With a ‘mission to harness the power of light to change the world’ no one would accuse M Squared of lacking ambition. Unlike a lot of sales pitches however, the company can point to numerous uses of its lasers that support its vision. Playing a central role in tackling climate change, SolsTiS was used to calibrate Tropomi, the spectrometer onboard the European Space Agency’s (ESA) Sentinel 5P satellite that observes and maps critical atmospheric pollutants, including nitrogen dioxide, ozone, formaldehyde, sulphur dioxide, methane and carbon monoxide. In healthcare, the lasers allow the non-invasive study of cancers and degenerative diseases such as dementia, motor neurone disease and Parkinson’s.

Lasers are used for research in numerous scientific fields and industries, ranging from quantum technologies and semiconductors to chemical sensing and biophotonics and the SolsTiS is used by over 200 organisations in 30 countries.

It was, though, the engineering inside the laser that appealed to the judges of the 2019 MacRobert Award. Lasers tend to be sensitive devices that operate at nanometre dimensions. When researchers are working on, for example, breath analysis, the last thing they want to do is to have to retune a laser when it gets bumped. Before SolsTiS, scientific lasers were largely experimental in themselves.

It takes clever engineering design to create laser systems that can deliver ‘the highest purity light yet produced anywhere in the world’. M Squared’s SolsTiS system stands out because of its precision, compactness, ruggedness, reliability and turnkey operation. SolsTiS delivers a step-change in continuous-wave laser technology, delivering single mode laser light with an ultra-narrow linewidth. The system is also fully automated and widely tunable, connected to the internet and operated via a webpage. All of this sits in a completely sealed unit that needs no alignment by the user.

**FROM RESEARCH TO PRODUCT**

M Squared had its origins in Dr Graeme Malcolm OBE FRSE’s PhD project on compact lasers at the University of Strathclyde. The University has a long reputation as a leading centre of research and innovation in laser technology and optoelectronics and was at the centre of Scotland’s optoelectronics sector. In 1992, Malcolm, along with Dr Gareth Maker, set up Microlase Optical Systems to turn their research into usable products. The two did not have to wait long for orders to come in. Indeed, they set up the business partly because, as research students, they were already supplying systems to other research groups.

As Malcolm put it at the time, “We were effectively pioneering the research we were doing at the University of Strathclyde then. Older generations of devices were six-foot long, highly complex and you needed a PhD to operate them. They needed 50 kW of power, were the size of a filing cabinet, and required gallons of water to keep them cool.”

Equipment like that wasn’t the sort of thing that anyone but a laser researcher would deploy as standard kit in their academic laboratory, let alone in industry. Malcolm and Maker wanted to develop a self-contained diode-pumped laser that was smaller than a shoebox – you could just plug it into the mains and light would come out. In 1999, the global laser businesses Coherent Inc. bought up Microlase Optical Systems and Malcolm became head of Coherent Scotland. This gave Malcolm and Maker the resources needed to develop the business. They could move on from selling lasers to laser scientists and begin the laser’s transformation into a usable and reliable device that non-specialist engineers could use almost as routine components in complete systems for whatever applications they had in mind that needed a very pure source of coherent light. They also moved into new wavelengths, and very short light pulse lasers, to broaden the range of applications, such as biomedical imaging.

In 2006, Malcolm and Maker left Coherent Scotland to set up another company to develop a laser system based on research they were doing at Strathclyde and elsewhere. The new company was M Squared, which gets its name from the two founders and the M2 parameter known as a laser’s ‘beam quality factor’. The idea was to produce a compact and totally automated version of the single frequency Ti Sapphire laser, the optical ‘engine’ inside the SolsTiS system.
LASERS TO CHANGE THE WORLD

It wasn’t just the laser that came out of M Squared’s work. The company also went on to create systems that were easy to use. For example, as long as you had a fibre optic cable and a detector, you could have a device ready to run it from a webpage with an internet connection.

CHALLENGES OVERCOME

As well as active and passive cooling, the project undertook work on 10 nanometre range, the engineers had to isolate the optical elements which were created by the circulated water cooling. The design of the hardware also had to isolate the optical elements from temperature variations and physical impact.

