Quantum technology shines bright

Ian Walmsley describes the role of optics and photonics in the UK's £270 million Quantum Technologies Programme, which aims to build a new generation of quantum devices

Why was the UK National Quantum Technologies Programme launched?

The main thrust is to develop quantum technologies into applications. Building on the UK's strengths in quantum-information science, it was recognized that now is the time to be using this science for applications that can have a real impact. A crucial first step is to have systems that are much better engineered than is possible in small research groups, since the breadth of expertise needed to achieve this demands a larger-scale operation.

What are its scope and timescales?

The programme will last five years and is based around a national network of "hubs" dedicated to different areas of quantum technology: sensing, imaging, cryptography, communications, simulation and computation. Four hubs were identified and are being led by the universities of Birmingham, Glasgow, Oxford and York. Overseeing the programme is an advisory board that recently published a strategy document highlighting the impact of quantum technology on finance, defence, aerospace, energy and telecommunications, as well as imaging and computing. If we take seriously the idea that the UK is in this for the long haul, then as a quantum-driven industry emerges we want to be seen as the place to invest.

Oxford University Images/Rob Judges

Light work Ian Walmsley, an experimental physicist at the University of Oxford, is director of the Networked Quantum Information Technologies hub.

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When we harness quantum entanglement, we can expect potentially more disruptive technologies such as secure long-distance communications, quantum simulators and, eventually, full quantum computers.

Which technologies do you think will have the biggest impact?

Applications such as sensing, simulation and communications have been identified for some time, but aiming at one or two killer applications would be a very risky strategy. The quantum-technologies programme recognizes that you need to consider all applications because we don't know which areas are going to be the most promising. Across the hub network, devices such as Glasgow's single-pixel cameras or Birmingham's miniature atomic sensors are examples of the kind of things that will demonstrate the success from a technology point of view. But from another perspective, the programme will also train a group of people in quantum engineering, some of whom will go into industry and some will start their own companies. Each hub allocates its own funding and has a significant budget for working with industry and other external partners, plus there is additional funding for skills training in quantum engineering. When the full training programme is operational, it is likely that well over 50 PhD students per year will take up positions across the UK.

Don't we already have quantum technologies?

It is 100 years since quantum mechanics came along, and we already have a range of technologies that emerged from the first wave of understanding. A semiconductor band gap is the result of quantum interference, for example, so although the transistor concept itself is not intrinsically quantum mechanical, the silicon-based transistors that power modern electronics are. Another example is the laser, which achieves light amplification by a quantum process called stimulated emission. Since the 1980s, however, we have increasingly been thinking about quantum mechanics in terms of information processing, whereby intrinsic quantum-mechanical features – namely superposition and entanglement – are harnessed directly. Enhanced precision measurements are an example of the sort of application possible, and recently this idea has been put to work in optical interferometers for detecting gravitational waves. Magnetic sensors based on electron spins in solids is another example, and people are also building atomic clocks in miniature form and developing gravity gradiometers using laser-cooled atoms.

What is going on at the hubs now?

The York hub is based on secure-communications technology, while at Glasgow the focus is on optical imaging and sensing. The Birmingham hub centres on sensing and metrology, focusing on devices to measure everything from gravity to magnetic fields with unprecedented sensitivity. At Oxford the Networked Quantum Information Technologies (NQIT) hub is dealing with optical networks that connect ion traps with the aim of developing the elements of a scalable quantum computer. For us, that really is a five year-long objective, whereas the Glasgow and York hubs could see earlier spin-outs because they are tackling more mature applications.

What is the role of optics and photonics?

Light straddles the boundary between the quantum and classical worlds, and has provided important insights into the nature of quantum mechanics. It also has the nice property that you can manipulate quantum properties at room temperature. In the Glasgow hub, light is the primary means by which you

Interview: Ian Walmsley

capture images. At Oxford, we use light as a carrier of quantum information, establishing entanglement between the nodes of a network. At Birmingham, light is the means for cooling and controlling atoms for new quantum sensors. The York hub, meanwhile, is concentrating on finding ways to carry out point-to-point quantum key distribution over optical networks. This ultra-secure communication protocol is already proven, but the challenge is to enable it to work over long distances – in particular to amplify optical signals without perturbing their delicate quantum properties. We also expect that there will be new opportunities arising from synergies between hubs.

Have you got a recipe for a scalable quantum computer?
Certainly it is known that, in principle, you can build a quantum computer entirely out of light. Nonetheless, you have to ask does each element of this system perform at the level that is needed in order that it can be scaled up and compete with conventional computers? It's not just about miniaturization, but about optimizing every component. Our approach is therefore to find the best qubits with the best entangling operations and the best technology for connecting them together. We can therefore identify the trade-offs that will allow us to build a scalable computer.

So, what is the best technology?
To begin with we are focusing on trapped-ion qubits linked by existing optical telecoms technology, but our networking approach is sufficiently flexible that we can consider qubits based on superconducting circuits or spins embedded in diamond. Trapped ions show better operational fidelity than has been demonstrated in other systems and we see no scientific obstacles. But what we need now is hundreds or even millions of these things all functioning in exactly the same way, which involves a lot of systems engineering. This is where the hub set-up adds value, since it allows us to work with systems and control engineers, computer scientists and others with whom we haven't collaborated in the past.

What is the role of industry?
Each hub not only has partnerships with several other UK universities and research centres, but also commercial firms. Having companies involved from the start allows us to identify needs and opportunities as they arise, and to divert resources so that new quantum technologies can enter into commercial use more quickly than if we were all working independently. The NQIT hub alone has more than 25 partners from industry and government, and the other hubs are similar in this respect.

Is there a limit to the applications of quantum mechanics?
I don't think so. We are building these machines with an eye on applications, but if we get to a point where we can build a universal quantum computer, then it will certainly lead to the discovery of new science and new applications. Richard Feynman famously observed that you cannot use conventional computers to simulate quantum systems above a certain size, so we have to build a quantum simulator. We'll surely learn new things about large-scale quantum systems when we have such a machine, and further applications – in designing new materials, for example – will be equally exciting.