capture everything – shape and dimensions, density, material flow and any porosity, cracks or inclusions. This data is stored in Voxels, which are 4-D pixels. This enables non-destructive testing (NDT), archiving, reverse engineering and investigation. The data can also be used to prevent counterfeiting of copyrighted or patented products.

### Industrial applications

CT is not a new technology. It's been widely applied in medicine since the 1970s, with CT scanners taking multiple X-ray slices to give doctors a complete 3D image of a patient's body. With the clarity of information provided improving dramatically recently, application in industry now offers similar advantages. Industrial applications may include traffic engineering, cast materials, plastics, rubber and the automotive industry.

Currently CT is still rarely employed in manufacturing, mainly because of speed issues and high costs and (in the UK), is still in the early stages of acceptance. Recently a French group, Minalogic, has attempted to rectify these issues by creating an X-ray rapid-tomography system for quality inspection on the production line. This project shortens the time required to inspect products from several minutes to only a few seconds, and so makes the CT scan practical for industrial quality control.

Meanwhile, the system designed by Wenzel UK offers a different advantage. Its small footprint and the company's own proprietary detector technology provide a major USP over competitors in this area. The system is able to process most materials of light density, including plastics, light alloys and carbon fibre.

### Effective

With its ability to measure and examine both the inside and the outside of a part in

extensive detail, CT could prove highly effective in industry. It can also accommodate multi-material assemblies, isolate individual components and analyse material flow in plastic and composite parts, as well as enabling manufacturers to rapidly develop new products and production methods. Material density is probably the biggest issue in CT development at the moment. Processing higher density components, such as a titanium turbine blade, currently requires huge amounts of power, which means bigger machines.

For more geometrically complex objects, planar computed tomography (PCT) offers a solution. State-of-the-art X-ray and detector technologies are used to visualise deviations in individual layers (2D) as well complete volumes (3D). The process is used mainly for electronic components and composite materials.

#### The new Wenzel exaCT® CT technology



Image courtesy of Wenzel Group

# Spectroscopy

Solids, surfaces, liquids, and gases – a huge range of materials can be analysed by spectroscopic methods, which are fast and accurate.

Essentially the interaction between matter and radiated energy, spectroscopy can be used in a broad range of applications including industrial process control, environmental monitoring and biotechnology.

Spectroscopy sensors are often used to determine gas permeation rates in difficult-to-penetrate materials or highly porous ones.





*“Terahertz spectroscopy is a fast, safe and reliable test that could help safeguard one of the UK’s most valuable industries.”*

### **Fake Burberry? There’s a spectroscopy solution!**

An estimated £3.5bn is lost each year through the production of counterfeit clothing. Now, a new technique – based on terahertz time-domain spectroscopy – has been developed to help customs officers ascertain whether items of clothing are fake, assisting them in the seizure and destruction of fake goods.

The technology was developed by the National Physical Laboratory (NPL) and involves terahertz radiation, the underused band which falls between microwaves and infrared light.

When a fabric sample is placed within the beam, the composition and structure can be ascertained, as different types of material give rise to varying rates of beam scattering and absorption. The fabric’s unique signature will indicate whether or not it’s genuine or a clever copy.

“Counterfeit clothes can look and feel almost exactly like the real thing and so customs officials need technological assistance to spot them,” said John Molloy, who worked on the project at NPL. “Terahertz spectroscopy is a fast, safe and reliable test that could help safeguard one of the UK’s most valuable industries”.

### **Developing tools to measure nanostructure**

Nanomanufacturing has come a long way; a key achievement is the development of manufacturing technologies that fabricate nanostructures formed from multiple materials. Such nanoscale integration of composites has enabled innovations in solar

cells, electronic devices and medical diagnostics. However, there has been little progress in measurement technologies that can provide information about these integrated nanostructures. Now, researchers at US-based Anasys Instruments and scientists at the University of Illinois have developed such diagnostic tools using atomic force microscope-based infrared spectroscopy (AFM-IR). The technology can identify nanostructures, by directing rapidly pulsed IR laser light on a sample, causing it to expand. Structures as minute as 100nm can be measured.

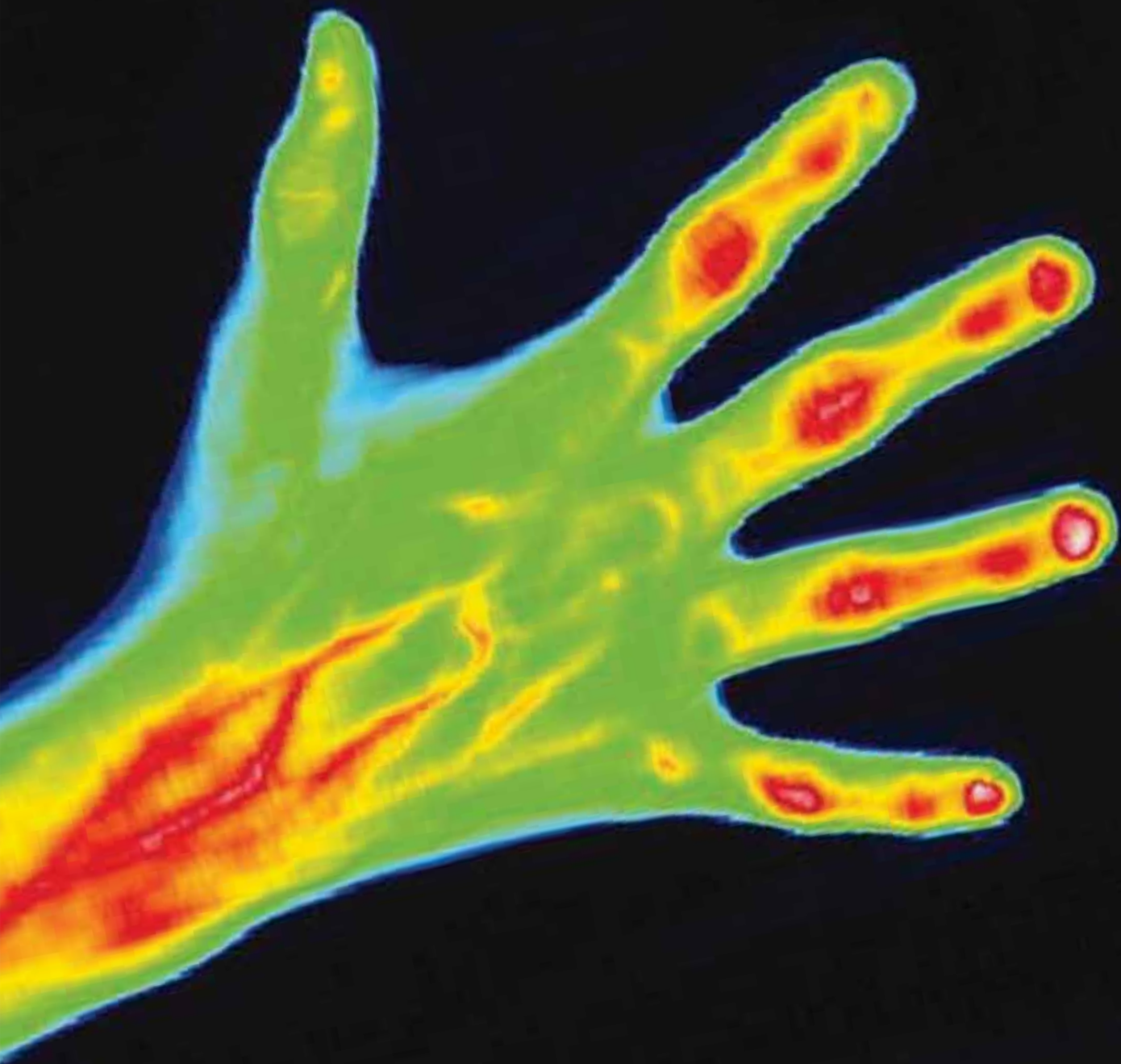
### **Slashing aircraft costs with holography**

