QUANTUM TECHNOLOGY

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The 'first quantum revolution' refers to the invention of several technologies, such as the laser and the transistor, that were enabled through an improved understanding of the quantum nature of light and electrons. This transformed every aspect of society: from smartphones, laptops and digital cameras to the internet and social media. The implications are endless.

Currently we are on the verge of a second quantum revolution based on technologies that explicitly rely on some of the more counter-intuitive features of quantum mechanics, namely superposition and entanglement. It is expected that the impact of the second quantum revolution will be as significant as the first. Indeed, many predict that quantum devices will be the defining technological advance of the coming decades.

ABOUT US

M Squared is a global quantum technology company and quantum technology systems integrator - the first choice for world-leading research institutions and innovation partners.

The company has enabled the quantum technology community since 2006 with its award-winning laser platform, SolsTiS, the backbone of many quantum technology systems and experiments. This laser system underpins some of the world's most accurate clocks and highest-impact quantum computing research programs.

Today, M Squared is at the heart of the international quantum supply chain, developing components, sub-systems, and sensors for commercial quantum applications, including optical atomic clocks and quantum sensors based on atom interferometry. M Squared is taking quantum technologies out of the lab and harnessing them for real-world applications that will directly benefit society in the near future.

> Quantum technology has the potential to be a global game-changer.
>
> **DR RUTH MCKERNAN**
> Chief Executive of Innovate UK

CONTENTS

OPTICAL SYSTEMS

FOR QUANTUM TECHNOLOGY

M Squared's scientific lasers are the tools of choice for investigating the quantum world.

SHINING A LIGHT ON QUANTUM MECHANICS

M Squared's work in quantum technology began in 2006 with the launch of its continuous-wave, narrow-linewidth titanium-sapphire laser 'SolsTiS'. This laser, with its ultra-pure light and low noise, is the ideal tool for quantum experimentation, where excess noise can easily destroy the subtle effects that quantum technologies seek to exploit. This award-winning laser platform has transformed the work of scientists globally, helping them to explore new phenomena in quantum and materials science. SolsTiS has been used in the development of many of the world's most accurate clocks, a demonstration of teleportation of quantum information, pioneering antimatter experimentation and the development of 'ion-drives' for space.

> M Squared's SolsTiS laser has completely transformed our quantum optics experiments at Durham. We have used it in several very different experiments that have all produced breakthroughs.

PROFESSOR CHARLES STUART ADAMS

Director of the Joint Quantum Centre, University of Durham

ENGINEERING PRACTICAL QUANTUM DEVICES

M Squared is developing smaller, cheaper, and more efficient quantum components, systems and subsystems and playing a key part in the emerging UK quantum technology supply chain. This includes the development of novel laser platforms, control electronics and physics packages.

Working with potential end-users, we are evaluating and benchmarking quantum technologies in practical applications. This is leading to sensors with unprecedented levels of sensitivity for measuring gravity, acceleration, rotation, magnetism, electric fields and time.

EXPANDING A TEAM OF QUANTUM SCIENTISTS

In delivering these highly advanced quantum technologies based systems, it is critical to work with the brightest and most dedicated scientists and engineers. To this extent, M Squared has established a multidisciplinary team of laser, optical, mechanical and electronic engineers, quantum scientists and project managers to deliver systems and solutions of the highest quality in very short time frames.

QUANTUM SENSING

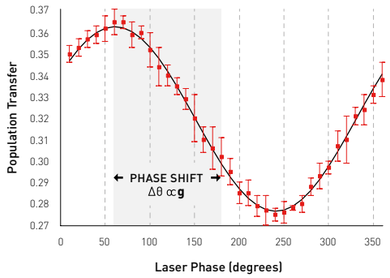
Sensors are all around us, embedded in commonplace equipment to measure physical quantities such as acceleration, rotation and the strength of electric and magnetic fields.
M Squared is moving sensing beyond its current boundaries by harnessing quantum phenomena to build quantum sensors; devices that measure physical quantities with an accuracy and precision that is beyond the capabilities of classical (or non-quantum) sensors.

