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**50 Years of
Lasers in Scotland**



The fiftieth anniversary of the laser is truly an event worth celebrating. From what started as a scientific experiment in a laboratory, the laser has grown and proliferated into a technology resulting in great economic benefit. Scotland's laser industry has been active in this field from the beginning and will no doubt have a hand in guiding the developments of the future.



Lasers: an everyday essential



Scottish milestones



Meeting tomorrow's challenges



Scotland's talent in lasers



The laser industry in Scotland today



Origins of Scotland's laser companies



Lasers and laser-enabled photonics in Scotland

Unlike conventional sources such as a light bulb or even the Sun, the light emitted by a laser has several unique characteristics that make it attractive for a massive range of applications. For example, one variety of laser light comes in the form of a thin beam continuously emitted in a single specific direction, contains just one colour and can be focused down to a tiny spot. Light from a bulb on the other hand contains a full spectrum of colours mixed together, is emitted over an extremely wide angle and cannot be focused to a small spot very easily.

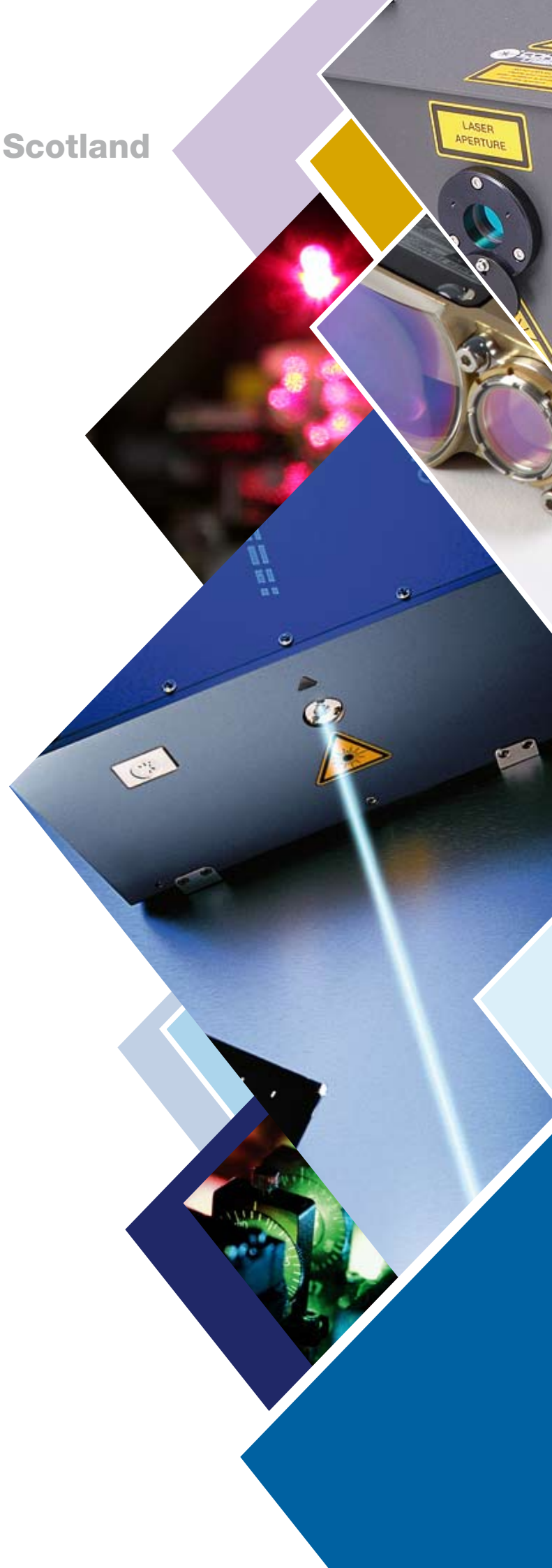
50 Years of Lasers in Scotland

This document showcases Scotland's laser industry, which contributed approximately £660 million to our nation's economy in 2009. This value has grown sequentially every decade since the 1960s as lasers have gone on to facilitate an ever wider range of products. Scotland's laser industry is key part of a booming worldwide business. 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 \$8.8 billion according to analyst Strategies Unlimited.

