RADIATION DESTRUCTION AND INTERNAL FRICTION IN SILICON SINGLE CRYSTALS

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The study of radiation defects in silicon single crystals of different orientation is carried out by means of methods of internal friction (IF) and electrical resistance. At the mechanical damping measurement a strategy of low-frequency flexible oscillations (f ~ 5 Hz) was used during the process of irradiation with α-particles. The descending curves and anomalous inverted hysteresis effect of IF versus amplitude of cyclic deformation were observed. The results were explained by the processes of ionization by induced infra-red radiation and charged dislocation-point defects association interaction.

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1. INTRODUCTION

Semiconductors with the diamond-type lattice, e.g. silicon, have found a broad using as elements of electronic of solids. The most important is a problem of providing a radiation stability of products from these materials under conditions of nuclear irradiation in atomic industry [1]. Its solution lies on the way of studying of deep physical and chemical processes, which run in the irradiated material. The problem of influence of irradiation with α-particles and of areas of crystalline structure distortion being forming on the processes of mechanical relaxations in silicon practically is not studied yet [2]. The difficulty consists in small runs of heavy charged particles with the energy about 5…10 MeV in the target, that creates inconveniences for the measurement of an amplitude dependency on damping of mechanical oscillations in fine brittle samples.

It is reasonable to use a high ionizing radiation for elucidation of the nature of radiation defects interaction due to the high sensitivity of mechanical damping, to the charged condition of the structure defects in semiconductors [3]. Of importance is also an aspect of studying a nature of the amplitude dependency of damping in semiconductors with covalent type of bonds in the lattice, where dislocations are considered practically still, laying in deep Peierls potential wells [4].

The aim of the present work was studying during α-irradiation the regularities of dislocation damping and influence upon it of charge conditions of areas of damaging in silicon single crystals with different orientations at stresses σ, which are below of macroscopic elastic limit.

2. EXPERIMENTAL PROCEDURE

As an object of recent studies the silicon of p- and n-types of the high purity with low density of dislocations N_d =10 см$^{-2}$ and electrical resistance 0.4 Ohm·cm with admixtures of boron and N_d =100 cm^{-2} with the electrical resistance 0.013 Ohm·cm with admixtures of stibium is chosen. The amount of oxygen was of about 10^{16} cm^{-3}. The ingots of silicon was made by the Chokhralski method and oriented with an accuracy 30′ by means of X-Ray diffractometer DRON-2,0. The plates were cut from discs $(410\pm20)\cdot10^{-6}$ m thickness and diameter of about $60\cdot10^{-3}$ m in perpendicular to the crystallographic direction <111>-type on the "ALMAZ-6" equipment. The samples for investigations were cut from discs in a strip shape, i.e. $6\cdot10^{-2}$ m length and $5\cdot10^{-3}$ m width, in <011> and <211> directions.

For the damping registration the method of flexural decay oscillations was used [2]. Logarithmic decrement $\delta = N^{-1} \times \ln 2$ serves as a measure of energy loss at double decreasing of amplitude after N oscillations. Determination of amplitude of sample oscillations by the thickness h and length l was realized by means of the laser beam on the method of mirror and scale, which was situated at the distance L ≈ 8 m, by means of the amplitude "a" oscillation of "bunny" on the scale in accordance with the expression: $\varepsilon_0 = a\cdot h \times (2Ll)^{-1}$. Specific electrical resistance ρ was defined by the four-probe method. The error of electrical resistance ρ measurements was ±0,3%.

For bombarding of the Si specimen with α-particles at a distance of about 0.003 m a container was placed in parallel to the sample surface. Plutonium sources with activity $3.7\cdot10^7$ Bk and $5.53\cdot10^7$ Bk, respectively were used. The α-particles of this sources have had the energy of about 5.1…5.5 MeV.

3. INTERNAL FRICTION RESULTS

Preliminary investigations of n-Si$_{<011>}$ before irradiation show that there is no amplitude dependence of the internal friction up to amplitude $\varepsilon_0^* \approx 3\cdot10^{-5}$, in accordance with data of other authors [5]. At $\varepsilon_0 > \varepsilon_0^*$ amplitude dependences of internal friction (ADIF) is observed. As amplitude is decreasing, one can observe ordinary hysteresis. In this case the curve of flyback goes higher than the curve of straight run. In n-Si$_{<211>}$ the ADIF maximum is observed at about $\varepsilon_0 \approx 1.2\cdot10^{-4}$, which was originated from dislocation kink movement at surfaces layers of crystal [6].

Further experimental investigations of a damping through the process of irradiation with α-particles at a flux density of about $5\cdot10^6$ particles·cm^{-2}·s^{-1} and $7,6\cdot10^6$ particles·cm^{-2}·s^{-1} have shown that the sample is hardened, i.e. a level and slope of the ADIF curve is decreased, the hysteresis is lowered. Moreover, under irradiation conditions as in n-Si$_{<211>}$, as well as, in n-Si$_{<011>}$

the anomalous inverse hysteresis is observed, i.e. the curve of flyback goes lower than the curve of direct run (fig.1). A small area of damping decreases at small amplitudes that was observed earlier in crystals of such orientation [2], and disappears after high-amplitude training of sample or decreases. However, through irradiation with α-particles it is stable (!) (fig.1). In annealed n-$Si_{<011>}$ crystals there is no descenting area [2]. However, it appears in the process of irradiation like in n-$Si_{<211>}$.

