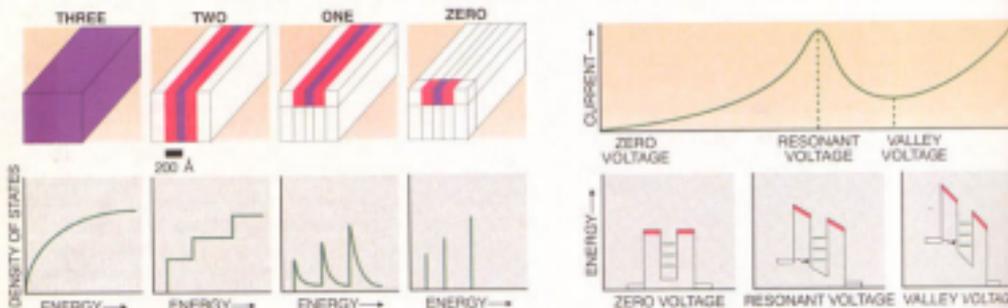


DIMINISHING DIMENSIONS

The dimensionality of a material can be reduced by sandwiching it between two layers of another material that has higher-energy electrons. This confinement changes the density of electron states, or specific energy levels, that will be filled by incoming electrons (left).

The current conducted by a quantum well device, shown by green energy levels (right), peaks when the energy level of the incoming electrons matches, or is in resonance with, an energy level of the quantum well. At higher or lower voltages, little current leaks through the device.



dred thousandths the thickness of a hair. Because these slivers are thinner than the characteristic wavelength of an electron, the particles are trapped.

Confined in such layers, electrons lose a degree of freedom. From an electron's vantage, the thin planes in Bellcore's light emitter have only two dimensions. Scientists can reduce a material's dimensionality further, too. A narrow strip sliced from one of the planes would be a one-dimensional wire. Dicing up a one-dimensional wire would be the ultimate reduction. This step yields zero-dimensional dots.

Reducing the number of dimensions of a material forces electrons to different energy states. Creating materials in which electrons demonstrate these unusual energy states is the heart of research on quantum devices. By controlling the physical size of a structure, researchers can induce predictable changes in electron energy. In this way, scientists can literally pick, or tune, the electronic properties they want. The fewer the dimensions, the finer the tuning. A zero-dimensional, or quantum, dot is considered analogous to custom-designing atoms.

This modern alchemy opens the way for fundamentally different electronic and optical devices. Instead of simple binary, or "off-on," electronic switches now used in computers, workers hope to fabricate multiple-switch devices and arrange them to function in parallel. These could lead to more powerful forms of computer logic and become the building blocks of dramatically smaller and faster integrated circuits. Some researchers even talk enthusiastically of "a supercomputer on a chip."

Another goal is highly efficient, tiny

lasers that could convey far more data along optical fiber networks than is now possible. Such fire hoses of data could pump enormous amounts of video, computer and telecommunications services and data directly into businesses and homes. And the marriage of such electronic devices and lasers might bring into being a long cherished dream: optoelectronic circuits, which integrate electrons and photons, thereby spanning faster, more powerful components for computers and telecommunications networks.

Bellcore is far from alone in its quest for quantum devices. The U.S. National Science Foundation funds a center at the University of California at Santa Barbara devoted to quantum confinement. IBM and AT&T Bell Laboratories, among others, have made pathbreaking contributions. Investigators in Germany, England, France and, of course, Japan are also making great strides in this area. The key issue all researchers face: how to fashion these novel materials—quantum wells, wires and dots—into working devices.

Dicing Up Dimensions

On the floor of Leroy L. Chang's office at the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y., is a matrix of neatly stacked manila files—vaguely reminiscent of the stacked layers of atoms that he and colleagues Leo Esaki and Raphael Tsu began toying with in the late 1960s. Their goal: to build structures that would trap electrons in dimensionally limited environments. "Confine an electron in two dimensions," Chang declares, "and it changes everything."

Materials that naturally confine electrons have long intrigued scientists. Graphite, an organic material that conducts current, consists of stacked two-dimensional sheets of carbon atoms. High-temperature ceramic superconductors, such as lanthanum copper oxide, have two-dimensional planes of copper and oxygen atoms interspersed with planes of other atoms [see "Superconductors beyond 1-2-3," by Robert J. Cava; SCIENTIFIC AMERICAN, August].

To build a lower-dimensional material deliberately, researchers must pay court to quantum mechanics. In any three-dimensional, bulk semiconductor, electrons take on a continuous range of different energy states when additional energy is added to the material by applying voltage. As a result, researchers cannot tap a specific energy level; they must accept what they get.

Quantum-mechanical theory portrays electrons as both particles and waves. Squeezing one side of a three-dimensional cube until it is no thicker than an electron wave is long traps electrons in a two-dimensional plane. In two dimensions, the so-called density of electron states—the energy levels electrons can occupy—becomes quantized. Electrons jump from one energy level to another in a steplike fashion. By studying what layer thickness induces what energy level, researchers can design the precise electronic characteristics of a material.

Electrons are not really confined by physical barriers, however; instead researchers must erect barriers of energy. Like water going downhill, electrons tend toward low-energy areas. So to trap electrons, investigators need only sandwich a material filled with low-en-