In Scotland, we are proud to have both a strong academic base and a thriving laser industry that manufactures cutting edge technology which is exported the world over. Our flair for innovation, engineering and manufacturing ensures that some of today's most sophisticated lasers and laser-based systems are designed, developed and manufactured on our shores. Thanks to the presence of multinational companies such as Thales, SELEX Galileo and Coherent Scotland, Scotland can claim to be a world leader in the design, development and manufacture of high-value lasers and systems.

The laser industry in Scotland is heavily export intensive, with over 90% of sales exported from Scotland, bringing significant wealth into the country. We often hear that the UK is no longer a manufacturing nation, but there are some 3000 people working in the laser-enabled photonics industry in Scotland who would dispute this. And thanks to our close network of leading laser companies and universities, Scotland's strong position within the global laser industry looks assured for years to come.

The year 2010 has a special importance to all working in the laser industry. In 1960, Theodore Maiman and colleagues at Hughes Research Laboratories in the US demonstrated the first laser. Fifty years on and laser technology has proliferated to such an extent that it now plays a part in all aspects of modern society and has truly revolutionised the way we live.



Lasers and laser-enabled photonics in Scotland

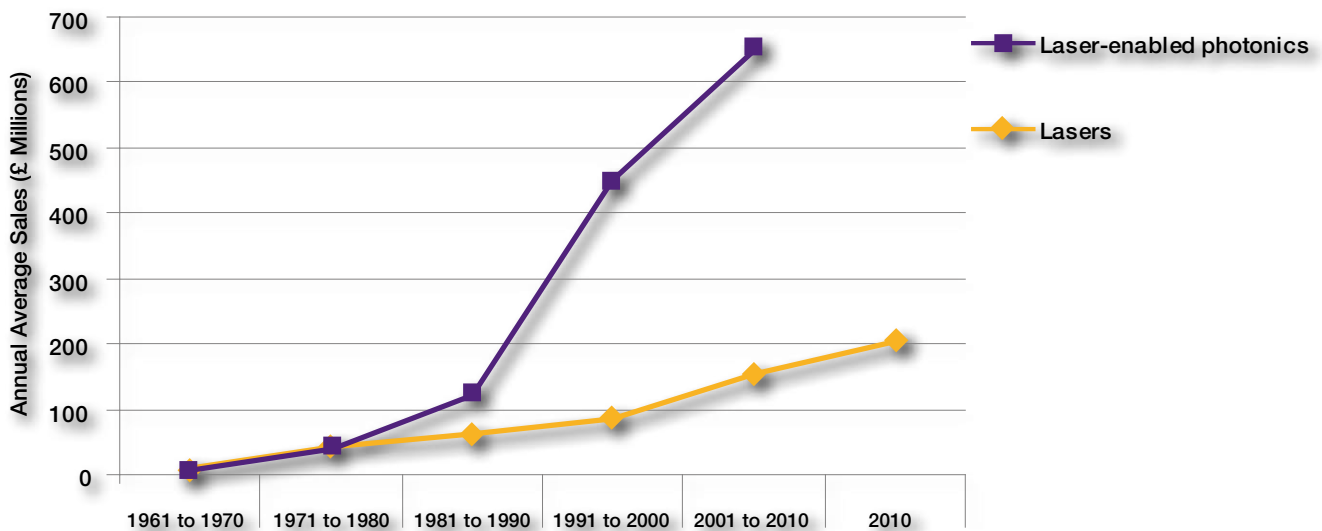
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The laser's contribution to the Scottish economy is twofold. While direct sales of lasers continue to play a part, an even larger contribution today comes from laser-enabled technologies, an industry which is encompassed by the term photonics.

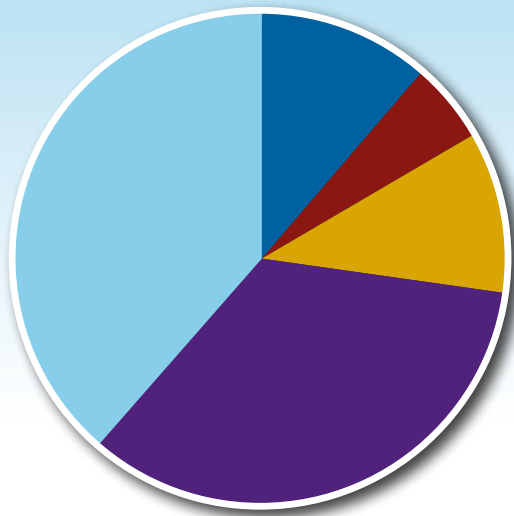
- Laser-enabled photonics sales in 2009: £660M
- Laser sales in 2009: £204M
- Laser-enabled photonics employment in 2009: 3,000
- Laser employment in 2008: 1,650
- Laser-enabled photonics sales have increased every decade since 1960s
- In excess of 90% of sales are exported from Scotland
- 10,000 person years in academic research in laser-enabled photonics over the last 5 decades
- 90,000 person years employed in industry in laser-enabled photonics in the last 5 decades
- Up to 20% of the workforce in Scottish laser companies are educated to postgraduate level: highly knowledge intensive
- Currently 82 companies in laser-enabled photonics in Scotland
- Scotland's laser companies invest on average 5% in R&D

