Ultra-Fast Quantum-Dot Information Storage

March 21 2008, Laura Mgrdichian

The information-storage market is dominated by two main types: Flash memory, used in memory sticks and cell phones, and dynamic random access memory (DRAM), which is the main memory in a personal computer. Both types have their advantages and disadvantages, but a new type of memory, based on tiny atom clusters, called quantum dots, may soon displace both of them.

In research published in the March 4, 2008, online edition of *Applied Physics Letters*, scientists from the Technical University of Berlin, in Germany, and Istanbul University, in Turkey, describe how they created a type of quantum-dot-based memory device that can save information at speeds of only a few nanoseconds (billionths of a second).

The paper's lead author, Technical University of Berlin scientist Martin Geller, explained to *PhysOrg.com*, “Flash memory, which is today's market-driver in the semiconductor industry, and which everybody knows from memory sticks, digital cameras, and mp3-players, has a slow write time. The semiconductor industry is seeking faster Flash memories, but hasn't found an ultimate solution yet. Our quantum-dot-based memory may provide long storage time without power consumption of Flash memory, as wells as a fast write time and better scalability to real-life devices."

To be fair, the other established predecessor of quantum-dot memory, DRAM, does have some excellent qualities. It offers very fast information-access times—under 20 nanoseconds—and the information

can be repeatedly written and rewritten on a DRAM; it has excellent so-called endurance. But a DRAM device has a big disadvantage: It is volatile, meaning the information has to be refreshed every ten milliseconds to be maintained, also resulting in a high power consumption.

“The very first prototype of our new quantum-dot-based memory scheme is already almost as fast as DRAM,” said Andreas Marent, a physicist at the Technical University of Berlin who took part in the research. “And in contrast to DRAM or Flash, the physical characteristics of quantum dots limit the write time to the picosecond, or trillionth of a second, range. That means a better device prototype should be more than 100 times faster than today's DRAM.”

The prototype consists of quantum dots of indium arsenide (InAs), a compound of the metals indium and arsenic, embedded in a layer of gallium arsenide (GaAs; gallium is also a metal). The GaAs layer is “p-doped,” which means it contains impurity atoms that impart it with excess free positively charge called holes. This InAs/GaAs structure is topped with a layer of “n-doped” GaAs, which contains extra electrons. Altogether, the structure is a p-n diode, an electrical device that allows current to flow only in one direction.

When a voltage is applied across this structure, the quantum dots become charged, which allows them to store bits of information, i.e. “0” or “1” values. Whether the quantum dots represent a 0 or 1 depends on the capacitance of the diode—how much charge it is holding. A larger capacitance indicates the quantum dots do not hold much positive charge, which equates to a “0.” A smaller capacitance means that the dots are filled with holes, representing a “1.”

Geller, Marent, and their colleagues say that the write times of their quantum-dot schemes are currently limited by the experimental setup

and certain physical characteristics of the memory structure. In the future, after they make improvements to the structure, they expect that write times faster than 1 nanosecond may be possible. Even picoseconds seem possible, since the structure's physical limitation is in that range.

Said Prof. Dieter Bimberg, who is the group's leader at the Technical University of Berlin and co-author on the paper, “Our results and patents demonstrate that quantum dots like these we are studying might, in just a few years, revolutionize semiconductor memory.”

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