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Synthesis of superhard materials

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Abstract

The paper reviews the advancements of synthesis of diamond and cubic boron nitride, methods of studying their structure and properties, processes of production of large and colored diamonds, composite materials and superconducting ceramics.

Keywords: Diamond; Cubic boron nitride; Diamond films; Ceramics; High pressures

In the XXIst century the superhard materials (synthetic and natural diamonds (SD and ND) and cubic boron nitride (cBN)) will be the most important and preferable tool materials because they allow highly efficient, precision and smooth machining of the hardest structural metals and alloys. The superhard materials are used as extremely sharp cutting tools, pastes and suspensions, as well as grinding tools to produce optical and electronic components. One cannot imagine efficient rock destruction tools for mining machines and headroaders, drilling equipment, and stone-working technologies without the use of superhard materials.

Applications of diamonds and cBN have been essentially expanded owing to the development of composite materials, synthesis of large and perfect-in-properties crystals, formation of polycrystals and ceramics, deposition of film coatings, synthesis of nano- and micron powders as well as elite powdered products.

Diamonds and diamond-like materials exhibit not only superhardness, but also high values of their other properties (heat conductivity, wear resistance, dielectric characteristics, capability of acquiring semiconducting properties, resistance to aggressive media without heating, optical characteristics, etc.).

V.N. Bakul Institute for Superhard Materials of the National Academy of Sciences of Ukraine, one of the largest Materials Science Centers in Europe is recognized to be the leader in the development and use of superhard materials.

The institute employs more than 200 highly qualified researchers and 300 engineers and technical workers. The institute occupies 18 ha of picturesque plot of land with buildings of the total area up to 100,000 m^2. Today this is a real technopark. The institute research and test laboratories as well as production enterprises of the ALCON science and technology diamond concern, which employs 800 people, offices of production and other services (power supply, polygraphy, etc.) as well as consulting and trade companies, which hold on lease some premises and territories of the institute, are located in the buildings. The institute and the ALCON diamond concern, whose products use the institute's developments, annually export superhard materials to more than 20 countries.

The institute was founded in 1961 and has worked in the following scientific directions:

- development of theoretical principles of synthesis of novel mono- and polycrystalline dispersed and film superhard materials over a wide range of pressures and temperatures;
- studies of high pressure–high temperature effect on phase transformations in substances and on the formation of specified characteristics of structural and functional materials;
- computer-aided modeling and working out of mathematical methods for prediction of physical and mechanical characteristics of superhard materials;
- studies of physical and chemical processes of fabrication of high-density technical ceramics and composite materials based on refractory compounds, superhard fillers and hard alloys;
- studies on physicochemical and mechanical interactions of tool with workpiece materials and on working out of fun-

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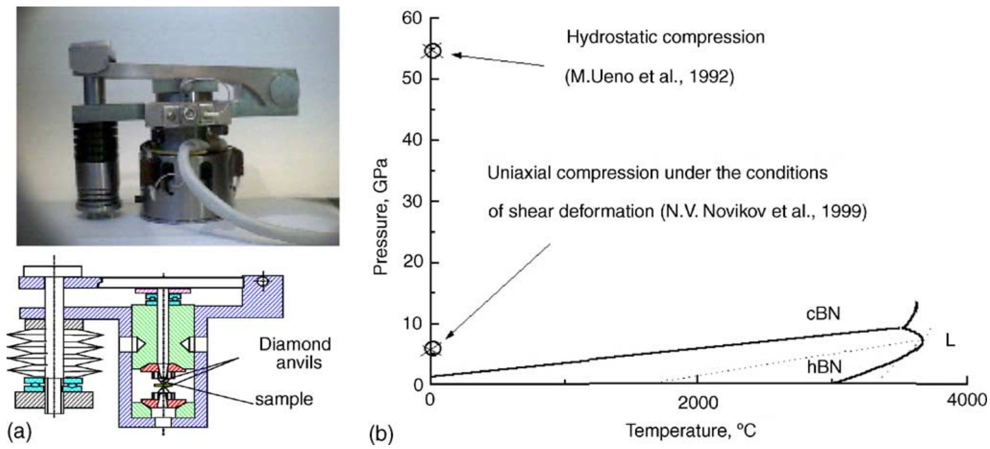