The laser's contribution to the Scottish economy

Average Annual Sales £ millions

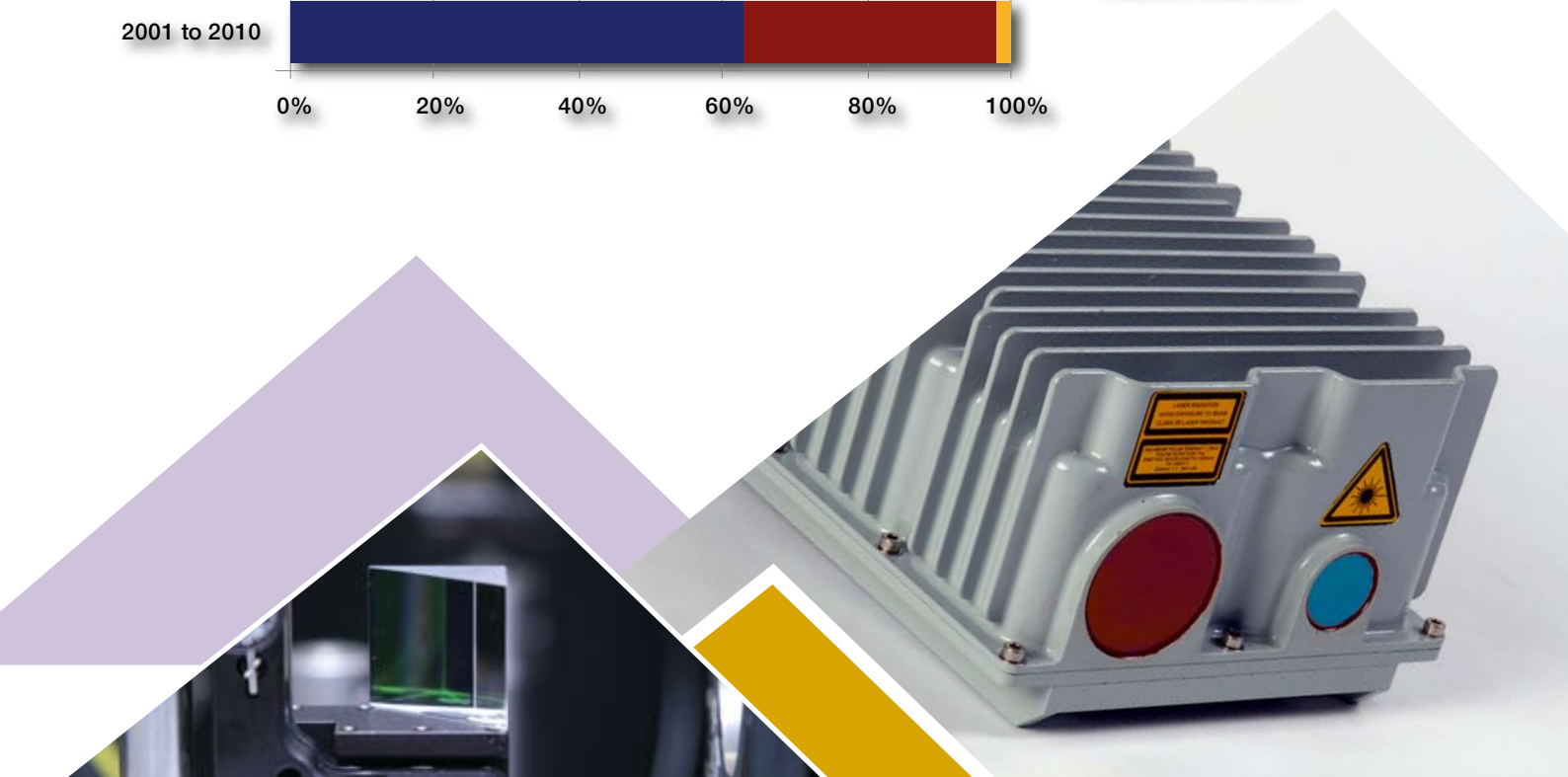
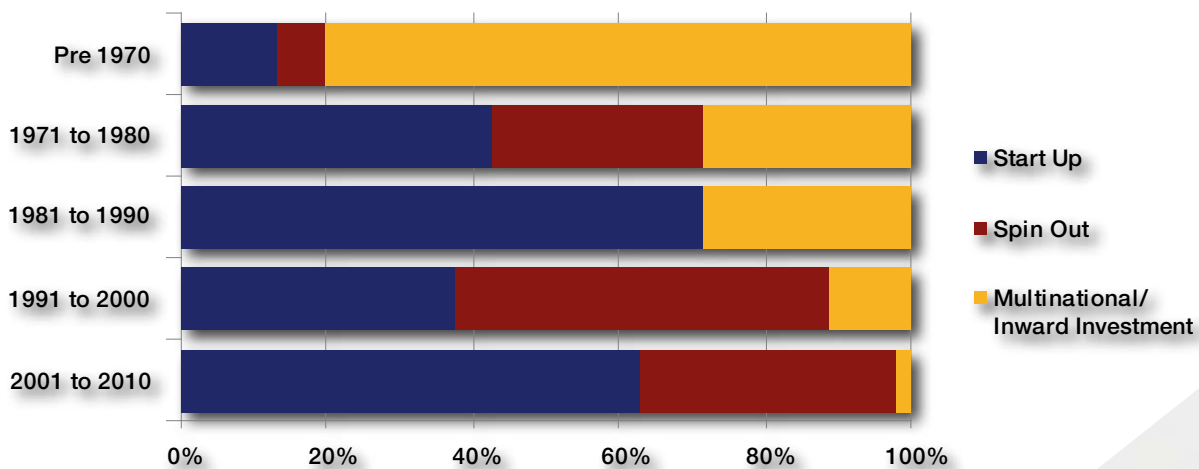


