Working on the edge

By Helen Knight

Nanotechnology has had more than its fair share of publicity over the past year. But amid the mixture of unrealistic hype and ill-informed hysteria surrounding the field, one area of nanotechnology with the potential to be hugely important for the UK remains relatively unknown: quantum computing.

Unlike conventional computers, which break information down to a series of ones or zeros, known as bits, quantum computers manipulate information in the form of qubits. These qubits have the strange property of being able to be both a one and a zero at the same time, theoretically enabling quantum computers to solve problems in a fraction of the time it would take a conventional machine to do the same thing.

Andrew Briggs, professor of nanomaterials at Oxford University, is leading research into technologies for developing the quantum circuits that would ultimately be used within quantum computers. The research project, called Nanoelectronics at the Quantum Edge, involves Oxford and Cambridge universities and Hitachi.

As part of the project Briggs and his team have been investigating three different technologies with the potential for use in building quantum circuits: nanofabricated quantum dots; self-assembled quantum dots; and recently discovered molecules called fullerenes, which have unique magnetic properties that can be used to encapsulate information.

Nanofabricating quantum dots involves printing individual silicon quantum dots - 3D pyramid structures - on to a semiconductor substrate using lithography. By carefully controlling the charge on these structures, they can be made to exhibit quantum behaviour, said Briggs.

'In the past few months we have made a significant breakthrough in demonstrating a single quantum dot technology. We can show the qubit evolving, from being entirely a zero to being entirely a one, and having this weird property of being both at the same time.'

The team has also been developing the self-assembly of quantum dots from gallium nitride, using a form of chemical vapour deposition in which layers of the material are formed on a heated substrate to create the 3D pyramid structures.

'We can excite a single quantum dot, and show it really is in a single qubit state, so it really does have that quantum weirdness. You can measure this and also tune the individual quantum dot. That will be important when you put two together, because it is like a piano tuner tuning the three strings for a given note - you
want to be able to tune it so they are in resonance,' said Briggs.

Fullerene molecules, in which a mesh of carbon atoms forms a hollow cage capable of trapping a variety of individual atoms or small molecules inside, are the newest of the materials the researchers are investigating for their ability to create molecular qubits.

When a nitrogen atom is placed inside the cage, it behaves in almost the same way as an isolated atom, and can be used to perform the role of a single qubit in a quantum computer. This is the case even when the cage is built into solid state structures. A number of the fullerenes can be grouped together inside a carbon nanotube to form a peapod structure.

'We have done some groundbreaking work in showing that these materials have properties that are absolutely superb for quantum computing,' said Briggs.

The fullerene cage protects the spin of the electrons inside, increasing the dot's 'coherence time' - the length of time before the dot loses the quantum information it is carrying. 'The quantum information stays there for a very long time without losing its coherence. We have also shown you can manipulate the fullerene with extremely high precision,' he said.

The researchers originally planned to choose a 'winner' from the three approaches to take forward for further development, but instead they found all three were promising. 'The major achievement of the project has been in understanding the properties of nanostructures and showing that each of them has fantastic potential for quantum computing.'

Another aim of the researchers is to build a small quantum circuit by September. If they are successful this circuit will consist of two connected fullerenes, said Briggs. 'We set ourselves a very ambitious goal at the beginning of the project, that by the end we will at least have shown how to produce a circuit.'

'We may succeed in producing a circuit of two qubits, the integration of which we can use to do quantum logic operations, or even have the basis for very simple quantum algorithms, the simplest of which would be the Deutsch-Josza problem.' This describes a mathematical problem that would normally only be solvable with many separate calculations, whereas a quantum computer would be able to reach the solution in a single step.

Although this is a simple algorithm in quantum computing terms, it would demonstrate that the researchers have the basis for building a full computer, providing the approach used can be expanded sufficiently, said Briggs. 'Each of the approaches we are using is scalable, so if we can do it with two qubits, we know we'll be able to extend it to large numbers of qubits.'

Briggs is also director of the Quantum Information Processing Interdisciplinary Research Collaboration (QIP IRC), which was established earlier this year and is funded with £10m from the EPSRC and £0.5m from the MoD over the next five years.

The collaboration involves Oxford, Cambridge, Bristol, Sheffield, York and Hertfordshire universities, Imperial College, University College London and the University of Wales Bangor, as well as Hitachi, Qinetiq, Toshiba's Cambridge Research Laboratory, Hewlett-Packard's Bristol Research Laboratories and the National Physical Laboratory.

'The project is a national activity, and involves different universities and companies collaborating in a focused and co-ordinated effort to maintain the lead the UK has in a number of areas of quantum information processing,' he said.

The programme will focus on the transfer of quantum information from one location to another. To this end, the researchers will investigate technologies such as the use of trapped ions (charged atoms) to store and move quantum information; single photon sources, which produce a single light particle - suitable for carrying quantum information - in response to an electrical signal; as well as the use of carbon nanotubes as 'interconnects' within a quantum computer.

'In every aspect of advanced quantum information processing this is going to be important, and it is an area where there could be a real opportunity to bring together experts from the UK. It is important that we do have a co-ordinated effort that builds on our strengths, because the whole field is becoming so exciting and active globally, and there are major efforts in other areas of the world, many of them building on ideas originated in the UK,' he said.

International activity in the field is only likely to increase as more is understood about the potential of quantum information processing, particularly in accessing and protecting secure information.
Quantum computers could crack conventional encryption codes, giving governments access to previously secure information, and potentially allowing non-government organisations access to national secrets. Conversely, quantum cryptography could produce 'uncrackable' codes, so demand for the technology is likely to be high, particularly in the US, said Briggs.

These will become important issues as quantum computing and communication develop, and the main way in which they are being addressed at the moment is that the US wants to be the first to have a computer capable of quantum cryptoanalysis. 'If it is going to become a reality, the US government wants to be the first to have it.'

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