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Abstract

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ON THE MORPHOLOGY OF CRYSTALS OF CUBIC BORON NITRIDE

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In 1961, Wentorf ([1]) reported that the new mineral he had synthesized—cubic boron nitride, not inferior to diamond in hardness—usually crystallizes in the form of tetrahedra and octahedra. He, together with Bundy ([2]), also established by X-ray diffraction that cubic boron nitride has a sphalerite-type structure. These contradictory data on the crystallography of cubic boron nitride and their inconsistency with the data of X-ray determinations prompted us to subject the cubic boron nitride crystals synthesized by us to a morphological investigation.

Preliminary goniometric measurements, carried out at our request by V. V. Nardov, showed that on crystals of cubic boron nitride the faces of the tetrahedron {111} occur most often (in all, 4 crystals of size 0.4 mm were measured), the faces of the tetragon-tritetrahedron {332} occur more rarely, and one face of the rhombic dodecahedron {110} was also found. At the same time V. V. Nardov noted that the quality of the faces was poor: on the goniometer they did not give "signals," but diffuse light fields. However, this did not prevent V. V. Nardov from tentatively assigning the crystals of cubic boron nitride to the pentagon-tritetrahedral or hexatetrahedral type of symmetry.

In further work on the synthesis, we succeeded in creating conditions for growing more perfect crystals of cubic boron nitride, 0.3–0.6 mm in size, suitable for crystallographic investigations (Fig. 1).

Subsequent investigations and measurements carried out by us on numerous (more than 100) crystals confirmed V. V. Nardov' s assumptions that crystals of cubic boron nitride belong to the hexatetrahedral type of symmetry ($F\bar{4}3m$).

The principal crystallographic form of crystals of cubic boron nitride is a combination of positive {111} and negative $\{\overline{111}\}$ tetrahedra. The habit of cubic boron nitride crystals and their twin intergrowths is determined by the form and relative development of the faces of both tetrahedra.

Crystals of octahedral appearance predominate, with a characteristic "apex" in the form of a double-pitched roof formed as a result of the combination of two hexagonal faces and two triangular faces belonging respectively to the positive and negative tetrahedra.

Very characteristic are flattened triangular and pseudohexagonal crystals, which are simple and polysynthetic twins of the combination, inherent in cubic boron nitride, of two tetrahedra of different sign.

In polished sections, polysynthetic twins of cubic boron nitride have the appearance of plank-like aggregates, themselves intergrown with one another at various angles (Fig. 2); the thickness of the individuals composing the twins varies over wide limits—from fractions of a micron to

Fig. 1

Fig. 2

Fig. 1. Crystals of cubic boron nitride. 25×

Fig. 2. Polysynthetic twins of cubic boron nitride. Reflected light. 150×

Fig. 3

Fig. 4

Fig. 3. Features of the surfaces of crystal faces of cubic boron nitride:
a —two growth spirals; *b* —inclusion of a small crystal of cubic boron nitride, pits ("black") from the falling-out of inclusions of cubic boron nitride, impurity inclusions;
c —ribbed depressions. 150×

Fig. 4. Surface of a face (plane of intergrowth) of a twin of cubic boron nitride. 150×

several hundred microns. As a rule, polysynthetic twins of cubic boron nitride contain numerous inclusions of impurities captured by them from the melt during crystallization.

Polished sections were also used to study the microhardness of cubic boron nitride. The microhardness was determined with a PMT-3 microhardness tester with a Vickers pyramid, under a load on the indenter of $p = 100$ g. The microhardness of cubic boron nitride ranges within 7300–10 000 kg/mm^2; the most frequently repeated values are 8500–8600 kg/mm^2.

Single crystals and twins of cubic boron nitride are bounded by faces of triangular, hexagonal, and trapezoidal form, belonging to the positive and negative tetrahedra.

Investigation in reflected light with a metallographic microscope makes it possible to detect, on the surfaces of the faces of the tetrahedron (of various form), vicinal faces and vicinaloids, growth layers and spirals, steps consisting of several growth layers, inclusions of small crystals and twins of cubic boron nitride, inclusions of impurities, etc. The growth spirals observed on the surfaces of the faces have a hexagonal form and are oriented parallel to the edges of the tetrahedron. On the surface of a crystal there may be a single or double spiral, or there may be several spirals located in the middle of a face or at its boundary. Growth spirals originate from inclusions in the crystal (Fig. 3a).

Pits, randomly distributed over the surface of the faces, formed as a result of fallout during chemical treatment of small crystals and twins of cubic boron nitride (Fig. 3b). Some crystals of cubic boron nitride had on the surface of their faces sinuous, spiral, ribbed, and leaf-like depressions differing in relief depth (Fig. 3c). These features of the face surfaces are caused by "dissolution" as a result of a shift of the crystallization conditions into the region of stability of hexagonal boron nitride. The accompanying evaporation of cubic boron nitride and condensation of the hexagonal modification in the form of scaly formations on the surface of cubic boron nitride crystals leads to the appearance on the faces of the crystals of the latter of ribbed and leaf-like impressions. With a deeply advanced sublimation process, the vertices and edges of cubic boron nitride crystals acquire rounded outlines.

The surfaces of the faces of pseudohexagonal (or triangular) form, belonging to twin formations of cubic boron nitride, are always rich in defects (Fig. 4). These faces are, in essence, the planes of intergrowth of twins and appear in the external bounding form only as a result of the disintegration of the latter into their constituent individuals when, by chemical treatment, the inclusions of side reaction products arranged in layers in the twins of cubic boron nitride are removed. It should be noted here that twin intergrowths of cubic boron nitride form during its crystallization in the stability region, but at a low temperature, from a viscous mother melt.

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CITED LITERATURE

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[2] F. P. Bundy, R. H. Wentorf jr., *J. Chem. Phys.*, **38**, 5 (1963).

Note: Figure translations are in progress. See original paper for figures.