GRAVIMETRY

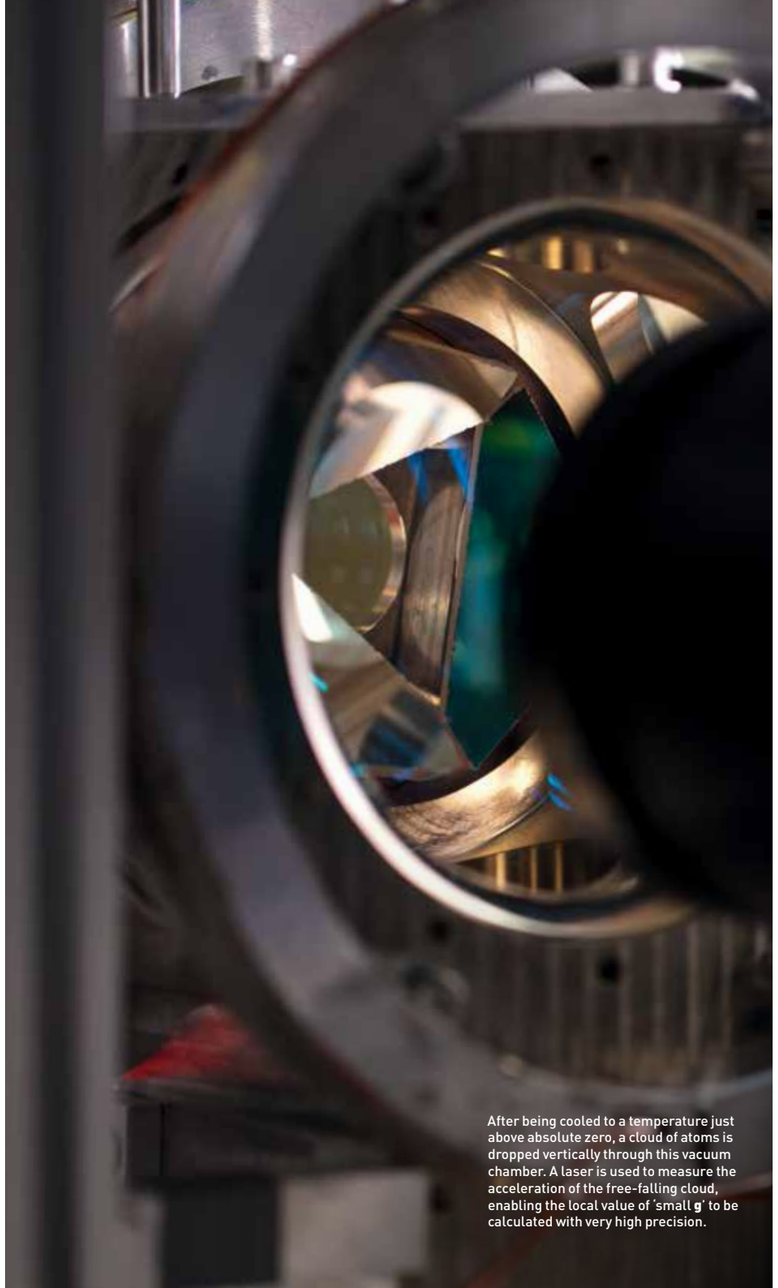
Every object with mass produces a gravitational field - the force that accelerates objects downwards is due to the gravitational field of the Earth itself. Whilst this acceleration due to gravity, or 'small **g**', may seem unchanging, it actually varies by tiny amounts depending on the mass and density of objects below the Earth's surface. The ability to detect these tiny changes in **g** would offer a transformative new capability to the numerous applications, from heavy industry to archaeology, that involve mapping out the underground world.

OUR WORK

We are using atom interferometry, a powerful technique that uses the interference of clouds of atoms at ultra-cold temperatures, to realise a quantum gravimeter. This will have sufficient sensitivity to detect these tiny variations in **g**, significantly enhancing applications ranging from oil and gas prospecting to earthquake detection. The system uses novel lasers, control electronics and vacuum systems to form a commercial instrument that will be robust enough to be taken out of the lab and used for real-world applications.



The gravimeter measures a phase shift Δθ that is proportional to the local value of acceleration due to gravity, or 'small **g**'. This phase shift measurement is enabled by a precisely tailored sequence of laser pulses that split, mirror and recombine a cloud of ultra-cold atoms to form an atom interferometer.



After being cooled to a temperature just above absolute zero, a cloud of atoms is dropped vertically through this vacuum chamber. A laser is used to measure the acceleration of the free-falling cloud, enabling the local value of 'small **g**' to be calculated with very high precision.

