U.S. Department of Energy
Energy Efficiency and Renewable Energy
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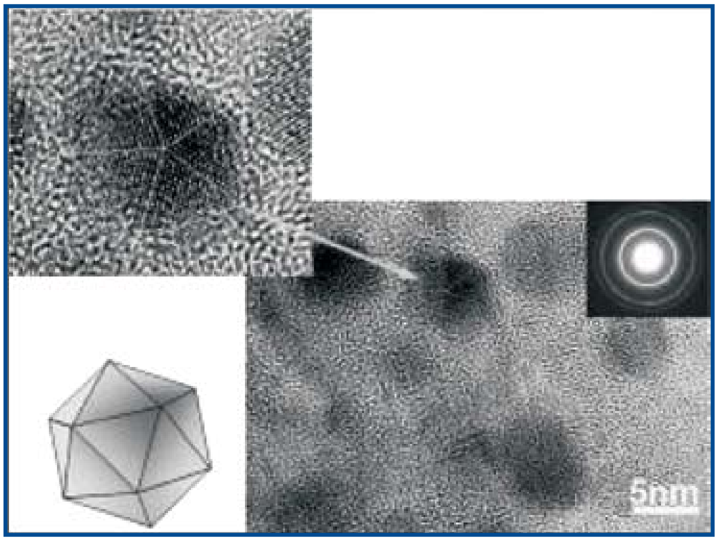
Novel Superhard Materials and Nanostructured Diamond Composites

Improved Wear and Abrasion Performance for Many Industrial Applications

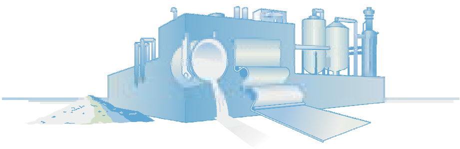
Diamond is the hardest material known to man, and discovering harder materials is a much sought-after goal. Superhard materials made of light elements such as boron, carbon, and nitrogen. The intrinsically strong and directional covalent bonds of these light elements lead to tight, three-dimensional networks with extreme resistance to external shear.

Novel superhard materials have become possible following the successful development of processes for producing synthetic diamonds and cubic boron nitride (CBN), at high pressures and high temperatures. The design and development of novel superhard materials are aided by first-principles theory and computational simulation. Carbon nitrides (C_3N_4) and boron carbon nitrides (BC_2N, BC_4N) are potential candidates because of the similarity of their proposed high-pressure phases to diamond crystal structure.

Designing new nanostructured superhard materials with novel properties and developing practical methods for their industrial production are the main motivations for this project. Nanocrystalline phases and amorphous phases enhance mechanical performance substantially. Such strengthening is caused by the decreasing number of vacancies and dislocations in crystals with diminishing sizes. In a nanostructured superhard composite, the size of a microcrack is smaller than the size of the nanocrystals, thus greatly reducing the propagation of microcracks. Grain size and phase fraction can be controlled by changing the pressure-temperature-time conditions. Special preparation of starting materials and careful selection of catalysts/solvents will also add to the successful synthesis of nanostructured superhard composites in the B-C-N system.



High-resolution TEM image shows sucessful synthesis of superhard nanostructured BC2N with a grain size of 3 – 8 nanometers.



Benefits for Our Industry and Our Nation

- Superior mechanical performance in hardness, toughness, strength, and wear resistance.
- High thermal conductivity, optical transparency, large band gap, and chemical inertness.

Applications in Our Nation's Industry

Nanostructured superhard materials may be applied in field work under extreme conditions for various industries, including the mining and petrochemical industries.

In hard rock mining and petrochemical exploration, drills are often required to bore through extremely hard geological formations. Rock drill bits are equipped with teeth designed to scrape and gouge. As the formation becomes denser and harder, the teeth may wear down quickly, resulting in reduced drilling efficiency and thus increasing downtime and replacement cost.

Their superb thermal, optical, electronic, and chemical properties also make superhard materials highly desirable in modern high-tech industrial applications as protective coatings, substrates for semiconductors, windows for optical devices, and anvils for high-pressure devices.

Project Description

The goal of this R&D project is to synthesize novel superhard B-C-N materials and to manufacture nanostructured diamond/SiC composites. The project covers a broad research scope of high-pressure, high-temperature synthesis, property characterization, and industrial implementation.

Barriers

- Lack of systematic works on mechanical, physical, and crystal structural properties in relation to superhard materials and synthesis conditions
- Contamination of superhard materials during ball-milling production process
- Lack of identified catalysts suitable for low pressure-temperature synthesis conditions
- Insufficient understanding of carbon diffusion and diamond graphitization processes at the nanoscale

Pathways

The objectives of this project will be achieved through (1) Synthesis of novel superhard materials in the B-C-N system and the production of nanostructured diamond/SiC composites at high pressure-temperature conditions in large-volume; (2) Characterization of mechanical properties of abrasive hardness, fracture toughness, and yield strength of the synthesized products; and (3) Implementation of bulk new superhard materials as machine cutting tools and inserts in rock drill-bits and the exploration of high-tech industrial usage of the products.

Progress and Milestones

- Characterize and develop synthesis technique for novel superhard B-C-N and B_6O materials (complete)
- Optimize synthesis of nanostructured diamond-SiC composites and B_6O nanocomposites (complete)
- Design, produce, and test nanostructured diamond-SiC inserts for drill bits (complete)
- Develop methods for bulk production of B_6O nanocomposites, and optimize brazing method for application to industrial tools (complete)

Commercialization

Polycrystalline diamond (PCD) was introduced to the market in the early 1970s. This made available to industry relatively large pieces of diamond at an economical cost. Annual sales of polycrystalline diamond products used in U.S. are about $500 million, and polycrystalline diamond compact (PDC) drills bits account for roughly one-third of the total worldwide rock bit market, with annual sales exceeding $200 million. Application of the nanostructured diamond-SiC composites is best suited to single cone boring bits. Project partners U.S. Synthetic and Sii MegaDiamond are leading U.S. superhard compacts manufacturers. They are working on synthesis of these nanostructured diamond-SiC composites and testing them with industry standards.

Project Partners

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Sii MegaDiamond, Inc.
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A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

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