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Diamonds are a Quantum Computer's Best Friend

A new kind of quantum computer is being proposed by scientists from the National Institute of Informatics (NII) and NTT Basic Research Labs, and the Technical University of Wien (TU Wien) in Austria.

The Quantum Computer is the Holy Grail of quantum technology. Its computing power would eclipse even the fastest classical computers we have today. A team of researchers from the National Institute for Informatics, NTT Basic Research Labs in Japan and TU Wien in Austria has now proposed a new architecture for quantum computing, based on tiny diamonds. A reliable quantum computer solving complex problems would have to consist of billions of quantum systems, a quantum machine like that is still out of reach. But the researchers are convinced that the basic elements of their newly proposed architecture are better suited to be miniaturized, mass-produced and integrated on a chip than previously suggested quantum computing concepts. "It will take time to put this architecture into mass production, however experiments with the new quantum computing architecture are already being undertaken at TU Wien", says Kae Nemoto (NII).

Fragile Quantum Superposition's

For decades, scientists have been trying to use quantum systems for logical calculations. "In a classical computer, one bit can only store a number: zero or one. Quantum physics, however, allows superposition of states. A quantum bit can be in the state zero and the state one at the same time – and this opens up unbelievable possibilities for computing", explains Jörg Schmiedmayer (TU Wien).

Such superposition states can be implemented in different kinds of quantum systems, such as ions, captured in electromagnetic traps, or in superconducting quantum bits. The architecture recently published in the journal "Physical Review X" is different: nitrogen atoms, which can occupy two different

spin-states, are injected into a small diamond. Every nitrogen atom is trapped in an optical cavity made of two mirrors. Via glass fibres, photons are coupled to the quantum system consisting of the cavity, the diamond and the nitrogen atom. This way, it is possible to read and manipulate the state of the quantum system without destroying the quantum effects in the diamond by decoherence.

Realistic Quantum Computers Need Error Correction

Each system – made up of mirrors, diamond and nitrogen atom – can store one quantum bit of information: zero, one, or an arbitrary superposition of both. But usually, such a quantum bit is very unstable. Error correction procedures are needed to build a quantum computer that works reliably. "Error correction is the key for large-scale information systems, as we use several bits to protect a bit of information in classical computation. Using error correction a quantum bit is not stored in one single quantum particle any more, instead, a complex architecture of interconnected quantum systems is required", says W. J. Munro (NTT).

The researchers determined how the cavities, diamonds and nitrogen atoms can be assembled to create an error resistant two dimensional quantum system, a so-called "topologically protected quantum computer". According to the calculations, about 4.5 billion such quantum systems would be sufficient to implement the algorithm "Shor-2048", which is able to calculate prime factors of a 2048-bit-number. "This number looks large, but this is a computer seriously larger than ones we humans have ever designed in the history. Whatever physical systems, such as ion traps and superconducting qubits, we use, it is unavoidable for such an information system to contain a very large number of components. Even with that large number of components, the architecture we presented stays relatively simple to implement and highly scalable", says Kae Nemoto. Further she says "Such estimations of required qubits have become possible only recently, and we believe that by solving optimizing packing problems, we can further reduce the number as well as the computational time significantly. We have already started working along this line and the indications are promising."

Only the Beginning

The diamond-based architecture has its advantages. Whole industries are currently working with diamonds and progress is rapid in terms improving their material science properties. W. J. Munro explains the advances from the

rapidly growing technology to be a huge advantage for the diamond-based architecture. “There are still obstacles to overcome to reach the scale, however many of them will be solved as we integrate in new advances in material science”. Connecting nitrogen-spins in solid materials opens up a path that could finally lead to a functioning quantum computer.

It may still be a long way to go until algorithms like Shor-2048 run on a quantum computer. But scientists believe that in the next few years it should become possible to entangle quantum building blocks, creating larger cluster-cells. Kae Nemoto from the National Institute of Informatics said “Once this happens, the scale up will be fast”. Further Jörg Schmiedmayer says “In the end, it all depends on whether we manage to enter an era of mass production and miniaturization in quantum technology. I do not see any physical laws that should keep us from doing that.”

For more details, see the paper “Photonic Architecture for Scalable Quantum Information Processing in Diamond” Physical Review X.
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