Fig. 1. General view and schematic representation of a high-pressure apparatus with diamond anvils and a device to rotate anvils at an angle from 0 to 360° (a), the rBN → cBN direct martensite phase transformation observed at 5.6 GPa at an axial load with shear strain (b).

damentals of the development of efficient superhard material tools and resource-saving technologies of machining metallic and nonmetallic materials;
- studies of physicochemical processes and mechanisms of rock destruction and the development of highly efficient drilling tools and technologies of their applications.

The institute uses high-pressure technique as the basic means of acting on a substance to synthesize novel materials and of studying phase transformations. Power presses up to 2500 and 14,000 t, solid high-pressure apparatuses with a working volume of tens and hundreds of cubic centimeters are used for laboratory experiments and production tests.

Unique research systems: a nanoindenter, a device for compression and twisting samples between diamond anvils, tunneling microscope with attachments for nanoindentation and registration of acoustic emission from microplastic deformations allow studies of phase transformations in a substance at a nanolevel (Fig. 1). Fundamental investigations are being conducted into the relation between the structure and properties of superhard materials (SHM) and their changes at various technological parameters and conditions of production.

Based on the analytical computer-aided modeling, calculations using the methods of mechanics and thermodynamics, as well as on X-ray diffraction analysis and the use of modern experimental technique, the objects of synthesis are fixed and technological procedure of the synthesis is ascertained. Combinations of substances, materials and techniques are being searched for, which allow efficient tools and functional materials, structural in particular, to be produced.

In the time that passed the institute has solved a number of large innovation tasks in the materials science, development of new technologies and equipment for SHM synthesis and machining of materials. We dwell on some of these results.

In the last 1960 and 1970s commercial technologies of diamond and cBN synthesis were developed. Since then tens grades of synthetic diamonds and cubic boron nitride that differ in physico-mechanical properties, a variety of composite tool and structural materials on the basis of SD and cBN have been produced. All these materials are widely and efficiently used in tools for machining various metallic and nonmetallic materials. SD and cBN powders produced in Ukraine following the institute-developed technologies are highly competitive at the world market and are exported to USA, Japan and Asian countries.

On the threshold of the new millenium in 2000 the institute researchers studied phase transformations in graphite-like boron nitride–carbon (BN–C) solid solutions at a pressure of above 18 GPa and a temperature of 2200 K using a diffraction of synchrotron radiation in diamond anvils with a laser heating and synthesized a novel high pressure phase, namely, cubic boron carbonitride (c-BC_2N). Hardness of the new material exceeds that of cubic boron nitride single crystals, which allows it to be next to diamond in hardness. Scientific journals have published communications about the achievement, it was patented and many world information agencies gave it considerable attention.

In 1992–1998 comprehensive studies on regularities of the directional crystallization of diamonds on seeds at high pressures and temperatures were conducted that made it possible to develop a method of synthesis of large diamond single crystals. A directional transfer of carbon from the source to a seed (p = 6.5 + 0.1 GPa, T = 1500 ± 2 °C) is realized in a toroid-type high-pressure apparatus under the conditions

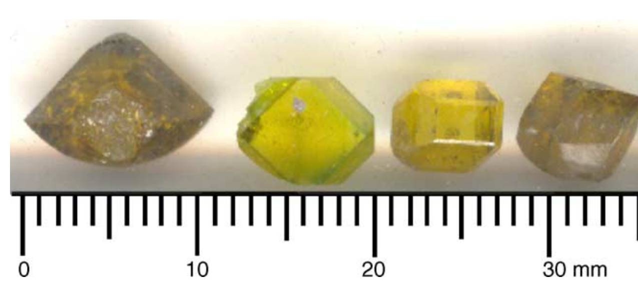

Fig. 2. Large diamond crystals grown by the temperature gradient method.