Just like cars, manufacturers are continuously aiming to make modern aircraft lighter, faster and more fuel efficient. This means introducing new advanced materials, composites and super lightweight structures, all of which need to be rigorously tested.

Currently, two separate tests – one using laser beams and one using thermal imaging – are relied on, to see inside the material under stress and detect problems in the structures caused by hidden defects. Now, European researchers have found a way to replace these with a single test which uses holography in the infrared spectrum and is quicker and less expensive.

The technology is now being fine-tuned for aerospace applications and spin-offs are already hitting the market, with German SME InfraTec marketing the new infrared cameras for a variety of industrial sectors.





# Photonics and Healthcare

Photonics has a long tradition of use in the fields of healthcare and life sciences.

In ophthalmology and dermatology, laser diagnosis and treatment have become standard procedure.

In the future, the role of photonics in healthcare and life sciences can only grow.

Revolutionary advances in photonics will continue to provide new ways of detecting, treating and even preventing major diseases at the earliest possible stage, improving patient survival rates and drastically reducing care costs.

# Imaging

Optical imaging uses light to interrogate cellular and molecular function – both in the living body as well as in the lab. Images can be generated by a whole host of methods, but commonly by interpreting photons of light ranging from ultraviolet (UV) to infrared.

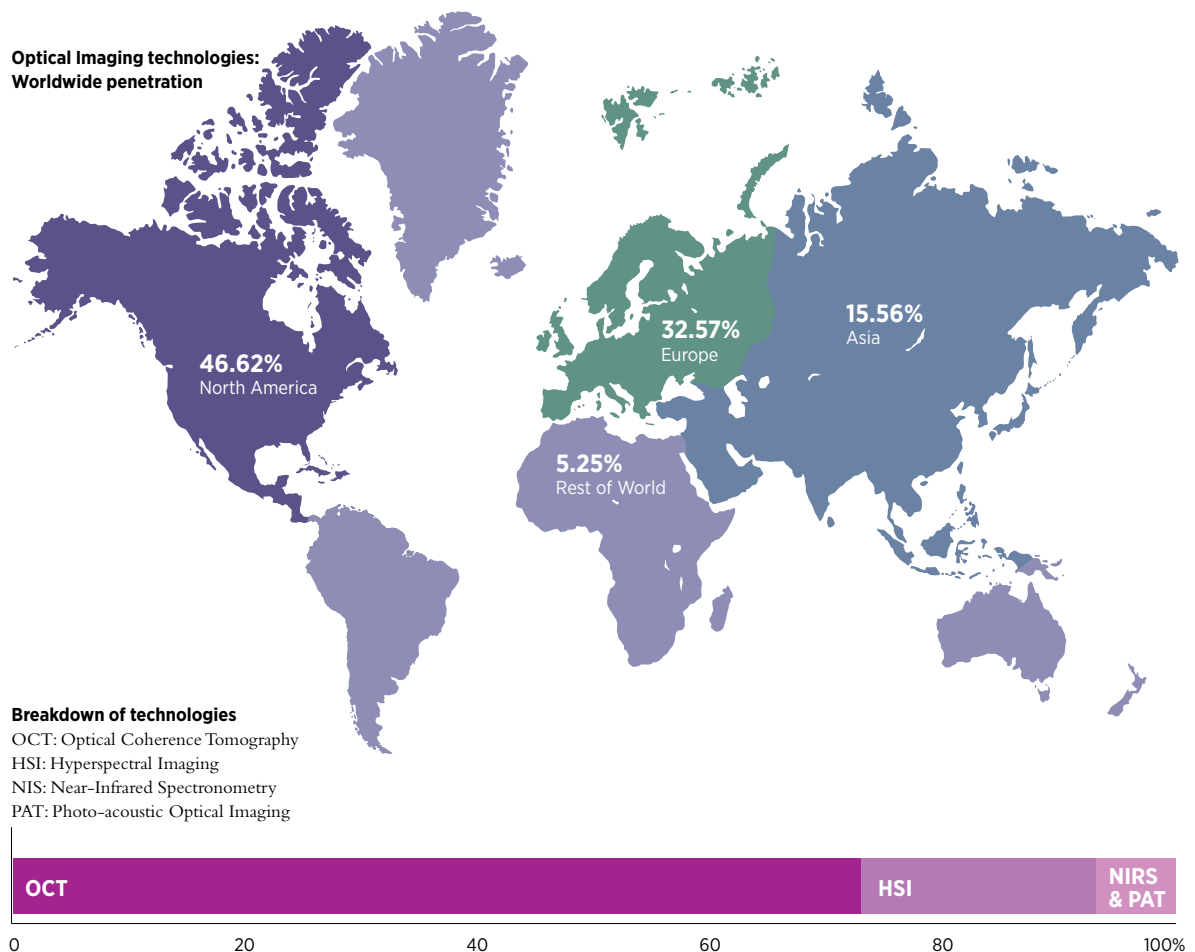
The major driving force in optical imaging techniques is the demand for easily-accessed in-depth imaging of the structures of the eye, surface tissues, mucosal, the gastrointestinal tract and vascular systems. These hold out the real promise of swifter and better diagnostic procedures.