Origins of Scotland's laser companies



- Pre-1970s Large companies start new laser divisions. Military leads the way with real applications
- 1971-1980 Major evidence of start-ups and spin outs
- 1981-1990 Start-ups see the opportunities in laser-enabled photonics
- 1991-2000 University spin-outs bring new technology to the market. Investment boom in photonics and the major companies expand
- 2001-2010 Recycling the entrepreneurs. Start-ups driven by second round entrepreneurs. Opportunity driven companies. Major companies continue to expand.

Each decade has seen significant differences in the way Scotland's laser companies were formed. Each decade has seen an increase in the number of companies being formed. Many of these companies have gone on to grow their laser activity and become major exporters from Scotland.





The laser industry in Scotland today

Scotland is in the enviable position today of having a highly successful laser industry that is backed up by a strong research base. There is also little doubt that going forward the laser industry will play a leading role in the economic development of Scotland and the UK as a whole.

Scotland's laser industry is hugely export intensive, with the majority of companies exporting upwards of 85% of their products generating a tremendous amount of wealth. It is also important to realise that the value to the economy is not only in products sold, but also in the business created by using UK-based suppliers and the long-term commitment companies give to customers to support their products.

A largely unrecognised fact is the scale of the manufacturing base that exists across Scotland and the opportunity this presents for the future. The fact that Scotland has lost its leadership position in older, heavy manufacturing industries should simply act as a catalyst to gain this position back in newer, high-technology industries such as photonics where the country's reputation is undisputed.

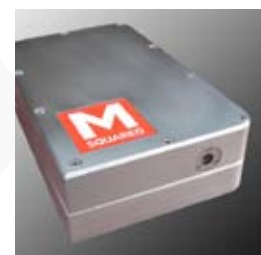


The largest players in Scotland today are Thales, which is based in Glasgow, and SELEX Galileo, which is situated in Edinburgh. Both of these companies manufacture products for the military market, in particular laser rangefinders and target designators. Thales supplies the British Army and several other armed forces around the world. At its peak, the highly-skilled workforce at its optronics site in Glasgow can manufacture several hundred high-performance laser rangefinders per month. Bolstered by its success in securing the contract to supply the laser for the Joint Strike Fighter, SELEX has a reputation as a leading global supplier of airborne targeting lasers.

