NATURE | SCIENTIFIC AMERICAN

Nanomaterial rivals hardness of diamond

A nanostructured and transparent form of boron nitride is harder than some forms of diamond.

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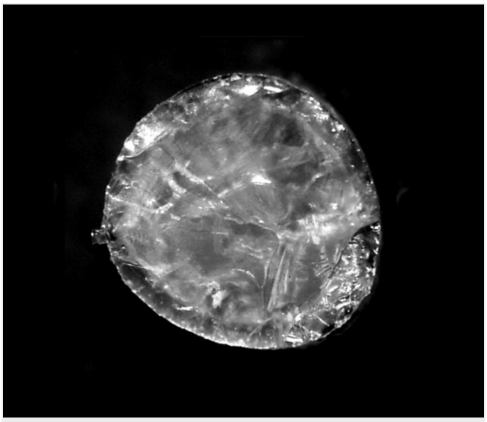
17 January 2013

An article by Scientific American.



Dongli Yu/Yanshan University

Cubic boron nitride is one of the hardest materials known.

It's only a matter of time before a movie villain pulling off the crime of the century needs a cutting tool that is harder than anything else on Earth. Perhaps it's a burglary that involves cutting into a case made of diamond—which, as we have all learned from countless heist films, is itself hard enough to cut glass. Or maybe it's a devious scheme predicated on boring a hole into the depths of the planet with the world's hardest drill bit.

Whatever the plot details, scientifically minded scriptwriters would do well to turn their attention to cubic boron nitride, a material that in many ways resembles diamond. Boron nitride can be compressed into a superhard, transparent form—but unlike diamond and many other materials known for their extreme hardness, it is based not on carbon but on a latticework of boron and nitrogen atoms. Computer simulations have indicated that a rare crystalline form of boron nitride would resist indentation even better than diamond if it could be synthesized into large samples, and laboratory experiments have shown that more attainable forms of the stuff already approach the hardness of diamond.

Now a new set of experiments on a nanostructured form of boron nitride have yielded even greater measures of hardness than before. The new material exceeds that of some forms of diamond, according to the authors of a study reporting the findings in the January 17 issue of Nature. (Scientific American is part of Nature Publishing Group.) But quantifying the properties of superhard materials is a tricky business, and at least one leading researcher remains unconvinced that the study's authors have found anything new.

For years scientists have worked to shrink the individual grains within material structures, because the boundaries between grains can arrest internal motion and help resist deformation, like a series of tiny walls within a larger structure. The essence of the researchers' strategy for this latest effort, says lead study author Yongjun Tian of Yanshan University in China, was to reduce the scale of the microstructures within the material by generating features called "ultrafine nanotwins." A nanotwin is a crystalline segment that mirrors the orientation of atoms on the other side of an interface (a so-called twin boundary) within a material. As such, a polycrystal made of nanotwin domains is a bit like a slab of plywood where the wood grain reverses direction in each successive layer. In the boron nitride polycrystals synthesized by Tian and his colleagues, the nanotwin segments are just 3.8 nanometers wide on average. (A nanometer is one billionth of a meter.)

The researchers fabricated their samples from round nanoparticles of boron nitride in which the atoms of nitrogen and boron form an onionlike structure of nested layers. Pressed into macroscopic pellets and subjected to intense pressure and heat, the nanoparticles coalesced into tiny grains comprising numerous twin domains. The onionlike precursors, Tian explains, contain numerous defects where crystals can nucleate under high temperature and pressure but resist rapid crystal growth, yielding numerous discrete pockets of crystalline order within a larger, somewhat disordered polycrystalline structure.

At temperatures above 1,800 degrees Celsius and pressures of up to 15 gigapascals (roughly 150,000 kilograms-force per square centimeter), the boron nitride pellets formed round lumps about two millimeters across that were "colorless and totally transparent, so that they look like glass and diamond in appearance," Tian says. He and his colleagues determined that those samples had a measured hardness of up to 108 gigapascals—slightly harder than synthetic diamond but less hard than polycrystalline diamonds made of nanoscale grains.

But Natalia Dubrovinskaia, a crystallographer at the University of Bayreuth in Germany, notes that measuring the properties of superhard materials is problematic because it requires the use of an even harder material for reference. The Vickers hardness test, for instance, which the new study's authors used to measure the hardness of nano-twinned boron nitride, gauges how a material responds to pressure from the point of a pyramid-shaped piece of diamond called an indenter. As increasing force (as measured in newtons) is applied to the diamond pyramid, the material's ability to resist indentation levels off at its so-called asymptotic value (as measured in gigapascals). But the test is predicated on the idea that the diamond will do the indenting, and not the other way around. "If the indenter is softer than the material under probe, it is absolutely meaningless," Dubrovinskaia says.

The pursuit of superhard materials is not just a quest to set records. Boron nitride already finds use in cutters that can slice through extremely tough materials, and Dubrovinskaia cites drilling for resource extraction as another application. "We still need really superhard materials to explore deeper and deeper into Earth's interior," she says. In some respects, such as stability at high temperatures, boron nitride is superior to diamond.

As such, she notes, "it probably would be a breakthrough in the field" if researchers proved that polycrystalline boron nitride boasted hardness values over 100 gigapascals. "The paper doesn't provide any proof that the material is so hard," she cautions. The data in the new study only show how the nano-twinned boron nitride responded to indentation loads with up to seven newtons of force. "But they report in the paper that they loaded at higher loads in this material and they obtained a lot of cracks around the imprint," Dubrovinskaia notes. If the hardness measures dropped off at higher loads, she says, the true value for the boron nitride samples might be closer to 80 or 85 gigapascals. That measure would jibe with numbers she and her colleagues reported in 2007 for another high-pressure, high-temperature synthesis of nanostructured boron nitride. In that work, published in Applied Physics Letters, Dubrovinskaia and her colleagues presented data from Vickers testing with loads of up to 10 newtons.

Nature | doi:10.1038/nature.2013.12241