Crucially, optical imaging procedures are

non-invasive, use no ionizing radiation and therefore present no risk to clinician or patient. They are also significantly cheaper compared to conventional radiology.

The major technologies currently used are Optical Coherence Tomography (OCT), Hyper Spectral Imaging (HSI), Near Infrared Spectroscopy (NIRS) and Photo-Acoustic Tomography (PAT). Currently, the optical imaging market is dominated by OCT, with over 70% of the market share.

Several UK universities have made key breakthroughs in the area, with a diverse range of projects winning funding and gaining attention.



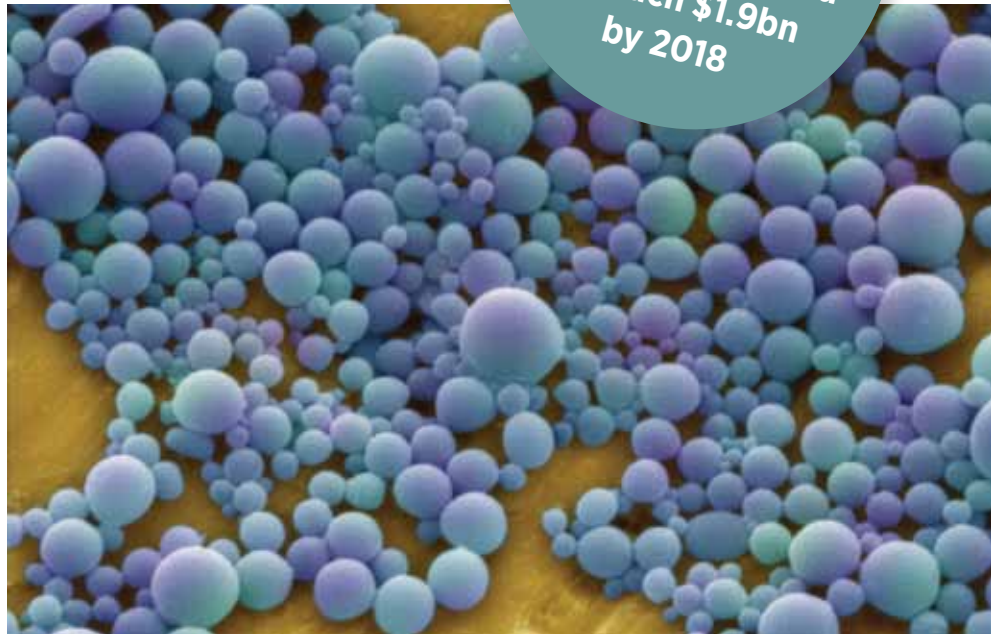


The value of the Optical Imaging Technologies Market is expected to reach \$1.9bn by 2018

## How does a nanoparticle go to work?

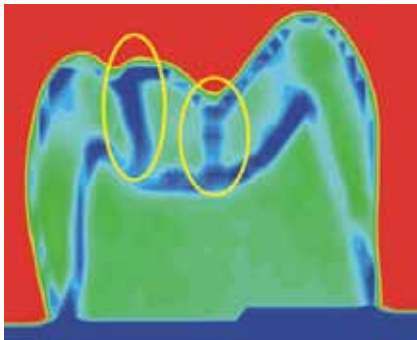
Advances in pharmaceuticals have created increasingly sophisticated nanoparticles for delivering drugs. However, many of the ways in which these delivery systems interact with organs at the cellular scale are not yet clear.

But the outlook is changing. Scientists recently mapped the circulation of a nanomedicine in the body using light and a system of lenses for magnification, a process called multimodal nonlinear optical microscopy. Natalie Laura Garrett and scientists from the University of Exeter and the UCL School of Pharmacy investigated the process by which a nanoparticle drug called GCPQ passed through a patient's body. They were successfully able to pinpoint its process with subcellular precision and in real time.



Nanoparticles. Annie Cavanagh, Wellcome Images

Images courtesy of TeraView Ltd



A comparison of terahertz-pulsed imaging with transverse microradiography and microhardness to measure mineral changes in enamel after treatment with fluoride dentifrices.

## The exciting new territory of the terahertz

In a bold new mission, what's been called the 'underused and uncharted' terahertz (THz) region of the electromagnetic spectrum is to be explored thanks to two separate £6.5m research projects.

The THz region lies between infra-red and microwaves. There's 30 times more bandwidth available in the THz region than in the entire allocated radio spectrum. If harnessed, this could offer massive scope for a host of applications, from medical imaging systems to 'super Wi-Fi'.

Currently, THz (or 'T-rays') are only used in full-body security scanners, to detect explosives, and spectroscopy systems for materials analysis. But they can also be used to detect increased blood flow around tumorous growths and identify molecules in living DNA.

The Coherent Terahertz Systems (COTS) Project is funded by the Engineering and Physical Sciences Research Council (EPSRC). It brings together expertise from University College London, Leeds and

Cambridge Universities. The COTS team aims to beat the hurdles facing current THz technologies – that they're complex, bulky and power-hungry.

Underlining the importance of the area, a parallel project is exploring a new way of producing T-rays. The X Prize Foundation, with sponsorship from Qualcomm, is offering £6.5m to the creators of a handheld device that can best diagnose a set of diseases. Researchers from Imperial College London and Singapore's Agency for Science, Technology and Research (A\*STAR) have leapt to the challenge, using nanotechnology to create stronger directional beams of T-rays.

It's hoped their new technique – creating a nanoscale antenna that amplifies the T-rays as they are generated – could allow future systems to be smaller, cheaper, more portable and easier to operate. It may even pave the way for a Star Trek-style tricorder diagnostic device in the not-too-distant future.

The value of the Optical Imaging Technologies Market is expected to reach \$1.9bn by 2018.

