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No more rough diamonds

Microelectromechanical devices need moving parts that can slide smoothly against one another when dry. A form of diamond made from a mosaic of nanocrystals might have what it takes.

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Courtesy Sandia National Laboratories, SUMMiT^{TM} Technologies, www.mems.sandia.gov

Artificial diamond could be the perfect material for making tiny machine parts, US researchers say.

They have measured the frictional properties of thin films of 'ultrananocrystalline' diamond (UNCD) grown from carbon-rich gas. They find that this material can be made as slippery as 'single-crystal' diamond, in which the material consists entirely of one big crystal[1].

As diamond is very hard, it might appear to be the ideal fabric for making microscopic machines known – depending on how small they are – as micro- and nanoelectromechanical systems (MEMS and NEMS). These devices, which typically contain moving parts such as cogs, gears and resonating cantilevers, have to be very resilient against wear and tear.

But conventional liquid lubricants don't work at the small scales at which these machine components are fashioned – perhaps just a few micrometres or so. The moving parts must operate while dry, which means that the materials from which they are made must themselves have very low friction.

Diamond looks promising from that perspective too. But it is not yet possible to fashion MEMS and NEMS parts from single-crystal diamond. These components are typically carved out of thin films of a material deposited on a substrate. The substrate is then etched away to free the parts.

Techniques for growing thin films of artificial diamond don't produce single-crystal films, however, in which the atoms are all lined up in one gigantic, regular lattice. Instead, these diamond-growth methods generate

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polycrystalline films: patchworks of many tiny crystallites welded together. They are usually not as strong, hard or smooth as single-crystal diamond. At present, MEMS parts are usually carved from thin sheets of silicon.

UNCD comes closer to single-crystal diamond. It is made by adding argon gas to the carbon-rich vapour used to deposit a diamond film[2]. The grains in UNCD are very small, and so the films are smoother than normal polycrystalline diamond. What's more, the large-scale frictional properties of a UNCD film are similar to those of single-crystal diamond.

All the same, it hasn't been clear whether the microscopic sliding behaviour of UNCD has the properties required of MEMS and NEMS components. In particular, no one had previously looked at the underside of a UNCD thin film – the side that bonds to the substrate, and which is exposed when the substrate is removed to free the component. It is this underside that would be subsequently involved in sliding friction against another surface.

Robert Carpick of the University of Wisconsin-Madison and his co-workers have now made nanoscale measurements of the frictional (tribological) and chemical properties of UNCD thin films, including this underside. To free the underside, they laid down the films on silicon wafers coated with a thin layer of silica, which they then etched away with acid.

Using an atomic-force microscope (AFM) to probe the topography of the film surfaces, the researchers found that the underside of the films was considerably smoother than the topside. Initially, the surfaces are contaminated with oxygen atoms, because oxygen from the air binds to 'dangling bonds' on carbon atoms at the diamond surface. But Carpick and colleagues found that the frictional characteristics of their films could be improved by coating them instead with hydrogen atoms, which can be easily done by exposing the films to a hydrogen plasma.

Even before this so-called hydrogen passivation of the surface, the work of adhesion (a measure of the stickiness) of the underside of the UNCD films was only about half that of silicon – the diamond films are far less sticky. This work of adhesion, measured by pulling the AFM probe tip away from the surface, was comparable to that of single-crystal diamond.

After hydrogen passivation, both the work of adhesion and the frictional force experienced by an AFM tip dragged over the surface were substantially lowered, and again comparable to the values for hydrogen-passivated single-crystal diamond. In other words, from a tribological point of view UNCD performs just about as well as single-crystal diamond, and much better than silicon. If it can be made economically enough, and if it can be easily carved to form shaped components, this nanocrystalline form of diamond looks set to be the material of the future for tiny machines.

References

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