Excited-state spectroscopy on a nearly closed quantum dot via charge detection

J. M. Elzerman and co-workers from Delft University of Technology, The Netherlands report about demonstration of a new method for measuring the discrete energy spectrum of a quantum dot connected very weakly to a single lead in the last issue of Applied Physics Letters (84, 23, pp. 4617–4619, 2004).

The history of computer technology has involved a sequence of changes from one type of physical realisation to another -- from gears to relays to valves to transistors to integrated circuits and so on. Today's advanced lithographic techniques can squeeze fraction of micron wide logic gates and wires onto the surface of silicon chips. Soon they will yield even smaller parts and inevitably reach a point where logic gates are so small that they are made out of only a handful of atoms. On the atomic scale matter obeys the rules of quantum mechanics, which are quite different from the classical rules that determine the properties of conventional logic gates. So if computers are to become smaller in the future, new, quantum technology must replace or supplement what we have now. The point is, however, that quantum technology can offer much more than cramming more and more bits to silicon and multiplying the clock-speed of microprocessors. It can support entirely new kind of computation with qualitatively new algorithms based on quantum principles.

The work of the past several years has greatly clarified both the theoretical potential and the experimental challenges of quantum computation. In a quantum computer the state of each bit is permitted to be any quantum-mechanical state of *a qubit* -quantum bit, or two-level quantum system. Computation proceeds by a succession of ‘"two-qubit quantum gates", coherent interactions involving specific pairs of qubits, by analogy to the realization of ordinary digital computation as a succession of Boolean logic gates. It is now understood that the time evolution of an arbitrary quantum state is intrinsically more powerful computationally than the evolution of a digital logic state The quantum computation can be viewed as a coherent superposition of digital computations proceeding in parallel.

Few-electron quantum dots are considered as qubits for quantum circuits, where the quantum bit is stored in the spin or orbital state of an electron in a single or double dot. The elements in such a device must have functionalities such as initialization, one- and two-qubit operations and read-out. For all these functions it is necessary to have precise knowledge of the qubit energy levels.

Standard spectroscopy experiments involve electron transport through the quantum dot while varying both a gate voltage and the source–drain voltage. This requires that the quantum dot be connected to two leads with a tunnel coupling large enough to obtain a measurable current.

Coupling to the leads unavoidably introduces decoherence of the qubit, causing the quantum information to be irretrievably lost. Therefore, the coupling to the leads must be made as small as possible. An alternative spectroscopic technique is needed, which does not rely on electron transport through the quantum dot.

J.M. Elzerman et. al. present spectroscopy measurements using charge detection. They developed a method that resembles experiments on superconducting Cooper-pair boxes and semiconductor disks which have only one tunnel junction so that no net current can flow. They use a quantum point contact as an electrometer and excitation pulses with repetition rates comparable to the tunnel rates to the lead, to measure the discrete energy spectrum of a nearly isolated one- and two-electron quantum dot.

A train of voltage pulses applied to a metal gate induces tunneling of electrons between the quantum dot and a reservoir. The effective tunnel rate depends on the number and nature of the energy levels in the dot made accessible by the pulse. Measurement of the charge dynamics thus reveals the energy spectrum of the dot, as demonstrated for a dot in the few-electron regime.

Their work demonstrates that an electrometer such as a quantum point contact can reveal not only the charge state of a quantum dot, but also its tunnel coupling to the outside world and the energy level spectrum of its internal states. It is thus possible to access all the relevant properties of a quantum dot, even when it is almost completely isolated from the leads.

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