*“More sophisticated laser products are dramatically simplifying what were very complex systems, 10–15 years ago.”*



### Advancing the attack on Alzheimer's

A £500,000 'super-resolution' microscope which might help tackle some of the most challenging brain diseases has been developed at the University of St Andrews, in a research partnership with Nikon.

The device will allow for investigations at a previously impossible level of detail, such as how neural pathways are affected in Alzheimer's disease.

Professor Frank Gunn-Moore of the School of Biology commented, "I hope to investigate how nerve cells talk to each other and, as such, how they make memories."

And it's not only the academics who are making strides in this area. Coherent Scotland Ltd recently received an Innovation Award from the Institute of Physics for their Chameleon laser. It's a one-box fully automated tuneable ultrafast laser system and is being used to make new breakthroughs in imaging Alzheimer's and also Parkinson's disease. The product has created 100 jobs for the company since it was introduced to the market 10 years ago.

### Moving medical devices from bench to hand

Usually, research biologists have multiple requirements for lasers when stimulating fluorescent cell and tissue markers. Up until now, meeting all them has been very difficult.

Derryck Reid and Christopher LeBurn of Herriot Watt University are looking to the future and see a widespread demand for the integration and miniaturisation of medical technology. They hope to pave the way for more diagnostic devices to make the leap from bench to hand.

Under the company name Chromacity, Reid and LeBurn have identified a distinct market gap for a compact, low-to-medium power widely tunable laser. One that's capable of replacing the many individual fixed-wavelength lasers needed for laser scanning fluorescence microscopy.

Chromacity's concept takes the form of a single tunable system, with a proposed cost 3–4 times cheaper than any similar product.

Reid and LeBurn – who combine more than 40 years experience in laser development – specialise in hyper-spectral imaging (HSI). This involves collecting and processing information to generate a spatial map of spectral variation. It records tens or hundreds of images from closely spaced wavelengths, or spectral bands, as opposed to just red, green, and blue, as in standard colour imaging. It's a technology which has multiple applications and they have assembled an IP portfolio to underpin their products, with two international patents filed.

Their growth model predicts a turnover of more than £10m within five years, making the company an attractive

acquisition for large microscope manufacturers like Nikon, Olympus or Zeiss.

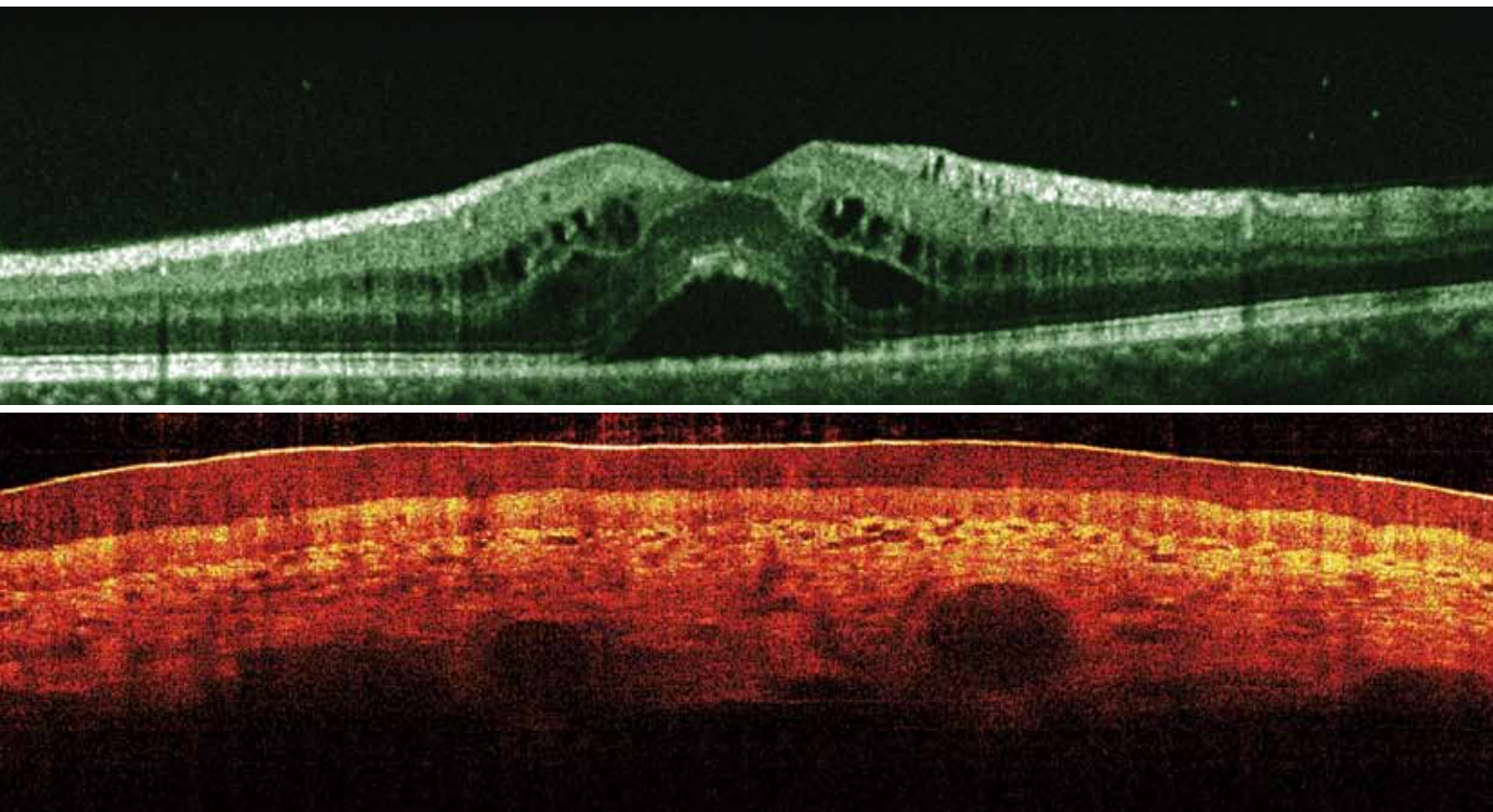
Reid describes their rationale: "At the millennium the excitement in photonics was all comms – but that has plateaued a little bit. Where the novelty is now is in systems integration."

"More sophisticated laser products are dramatically simplifying what were very complex systems 10–15 years ago. They're also more robust, with start-up times of seconds, rather than minutes."