SolsTiS also required optical innovations to fit a long optical path into a small space, using a ‘bow-tie’ arrangement of four mirrors. Additional optical elements in the light path refine the light output so that the laser output has an extremely narrow linewidth – the narrowest of any commercial system – and a single mode across its whole tuning range. To do this, the engineers not only had to devise their own approach to mounting the optical components to maintain the stability of the system, but also developed precision adjusting elements and control software to compensate for unforeseeable movements as well as maintaining wavelength tuning. It was, says David Delphy, the MacRobert Award judge and former Chief Executive of the UK Innovation and Technology Satellite Communications Centre.

SolsTiS is single mode across its whole tuning range. To do this, the mirrors were designed to be rigid and not allow the laser to flex. Additional optical innovations included careful mechanical design to fit long optical paths into a small space, using a ‘bow-tie’ arrangement of mirrors.

QUANTUM TECHNOLOGY

More recently, M Squared has transitioned into research into quantum technology, with research meetings engineering quantum technology. M Squared was awarded the MacRobert Award for SolsTiS as the backbone of many quantum technology systems and experiments. The laser’s ultra-pure light and low noise makes it the ideal tool for quantum experiments, where excess noise can easily destroy the subtle effects that quantum technologies seek to exploit.

The team maintains that SolsTiS is “the de facto standard laser system used in the development of quantum technologies and experiments.” It is also used extensively in several approaches to quantum computing, including leading research at Oxford, Sussex and Imperial universities. SolsTiS is also responsible for many new advances in quantum sensing.

SolsTiS was used by researchers at Imperial College London and M Squared has produced the world’s first transportable, stand-alone quantum accelerometer incorporating the SolsTiS system (Reducing the optical and mechanical impact). The device has a response range of 0.001 to 0.2 g at a noise floor of 10^-8 g/√Hz.

QUANTUM ACCELEROMETER FOR NAVIGATION

One sign of the commercial impact of the SolsTiS system is the recent development of the world’s first transportable, stand-alone quantum accelerometer incorporating the SolsTiS system (Reducing the optical and mechanical impact). The device has a response range of 0.001 to 0.2 g at a noise floor of 10^-8 g/√Hz.

The accelerometer uses quantum interference of matter waves to measure horizontal accelerations with ultra-high accuracy. It is designed to be used in applications where excess noise can easily destroy the subtle effects that quantum technologies seek to exploit.

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M Squared describes SolsTiS as the backbone ‘engine’ behind much of its work, for experiments on the Ultimate Single Image large structures at cellular resolution, measurements that are critical to modern biological understanding. The technology also enables Life science imaging at individual cell level, including neurons in the brain.

The company says that its lasers have enabled breakthroughs in areas as diverse as dementia research, cancer diagnosis and whiskey maturation. In 2015, M Squared opened a specialised biotechnology laboratory on the SolsTiS site, the Surrey Research Park.

The quantum accelerometer uses quantum interference of matter waves to measure horizontal accelerations with ultra-high accuracy. It identifies its starting location, and precisely measures acceleration from there. As a business, it is “the purpose of this is to navigate ships and submarines, and perhaps other vehicles in the future.”

The global navigation satellite system (GNSS) that underpins many location systems is susceptible to disruption or denial, either deliberate or natural. Estimates suggest that interfering with GNSS for just five days could cause £3.2 billion of economic damage to the UK alone. “Quantum sensors, including our accelerometer, offer a new way to achieve accurate navigation without the need to send communications back and forth to satellites,” says M Squared.

M Squared and Imperial College are developing a commercial quantum navigation system. Their aim is to achieve the highest possible sensitivity and to provide accurate positioning, even over long journeys. Their quantum accelerometer recently showed a positional accuracy within 2 kilometres after one month’s use, a substantial improvement in state of the art accuracy.

It’s a design that one magazine described as ‘counter-intuitive’. The company has a turnover of more than £10 million a year and says it has more than 100 people, most of them in technical roles. The business is doubling in size every two to three years, fuelled by reinvesting 10% to 20% of its revenue in R&D. SolsTiS accounts for 85% of the company’s sales.

The company’s quantum products include a £2.9 million R&D grant to M Squared from the UK’s Quantum Technologies Innovation Network, launched by the UK government to support the development of quantum technologies.

Dr Graeme Malcolm OBE FREng FRSE is CEO and Co-Founder of M Squared, a multi-award winning photonics and quantum technology company. He is a Fellow of the Royal Academy of Engineering, The Royal Society Edinburgh, and the Institute of Physics and his achievements include an OBE for his services to Science and Innovation, the Swan Medal from the Institute of Physics, and Entrepreneur of the Year at the Amazon Growing Business Awards.

BIOGRAPHY

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