SCIENCE

29 NOVEMBER 1991
VOLUME 254
NUMBER 5036



# Room at the Bottom

Scales and magnitudes are part of the stuff that scientists love. Cosmology and megascales on the one hand, and atoms (or subatomic particles) and microscales on the other, give us a sense of how grand nature is and how consistent our physical pictures are.

In 1959 Richard Feynman gave a lecture, later reprinted, entitled "There's Plenty of Room at the Bottom" (see Research News, p. 1300). In his usual prescient way, Feynman suggested a variety of experiments and technologies that might be achieved at very small scales. This is an area that is currently getting a lot of hype. Some recent suggestions sound like science fiction, although we are not yet seeing articles titled "Honey, I Shrunk the Factory." Nevertheless, terrific advances have been and are being made. In this issue, we explore some progress in manipulating matter on very small scales. The technology and science range from manipulating individual atoms to manufacturing macrostructures such as sensors. We leave biologically based fabrication to future issues, but see the News and Comment article by Freedman, p. 1308, as well as some comments by Whitesides, Mathias, and Seto.

Whitesides *et al.* deal with the problem of molecular self-assembly and nanochemistry. "Nanostructures" have dimensions of about 10 to 1000 angstroms, a size that is small by engineering standards, common by biological standards, and large to chemists. Many biological structures are formed by molecular self-assembly. The spontaneous aggregation of molecules using noncovalent bonds to form a well-defined structure is a critical component of biological synthesis. Self-assembly is discussed as a strategy in chemical synthesis with the potential of generating nonbiological structures of this size.

Stroscio and Eigler discuss atomic and molecular manipulation with the scanning tunneling microscope. Until recently, we depended on the collective behavior of molecular systems to understand their structure. Diffraction and absorption experiments reveal much about molecular structure by simultaneous study of a large number of similar or identical molecules. Now, scanning tunneling microscopy allows us to look at individual atoms and has become a critical tool for exploring structure at the atomic level. One of the most recent exciting developments in this field is the ability to move single atoms, place them at selected positions, and build structures atom by atom.

Sundaram, Chalmers, Hopkins, and Gossard describe new advances in quantum devices. In particular, quantum wires and quantum wells, in which electrons are confined to potential wells in one and two dimensions, will lead to new electrical and optical properties. Using epitaxial deposition, one can readily make two-dimensional artificially quantized structures. By means of atomic steps on single-crystal surfaces it is possible to make very small (less than 100 angstrom diameter) wires. Electrons can also be released and controlled in the third dimension. For example, a parabolic potential can be realized by synthesizing a graded $Al_xGa_{1-x}As$ alloy with a parabolic mole-fraction profile. This article and a related Research News article by Graff (p. 1306) discuss important and interesting progress in this area.

Finally, Wise and Najafi describe microfabrication techniques for integrated sensors and microsystems. This technology provides the interface between very large scale integrated circuits and non-electronic monitoring and control. Using photolithography to provide a mask, followed by etching, one can produce various kinds of sensors, most recently flowmeters and accelerometers. Owing to high-volume production, the costs of these sensors and actuators can be exceedingly low, and they are already beginning to revolutionize much of the complex control machinery that we deal with every day. Biomedicine and automated manufacturing are areas in which these devices will be especially important.

Much of what we see here was foretold by Feynman, although the techniques that are actually in use today were not apparent at the time of his lecture. It is clear that he would have been gratified by the progress that has been made and the promise of more to come. There is, indeed, room at the bottom, and we are beginning to move in.

—JOHN I. BRAUMAN