The duo are currently seeking investment for the company during its start-up phase. LeBurn has secured a Royal Society of Edinburgh Enterprise Fellowship, to help with the initial costs of the spin-out and provide business support to push Chromacity forward.

#### FAST FACTS: FLUORESCENCE LASER SCANNING MICROSCOPY (LSM)

- Very strong excitation light is concentrated on small spots of the specimen, enabling detection of low concentrations of fluorescent substances.
- Low levels of auto-fluorescence generated provide images of great contrast, even with weakly fluorescent specimens.
- Permits the visualisation of multiple focal layers of the specimen and 3D image reconstructions.
- Allows the comparison of different images of the same specimen area, enabling multi-parameter analysis of cells.



*Images courtesy of Optos and Vivusight*

# Optical Coherence Tomography

**Using light waves to tune into the market**

Similar to ultrasound imaging, except with higher resolution and using light instead of sound, optical coherence tomography (OCT) is one of the most exciting and fast growing technologies in the life science sector. Non-invasive, it promises great advances in the understanding of neurological and other disorders of the human body and each new discovery is greeted with waves of enthusiasm in the medical community.

Since the first work on OCT in the late 1980s and early 1990s, dozens of companies and hundreds of research groups have been formed, thousands of research articles have been published, and approximately 100 million patients have been scanned using the technology.

Applications for its use are still emerging and, in the UK, there's a wealth of startup activity, fuelled by a steady upward trend in investment.





### Seeing beneath the surface of skin cancer

UK startup, Michelson Diagnostics, has earmarked non-melanoma skin cancer (NMSC) as its area of expertise and believes the OCT impact here can be enormous.

NMSC is the most common type of cancer in the developed world. It's particularly prevalent in elderly Caucasians with a lifetime of sun damage to their skin.

The market for NMSC treatment is vast, and growing: incidence of the disease is increasing about 4% per annum due to changing demographics and modern tanning habits. Each case of NMSC in Europe costs an estimated £500–£1,000 to treat. A Department of Health paper put the annual NHS bill at over £100m. Most of this is due to the actual and overhead costs of performing surgical biopsies and excisions of tumours.

### Cutting the guesswork out

Currently, NMSC is diagnosed visually and then by taking a skin biopsy, but this type of diagnosis is inaccurate; biopsy is painful, costly, slow (2 weeks for a result) and leaves a scar.

These are all factors which a new scanner, recently launched by Michelson Diagnostics, seeks to ameliorate. Their 'VivoSight' is the first EU and US approved OCT scanner for diagnosis and monitoring of NMSC and other skin conditions. It's already being used in a number of dermatology clinics in the US and Germany. It's lightweight and has a

manoeuvrable probe, which is placed against the skin and produces real time images that can identify diagnostically important features at 10 times the resolution of ultrasound.

Enabling immediate decisions on diagnosis saves time and money and reduces the number of unnecessary biopsies; better assessment of the scope of lesions also allows greater use of non-invasive, non-scarring treatments such as creams and photodynamic therapy (PDT).

### OCT had revolutionised the diagnosis by enabling the scanning of deep tissue.

The majority of clinics are constrained by small consulting rooms. So the more compact the machine, the better. With the help of assistance from the Technology Strategy Board, Michelson Diagnostics are working to upgrade VivoSight into an even lighter and more compact unit that can be quickly moved in and out of small spaces. This measure would make a big difference to the take-up of the technology and advance their company vision of having a VivoSight in every dermatology clinic in the developed world.

### Looking to the future

OCT has been particularly successful in ophthalmology, having revolutionised the diagnosis of eye diseases by enabling the scanning of deep tissue. Previously, ophthalmologists had to make what amounted to an educated guess about the

underlying condition of the retina using only a picture taken from the front.

In addition, eye exams are uncomfortable, especially for young children, so it is difficult to conduct a complete exam and view the entire retina. This limitation was made cruelly apparent to engineer Douglas Anderson when, in 1992, his five-year-old son went blind in one eye as the result of a retinal detachment being detected too late. The experience motivated Anderson to set up Optos and develop a patient-friendly retinal imaging product that would easily capture a widefield image of the retina. The resulting product was a scanning laser ophthalmoscope, capable of capturing an image of nearly the entire retina, without the need for inconvenient pupil dilation and in a single examination.

### All-in-one system

With the acquisition of OPKO Instrumentation in 2011, Optos moved into the arena of OCT diagnostic devices and optical ultrasound scanners. Their product portfolio now includes the 'all-in-one' OCT SLO system, which combines industry-leading spectral OCT imaging with a confocal scanning laser ophthalmoscope (SLO) in one highly advanced instrument.

The confocal SLO provides high-resolution images and retinal tracking before, during, and after the OCT scan. A 'lock and track' function of the SLO ensures the follow-up scans are obtained from the same location without

relying on the operator's subjective judgment. Suited to a range of eye disorders (from tears, glaucoma and diabetic retinopathy through to systemic diseases, such as hypertension and certain cancers), the technology enables both diagnosis and tracking.

### Visionary funding

At present none of this technology comes cheap. At Optos, Anderson devised an innovative business model whereby the company retains ownership of the devices and the clinic pays them a fee for each examination performed. It's a measure that seems to have worked because Optos now have over 4500 customers worldwide, with over 40 million eye exams taken to date.

The Optos approach shows that, despite the current focus on OCT by many startups, inventive approaches to funding are as necessary as visionary technology.



*The 'all-in-one' OCT SLO system courtesy of Optos*

## The future trends of OCT

By Adrian Podoleanu, Professor of Biomedical Optics, University of Kent



In recent years, the efforts of joint teams of hardware developers and clinicians have pushed the performance of OCT from

applications restricted to imaging the eye to a wide range of tissue types.

No other technology offers patients and physicians non-invasive, non-contact subsurface images with such a high depth resolution. In ophthalmology, OCT has allowed imaging of the back of the eye with 100 times better depth resolution than that using confocal scanning laser ophthalmoscopy.

In endoscopy, it's the only technology capable of high resolution imaging, with more than 15 times the depth resolution of high frequency ultrasound.

