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The peculiarities of natural plastically deformed diamond crystals from "Internatsionalnaya" pipe (Yakutia)

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Abstract

An internal structure of a representative collection of plastically deformed diamond crystals from "Internatsionalnaya" kimberlite pipe among which are brown, gray-smoky, purplish-pink crystals has been studied by synchrotron radiation (Laue-SR method). The obtained data made it possible to classify the studied crystals by the degree of deformation and polygonization. The results obtained by Laue-SR method correlate well with IR spectroscopy data.

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1. Introduction

A representative collection of plastically deformed diamonds (40 samples) from 'Internatsionalnaya" kimberlite pipe among which are the crystals of brown (group I), gray smoky (group II), purplish pink with brown or gray hue (group III) and purplish-pink color (group IV) has been studied by Laue-SR method [1]. The size of the crystals is 1.5–2 mm.

Brown color of diamonds is associated with the defects formed on the broken bonds of dislocations, which appear during plastic deformation (PD) [2]. In this case, the absorption increases in UV range and the absorption edge shifts into the long-wave range up to 650 nm. A number of absorption bands (4065 and 4170 cm^{-1}), termed in literature as "amber centers" due to the color of diamond in which they have been first observed, appear in IR spectrum [3]. The defects, which are caused by the broken bonds on the dislocations, are observed by electron paramagnetic resonance (EPR) method as well. It is known that annealing of brown diamonds at high pressure and temperature (PT parameters) causes the decrease of dislocations density and change of diamond color [2]. However, there is currently no model of defects responsible for the brown color of plastically deformed diamond crystals and there is no way to explain the processes which cause the brown color loss due to annealing at high-PT parameters [2,3].

The study of asterism, total or residual deformation, polygonization and changes of spots on lauegrams caused by reorientation of crystalline lattice makes it possible to investigate the crystal internal structure changes under the action of high temperatures and pressures resulting in the crystal deformation [1].

The object of this work is to study the internal structure of natural diamond crystals of different color. It is of interest both to understand physics of processes during plastic deformation and further thermal annealing and diamond genesis.

2. Experimental

Laue-SR method with the use of power synchrotron radiation (INP, SB RAS, VEPP-3) has been used to study the internal structure of diamond crystals of different

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color. Relative to the traditional X-ray Laue method, Laue-SR method makes it possible first to elevate resolution by approximately to the order of magnitude and second to avoid orientation extinction inherent in monochromatic methods.

X-ray contrast appears in the course of exposure from imperfect diamond crystals in polychromatic (synchrotron) radiation due to the peculiarities of this radiation, i.e. small divergence of ray bundle ($\sim 10^{-4}$ rad) and wide range of wavelengths of the used X-rays ($\lambda = 0.3$–4 Å). The image contrast results from disorder of crystalline lattice fragments (orientation contrast). The increase of intensity of rays diffracted from the imperfect parts of the crystal, which causes the black-out film (kinematic contrast), is another effective process of contrast formation. In the first case, Laue-SR method provides a way of studying the internal structure of crystals, in the second—the distribution of dislocations.

"Amber centers", which usually appear in plastically deformed diamond crystals, are characterized from the study of absorption spectra in the IR range. IR spectra have been recorded on FTIR BRUKER VERTEX 70 spectrometer with the use of HYPERION 2000 microscope.

3. Results and discussion

The results of study are illustrated in Figs. 1–5 and Table 1. Fig. 1a demonstrates a lauegram of brown diamond. Its laue-spot (a topogram) is shown in Fig. 1b. Figs. 2–5 demonstrate typical topograms of corresponding diamond groups. The characteristics of the studied diamonds (by Laue-SR and IR spectroscopy results) are presented in Table 1.

Laue spots are very elongated at the lauegrams of brown and gray-smoky diamonds (groups I, II) suggesting very high plastic deformation of crystals (Figs. 1b, 2 and 3).