APPLICATIONS

Underground infrastructure assessment

Locating underground structures, such as water and gas pipes buried deep underground, to enhance ground survey analyses and minimise disruption from civil engineering works

Mineral exploration and extraction

Mapping out deposits of oil or gas beneath the Earth's surface to enable more efficient resource exploration with lower environmental impact

Earth observation

Monitoring seismic activity and helping to predict natural disasters like tsunamis and volcanic eruptions

Archaeological surveying

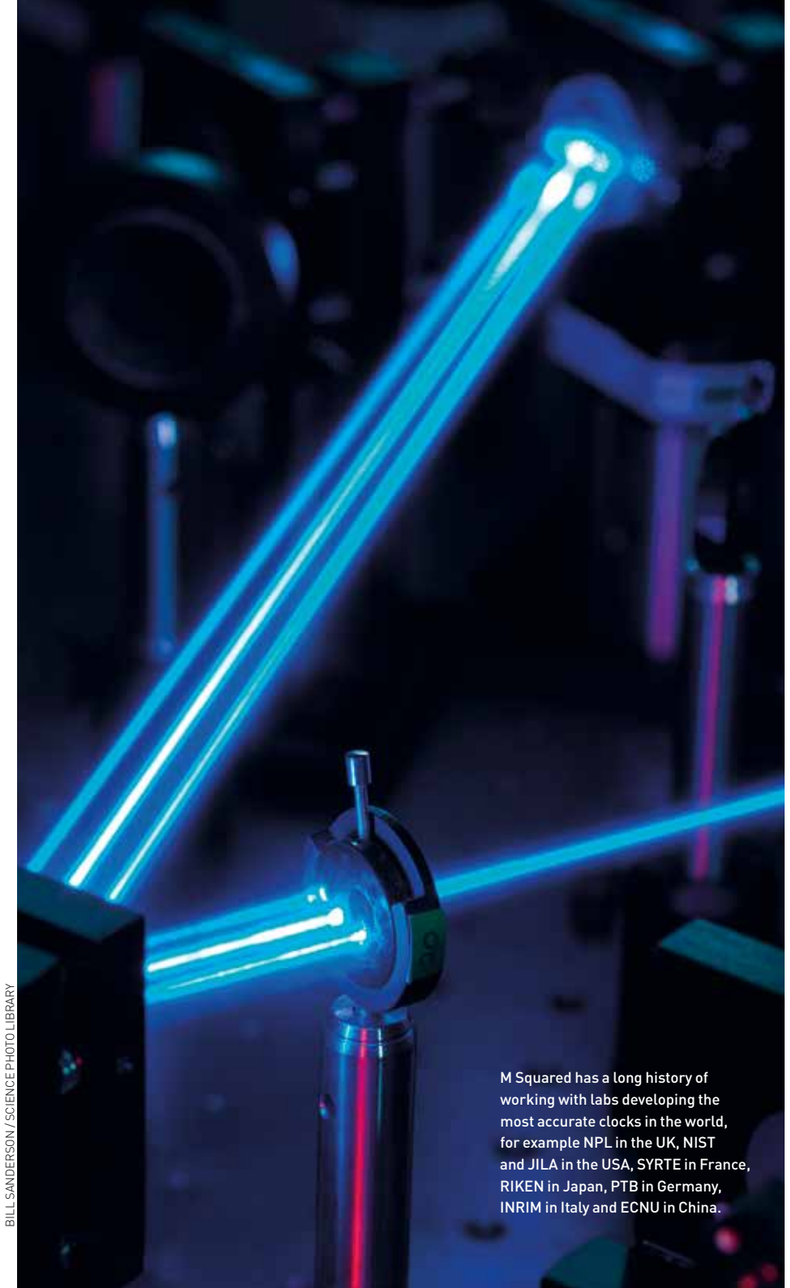
Non-invasive surveying of sites of archaeological interest

CLOCKS

Precision timing plays a vital role in the global economy and is critical to many technologies, such as high-speed financial trading, satellite navigation and broadband communication. Microwave atomic clocks, which are currently used to define the second itself, work by counting the 'ticks' of a microwave field that is referenced to an atomic transition. Optical atomic clocks work on a similar principle, except a laser beam is used to provide the ticks at a much greater frequency, offering a 100 x improvement in stability.