OCT is now increasingly being used with complementary imaging modalities, and augmentational technologies such as adaptive optics (AO) and tracking. Some of these combinations have evolved from bench systems into the clinic, and none is without some level of restriction. For instance, imaging methods that are very fast, such as

spectral domain OCT (SD-OCT), operate under fixed focus – limiting the accuracy of three-dimensional (3D) acquisition. However, because of its speed advantage, SD-OCT will probably dominate the imaging of moving organs, as it's more suitable for hand-held probes.

I expect that, in a few years, the broadband sources essential for ultra-high depth resolution will become more available and more compact – and so the combination of OCT with other modalities should evolve even further. The addition of curing tools such as laser scalpels and ablation lasers to OCT imaging channels is a very real possibility.

The quest for faster, higher-resolution patient imaging has ensured OCT a rapid evolution in the last decade. I believe this synergy of effects will continue to drive our imagination to invent other combined configurations. Transferring the information provided by one technology to a different one, or combining technologies to obtain higher-quality information and deliver better patient outcomes.

I've no doubt that highly adventurous avenues lie open to expand OCT's capabilities.

### FAST FACTS

- Optical coherence tomography (OCT) is the process of imaging the cross-sectional microstructure of tissues using optical backscattering or backreflection. It was first demonstrated in 1991.
- Imaging up to 2 to 3mm deep can now be achieved in most tissues. Although these imaging depths are not as deep as with ultrasound, the resolution of OCT is 10–100 times finer.
- OCT is now widely accepted for clinical diagnostics in ophthalmology, dentistry, cardiology, dermatology and has recently broadened its application to cancer detection.
- In combination with catheters and endoscopes, OCT can help determine if tumour cells have broken through to deeper tissue layers – avoiding time-consuming and sometimes hazardous biopsies.

### RECENT UK RESEARCH

- In order to improve our understanding of diseases like scleroderma (hardening of the skin) and Reynaud's disease (reduced blood flow in the skin), Mark Dickinson at the University of Manchester has been working with a network of local hospitals to develop OCT for studying blood flow.
- Another potential new application of OCT is in tissue engineering. Steve Matcher is leading a group at the University of Sheffield investigating if OCT can be used to monitor the invasion of melanoma cells in a tissue-engineered skin construct. This would not only help clinicians design the optimum treatment regimens for individual patients, as well as offering an alternative to animal testing.
- Pierre Bagnaninchi at the University of Edinburgh is developing an optical coherence phase microscope. This will be used to monitor optical signatures related to the multiplication and differentiation of stem cells for use in the regeneration of tissues such as bone and liver.

# Endoscopy



*LED Multiplexer prototype. Image courtesy of Cymtec Ltd*

With an ageing population, increasing prevalence of chronic disease and patient preference for minimally invasive surgeries, the tide is turning toward ‘gentler’ therapies that can cure serious illnesses but also have fewer serious side effects.

Endoscopy fits into this category. It’s the generic term for an instrument used to examine

the interior of a hollow organ or cavity of the body. Unlike most other medical imaging devices, endoscopes are inserted directly into the organ and demand for them has recently exploded.

The global endoscopy device market was valued at \$6.1bn in 2011 and is expected to be \$9.7bn in 2016. North America is the largest market, followed by Europe and Japan.



#### FAST FACTS

- There's a surge in demand for visualisation systems – due to the advent of HD cameras, 3D HD and growing usage of high colour precision HDTV in hospitals.
- Endoscopy offers physicians the facility to perform surgeries in their offices. This means reduced recovery times and lower risk of secondary infection.
- Because of health scares, there is also an increased demand for disposable endoscopic devices over reusable equipment. (Recently, a patient in the US sued successfully, after allegedly catching Hepatitis C from a colonoscopy.)

# CYMTEC

## Changing the face of endoscopy

“We call it disruptive technology. This will wipe away any bulb-based system.”

Ron Yandle is being a bit cloak-and-dagger. He is careful how he chooses his words, and no wonder.

His company, Cymtec Limited, based in Caerphilly, Wales, operates in a technology industry where intellectual property is crucial in order to generate first-to-market products. They have recently filed a patent for an LED multiplexer that will change the scope of endoscopy.

Endoscopy systems enjoy a significant portion of the available business in the medical devices market, but the problems with current devices are varied. They have a low colour gamut, many cannot fluoresce tissue (a key requirement for chemically-marking and identifying cancerous cells) and are expensive to maintain.

Ron Yandle explains the basic principles:

“With a standard endoscope, you have a box with a bulb – connected to either a fibre optic or liquid filled light guide – which has a camera and a light attached to the end of it. All that bulb does currently is give white light.

“In 2009, Imperial College came to us with a proposal – to incorporate red, green and blue LEDs in one light source, with the facility to adjust the intensity of colours. In addition, they wanted something that could also provide UV light, so that chemical markers could be employed to make cancerous tissues fluoresce.”

LEDs are a widely-used source of low-cost, ultra-bright, nontoxic lighting. However, they too have their issues, in particular with regard to multiplexing (that is, combining multiple LEDs into one light stream).

What Cymtec devised neatly surmounts these issues. Their NeoLite multiplexer has demonstrated over 40% more optical light coupling than the current best reported results. This was achieved with an innovative (but closely guarded) approach,

which allows very little loss of light from coatings, clipping and polarisation, while crucially keeping costs low.

The NeoLite is also energy efficient, generates less heat and provides excellent colour versatility. Surgeons will be able to view images which are far clearer than those they currently have available and, the UV light will allow them to fluoresce tissue, and thus better discriminate the cancerous cells from healthy ones. All of which means less need for invasive biopsies and improved scope for better patient outcomes.

Using UV light in endoscopes is a relatively unexplored area. The NeoLite will also abolish the need for bulb changing, which effectively means the endoscopy system becomes sealed for life, making it more efficient and more hygienic.

Ron Yandle's partner and the company's CTO, Nigel Copner, Professor of Optoelectronics at the University of South Wales, says, “By understanding the losses in the typical lighting schemes, we have innovated simple, low-cost designs. For digital displays we've demonstrated onscreen brightness that's twice that

of the nearest competition. This patented technology will provide enormous commercial differentiation for our customers in the projection and endoscopic markets, which are worth over £200m each year. They will also allow a true long-life replacement to the Xenon light source, currently widely used in both endoscopy and digital displays.”

Cymtec have almost completed the build of their prototypes. These need to be CE marked (a mandatory conformity for products sold in the EU) before human trials can begin in the latter part of 2013. Once trials are complete, the company, which since 2007 has been largely self-financed (with contributions from Finance Wales and the National Institute for Health Research), will be in a position to create employment in South Wales.

