Computing with charged quantum-dot arrays

To add two digits, a conventional computer chip must shuffle vast numbers of electrons through an array of transistors. Devices requiring far fewer electrons for such operations offer potentially faster computation with greatly reduced size and energy consumption.

Now, a team of researchers has proposed a novel scheme for harnessing individual electrons, confined to tiny structures known as quantum dots, to encode information and perform addition and other operations involving computer logic. Craig S. Lent, P. Douglas Tougaw, and Wolfgang Porod of the University of Notre Dame in Indiana described the scheme at a workshop on physics and computing held last month in Dallas.

The research builds on recent advances in the fabrication of microscopic semiconductor "boxes," whose walls keep electrons confined to a small region of the material. Researchers have been able to detect and, to some degree, control the number of electrons trapped in these quantum dots (SN: 2/20/93, p.118). New experiments have also shown that electrons can tunnel from one quantum dot to another if the two dots are sufficiently close together.

Lent and his colleagues base their scheme on a unit, or cell, consisting of five quantum dots. With one dot in the center and one at each corner of a square, electrons can readily tunnel between any two of these sites.

Supplied with two electrons, a cell settles into one of two possible configurations in which the electrons occupy dots on opposite corners of the cell (see diagram). These orientations represent two distinct cell states.

Strung together into rows and other patterns, such cells serve as the building blocks of the logic circuits required for computation. The cells are sufficiently far apart that practically no electron tunneling occurs between dots of adjacent cells, but electrical forces between the cells enable one to influence another.

Thus, it's possible to create a "binary wire" made up of a row of cells, all initially in the same state. Switching the cell state at one end of the string causes a chain reaction that flips the states of the remaining cells one by one.

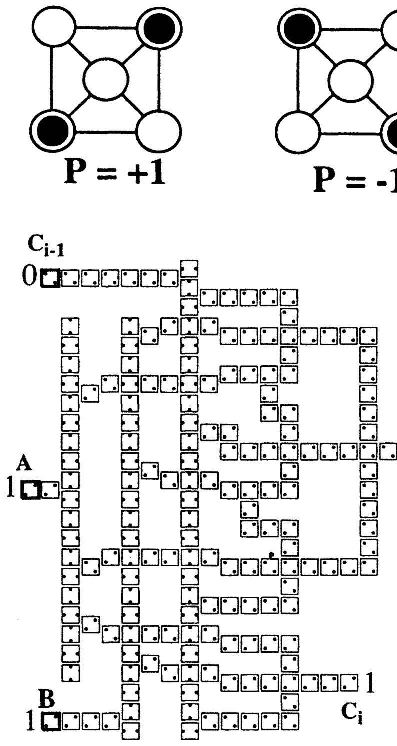
Lent and his coworkers have also created more complicated configurations that correspond to various logical devices. Their calculations and computer simulations, which involve quantum theory, suggest that such devices would function as required.

The researchers are now looking into the feasibility of fabricating these quantum-dot arrays. "We think we can make this work," Lent says.

How well the resulting devices function will depend on how easy it is to set the initial states of the cells and to detect a device's final output states. Moreover, it isn't clear yet what influence stray electrical charges in the surrounding material and other defects may have on these arrays.

Nonetheless, this scheme represents an interesting case of potentially useful quantum computing that exploits the emerging technology of quantum-dot fabrication, the researchers conclude. On nanometer scales, coding information in quantum-dot states provides an attractive alternative to the standard approach of using currents and voltages.

— *I. Peterson*



On average, two electrons distributed across a set of five quantum dots will tend to congregate at opposite corners of the cell to create two distinct arrangements (top). Such cells can be laid out in patterns to serve as particular logic elements. This example shows a binary adder in which output S is the sum of bits A and B (bottom).

Lent et al.

Metal dendrites sprout in microgravity

It looks like "a forest of tiny metal pine trees," says Martin E. Glicksman, a materials scientist at Rensselaer Polytechnic Institute in Troy, N.Y.

Each time a molten alloy cools, changing from a liquid to a solid, a rough-edged carpet of treelike spindles sprouts along the interface where the two states meet. Scientists call these tiny branching structures dendrites, derived from the Greek word for tree.

When observing this metal forest under a microscope, one sees metal trees growing so closely together "that their trunks and branches intermingle," Glicksman said this week at a meeting of the Materials Research Society in Boston.

Indeed, every engine block or soda can hardening from molten alloy forms such dendritic sheets along the edge where the liquid turns solid. Once the alloy has completely hardened, the interlocking dendrites imprint in the material a complex three-dimensional pattern called the microstructure.

That pattern, says Glicksman, strongly affects the material's strength, ductility, and electrical properties, as well as its tendency to crack and corrode. Thus, in order to improve alloy quality, scientists want to understand more thoroughly how metal dendrites grow during solidification.

A key factor influencing dendritic growth is the convective currents of heat flowing in molten metal. On Earth, with its strong gravitational fields, those currents are difficult to control or avoid. So Glicksman and his colleagues proposed to measure dendritic growth in space.

On March 4, the space shuttle Columbia carried the Isothermal Dendritic Growth Experiment into orbit for 9 days, soaring 163 nautical miles above sea level in a low-Earth circular orbit. Still and video cameras surrounding a thermostatic chamber recorded the growth of dendrites in succinonitrile, a transparent, nonmetallic material with a conveniently low melting point that mimics metal in the way it solidifies.

With gravity lowered to less than one-thousandth of Earth's, the team repeatedly raised and lowered the temperature of the succinonitrile, watching it melt and resolidify. Slow-scan video cameras captured the emergence of dendrites on the end of a "stinger tip" immersed in the gently freezing fluid, while two 35-millimeter cameras snapped 400 pictures of sprouting crystal trees. Other sensors measured physical details during dendritic growth.

With the low-gravity experiments completed, scientists compared the data generated in space with similar information obtained on Earth. As a result, they can now see more precisely how convection currents, which alter the way heat diffuses through a cooling metal, can influence the growth rate and curvature of dendrites.

Such information, the scientists maintain, may now give metallurgists on Earth an added edge as they strive to make lighter, stronger, more reliable alloys for the machinery needed in the next century.

— *R. Lipkin*