that DNA synthesis at the scale of the yeast genome will require either armies of scientists — such as the wonderful group of undergraduate students currently working on similar projects[8] with Dymond and co-workers — or new methodologies. The authors' landmark work[1] confirms that automated DNA synthesis and assembly techniques are becoming necessary, and that the total synthesis of genomes is likely to supersede piecemeal approaches to genome modification. Given a little push here and there from technological advances, the age of designer genomes is nigh. ■

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QUANTUM PHYSICS

Single electrons take the bus

Single-electron circuitry is a promising route for quantum information processing. The demonstration of single-electron transfer between two distant quantum dots brings this technology a step closer. SEE LETTERS P.435 & P.439

TAKIS KONTOS

The realization of electronic machines that exploit the laws of quantum mechanics is a dream for many physicists. Among the different architectures proposed so far for meeting this goal, one very promising option is based on quantum dots: nanometre-sized electron boxes, or conducting islands, that can comprise as little as one electron. As with classical electronic devices, the construction of such a quantum machine requires 'wires' to connect up the elements of the machine's internal electronic circuitry. But in the quantum world, making such wires is not a trivial matter.

Two papers in this issue, one by Hermelin *et al.*[1] (page 435) and the other by McNeil *et al.*[2] (page 439), demonstrate wires, or 'buses', that can carry only a single electron and interconnect two distant quantum dots. These findings provide a building block for the implementation of large-scale networks of quantum dots, which will be necessary to scale-up techniques for local quantum manipulation that are currently performed only at the single-quantum-dot level[3].

In quantum dots, confinement can be such that the characteristic charging energy of the dot — the energy it takes to add an extra electron to it — exceeds thermal fluctuations at cryogenic temperatures. In such a situation, known as a Coulomb blockade, electrons passing through the quantum dot have to do so one by one. This fact, combined with the discreteness of the quantum dot's energy spectrum, makes the dots ideal sources of single electrons[4].

The usual way to extract a single electron from a quantum dot is to raise the last occupied energy level of the dot to well above the characteristic energy (the Fermi level) of the electronic reservoir to which the dot is coupled. This can be done with the help of an electrostatic 'gate' electrode. In this manner, the electron 'sitting' on the last occupied energy level is forced energetically to 'fall off' into the electronic reservoir; conversely, an electron can be absorbed from the electronic reservoir by lowering a previously unoccupied energy level below the Fermi level. Because an electron emitted in such a way rapidly mixes with other electrons in the electronic reservoir, knowledge of that electron's initial electronic state will be deficient, and any quantum information stored in the electron will be lost. This explains why extracting an electron from a dot and capturing it in another one is far from trivial.

To isolate a single electron and implement a single-electron bus, Hermelin *et al.*[1] and McNeil *et al.*[2] took an alternative approach that involves moving a quantum dot rather than acting directly on its energy levels. The basic idea is to distort the electrostatic potential that traps the dot's electron, using an acoustic wave that propagates across the surface of the device hosting the dot. The acoustic wave, which is induced by a microwave pulse, allowed the authors to expel a single electron from the dot and, subsequently, to transfer it to a receiving dot through an empty channel, in which the electron 'surfs' on the acoustic wave.

Hermelin *et al.* and McNeil *et al.* demonstrated successful single-electron transfer between the dots by detecting coincident emission and capture at both dots. These were detected with devices that are routinely used for charge detection in quantum dots[3]: sensitive electrometers that are placed closed to the dots. The efficiency of the authors' approach[1,2] was such that it allowed, for example, McNeil *et al.*[2] to reliably transfer single electrons back and forth between the dots over a cumulative distance of about 0.25 millimetres — nearly a macroscopic distance. Hermelin *et al.* went on to show that, after initially loading a dot with two electrons, it is possible to split them apart: one stays in the dot and the other is captured by a receiving dot.

These experiments[1,2] are particularly relevant with a view to using single-electron buses for retrieving and distributing quantum information stored in quantum dots that are embedded in complex networks. It has been shown[3,5] that electronic spin can be manipulated quantum mechanically with ever-increasing fidelity. It is therefore possible to imagine manipulating an information-encoding single spin in one quantum dot, then transporting it to another distant dot in the network. What's more, by using a double quantum dot, one could foresee the creation of an arbitrary two-electron superposition spin state[5] and its transfer between distant quantum dots. This would pave the way for studying quantum entanglement of two electrons in a solid-state environment.

All of these exciting possibilities offered by the set-ups of Hermelin *et al.* and McNeil *et al.* require that single-electron transfers do not degrade quantum information, an aspect that is not addressed in their work. Because new electron-manipulation techniques always come with unexpected dissipation mechanisms, it is not clear whether the electrons can retain their spin state, and so the encoded information, during their travels in the channel. However, recent advances in spin manipulation and control[5,6] call for optimism. We should therefore be confident that the demonstrated single-electron bus will go quantum in the not-so-distant future. ■

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