EDITORIAL

Microstructural Engineering of Materials

A piece of blackboard chalk and a clam shell are chemically almost identical in composition, but the chalk will snap far more easily. The difference in the performance of these two materials originates in their microstructure; in the shell, secreted biomolecules align the crystallites of calcium carbonate during growth. Materials scientists and engineers seek to improve materials in their formation or processing or both, and often the improvements come through alteration of the microstructure of the material. Materials science continues to move from a discipline that explains why materials have been improved to a predictive science that puts forward new ideas for experimental trial. This special issue of *Science* focuses on some of the ways in which materials scientists analyze microstructure [see the related News section (p. 1213) on the uses of synchrotron radiation] and relate it to properties and develop new ways to improve materials.

Although polymers are amorphous materials, they can still exhibit microstructure that influences their properties. For example, block copolymers contain sections of different chemical compositions that can phase-separate to create highly complex microstructures. Such structures could find use in patterning surfaces for devices or creating optical waveguides. Muthukumar *et al.* (p. 1225) discuss how molecular interactions can be pitted against each other to produce organization on several length scales at once in polymers and related liquid-crystalline and surfactant materials.

In order to improve a material by design, it is usually necessary to know how the existing material works. Nature, however, can be stingy with its secrets. Precipitation-hardened aluminum alloys, which are the backbone of many airframes, are hardened by the formation of small hard clusters within the metal. Such clusters are extremely small and are randomly arranged, thus placing great demands on both electron microscopy and diffraction methods. Zanderbergen *et al.* (p. 1221) show how electron microscopy can be used to identify the precipitates that strengthen aluminum-magnesium-silicon alloys.

Microstructures do not have to be highly ordered at all scales to be useful; Decher (p. 1232) discusses how multilayered thick films can be built up from alternating layers of polyelectrolyte anions and cations, an approach that can be extended to include inorganic colloids and proteins. Although the boundary between layers can be "fuzzy," this can be advantageous in optics (where a lack of defects can prevent unwanted light scattering) and in applications such as drug delivery and gas separation, where the material can respond to changing loading conditions.

Metallic alloys, especially ferrous alloys, have become increasingly complex in terms of the number of alloying elements that are used; such complexity makes empirical trial-and-error searches for new compositions slower, more difficult, and more expensive. Olson (p. 1237) discusses how computational methods are speeding the search for new alloys that are lighter, tougher, and more corrosion-resistant.

Proteins, glycoproteins, and polysaccharides can impose order on mineral phases to produce the remarkable properties of bones, teeth, and shells. Stupp and Braun (p. 1242) review how these lessons from nature can be applied to artificial systems. Not only can ceramics be tailored by small amounts of organic templates, but semiconductors can be templated to produce nanostructured materials with altered electronic and optical properties.

Polymer microstructure need not be static; materials whose microstructure responds to dynamic conditions have potential as sensors and actuators. Chen *et al.* (p. 1248; see the cover) used optical measures of rheology along with x-ray scattering to show how the orientation of the layered structure within certain diblock copolymers can be changed dynamically by shear within the material.

These are but a few of the many ways in which scientists and engineers have altered microstructure to create better materials. New approaches are blurring the traditional categories of metals, ceramics, and polymers, and insights from one class of materials are used to improve another. The benefits of this work are not only scientific insights but also better use of the limited resources we have on hand.

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