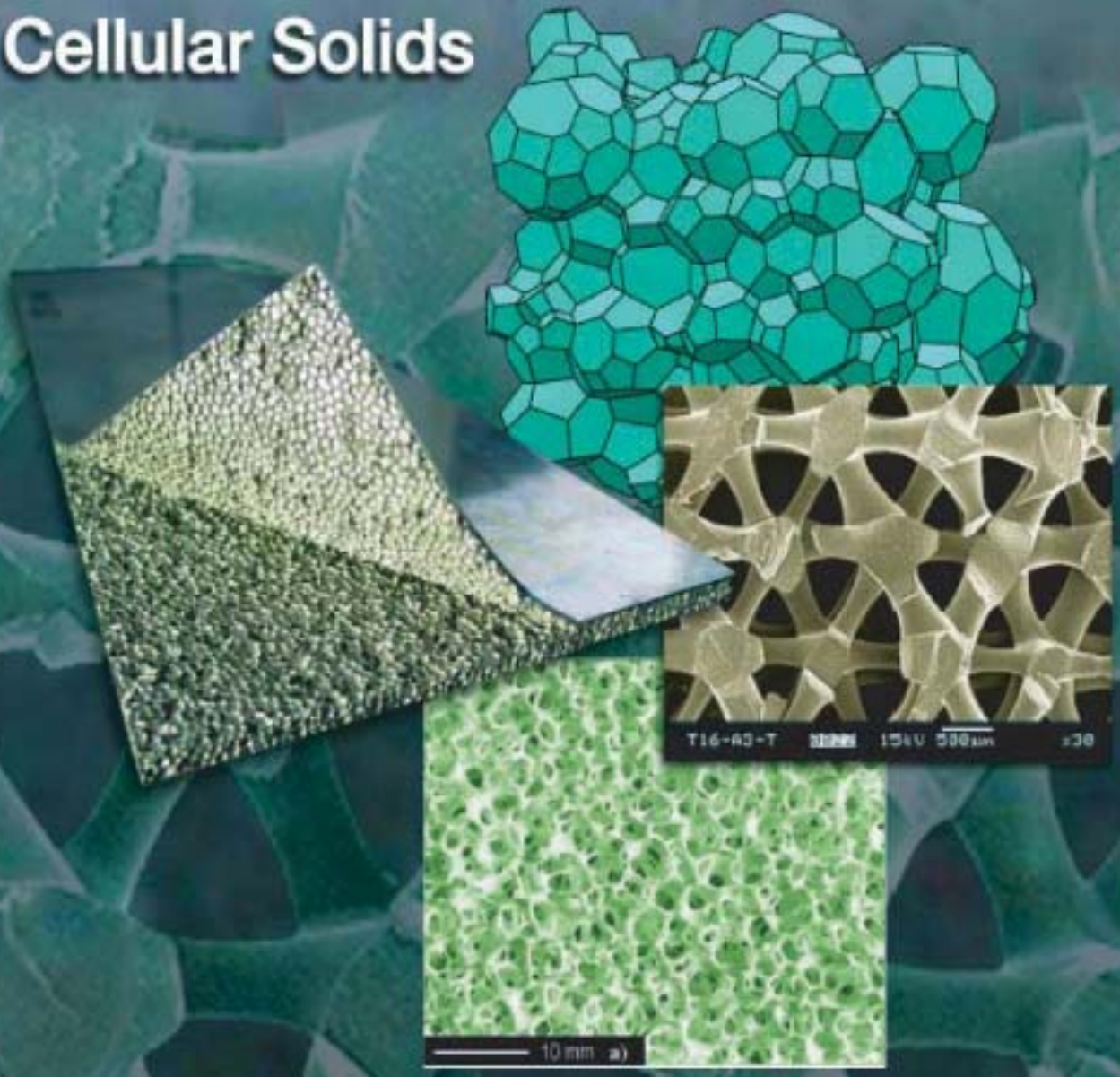
MRS BULLETIN

Serving the International Materials Research Community

A Publication of the Materials Research Society

April 2003, Volume 28, No. 4

Cellular Solids



Fullerenes Add Motion to Micromachines

In order to make machines on the molecular scale, researchers need to be able to fabricate components that are analogous to those of macromachines, such as gears, wheels, pistons, valves, and bearings. Fullerenes, with their sphere-like structure, would seem to be ideal for use as bearings, but early work involving these C_{60} molecules between two surfaces was less than encouraging. Multilayers of C_{60} between plates deformed elastically, leading to high friction. However, results reported in the February 7 issue of *Physical Review Letters* suggest that monolayers of C_{60} sandwiched between silicon surfaces coated with graphite may produce a nearly frictionless bearing system for use in micromachines.

While graphite is a well-known lubricant, its function in this bearing system is not one of lubrication. Rather, the hexagonal carbon faces on the top and bottom of the C_{60} molecule "mesh" with the six-member carbon rings that form the sheets of the graphite sandwich to form nanogears; these nanogears allow the C_{60} molecules to roll between the graphite layers, acting as bearings. The action is similar to rolling a ball between the hands by moving them in parallel but opposite directions.

