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Physics

Amplitude Dependent Inelasticity in Undoped Polycrystalline Germanium

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ABSTRACT. Amplitude dependence of internal friction and shear modulus of undoped polycrystalline germanium have been investigated. Maxima of internal friction and shear modulus defects are observed at low and high amplitudes of oscillation deformation at different fixed temperatures. It is supposed that they are caused by breakaway of geometric kinks and segments from the pinning points on the 60^0-edge dislocations in germanium. *© 2010 Bull. Georg. Natl. Acad. Sci.*

Key words: germanium, internal friction, shear modulus, polysynthetic twins.

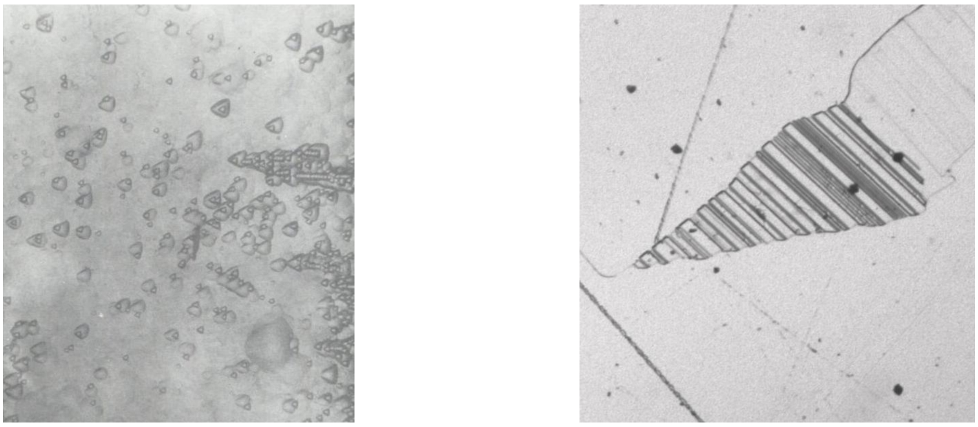
Structural-sensitive electrical, optical and mechanical properties of semiconductive crystals substantially depend on the types and concentration of point defects, dislocations and character of their interaction. In conditions of exploitation, deformation and irradiation can be caused by an increase of the temperature of semiconductive material. The state and character of interaction of structural defects can change accordingly, leading to destabilization of the working characteristics of devices made with these materials. In this aspect, it is necessary to study comprehensively the nature of the origin, thermal stability, electrical activity and mechanisms of interaction of various structural defects in each specific semiconductive crystal. From this point of view, undoped polycrystalline germanium of high purity has not been much explored.

In the present work, the microstructure and anelastic characteristics of n-type semiconductive germanium, obtained by the floating zone melting method are studied. In experimental samples the content of oxygen is $1\cdot10^{16}cm^{-3}$, concentration of carriers – electrons $\approx1\cdot10^{14}cm^{-3}$. According to data, mobility of electrons is extremely high, varying in the range of 40000–50000 $cm^2\cdot V^{-1}\cdot sec^{-1}$.

Study of the microstructure was carried out on optical microscope Neophot – 32. After standard mechanical and chemical treatment of the surface, monocrystalline areas of different sizes were observed in the structure of the sample. In areas of large sizes (1.0–5.0 mm) disorderly located etching pits and alternation of light – dark strips were observed, caused by the presence of twins (Fig.1). Average density of dislocation ~ $510^{-3}cm^{-2}$.

Amplitude dependence of the mechanical characteristics of undoped germanium was studied by the method of registration of the frequency of oscillations and logarithmic decrement of damping of free torsion oscillations at different temperatures. Measurements were carried out in vacuum ~10^{-3}Pa in the range of 0.5 – 5.0 Hz. frequency and $1\cdot10^{-5}$ - $1\cdot10^{-3}$ oscillation deformation.