The global endoscopy device market is expected to be valued at \$9.7bn in 2016

This market  
is projected  
to reach around  
\$2.6bn  
in 2014

# Photodynamic Therapy

**P**hotodynamic Therapy (PDT) uses a light-activated drug to kill cancerous cells.

While its potential has been known for over a hundred years, the development of modern PDT has been gradual, requiring scientific progress in both photobiology and cancer biology, as well as the development of modern photonic devices, such as lasers and LEDs.

The PDT market was worth \$1.3bn in 2008, which increased slightly in 2009 to \$1.5bn. It's projected to reach around \$2.6bn in 2014.

Right: The Ambulight plaster, and far right: The Ambulight System. Images courtesy of Ambicare



## The humble sticking plaster gets high-tech upgrade.

They've served us well for simply patching up small cuts and grazes, but now the humble sticking plaster is going high tech. Embedded with light-emitting diodes (LEDs), plasters are being used to treat skin cancer in combination with light-sensitive drugs.

The LED plaster is the brainchild of Scottish firm Ambicare who have named it the Ambulight. It's both simple to operate and portable, meaning that patients can go about

their daily routine while receiving PDT.

"At the moment, patients have to attend a central hospital, which creates a bottleneck," says Paul Donnelly, CEO of Ambicare. "Ambulight makes treatment by your local GP an option, which makes PDT accessible to a much wider patient base. Not only does this offer cost savings, it also reduces waiting lists."

"The whole device is disposable and is designed for one use only. You have the light-activated cream applied at your local surgery. You then put the Ambulight on straightaway and wear it for six hours."

According to Donnelly, one added benefit is that patients experience less pain when using Ambulight compared with conventional PDT.

"The only drawback is that we can only treat lesions with a maximum diameter of 24mm at their widest point," he says, "and we have some physical limitations as to where the Ambulight can be attached to the body. For example it's not possible if it's a very highly curved area, such as the bridge of your nose."

Having been granted a CE mark at the end of 2009, the company is hoping more

clinicians will see the attraction of the light-emitting technology and Donnelly believes the figures speak for themselves: "By moving PDT out of the hospital, you could save £600–800 per treatment."

## PDT beats infection in chronic leg ulcers.

Another major application for PDT is in combating infection. Safe and convenient, it can be adapted for use in non-hospital settings, such as GP surgeries or patients' homes.

In a study conducted by Lesley Rhodes from the University of Manchester, findings showed that after three months 50% of ulcers treated with PDT had healed completely, compared with only 12.5% of those in the placebo group.

The patients in the study had an antimicrobial or a placebo lotion applied to their wounds before both groups were exposed to an 'activating' red light.

There was a significant reduction in the bacterial load of all wounds treated with PDT immediately after treatment.

*“Embedded with LEDs, plasters are being used to treat skin cancer in combination with light-sensitive drugs.”*

#### **PDT ADVANTAGES**

- Avoidance of both surgery and radiotherapy.
- Minimally invasive and significantly less toxic.
- Can destroy cancers with a single 20-minute session.
- Scarring is unlikely.
- Highly precise direction of laser light possible with optical fibres.
- Resistance does not develop with repeated treatment.
- Total cost of drugs used is just £235 – a huge saving compared to other NHS treatments and drug therapies.

#### **PDT LIMITATIONS**

- Needs light directed to the appropriate site and tissue depth to be effective. So, currently only effective for cancers near the body's surface.
- Is not ablative, so doesn't yield material for histological diagnosis.
- Skin photosensitivity, which can last several weeks, is inevitable.



# Laser Eye Surgery

The global market for ophthalmic lasers will rise to \$804m by 2015

In the UK, around 30% of people 65 and over have visually impairing cataracts. It's estimated that 225,000 new cases can be expected each year, with around 300,000 cataract removals performed annually.

## MARKET STATISTICS

- According to Global Industry Analysts, the market for ophthalmic lasers will rise from \$591.5m in 2011 to \$804m by 2015, a compound annual growth rate of over 7%.
- North America represents the largest market for both ophthalmic lasers in general and refractive laser surgery in particular, with Europe the second largest.
- The global market for cataract surgery devices of all kinds was valued at \$3bn in 2010, and is expected to exceed \$3.8bn by 2017. The bulk of this is for artificial intraocular lenses (IOLs), used to replace the eye's natural lens.
- The majority of surgically implanted IOLs are standard monofocal lenses, but premium multifocal IOLs are gaining in popularity. Premium IOLs are engineered to mimic the eye's natural process of distance variation, so, post-surgery, glasses are often not required. The higher price tag of premium IOLs means that, although they accounted for 13% of the US market in 2010, they contributed 39% of total IOL revenue.

## Femtosecond Lasers set to revolutionise cataract surgery

Cataract surgery currently involves removing the eye's natural lens and replacing it with a synthetic intraocular lens (IOL), made from acrylic or silicon material. A small incision in the eye allows a probe to be inserted. The natural lens is broken up in-situ, often with a metal tipped tool vibrating at ultrasonic rates. Vibrations are used to liquefy the lens, which is then sucked out. This procedure can, very occasionally, cause damage to surrounding structures, leading to future complications.

The big advantage of the femtosecond (i.e. ultra-fast) laser is micro-level accuracy and needle-free, blade-free surgery. It has the potential to carry out lens extraction or cataract surgery through a pin-prick incision, and has been called the greatest breakthrough in cataract surgery in the last 25 years.

First, using optical coherence tomography (OCT), a detailed three-dimensional image of the inside of the eye is created. Controlled by a computer, the laser then fragments the cataract while also automatically creating an opening into the eye. After this, lens implantation is carried out in the same way as in the traditional operation. The whole procedure takes just a few minutes, compared with about half an hour previously.

The UK's first cataract procedure using a femtosecond laser took place at the London Eye Hospital (LEH) in 2012. Consultant ophthalmic surgeon Bobby

Qureshi employed an Alcon LenSx laser system. He said, "It has a very user-friendly interface and produces consistent results every time. The laser is usually on for less than 60 seconds during the procedure."

But a significant potential barrier for broader adoption in the NHS and throughout the UK is expense – most femtosecond systems come in around the £250,000 mark.