The lattice of plastically deformed crystal is profoundly distorted. In this case, the spots of lauegrams extend significantly in radial direction. The higher is the degree of crystal deformation, the longer are the spots and their forms are distorted greatly. This phenomenon is designated as asterism and depends on the deformation of reflecting plane nets [1]. In this case, the crystal topograms represent a complete loss of the form of crystal projection. The size of laue spot is several times greater than the real crystal size.

It is known that an intensive generation of grouped and rearranged dislocations occurs in different ways during PD [4]. This process results in changes of the main images of the diffraction topograms. In this case, laue spots are liable to take different forms such as veiled (Fig. 1b), needle like (Fig. 2) or branched (Fig. 3). These diamonds (I, II groups) have not been subjected to natural annealing: laue spots have a strong asterism, what is meant by significant deformation of crystals. Furthermore, they do not show polygonization, and the intensity of absorption bands by "amber centers", which characterize plastically deformed diamonds, is significantly higher than for brownish-pink or grayish-pink diamonds (group III) undergone polygonization (Table 1).

Purplish-pink diamonds of III and IV groups (Figs. 4 and 5) have laue spots with quasi-linear striation as a result of polygonization. The size of laue spots corresponds to the crystal size and asterism disappears, i.e. dislocation rearrangement takes place during polygonization.

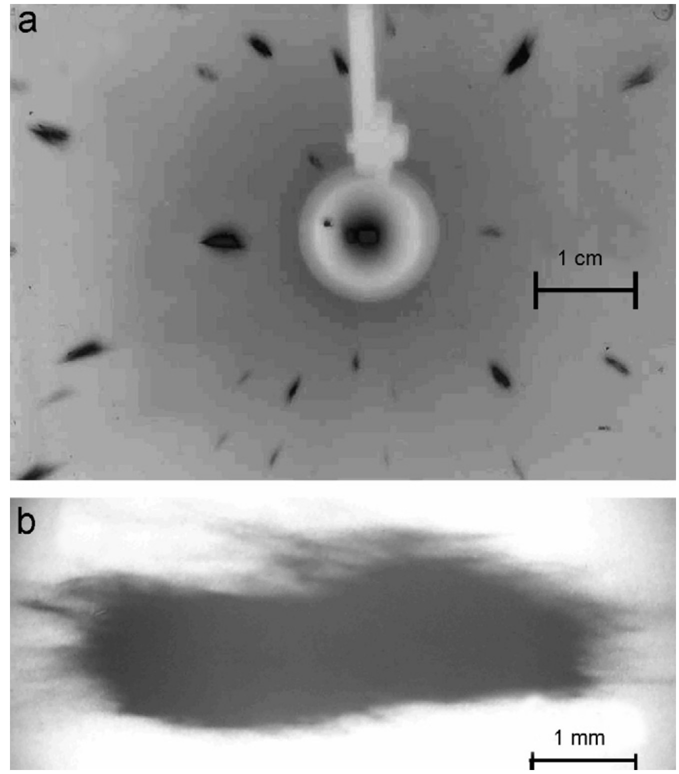

Fig. 1. (a) The lauegram of the strong deformation brown diamond (sample No. 10). Laue spots elongated in radial direction—strong asterism and (b) veiled-like structure of the laue spot.

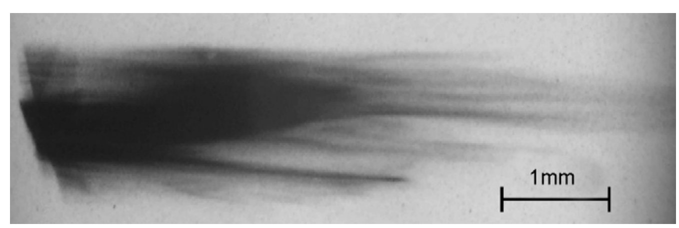

Fig. 2. The structure of the needle-like laue spot of the brown diamond (sample no. 12).