Amplitude dependences of internal friction $Q^{-1}(\varepsilon)$ and shear modulus $\frac{G}{G_0}(\varepsilon)$ of the Ge samples were measured during consecutive increase of amplitude.



a b

Fig. 1. Microstructure of polycrystalline germanium: a) Dislocation in monocrystalline region; b) Polysynthetic twins packet

Results of measurements of $Q^{-1}(\varepsilon)$ at different temperatures are presented in Fig. 2. Internal friction is not changed at room temperature in a wide range of amplitude of oscillation deformation. Internal friction reaches maximum at $\sim 2\cdot 10^{-4}$ amplitude, after this its decrease is observed. Curves $Q^{-1}(\varepsilon)$, plotted according to the results of measurements, in conditions of increase and decrease of oscillation amplitude are mutually combined. It shows that at room temperatures, in the process of oscillation deformation up to $1\cdot 10^{-3}$ changes do not take place in the germanium dislocation structure.

The increase of temperature of measurement up to 420K leads to an appreciable increase of internal friction background in the amplitude independent interval and decrease of amplitude deformation of maximum of $Q^{-1}(\varepsilon)$ to $5\cdot 10^{-5}$ and in this case, according to the results of measurements of $Q^{-1}(\varepsilon)$ during the decrease of oscillation amplitude, changes are not observed in the dislocation structure.

During further increase of temperature up to 550K critical strain amplitude decreases to $5\cdot 10^{-5}$, without showing any signs of microplastic deformation in the structure of Ge samples. The characteristics of $Q^{-1}(\varepsilon)$ of undoped germanium are presented in Table 1.

Above 620K temperature maxima disappear and slight linear increase of internal friction is observed in the range of amplitude $1\cdot 10^{-5} - 5\cdot 10^{-4}$. The critical value of amplitude decreases with increase of temperature of measurements. The character of variation of $Q^{-1}(\varepsilon)$ is kept up to 1020K temperature. In the range of 300–1020K curves $Q^{-1}(\varepsilon)$ plotted according to the results of measurements, in the process of increase and decrease of oscillation amplitude are practically identical. Consequently, it can be supposed that in the undoped high-purity germanium, in conditions of oscillation deformation $\sim 1\cdot 10^{-5} - 1\cdot 10^{-3}$, up to 1020K significant changes are not observed in dislocation structure.

Peculiarities of variations in the structure of defects in Ge crystal during dynamical deformation are shown in amplitude dependences of relative value of shear

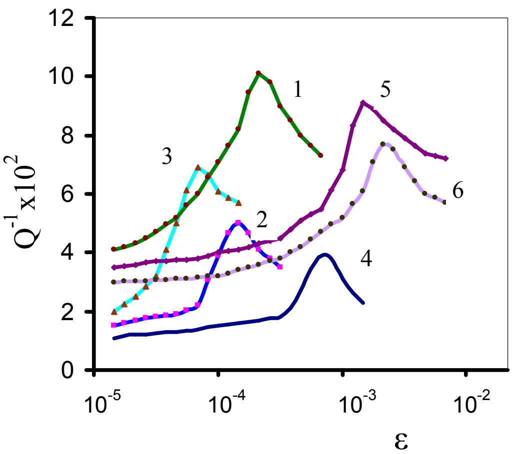


Fig. 2. Amplitude dependence internal friction in the polycrystalline germanium at various temperatures: 1-300K; 2- 420K; 3-550K; 4-620K; 5-870K; 6-1020K

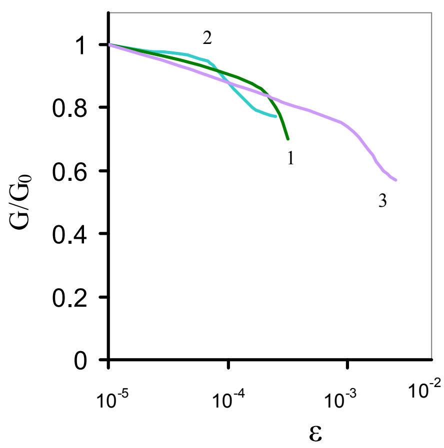


Fig. 3. Amplitude dependence of relative shear modulus of polycrystalline germanium at various temperatures 1-300K; 2- 550K; 3-1020K.