"We make money in manufacturing and support," commented Dave Clark, Director, Optronics at Thales. "We don't manufacture, sell and forget. We support our products for 10 to 15 years and longer in some cases. We make long term investments to get long term returns."

Coherent Scotland is based in Glasgow and has gone from strength-to-strength in the last decade and now employs over 100 people, 18 of which hold a PhD. From its base on the West of Scotland Science Park, the company manufactures four main product lines: the MBR and MBD lasers that were initially pioneered by Microlase, the Azure for industrial environments such as the semiconductor capital equipment market, the Chameleon for multiphoton microscopy and the Talisker picosecond fibre-based laser for micromachining.

Also based on the West of Scotland Science Park, M Squared Lasers is pioneering new laser technologies such as sources emitting in the mid-infrared and terahertz regions. Applications of these lasers include homeland security and remote sensing and have helped the company's annual revenue move into the multi-million scale. And finally some forty years on from its initial inception, Edinburgh Instruments turns over approximately £6 million annually and supplies lasers for an ever-increasing range of applications.



Scotland's talent in lasers

Ask anyone in Scotland's laser industry why they are based in Scotland and the answer will be the same: the extraordinary pool of talent available thanks to the high concentration of universities producing graduates specializing in lasers and photonics.

Two examples worth noting are the MSc in Photonics and Optoelectronic Devices which has been run jointly by St Andrews and Heriot-Watt universities since 1981 and the more recent Engineering Doctorate (EngD) programme that is offered by four of Scotland's universities: Glasgow, Heriot-Watt, St Andrews and Strathclyde.

Students on the one-year MSc course complete a three-month placement in industry while candidates studying for an EngD spend three of their four years working in a participating company under the guidance of an industrial supervisor on an applied research project. Both of these activities have been a major source of laser engineers and have provided generations of highly talented individuals. The link between academia and industry will become increasingly vital going forward and is widely seen as essential for sustainable recruitment and product innovation.

"The talent pool is very stable," commented Allan Colquhoun, University Liaison and Emerging Technologies Manager at SELEX. "Our relationship with universities helps both research and recruitment. We have taken students from the MSc for over 20 years and it is a useful route for graduates to move from research into industry."



Meeting tomorrow's challenges

The stable nature of the talent pool is also reassuring looking forward as laser technology continues to feed into ever more areas of our lives. In September 2009, the European Commission recognised photonics as one of five key enabling technologies that will secure future prosperity. This highlights both the economic importance of photonics and its ability to address some of the major challenges facing modern society.

One such challenge is addressing the needs of an aging population, which will place an ever increasing demand on health services. Biophotonics is an active area of research in Scotland and the role that lasers can play in medicine is still very much under investigation. Just one example is a technique known as transfection, which is being used to shed light on the development of Alzheimer's disease. Here, researchers use a laser to create a tiny hole in a single cell allowing DNA or drugs to enter the cell and their effects to be monitored.

The safety and security of our nation's borders is sadly never far from the media spotlight. Lasers are the ideal technology with which to create a range of sensors for everything from detecting explosives to providing countermeasures such as confusing inbound heat-seeking missiles.

Scotland's deep-rooted heritage serving the military market will ensure that laser-based systems for defending land, sea and air borders will continue to be designed and manufactured in Scotland for years to come. M Squared Lasers for example is currently working with DSTL Porton Down to develop laser-based tools to detect threats from a safe distance. The idea is to use a laser emitting mid-infrared light, supplied by M Squared, to see and identify tiny drops of hazardous material.

Other major areas of development will be using lasers to promote a green economy and enable broadband access for all. The Scottish laser industry is playing a key role in a number of applications ranging from developing lasers for the manufacture of solar cells and pollution monitoring through to investigating lasers for next-generation high-speed optical communications.

Scotland has played a key role in advancing laser technology over the last 50 years. We are a nation that boasts a prosperous core industry, an expert manufacturing base and leading academic institutions and are ideally placed to ensure that we maintain our position at the forefront of the laser industry.

Our understanding of lasers has improved significantly over the last 50 years and Scotland has made some key contributions.