OUR WORK

With optical clocks based on neutral atoms, the reference laser interrogates atoms that are distributed amongst an 'optical lattice' of trapping sites. This arrangement freezes out much of the motion of the atoms, enabling their resonant frequency, and therefore time, to be measured with unprecedented precision. Using novel laser sources, control systems and vacuum chambers, M Squared is developing a strontium lattice clock that will be more mobile and compact than the lab-sized systems that constitute the current state of the art. The optical lattice itself is created by forming a standing wave of light from a low-noise and high-power laser – these requirements make M Squared's SolsTiS platform the 'lattice laser' of choice for time standards laboratories around the world (see caption).



BILL SANDERSON / SCIENCE PHOTO LIBRARY

M Squared has a long history of working with labs developing the most accurate clocks in the world, for example NPL in the UK, NIST and JILA in the USA, SYRTE in France, RIKEN in Japan, PTB in Germany, INRIM in Italy and ECNU in China.

APPLICATIONS

Satellite-free navigation

Quantum gyroscopes, accelerometers and clocks will enable submarine navigation to improve from 2 km accuracy over a 24-hour period to 100 m over several months

Deep space navigation

On-board atomic clocks will enable spacecraft to navigate through deep space autonomously

Financial trading and timestamping

Protecting the integrity of electronic financial trading and preventing losses due to timing errors in the financial sector

Long-baseline interferometry in astronomy

Enabling a new era in radio wave astronomy by providing precise timing synchronisation between observing posts in multi-element telescopes, such as the Square Kilometre Array

High speed internet

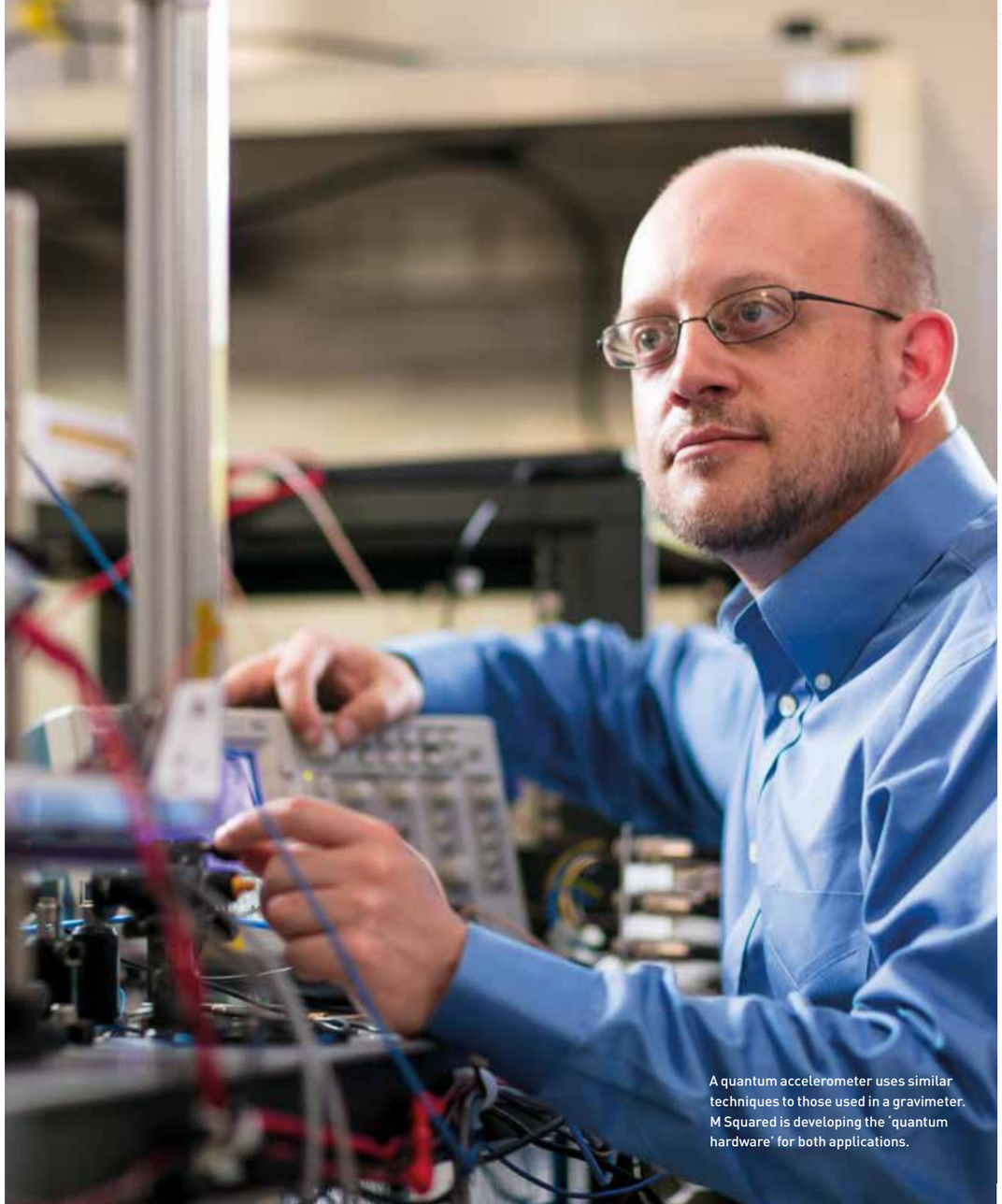
Increased clock stability allows more data to be packed into the optical fibre networks that form the internet, providing direct benefits to the global economy

