Silicon chips for optical quantum technologies

A team of physicists and engineers has demonstrated exquisite control of single particles of light – photons – on a silicon chip to make a major advance towards the long sought after goal of a super-powerful quantum computer.

Dr Jeremy O'Brien, his PhD student Alberto Politi, and their colleagues at Bristol University have demonstrated the world's smallest optical controlled-NOT gate – the building block of a quantum computer.

The team were able to fabricate their controlled-NOT gate from silica wave-guides on a silicon chip, resulting in a miniaturised device and high-performance operation.

"This is a crucial step towards a future optical quantum computer, as well as other quantum technologies based on photons," said Dr O'Brien.

The team reports its results in the March 27 2008 *Science Express* – the advanced online publication of the journal *Science*.

Quantum technologies with photons

Quantum technologies aim to exploit the unique properties of quantum mechanics, the physics theory that explains how the world works at very small scales.

For example a quantum computer relies on the fact that quantum particles, such as photons, can exist in a "superposition" of two states at the same time – in stark contrast to the transistors in a PC which can only be in the state "0" or "1".

Photons are an excellent choice for quantum technologies because they are relatively noise free; information can be moved around quickly – at the speed of light; and manipulating single photons is easy.

Making two photons "talk" to each other to realise the all-important controlled-NOT gate is much harder, but Dr O'Brien and his colleagues at the University of Queensland demonstrated this back in 2003 [*Nature* 426, 264].

Photons must also "talk" to each other to realise the ultra-precise measurements that harness the laws of quantum mechanics – quantum metrology.

Last year Dr O'Brien and his collaborator Professor Takeuchi and co-workers at Hokkaido University reported such a quantum metrology measurement with four photons [Science 316, 726].

Silica-on-silicon wave-guide quantum circuits

"Despite these and other impressive demonstrations, quantum optical circuits have typically relied on large optical elements with photons propagating in air, and consuming a square metre of optical table. This has made them hard to build and difficult to scale up," said Alberto Politi.

"For the last several years the Centre for Quantum Photonics has been working towards building controlled-NOT gates and other important quantum circuits on a chip to solve these problems," added Dr O'Brien.

The team’s chips, fabricated at CIP Technologies, have dimensions measured in millimetres.

This impressive miniaturisation was permitted thanks to the silica-on-silicon technology used in commercial devices for modern optical telecommunications, which guides light on a chip in the same way as in optical fibres.

The team generated pairs of photons which each encoded a quantum bit or qubit of information. They coupled these photons into and out of the controlled-NOT chip using optical fibres. By measuring the output of the device they confirmed high-fidelity operation.

In the experimental characterisation of the quantum chips the researchers also proved that one of the strangest phenomena of the quantum world, namely “quantum entanglement”, was achieved on-chip. Quantum entanglement of two particles means that the state of either of the particles is not defined, but only their collective state.

This on-chip entanglement has important applications in quantum metrology.

“As well as quantum computing and quantum metrology, on-chip photonic quantum circuits could have important applications in quantum communication, since they can be easily integrated with optical fibres to send photons between remote locations,” said Alberto Politi.

Source: University of Bristol