

Hardness and Elastic Properties of Superhard and Ultrahard Materials (DMR-1508577)

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NON-TECHNICAL DESCRIPTION: Society has long been fascinated by diamond as the hardest known substance. Can a material harder than diamond be created? Answering this question is not so straightforward because the very definition of hardness employs diamond as the reference, and when materials under test approach or potentially exceed the hardness of the diamond-based indenter, results are difficult to interpret. A new class of superhard materials is being developed based upon nano-polycrystalline or nano-twinned structures of diamond and related compounds containing carbon, boron and nitrogen together in the same structural configuration as diamond. These materials are synthesized at high pressures and high temperatures in large-volume presses. Physical properties of novel superhard materials are investigated using a newly-developed ultrasonic system that measures the speed of sound waves at GHz frequencies. The results precisely determine physical properties such as the shear modulus, which are fundamentally correlated to hardness. New materials rivaling or potentially exceeding natural diamond in hardness and thermal stability can make possible the fabrication of ultrahard machine parts that do not burn or wear down under stress.

TECHNICAL DETAILS: High-pressure high-temperature synthesis of single-crystals intermediate in composition between cubic-boron nitride (c-BN) and diamond demonstrate a solid-solution wherein hardness and thermal stability are optimized for a certain range of compositions. Identifying the ideal composition requires improved measurement and theoretical understanding of hardness-elasticity relationships. Whereas conventional hardness measurements on materials harder than c-BN are difficult to interpret because of plastic deformation of the indenter, a novel GHz-ultrasonic interferometer is developed to measure the elastic constants of materials in the superhard and ultrahard classes with very-high precision. Under that direction, diamond-like compounds containing carbon, nitrogen, and boron and having nano-polycrystalline or nano-twinned structure are targeted to produce materials without cleavage, with high thermal stability, and with hardness rivaling and potentially exceeding natural diamond. The research improves the fundamental understanding of the relationship between hardness and elasticity thus advancing the ability to design and predict the properties of ultrahard materials. The proposal is timed to take advantage of newly developed synthesis techniques and characterization methods. Graduate student training focuses on skills for job placement in related fields in industry, academia, and at the National laboratories. Outreach activities feature participation in Project Excite, a program providing after-school enrichment experiences in science and mathematics to minority students from local elementary schools.