▶▶▶▶ The 1960's

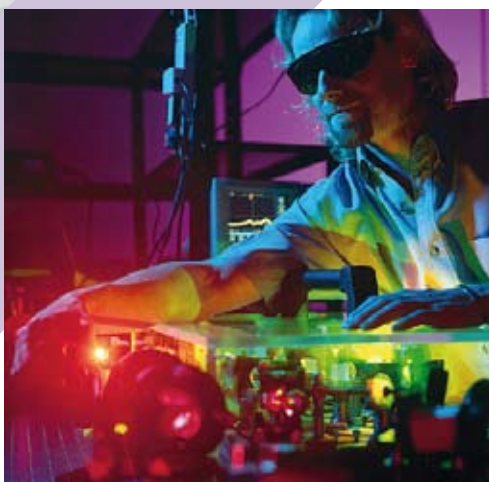
Scotland's laser industry can be traced back to two strong optical engineering companies supplying into the military market: "Barr & Stroud" and "Ferranti". In the early 60s, both companies were quick to realise the benefits of laser technology and started actively researching a range of sources. A significant milestone saw Barr & Stroud producing the first military laser rangefinder just seven years after the invention of the laser, which was subsequently fitted on to all Chieftain tanks. The ruby-laser-based product was designed and manufactured entirely in Glasgow. More efficient versions of this technology based on Nd:YAG lasers, and, most recently, eye-safe versions using Er technology, have subsequently been fitted to all British main battle tanks, again with the development and manufacture being done in Glasgow. Alongside this industrial activity, Scotland's universities were ramping up their laser research. At St Andrews University for example, Arthur Maitland was leading the laser group in understanding and developing gas discharge lasers. ▶



Arthur Maitland started the laser physics group in St Andrews in 1963 and was a pioneering figure in the research community. Having worked in industry prior to his academic career, what set Maitland apart was his strong belief that, where appropriate, research should be transferred from the lab into industry. One way of achieving this was to encourage PhD students to move into industry – an effective way to transfer knowledge by the movement of people. Maitland's research led to the development of a gold metal vapour laser in the late 1980s, which was used by clinicians at Ninewells Hospital in Dundee for photodynamic therapy.

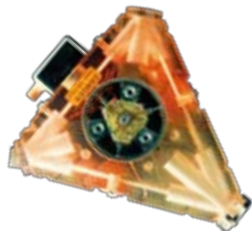
The 1970s

In 1970, Heriot-Watt University in Edinburgh established the UK's first research park on an academic campus giving rise to the term "on-campus industry". A year later, Edinburgh Instruments spun out of Heriot-Watt and had the honour of being the first private company on the park. At that time, Heriot-Watt was investigating tunable lasers, and in particular a system known as the spin flip Raman laser that needed to be pumped by either a carbon monoxide or a carbon dioxide laser. Maintaining its close ties back to the university, these carbon monoxide and carbon dioxide lasers became the first products of Edinburgh Instruments, and are still manufactured by the company to this day. In 1973, Ferranti unveiled what was claimed to be the world's first true industrial carbon dioxide laser. Derivatives of this product were used in industries such as steam turbine manufacture, aerospace, automobile manufacture, ship building, metal fabrication and many more. In St Andrews, researchers were also looking into carbon dioxide lasers thanks largely to the arrival of A. L. S. "Tony" Smith. In 1979, Smith moved to Strathclyde University to take up the chair of experimental physics.



Wilson Sibbett is responsible for what many people believe to be the single piece of work that revolutionised ultrashort pulse generation: Kerr-lens modelocking (KLM) in a titanium-sapphire laser. Demonstrated in May 1990, KLM is simple way of producing laser pulses that last just a few femtoseconds (10^{-15} s). This research expanded rapidly the entire field of femtosecond science and technology with its staggering list of applications, which includes corrective laser eye surgery. Sibbett still heads the ultrashort-pulse laser research group at St Andrews, which is currently investigating uses of femtosecond pulses in biophotonics and communication.

