Scientists Create First Non-Carbon Material with Near-Diamond Hardness

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Research scientists have created the first non-carbon-based material with a hardness approaching that of diamond. Their work could have a significant impact on technologies and industries that rely on diamond as a cutting and drilling tool and abrasive.

The material is a boron nitride “nanocomposite.” This means that, rather than consisting of one large continuous crystal, it is made of crystalline boron-nitride grains that are each a few to several nanometers in size. Although research groups have previously reported boron carbonitride materials, claimed to be the second and third hardest materials after diamond, the particular versions, or “phases,” of those materials were unstable at high temperatures. In industry, this is a major drawback.

“The real breakthrough would be a bulk material that is hard, tough, *and* thermally stable, and thus ideal for cutting and drilling. We are the first to synthesize a bulk noncarbon material that fits this description,” said Natalia Dubrovinskaia, a researcher with the University of Heidelberg and the University of Bayreuth, both in Germany, to *PhysOrg.com*. Dubrovinskaia is the lead author of the paper describing the new material, which appears in the March 8 edition of *Applied Physics Letters*.

For many materials composed of crystalline grains, also referred to as polycrystalline materials, there is a grain size for which the material's hardness is optimized. This size is often in the nanometer range.

Along this line of thought, Dubrovinskaia and her colleagues synthesized and conducted several experiments on a series of polycrystalline and nanocrystalline phases of boron nitride. This characterization included measuring the samples' “Vickers hardness,” a test that assigns a hardness value to a material based on how readily it is indented by diamond. That value can be expressed in terms of the pressure applied by the diamond – using the pressure unit “pascal” – before it makes an indentation. For very hard materials that usually means billions of pascals (gigapascals, GPa). Single-crystal diamond, the hardest type, has a hardness of about 100 GPa.

The boron nitride nanocomposite synthesized by Dubrovinskaia and her group displayed a maximum hardness of 85 GPa at a grain size of about 14 nanometers, and is thermally stable up to 1600 degrees Kelvin (about 2400 degrees Fahrenheit). The material's hardness arises from two factors: the nanoscale-grain-size effect and each grain's two-phase composition. That is, each grain has a nanoscale crystalline structure *and* a sub-nanoscale structure. This complex composition significantly increases the bulk material's mechanical strength.

Prior to this research, the next hardest known material after single-crystal diamond was cubic boron nitride, a single-crystal phase of the material, which has a Vickers hardness of 50 GPa. That leaves a rather large 50 GPa gap.

“This gap can be filled by boron nitride nanocomposites, particularly by tuning their grain size and the compositional structure of the grains,” says Dubrovinskaia. “These materials may come to play an important role in industry.”

Citation: Natalia Dubrovinskaia, Vladimir L. Solozhenko, Nobuyoshi Miyajima, Vladimir Dmitriev, Oleksandr O. Kurakevych, and Leonid Dubrovinsky, “Superhard nanocomposite of dense polymorphs of boron

nitride: Noncarbon material has reach diamond hardness." *Appl. Phys. Lett.* **90**, 101912 (2007)