ACCELEROMETRY

A quantum gravimeter measures the vertical acceleration of a cloud of ultra-cold atoms. Extending this idea to all three spatial dimensions results in a 3D quantum accelerometer; a device that uses atom interferometry to precisely measure accelerations in any direction. Combining this with quantum gyroscopes and clocks will enable a navigation device that is highly accurate and completely independent of satellite navigation systems.

OUR WORK

M Squared is helping to develop the UK's first commercial 3D quantum accelerometer with collaborators at Imperial College London. We are perfecting the 'quantum hardware' that is required to transform this currently lab-based concept into a fully commercialised quantum sensor - one that will be accurate and robust enough to supplant current state of the art navigation systems. For example, the accelerometer requires a laser system that can produce the complicated sequences of optical pulses that create and manipulate quantum superpositions of cold atoms – the essential feature of an atom interferometer. M Squared has developed a laser system that is perfectly tailored to this demanding task; two phase-locked lasers produce a beam with a unique combination of high power, exceptionally low noise and a high degree of tunability – all essential ingredients in realising a highly sensitive 3D quantum accelerometer.

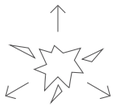


A quantum accelerometer uses similar techniques to those used in a gravimeter. M Squared is developing the 'quantum hardware' for both applications.

APPLICATIONS

GPS-free navigation

Accurate navigation in submarine and subterranean environments or other areas where GPS cannot reach or is hampered by interference from terrain, buildings and weather



Threat detection

Three-axis interferometry will enable the detection of heavy objects that may be shielded from view, such as nuclear material in trucks or trains

QUANTUM COMPUTING

Globally, the race is on to build a fully functional quantum computer; a device that exploits quantum mechanical effects to perform computational tasks that are not currently tractable, even with the world's most powerful supercomputers. Quantum computation is not simply a faster implementation of conventional computing, but a fundamentally new and more powerful way of processing information, and one that will enable a myriad of new applications. M Squared is developing the highly engineered laser systems, photonic devices and electrical instrumentation that are required to meet the extreme technical requirements of this revolutionary technology.

COMPUTING

Conventional information processing is based on storing and processing data as bits; units of information that have two possible states, 0 and 1. Quantum computation similarly utilises units of information that can be 0 or 1, but also a quantum-mechanical superposition of both at the same time. Processing information with these quantum bits, or qubits, offers a degree of parallelism that can be exploited to offer huge reductions in the time required to complete certain computational tasks.

OUR WORK

A qubit can be represented by a single cold atom. Quantum logic operations, which are used to implement calculations with a number of qubits, are realised via finely tuned laser fields that interact with the atomic energy levels. M Squared has developed laser systems that exhibit the low-noise and high degree of tunability required to implement logic operations with a sufficiently low error rate for quantum computation to be practical. Using our SolsTiS platform, Professor Saffman at the University of Wisconsin has demonstrated logic operations with neutral atom qubits with a world-leading error rate. For qubits based on trapped ions, we have developed a phase-locked laser system that is used by Professor Lucas at the University of Oxford and Professor Blatt at the University of Innsbruck to conduct world-leading research in practical quantum computation.

For trapped-ion quantum computing, the electric fields that are used to trap the ions must be modified in order to shuttle the qubits between distinct locations, such as specific zones for memory or logic operations. M Squared is developing the low-noise and high-speed electronics that are required to shuttle the ions between these zones without destroying the delicate quantum information that is stored in each qubit. We are also developing the technologies that will be required to realise a 'quantum network' of distinct processing nodes, such as single photon sources and frequency conversion modules.