The 1980s



The word most associated with this decade is renaissance. Academic research and industrial activity were gathering significant momentum thanks to the insatiable desire for more efficient and compact sources offering higher powers and operating at new wavelengths. A significant development saw the inefficient flashlamp-pumped laser technology of earlier years being superseded by diode-pumped solid-state (DPSS) lasers. The commercial implications of this development cannot be overstated. In 1982, thanks to the efforts of Tony Smith, Strathclyde University created its first chair of photonics, which was held initially by Brian Henderson. Allister Ferguson joined Strathclyde University in 1989 to take up a chair in photonics. Meanwhile, at Ferranti's site in Edinburgh, ring laser gyroscopes formed a key part of the guidance system onboard the European Space Agency's Ariane rockets.

The 1990s



The 1990s marked a turning point in Scotland's laser industry as commercial activity began to ramp up and the laser became much more of an enabling technology. A case in point is Microlase. "In the early 1990s, my research group was developing miniature DPSS lasers and knew that there were tremendous commercial opportunities. People wanted to buy these systems but couldn't," recalls Allister Ferguson, now Deputy Principal Professor Research and Knowledge Exchange at Strathclyde University. "Myself, Graeme Malcolm and Gareth Maker spun-out Microlase from Strathclyde in 1992 and the company grew spectacularly and was sold to Coherent - the world's largest laser company - in 1999 and renamed Coherent Scotland." In academia, Wilson Sibbett and colleagues at St Andrews University discovered Kerr-lens modelocking and opened the floodgates to the field of practical ultrashort-pulse lasers. Collaboration with industry was also in evidence as Strathclyde University established its Institute of Photonics and St Andrews its Photonics Innovation Centre. The goal of both was to bridge the gap between academia and industry.

The 21st century

Today, Scotland boasts around 80 laser-enabled photonics companies and estimates by the Scottish Optoelectronics Association put the industry's annual turnover in terms of laser-enabled photonics sales in the region of £660 million. Two of the largest employers are Thales, which incorporates what was Barr & Stroud in Glasgow, and SELEX Galileo, which absorbed Ferranti's activities in Edinburgh. In the early 2000s, SELEX Galileo won the contract to supply the laser that will perform rangefinding and target designation onboard the Joint Strike Fighter – the biggest aircraft programme globally and a significant win for Scotland.

It is also worth noting that the lasers produced by both Thales and SELEX Galileo are the cornerstone of much larger, integrated instruments. "The laser facilitates the development of products with much higher value," explains Dave Clark, Director, Optronics at Thales. "The value of the lasers is worth several tens of millions of pounds a year to my company but when you add in sales of these larger instruments, this figure rises to around 100 million pounds a year."

Coherent Scotland recently shipped its 1000th Chameleon laser, a highly complex laser system that produces femtosecond pulses. With each of these lasers being designed and manufactured entirely in Scotland and having a list price of over \$200,000, this milestone is a significant achievement. Chameleon lasers are used in biomedical fluorescence spectroscopy, where they are helping scientists push medical research and discovery to new levels.



Coherent Scotland also remains a significant employer and contributor to the Scottish economy. "The total economic impact from Microlase and Coherent Scotland from 1992 to date will be around quarter of a billion dollars in system sales," said Graeme Malcolm, founder of Microlase. Malcolm left Coherent Scotland to form M Squared Lasers in 2006 and is looking to emulate his success with Microlase. "M Squared has grown rapidly and our business now generates multi-million pound revenues," he said. "It has been standard for our revenues to double year-on-year since our inception in 2006."

Lasers: an everyday essential

Laser technology has come a long way in the past 50 years. In the early days, lasers were very much seen as a scientific curiosity and dubbed a “solution in search of a problem” due to the lack of real-world applications. The picture today is radically different as lasers are at the heart of many of the products and innovations we now take for granted. You only have to ask yourself “what would happen if all laser-enabled technologies stopped working” to see the extent to which we now rely on the laser.

In this worst-case scenario, one massive gap would appear in telecommunications. Laser-based fibre-optic telecommunication systems have widely replaced copper-wire based networks so there would be no dialling tone when you pick up the phone. Switching to your mobile phone would not be an option, as mobile networks also rely on the same fibre optics. The ability to communicate over the internet would also be lost as lasers have played a leading role in the advent of the world-wide-web. Traffic lights, cash dispensers, points of sale and indeed anything communicating over a network would find its connection severed.