Table 1

Physical-mechanical characteristics of undoped polycrystalline germanium

Temperature of measurement, K	Amplitude of relative deformation	Elastic limit, kG/mm^2
300	$4 \cdot 10^{-4}$	0.8
420	$2 \cdot 10^{-4}$	0.3
550	$7 \cdot 10^{-5}$	0.2
620	$8 \cdot 10^{-4}$	2.0
870	$2 \cdot 10^{-3}$	1.2
1020	$4 \cdot 10^{-3}$	0.32

modulus (Fig.3). Irrespective of the temperature of measurement at high intensity internal friction, shear modulus defects are observed. It follows the decrease of shear modulus, independent of the amplitude of oscillation deformation. Curves $G/G_0(\varepsilon)$, corresponding to the increase and decrease of amplitude of oscillation deformation, are identical up to the temperature of measurement 550K, showing an absence of any significant changes of forces of interaction between atoms and of different dislocations mobility in the crystalline lattice of germanium in the range of 300 – 450K.

The values of elastic limit at different temperatures are determined by the known formula: $s=G \cdot \varepsilon$ where G is shear modulus, ε strain amplitude. The shear modulus of polycrystalline germanium at room temperature is 4030 kG/mm^2 [1]. Within the limits of dislocations string model [2] by the results of estimation of critical amplitudes of oscillation deformation at fixed temperatures energy of breakaway elements of dislocations from pinning points are determined. For the temperature ranges 300-550K and 550-1020K the values of 0.80 and 1.35-1.40 eV are obtained, respectively. Corresponding to data [3] 0.80eV is close to the energy of breakaway of geometrical kinks on the edge-60^0 dislocation in germanium. The value of the energy of 1.35-1.40eV is close to the energy of breakaway of segments on the edge 60^0 -dislocation. Thus, observed amplitude dependence internal friction in germanium is caused in the range of 300-550K by reversible process breakaway – pinning of the geometrical kinks, and in the range of 550-1020K by reversible process of breakaway – pinning of the dislocation segments on the edge -60^0 dislocations.

The presence of sets of thin twins in microstructure, does not influence amplitude dependence of the internal friction and shear modulus. In conditions of low concentration of point defects (impurities, vacancies), interaction energy of twinning dislocations and pinning centers is low. It is supposed that observing of breaking effects of twinning dislocations in germanium is possible in the area of low strain amplitudes and temperature of measurements.

Profound analysis of the mechanisms of interaction of different dislocations with point defects in the crystalline lattice of germanium necessitates further investigation of the amplitude dependence of inelastic characteristics under the influence of deformation, thermal treatment and doping by isovalent and electrical active impurities.

ფიზიკა

არალეგირებული პოლიკრისტალური გერმანიუმის ამპლიტუდაზე დამოკიდებული არადრეკადობა

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შესწავლილია არალეგირებული პოლიკრისტალური გერმანიუმის შინაგანი ხახუნის და ძვრის მოდულის ამპლიტუდური დამოკიდებულება სხვადასხვა ფიქსირებულ ტემპერატურებზე. რხევითი დეფორმაციის დაბალ და მაღალ ამპლიტუდებზე გამოვლენილია შინაგანი ხახუნის მაქსიმუმი და ძვრის მოდულის დეფექტი. გამოთქმულია მოსაზრება, რომ ისინი განპირობებულია კიდურ 60-გრადუსიან დისლოკაციებზე არსებული გეომეტრიული ღუნვებისა და სეგმენტების მოწყვეტით დამაგრების წერტილებიდან.

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