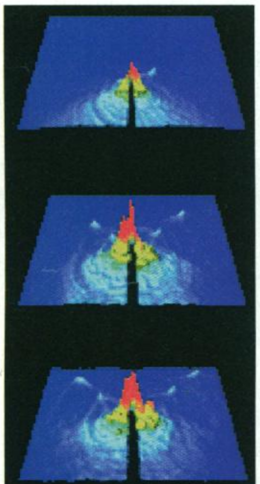
Control and Use of Defects in Materials

Defects bring to mind imperfection and blemish, but for materials, what might be considered a defect may lead to dramatic performance improvements over the "ideal" material. Certainly, defects can limit what materials can do—for example, the theoretical strength calculated for crystalline solids is almost never observed in the laboratory because real materials generally contain a certain number of dislocations that can provide sites for the material to crack and fail. However, whereas pure corundum (alumina) has its uses as a hard grinding material, it is the presence of defects—trace metal impurities such as iron or chromium—that produces the electronic transitions that create the beautiful colors of rubies and sapphires. This special issue of *Science* focuses on the ways that scientists and engineers work around, and with, defects to get the most out of materials.



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For many applications, the choice of material is dictated by how it fails—for example, its fracture behavior. Metals can fail at welds and from repeated stressing (fatigue), depending on whether they remain ductile and blunt cracks that form or become brittle and let cracks extend rapidly over large distances. Computational models can now treat many of these problems from the atomic level, simulating the behavior of hundreds of millions of atoms. Such models help interpret experimental data, such as electron micrographs and high-speed movies of crack propagation.

The semiconductor revolution was made possible by the ability to add impurities deliberately to otherwise pure materials as dopants to control properties such as conductivity. Interfaces are especially challenging, as a poor interface can create dislocations throughout the entire growth layer that will render a device useless. One amazing exception has been the indium gallium nitride family of blue and green light-emitting diodes and laser diodes. These devices can recombine charge carriers to produce light, despite the enormous number of dislocation defects that form during the growth of these devices. Although charge carriers (electrons and holes) are the backbone of semiconductor technology, moving charges costs energy, creates heat, and places limits on performance. Electrons have spin, and electronics based on spin physics and magnetism is increasingly attracting attention. Efforts are underway to use dopants to create ferromagnetic analogs of the conventional semiconductors in wide use today.

Atomic-scale defects usually are thought of in the context of crystalline materials—amorphous materials, such as glass and plastic, seem somehow uniform. However, large defects such as cracks quickly limit transparency—hence glass optical fibers, which outperform plastic fibers over long distances, are difficult to use in the local setting of an office, where sharp bends and turns are needed. Yet, there is evidence that the limitation of plastic fibers, their dispersing of signals, is caused by fluctuations in density and concentration at a local level. This effect might be harnessed to improve the signal-carrying capacity of these materials.

One emerging class of materials combines impressive electronic, mechanical, and thermal properties in a small package—carbon nanotubes. Defect-free, single-wall nanotubes exhibit exceptional strength, and the presence of a few defects can lead to unusual electronic behavior. The difficulties in making large amounts of these materials are being overcome, and they are already finding a use in making insulating plastics more conductive.

Semiconductors, once exotic, are now commonplace because of the efforts made to understand and control defects, and a similar fate may await carbon nanotubes. Whatever new materials are found, performance goals will likely demand the control, use, or elimination of defects.

—PHIL SZUROMI AND DANIEL CLERY

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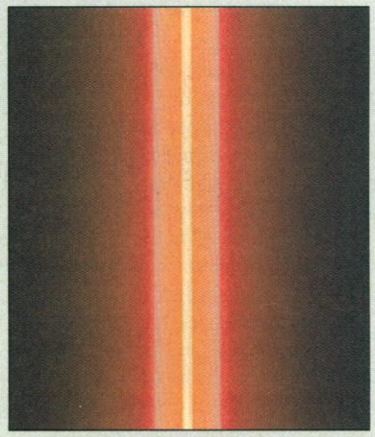

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