M Squared phase-locked laser system as used to produce the highly tailored pulses of light that implement logic operations in a trapped-ion quantum computer.

APPLICATIONS

Encryption and security

Quantum computers can factorise large numbers much faster than classical ones, making them the tool of choice for defeating current encryption protocols

Database searching

Finding entries in an unsorted database is much faster with a quantum computer – this will offer significant benefits in the data-driven economy of the future

Optimisation problems

Otherwise known as the travelling salesman problem; finding the most efficient route amongst many options will lead to better transport networks with less traffic

Quantum simulation

Quantum computers can simulate new materials and compounds in a way that is impossible with classical computers, leading to an enhanced understanding of materials such as high-temperature superconductors

Drug discovery

Simulating molecular structures is central to creating new and more effective pharmaceuticals – quantum computers can execute this task much more efficiently than classical ones, leading to faster and more efficient drug discovery

OUR AMBITION

> The huge promises of quantum technologies are already starting to become tangible.

DR GRAEME MALCOLM OBE

CEO and Founder, M Squared

OUR FUTURE IN QUANTUM

Governments, leading scientists and tech-giants have all highlighted the enormous potential of quantum technologies, leading to worldwide efforts in bringing these revolutionary devices to market. M Squared was an early instigator of these efforts in 2006 with the launch of our 'SolsTiS' laser platform, and we have been enabling the quantum community ever since.

Today, we are continuing to commercialise novel quantum hardware, often through collaborations with some of the leaders in the field. From our award-winning laser and electronic instrumentation platforms that enable scientists to push the frontiers of quantum science, to our fully integrated quantum sensors that are set to revolutionise a range of practical applications, M Squared is set to expand on its role as a key player in the quantum technology landscape.

COMPANY HIGHLIGHTS

MOVING SCIENCE
FROM THE LAB
INTO THE REAL WORLD
WITH OVER
230 PATENTS

INNOVATION DIVISION
RUNS COLLABORATIVE
PROJECTS WORTH AROUND
£20 MILLION

AWARD-WINNING PRODUCTS
HAVE SUPPORTED A NUMBER OF
WORLD FIRSTS
INCLUDING THE FIRST DEMONSTRATION OF UNCONDITIONAL AND FULLY DETERMINISTIC **QUANTUM TELEPORTATION** AND THE FIRST **STABLE ULTRA-COLD MOLECULES**

EMPLOYIING
100
TALENTED AND PASSIONATE
SCIENTISTS, ENGINEERS AND COMMERCIAL STAFF

FOUNDED IN 2006
BY PHOTONICS EXPERTS
DR GRAEME MALCOLM OBE & DR GARETH MAKER
WHOSE INNOVATIVE PRODUCTS
HAVE GENERATED OVER
£0.5 BILLION

SERVING A GLOBAL COMMUNITY
OF CUSTOMERS ACROSS
30 COUNTRIES

PARTNERS

M Squared works with game changers, leading researchers, organisations and governments to accelerate the exploitation of quantum science.

The company is a founding industry member of the UK National Quantum Technology Programme, through which it works in close collaboration with the UK Quantum Technology Hubs, supplying equipment, resources and engineering know-how. M Squared is also an Industrial Member of the European Commission's Quantum Technology Flagship Expert Group and on the board of the UK Knowledge Transfer Network's Quantum Technologies Special Interest Group (QT SIG), helping to shape the quantum landscape.

CONTACT

Whether you are looking for information or you'd like a question answered, don't hesitate to reach out to us by phone or email. Our quantum team at our innovation headquarters will be more than happy to help you.

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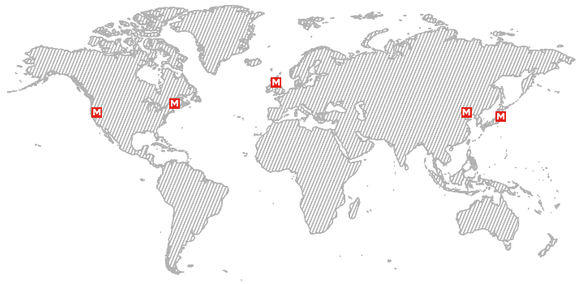

A complete list of our global locations is available on our website.

THE FUTURE, MADE POSSIBLE