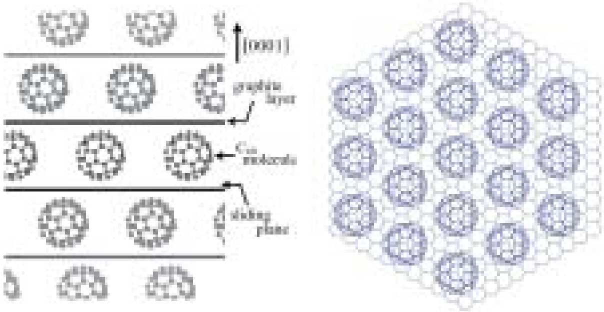
Super-slippery at Nano-scale

Great progress is being made in the development of micromachines, which hold the promise of exciting new products and industrial processes. But, before they can fulfill their potential as the basis for a new industry, a major hurdle must be overcome – the sticky problem of friction. At nano-scale, where measurements are made in billionths of a meter, microscopic surface irregularities can be major obstacles and intermolecular attraction is significant. Because of this, many researchers have dismissed micromachines as devices incapable of motion.

A microrotor developed recently at the University of Tokyo, for example, has promise as a micromachine part, but it only works under the most ideal conditions. The slightest surface impurity, even a few stray water molecules, can put the rotor out of alignment, whereupon intermolecular forces grip it like superglue and its bearing seizes up irreparably. What is needed is a nano-scale lube job.

This is why a new "super lubricant," developed by Prof. Naoru Sasaki at Seikei University and Prof. Koji Miura at Aichi University of Education, is generating such excitement in the nanotech community.



COURTESY NAORU SASAKI

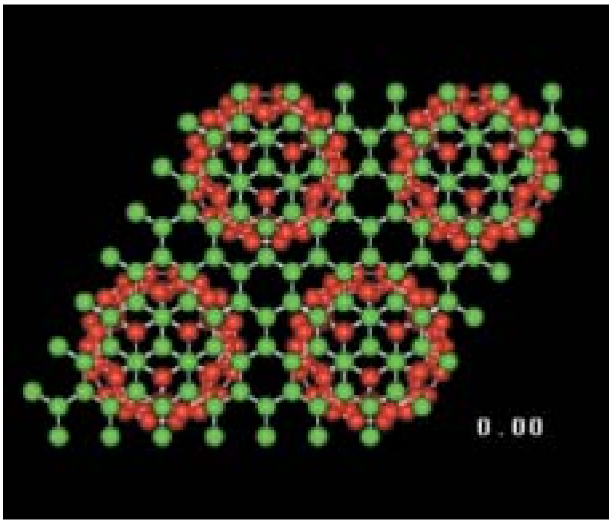
After 15 days at 600ºC, open the oven and take out the C_{60} intercalated graphite film flake (from left: cross-section, from above).

ROBERT CAMERON

Naoru Sasaki leads the theoretical aspect of developing a lubricant for micromachines.

The material comes in two forms. One consists of a monolayer of soccer-ball-shaped fullerene C_{60} molecules (named after American scientist Buckminster Fuller), which, kept evenly spaced by intermolecular forces, roll between thin sheets of graphite, in a kind of fullerene sandwich. The other form is an "intercalated graphite film," which consists of alternating close-packed C_{60} monolayers and graphite layers. Researchers have long suspected that fullerenes would form the ultimate lubricant, but a practical application has eluded them.

Sasaki says the intercalated form is the most promising, since the unlimited number of sliding planes mean that "durability should be excellent."



COURTESY NAORU SASAKI

Simulation model of graphite/C_{60}/graphite system.

Another pesky problem, water adsorption (in which a material reacts with water molecules in the air, changing its surface properties), can be largely avoided. "There is negligible influence from water adsorption because the sliding planes are situated inside the film," says Sasaki.

The superlubricant was created by baking C_{60} powder and expanded graphite in a vacuum at 600ºC (about 1,100ºF) for 15 days, resulting in a 2.3-by-2.3mm intercalated graphite flake. The surface friction of this flake was then measured in the standard way by dragging a needle (attached to a cantilever and a measuring instrument) across it. The material exhibited superlubricity – frictional forces so close to zero as to be indistinguishable from background interference, and with none of the stick-slip pattern typical of surface friction. Surprisingly, the same results were obtained no matter which direction the needle was dragged across the intercalated graphite flake.

Sasaki and his grad students form the theoretical side of the team, doing the math and computer modeling. Miura and his students make the samples and conduct the experiments.

Sasaki theorizes that if one plane of the flake becomes jammed at some point, adjacent planes take over and slide past it. This property is useful from a practical standpoint, but is also interesting theoretically.

"This can be considered a kind of intelligent film with a multistage friction mechanism," Sasaki says.

The breakthrough could quickly lead to a host of new products. Companies have already contacted Sasaki and Miura about numerous applications – including wristwatch bearings, engine oil, machine parts and ski wax.

Another intriguing possibility mentioned by Sasaki is "nano-trucks." These would be platforms so small that they would hold only a few individual molecules. Running across a two-dimensional surface on tracks of superlubricant, and possibly controlled by electric fields, fleets of millions of nano-trucks could act as mechanical catalysts, colliding to bring molecules together, a few dozen at a time, for precise control of both the scale and location of chemical reactions. Being able to work in a controlled way at molecular level could also make nano-trucks useful in assembling such objects as nanoelectronic components.

Sasaki is now working to figure out just why the material is so friction-free. It may be that the fullerenes roll and the graphite layers shift, but there could be other forces at work.

"The mechanism has not been completely clarified," he says. "The measured friction is not exactly zero, but it's very close." The dynamics of C_{60} molecules are extremely complex, and Sasaki wants to know exactly what happens when he drags that needle across the intercalated graphite wafer.

Robert Cameron is a freelance writer based in Tokyo. The *ACCJ Journal* welcomes suggestions for this column, which focuses on commercialization of scientific and technological advances.