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Internal Friction in β-Rhombohedral Boron, Doped with Cobalt

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ABSTRACT. In β-rhombohedral boron, doped with cobalt, relaxation and nonrelaxation maxima of the internal friction caused by motion of twinnings boundaries and stacking faults in planes of {100} system were revealed. Regularities of changing activation characteristics of relaxation internal friction of β-rhombohedral boron under the influence of doping with cobalt were established. *© 2011 Bull. Georg. Natl. Acad. Sci.*

Key words: *internal friction, boron, activation energy, shear modulus.*

For β-rhombohedral modification of boron characteristic defects are twinnings and stacking faults situated in planes of {100} system. These defects, interacting with vacancies and impurities, considerably influence the structural-sensitive physical properties, in particular, elastic and inelastic characteristics of bulk samples of boron. Attention to determining the role in the formation of mechanical, thermal, semiconducting and other properties of planar dislocation defects is paid in [1-3]. Microscopic mechanisms of the change of the structural-sensitive physical-mechanical properties of boron are at the stage of research.

The microstructure and temperature dependence of internal friction and relative shear modulus of β-rhombohedral boron, doped with cobalt at the concentration of 2 at% were studied. The bulk specimens are obtained by melting in the resistance furnace in crucible of boron nitride in the environment of pure argon.

Absolute values of shear modulus were estimated by a method of comparison of torsion oscillations of the standard and investigated specimens of identical sizes. Internal friction and relative shear modulus were determined by the method of registration of logarithmic decrement of damping and frequency of torsional oscillations. Activation characteristics of relaxation internal friction were measured by the standard method [1].

Study of the structure on optical microscope Neophot-32 has shown a polycrystalline structure of samples. The sizes of grains change within 0.05-0.5mm. Doped samples, in comparison with undoped, are characterized by more granular structure 0.05-1.00mm.

In the internal structure of relatively larger grains growth twinnings and packets of thin twinnings of deformation origin are revealed. The analysis has shown that in the doped samples inhomogeneous distribution of packets of thin twinnings dominates.

Absolute values of the shear modulus are calculated from a known equation $G = G_0 \cdot \frac{f^2}{f_0^2}$, where G_0,f_0 are shear modulus and frequency of oscillations of the standard sample (iodine vanadium), and G and f – similar characteristics of the investigated samples at room temperature.

In temperature spectrum of internal friction of undoped β-boron, at the frequency of 1.2Hz torsional vibration intensive maxima at 250 and 340°C, and also a wide maximum with small intensity in the area of 450°C are observed (Fig. 1.1). The internal friction spectrum is thermally stable. It does not change in a heating-cooling cycle in the range of 20-800°C, as well as under the impact of

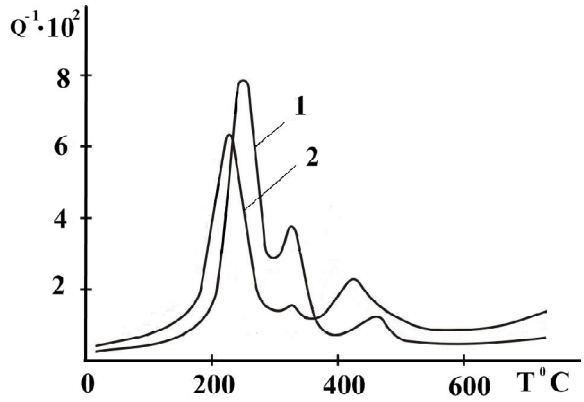

Fig.1. Temperature spectrum of internal friction of β–rhombohedral boron
1. β-B, f_0=1.0 Hz; 2. β-B:Co, f_0=1.2 Hz.

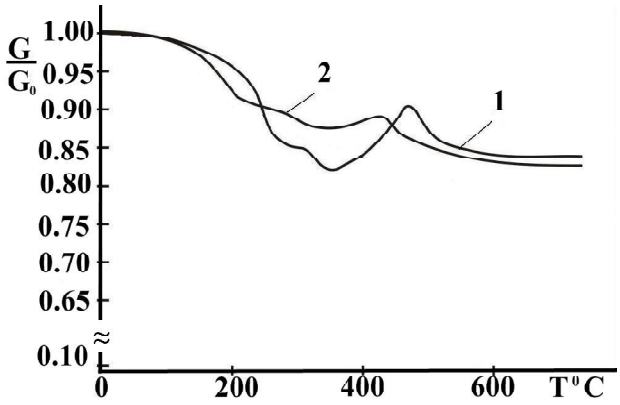

Fig. 2. Temperature dependence of relative shear modulus of specimens of β-rhombohedral boron
1. β-B, f_0=1.0 Hz; 2. β-B:Co, f_0=1.2 Hz.

annealing in vacuum at 700-800°C for 5hrs. All three maxima show amplitude dependence of intensity.