In fact, if all laser-enabled technologies were to stop working, the effects would be widespread and felt in every sector of modern society. For example, lasers are used in medicine for applications such as corrective eye surgery, cancer treatment and even as precise and sterile scalpels in surgery due to the unique properties of laser light. One of the main uses of lasers in industry is an area known as materials processing where high power beams cut thick plates of steel. Lasers can also weld metal plates together and can be found on the production lines of many of today’s largest automotive makers. In the military, lasers are used for rangefinding and target designation, a particular specialism of Thales and SELEX Galileo who are both based in Scotland.



It is also challenging to find a consumer product that has not been touched in some way by a laser. As early as 1974, barcode scanners made their debut in supermarkets and in 1982 the now humble CD player was the first widely available laser equipped consumer device. Today, as well as assisting the manufacture of consumer goods, lasers are found in products such as high-definition Blu-Ray Disc systems, gaming platforms such as the PlayStation3 and of course laser printers. In future, lasers could even be used as the light source within tiny colour projectors that are built-in to laptops and mobile phones to allow us to view photographs or presentations at our convenience.

In November 2009, a saboteur sliced through an underground fibre-optic cable in San Jose, California, causing severe and widespread disruption across Silicon Valley. Residents and businesses alike had no landline, mobile or internet service, traffic lights and ATMs stopped working and even the 911 emergency services number was out of action for a time. The act prompted telecommunications giant AT&T to offer a \$250,000 reward for information and led to a manhunt involving both local police and FBI. This crime shows the extent to which we take laser-enabled technologies for granted.

We gratefully acknowledge the following organisations for their help in preparation and sponsorship of this document.



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How many lasers do you have in your house? You might initially think this would just be one or two, but you would be wrong. Lasers are found in many everyday items such as (i) CD players and CD-ROM drives (ii) DVD players and DVD-ROM drives (iii) CD and DVD burners (iv) high-definition Blu-Ray Disc technology (v) gaming platforms such as PlayStation3 (vi) printers (vii) laser pointers (viii) spirit levels and (ix) tape measures. They are also routinely used for marking purposes, such as writing best-before dates on to packets and bottles.



Dunfermline-headquartered OPTOS was founded in 1992 by Douglas Anderson after his then five-year-old son went blind in one eye when a retinal detachment was detected too late. Anderson's company now produces a patient-friendly laser-based instrument that takes a high-resolution image of up to 82% of the retina in single capture lasting just a quarter of one second. Approximately 4000 of these devices have been installed worldwide. A true Scottish success story.

Compound Semiconductor Technologies (CST) is a specialist semiconductor device manufacturer based in Hamilton, Scotland. The company supplies customers in the UK, US, Europe, China and Japan, and is recognised globally as one of the leading suppliers of bespoke laser diode chip solutions from prototype to high volume. These devices are used for a wide range of applications in the telecommunications, defence, medical, consumer and industrial markets.



Photonics is an enabling technology and lasers will certainly play an ever-increasing role in society. In the quest to generate a green economy, lasers will be used on wind farms and on the turbines themselves to optimize the blade positions and generate the maximum amount of energy from strong gusts of wind. Research is ongoing at Strathclyde University to produce miniature lasers that can be mounted on turbines to monitor wind speed and direction.



Founded in 1987, the Lasers and Photonics Application Group at Heriot-Watt headed by Howard Baker and Dennis Hall 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 its design exceed \$900 million.

"I joined Coherent Scotland in 2001 after completing my MPhys in Optoelectronics and Laser Engineering at Heriot-Watt University," recalls Ian MacGillivray. "I started working on one of the development projects at the time, the Chameleon ultrafast laser. The Chameleon has gone on to become one of Coherent's most successful products and Coherent Scotland has more than tripled the headcount it had when I joined. I am now Engineering Development Manager, responsible for existing scientific products such as the Chameleon and the development of new products like it."



John Barr, Chief Engineer for Advanced Targeting at SELEX Galileo, recalls that: "Winning the contract for the sophisticated multi-wavelength designators for the Joint Strike Fighter provided a firm foundation for the development of a family of high performance laser rangefinders, designators and illuminators. The performance, reliability and competitive cost base has enabled SELEX Galileo to win development and production contracts on a further 3 US platforms, in each case displacing an incumbent supplier. Today, we are manufacturing and delivering more than one high-value laser each and every day in Edinburgh and generating a revenue in excess of £50M every year on lasers alone. This is a tribute to the engineering and production skills of the workforce here in Edinburgh and in turn a reflection of the academic base focussed on photonics in Scotland."

50 Years of Lasers in Scotland

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