However, if costs were to come down, with more than 400,000 cataract procedures each year in the UK alone, the scope for suppliers of femtosecond lasers is massive.





### Space tech offers potential giant step in detecting eye disease

Age-related Macular Degeneration (AMD) is the developed world's leading cause of blindness.

Within the next decade, the number of AMD sufferers in the UK is expected to rise to 750,000. More than 1% of over 60s currently suffer from some sort of AMD.

Now engineers at the UK Astronomy Technology Centre have come together with scientists from Cardiff University's School of Optometry and Vision Sciences to develop a 'retinal densitometer,' which can pick up the earliest stages of AMD by measuring, in the minutest of detail, how the eye responds to light. Astronomy and medicine may seem an unlikely pairing, but the same instruments that help telescopes spot the dimmest of distant stars can also detect light inside the human eyeball.

Cardiff University's Dr Tom Margrain explains: "Ten years ago, there were no real

treatments for AMD so there was little support for this type of early disease detection technology. Over the past year or so, early approaches to treating AMD have become a significant research area, as have the tools to perform such analysis. Also, sometimes it takes an interaction between two different disciplines – in this case ophthalmology and space technology – to solve the problem."

The project is funded by the UK's National Institute for Health Research's Invention for Innovation programme and also by the Science and Technology Facilities Council (STFC), which was responsible for setting up the collaboration.

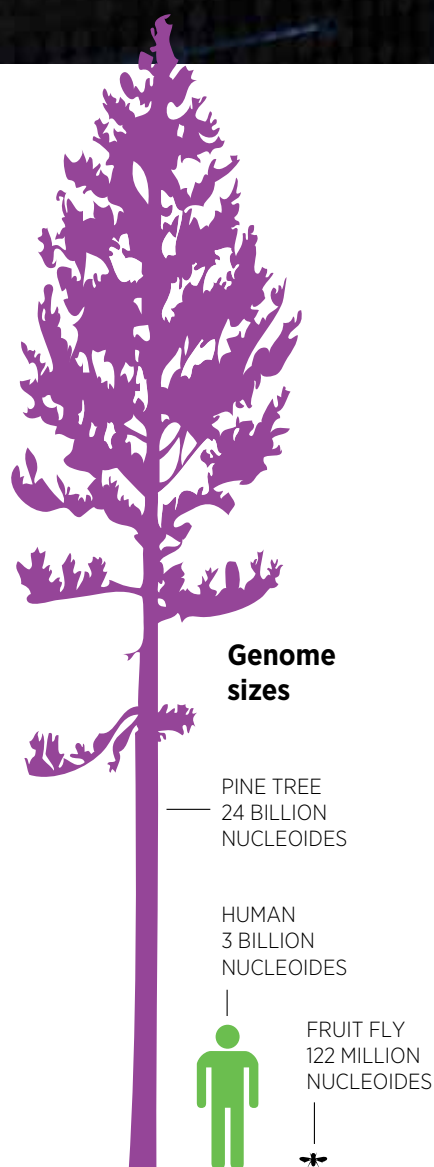
Dr Dave Melotte, Innovation Manager at the UK ATC commented: "Astronomy and vision science might seem poles apart but, put the right experts together and they are able to achieve things that would be impossible by either group in isolation.

"We aim to produce a commercial device. There has been a lot of interest from companies working in this field."

*"Astronomy and vision science might seem poles apart but, put the right experts together and they are able to achieve things that would be impossible by either group in isolation."*

# Genetics and Data

Moore's law is frequently re-versioned but roughly predicts the doubling of computing power every two years. However, DNA sequencing is becoming faster and cheaper at a pace that far exceeds this.



## What's to be done with the deluge of DNA data?

At BGI in China, the world's largest genomics research institute, 167 DNA sequencers work round the clock, producing the equivalent of 2,000 human genomes a day.

This amount of data simply cannot be transmitted via the internet or other digital lines of communication. Almost comically, BGI sends its clients and collaborators their data on computer disks, via FedEx.

So, while the long-awaited threshold of a £1,000 pricetag for sequencing one genome may be on the horizon, this excludes the cost of making sense of that data, which is becoming a bigger and bigger part of the total spend. And, while it remains significantly more expensive to analyse a genome than to sequence one, the routine use of genetic sequencing in medicine is delayed.

## Seagate: seeing the way forward

Worldwide, it's estimated there are 2,000 sequencing instruments, annually producing enough data to fill a stack of standard DVDs more than 2 miles tall. With sequencing capacity increasing at the current rate, next year the stack would be around 6 to 10 miles tall. In the next five years the DVDs would reach well into space.

Seagate, in Northern Ireland, have developed a technology that will soon double the storage capacity of disks and could

increase it twenty-fold within ten years.

The technology, called heat-assisted magnetic recording (HAMR), involves heating the magnetic regions on a disk that hold individual data bits, allowing those regions to be made smaller. Iron-platinum disks are heated with a short laser pulse when the head applies a magnetic field to write data.

The biggest issue with the new head is that it needs to focus light onto 25-nanometer-wide spots, which is tough with conventional lens-based optics. To get round this, Seagate uses a parabolic mirror that focuses light down to a quarter of its wavelength, making 100-nanometer spots. To tighten that even more, the researchers use a tiny gold antenna that collects light and reemits it at a 30-nanometer spot. "It's a gold piece that has to be appropriately shaped," says Ed Gage, Seagate's principal technologist of heads and media R&D. "We've tried a number of different antenna shapes."

However, plenty of engineering challenges remain. Seagate presently need to use an external laser to shine light on the parabolic mirror, although it has been possible to put a laser into the recording head.

HAMR may still have some way to go but, with the future needs of recording head technology overlapping with many others in the fields of nanophotonics and integrated photonics, the technology holds great promise, with applications not just in life sciences, but also energy harvesting, telecoms, security and even refrigeration.





This brochure was produced by the Photonics group of the Knowledge Transfer Network on behalf of the UK photonics community and the Photonics Leadership Group. More information on the Photonics Leadership Group can be found on **[www.photonicsuk.org](http://www.photonicsuk.org)**

**Contact:** [photonics@espkn.org](mailto:photonics@espkn.org)

Photonics Brochure  
KTN, Photonics Group  
Bailey House  
4-10 Barttelot Road  
Horsham  
West Sussex RH12 1DQ  
**[www.innovateuk.org](http://www.innovateuk.org)**

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