In the area of high amplitude of oscillatory deformation ($\sim 1\cdot 10^{-3}$) the maxima are shifted by 10-20°C towards low temperatures, their intensity simultaneously increases approximately by 20 %. Temperatures of maxima at 250 and 450°C change with changing of frequency of torsional vibrations. According to the theory [3], these maxima are of relaxation origin. The third maximum strongly decreases with the increase of oscillations frequency to 5 Hz. The temperature of the maximum of internal friction does not change. Similar maxima have nonrelaxation origin.

Doping with cobalt causes shifting of maxima towards low temperatures, decreasing of the intensity of relaxation and nonrelaxation maxima (Fig. 1.2). In the sample doped with cobalt, amplitude of oscillatory deformation increases 3-5 times. The critical value of amplitudes for nonrelaxation internal friction does not change in the range of 300°C.

Activation characteristics of relaxation internal friction of various samples of β-boron are presented in Table.

The defects of the structure, responsible for the origin of relaxation and nonrelaxation internal friction in undoped and cobalt-doped samples, of β-boron, cause also the presence of rather complicated temperature dependence of relative shear modulus (Fig.2). In undoped β-boron, shear modulus decreases by 10 % in the area of the most intensive relaxation maximum of internal friction (Fig. 2.1). Its further decrease occurs at other maxima (320, 450°C), however, in the range of temperatures (320-450)°C anomalous increase of shear modulus is observed.

In boron, doped with cobalt, defect of shear modulus is observed at temperature of internal friction maxima, and also its anomalous increase in the range of temperatures between the second and third maxima. However, these changes of shear modulus are manifested in smaller degree (Fig. 2.2).

The experiments showed that at certain critical values of the amplitude of oscillations, the intensity of relaxation maxima of internal friction becomes dependent on amplitude oscillatory deformation. In doped samples of $\hat{a}$-rhombohedral boron the critical values of amplitude deformation decrease. According to the theory [4], similar relaxation processes are connected with, the breakaway of elements of dislocations (kinks, segments) from pinning points. In boron dislocation structure is generated in the form of twinnings and stacking faults in planes of {100} system [5].

In cores of partial and twinning dislocations unsaturated bonds which interact with free current carri-

Table

Characteristics of internal friction maxima of β-boron

Specimens	Temperature of maxima, °C	Activation energy, eV	Frequency factor, sec^{-1}	Relative intensity, $x10^2$	Internal friction nature
β-B	250	1.35	$2\cdot 10^{12}$	8.0	Relaxation
	320	–	–	3.5	Nonrelaxation
	450	2.20	$3\cdot 10^{14}$	1.0	Relaxation
β-B:Co	230	1.20	$1\cdot 10^{12}$	6.0	Relaxation
	300	–	–	1.5	Nonrelaxation
	430	2.00	$1\cdot 10^{14}$	2.5	Relaxation

ers were generated. In the doped samples of boron, the concentration of free current carriers increases, accordingly, broken bonds in the cores of various dislocations are substantially compensated. As a result, pinning forces of twinning and partial dislocations can decrease and, hence, their motion in the field of external mechanical stress will occur at decreased values of activation energy.

It is assumed that in β-rhombohedral boron doped with Co, the intensive relaxation processes are caused by motion of twinnings boundary 200-250 °C and reversible process of reduction-expansion of stacking faults in planes of {100} system.

Earlier it was shown [6] that in undoped β-rhombohedral boron in the range of temperatures of 300-350^{0}C under the influence of heating-cooling cycle, the process of redistribution of residual impurity atoms of order-disorder type proceeds. This process causes nonrelaxation maximum of internal friction near 300^{0}C. The results obtained are interesting in developing semiconductor *n*- and *p*-type crystals of β-rhombohedral boron with given electrophysical properties.

მასალათმცოდნეობა

შინაგანი ხახუნი კობალტით ლეგირებულ β-რომბოედრულ ბორში

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კობალტით ლეგირებულ β-რომბოედრულ ბორში გამოვლენილია რელაქსაციური და არარელაქსაციური შინაგანი ხახუნის მაქსიმუმები, რომლებიც განპირობებულია {100} სისტემის სიბრტყეებში ორეულების საზღვრების და წყობის დეფექტების მოძრაობით. შესწავლილია ლეგირების გავლენა β-რომბოედრული ბორის რელაქსაციური შინაგანი ხახუნის აქტივაციური მახასიათებლების ცვლილების კანონზომიერებაზე.

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