K. Miura and S. Kamiya of Aichi University of Education in Kariya, Japan, along with N. Sasaki of Sekei University in Tokyo, used frictional force-mapping techniques to show that C_{60} forms a close-packed monolayer on graphite. Furthermore, the monolayer can be formed initially with hexagonal faces of C_{60} maintaining AB stacking with the hexagonal carbon rings of the graphite on both sides of the sandwich.

When a small torque is applied to the system, the C_{60} molecules roll, ideally in a direction that will find their hexagonal faces once again aligned with the hexagonal rings of the graphite sheets on either side. However, because the C_{60} molecule is not composed exclusively of hexagonal faces but includes pentagonal faces as well, there is no guarantee that this ideal alignment will occur each time. If a pentagonal face of C_{60} comes into contact with the graphite hexagon, the gear will briefly stick until thermal energy causes rotation of the C_{60} so that a hexagonal face once again matches up with the graphite sheet. From this position, the C_{60} bearing can then turn again. The bearing system thus moves by a stick-slip mechanism at room temperature. Because the energy required to overcome the sticking is relatively low, the researchers believe that at slightly elevated temperatures, the bearings will roll smoothly.

This first demonstration of a practical molecular bearing system, coming as it does with a fundamental understanding of the mechanism involved, could help add the long-awaited capability of movement to previously static micromachines.

"Silicon substrates covered with graphite should be useful as movable parts of nano- and micromachines," said Miura. "This system is expected to be useful in MEMS [microelectromechanical systems] devices."

Jean Michel Martin, head of the Department of Materials and Surface Science at the Ecole Centrale de Lyon in France, while finding these results important, expressed concern that the experiments were not conducted in a high vacuum environment.

"The presence of water molecules and even oxygen molecules are well known to interact with C_{60} and graphite flakes," he said. If present, these molecules could

be playing a role in the proposed stick-slip mechanism.

TIM PALUCKA

Two-Photon Polymerization of Organically Modified Ceramics Used in 3D Microfabrication

Two-photon polymerization (2PP) of photosensitive acrylates and epoxies has been used in recent years to fabricate three-dimensional (3D) microstructures such as photonic crystals and mechanical devices. Femtosecond laser pulses, which initiate the 2PP, can achieve submicrometer resolution when tightly focused into the volume of liquid resin. B.N. Chichkov of Laser Zentrum Hannover, R. Houbertz of the Fraunhofer-Institut für Silicatforschung in Würzburg, and co-workers have extended this technique to a commercial multifunctional inorganic–organic hybrid polymer that has properties advantageous for photonic applications. They have applied this technique to the fabrication of microstructures and photonic crystals with a structure size down to 200 nm and a periodicity of 450 nm.

As reported in the March 1 issue of *Optics Letters*, the material employed for 2PP was ORMOCER, an acronym for organically modified ceramic, developed at the Fraunhofer-Institut für Silicatforschung. The researchers recognized that ORMOCERs, which are produced by a sol-gel method, have many properties important for photonics, such as an adjustable index of refraction in the range of 1.47–1.56, high optical transparency with low losses for both the resin and polymerized material, high chemical resistance, and exceptional thermal and mechanical properties. Specifically, ORMOCER-1 is designed for UV photolithography and contains the UV-sensititve Irgacure 369 initiator. All ORMOCERs are transparent in the IR and especially at 780 nm, so that Ti-sapphire laser pulses can be focused into the volume of liquid resin.

The research team used a Ti-sapphire oscillator with a repetition rate of 80 MHz, a pulse duration of 80 fs, and a laser wavelength of 780 nm. A mechanical shutter with a minimum switching time of 5 ms controlled the number of laser pulses and the radiation time. Femtosecond laser pulses were focused with a 100× oil-immersion-lens microscope objective with a numerical aperture of 1.4 and $n_{oil} = 1.515$ for index matching. The researchers said that resolution beyond the diffraction limit can be achieved because of the threshold behavior of the 2PP process.

The researchers developed expressions for the diameter and length of the polymerized volume (volume pixel, or voxel) as functions of laser power and irradiation time. By curve-fitting the experimental data to these expressions, the researchers were able to determine the expressions' unknown parameters, which in turn define the lateral and axial resolution of the objective (340 nm and 1.2 µm, respectively).

The researchers demonstrated 3D microstructuring with femtosecond lasers and fabrication by 2PP by presenting scanning electron micrographs of a micrometer-scale statue of the Venus de Milo. The researchers scanned the laser beam with an x–y galvo scanner and moved the sample in the z direction with a translation stage. In order to speed fabrication, only the shell of the statue was irradiated with femtosecond laser pulses. After washing out the remaining liquid resin, the statue was irradiated with UV light for final polymerization of the inner body. Total fabrication time was about 5 min. The researchers also fabricated microcapsules from ORMOCER-1, which is biocompatible and can be used in medical applications. A third demonstration was the fabrication of a photonic crystal, which was built up from individual rods with diameters of 200 nm and an inter-rod spacing of 250 nm. Total fabrication time was about 10 min.

The researchers said they expect that