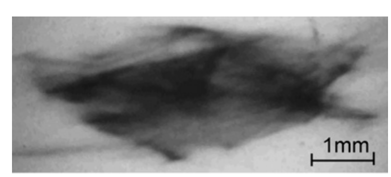

Fig. 3. The branch-like laue spot of the very imperfect gray diamond (sample no. 9).

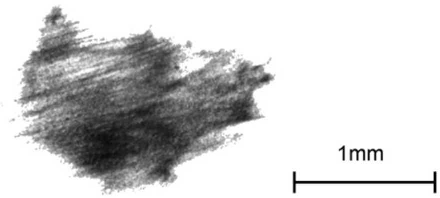

Fig. 4. Distinct manifestation of polygonization in the form of quasi-parallel bands of the laue spot of the purplish-pink diamond (sample no. 36).

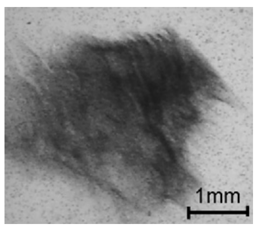

Fig. 5. Quasi-linear striation of the laue spot of the pink diamond (sample no. 26).

Table 1
Characteristics of examined diamonds from "Internatsionalnaya" pipe (Yakutia)

No. gr.	No. sam.	Laue-SR		IR spectroscopy		Typical topograms
		PD	p-g	α_{4065} (cm^{-1})	α_{4170} (cm^{-1})	
I	12	+	–	0.94	0.83	See Fig. 2.
	25	+	–	0.70	0.50	
	10	+	–	0.58	0.57	
	21	+	–	0.50	0.50	
II	9	+	–	0.65	sh.	See Fig. 3.
	22	+	–	0.68	sh.	
	33	+	–	0.62	sh.	
	34	+	–	0.43	sh.	
III	14	+	+	0.33	0.32	See Fig. 4.
	19	+	+	0.34	0.17	
	18	+	+	0.20	0.10	
	17	+	+	0.13	0.07	
	36	+	+	0.10	sh.	
IV	2	+	+	—	—	See Fig. 5.
	4	+	+	—	—	
	5	+	+	—	—	
	8	+	+	—	—	
	26	+	+	—	—	

Note.: gr.—group; sam.—sample; PD—plastic deformation; p-g—polygonization; α_ν—absorption coefficient on the frequency—$\nu\,cm^{-1}$; sh.—shoulder; (+)—well-expressed phenomenon; (–)—absented phenomenon.

Dislocation motion causes to rearrangement from horizontal rows of dislocations in sliding planes to vertical walls, which are boundaries of polygonization blocks–grains. Crystalline structure of the grains is more perfect. For crystals, which have been underwent polygonization, laue spots have quasi-paralleles striation that reflects dislocation distribution in crystals.

It will be noted that dislocation walls may be formed both by polygonization as a result of annealing after the drastic deformation and during plastic deformation, when sliding along just one system of parallel planes take place [4]. Planes (1 1 1) are sliding planes of diamond. The formation of boundary walls of dislocations during PD is a dynamic polygonization as opposed to static polygonization by annealing. As for now, the static annealing polygonization can in no way be distinguished from the dynamic one by the results of Laue-SR topograms. To do this requires complex study by spectroscopic methods and EPR along with Laue-SR method.

The results obtained by Laue-SR method correlate well with IR spectroscopy study (Table 1). The intensity of "amber centers" of group III diamonds falls off and "amber centers" of group IV purplish-pink diamonds are not observed in IR range.

4. Conclusions

The obtained results allow PD degree of colored diamonds from "Internatsionalnaya" pipe (Yakutia) to be determined.

Brown and gray-smoky diamonds are plastically deformed to a large degree. PD is characterized by high density of dislocations resulting in asterism of diffraction laue spots.

Polygonization is specific to purplish-pink diamonds. The fragments with more perfect crystalline lattice, which are separated by dislocation boundary walls, characterize the internal structure of these diamonds. Dislocation boundary walls formed by polygonization give birth to quasi-linear striation of diffraction laue spots.

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