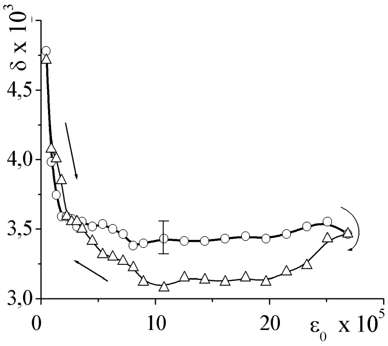

Fig.1. Amplitude dependence of damping during α-irradiation of n-$Si_{<211>}$, showing prominent anomalous hysteresis

4. ELECTRICAL RESISTANCE RESULTS

The investigations of changing a specific electrical resistance at different moments, i.e. in the moments of beginning, completion of irradiation and in its process show the following. During a time of measurements an increasing of electrical resistance by several percent occurs. At the moments of beginning and completion of irradiation in the semiconductor with the electronic conductivity there is almost no significant changing. On the other hand, in p-Si (fig. 2) with holing conductivity more expressed changes of ρ are observed at that very moment of beginning and especially completion of irradiation (see fig.2, dashed lines). When the irradiation is stopped, a long term relaxation to equilibrium level of conductivity originates.

5. DISCUSSION

The α-radiation with the energy at about 5 MeV possess not high penetrating ability, i.e. it is tens micrometers and can not just influence upon processes in the volume of sample of investigated thickness. However, at irradiation of silicon by α-particles, when the α-particles with the energy of 5,1 MeV is introduced, a part of the energy, approximately 3.1 MeV, emanate as electromagnetic radiation in the far infra-red area of the spectrum [7], where silicon is transparent. At energy of quantum of light greater than 1.09 eV (that is the width of forbidden area in silicon under 300 K) in the sample throughout the volume the generation of carriers of charge due to the internal photoeffect will be observed as a results of silicon electrons transition from the valent area to the area of conductivity. Alongside with this there will be a greater probability to observe a generation of carriers as a result of ionizing of the admixture atoms which are based in nodes.

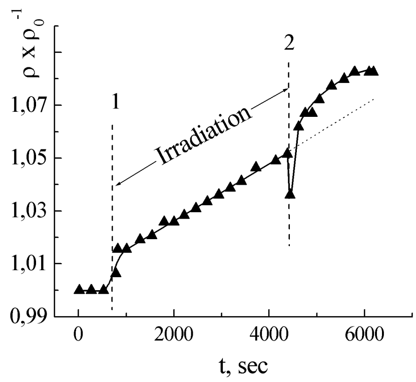

Fig.2. Specific electrical resistance ρ dependence versus time of irradiations and relaxation effects in p-$Si_{<011>}$; flux of irradiation is $5\cdot10^6$ particles$\cdot cm^{-2}\cdot s^{-1}$ ($\rho_0 = \rho$ at t = 0); 1 – start of irradiation; 2 - completion of irradiation

In accordance with [8], a dislocation in n-type crystal, behave oneself as a linear negative charge. Due to electrostatic interaction of ionizing atoms and dislocations they can form stable complexes. Formation of such complexes is evidencet by a growing of electrical resistance in the process of irradiation (fig. 2). As far as, after removing the source of α-radiation, a jump of electrical resistance is observed with the area of quick and slow relaxation. As a result, one can assume an existence of areas, the charge condition of which is changed with a significant time of lagging. In p-Si at the beginning of irradiation a jump of electrical resistance is observed during 40 s. It is connected with changing the main current carriers, i.e. holes before irradiation are changed on electrons at irradiation. However, when irradiation is stopped, more complex relaxation is observed.

First, after stopping bombardment with α-particles as a result of disappearance of non-equilibrium electrons, which was induced by internal infra-red radiation, and transition to holing electrical conductivity, the electrical resistance sharply falls, for tens of seconds (fig.2, dashed line 2). Hereinafter a process of relaxation of surplus main carriers begins, which continue for hundreds of seconds. It is connected with penetration of the holes inside the area of damage. The recombination of holes with internal electrons of clusters gradually raises the electrical resistance (see growing area in fig.2 with the saturation above dashed line 2). It links with reducing of concentration of non-equilibrium main carriers. Thereby, the irradiation forms associations from electrically active admixtures and spatial division of main and not main carriers.

From received results is seen that in silicon two components exist at least, which influence of hardening. The first component is connected with forming of the structural damaging and elastic interaction of kinks on dislocations with them. The second component is connected with ionizing of atoms and spatial dividing of charge in the process of irradiation and as a result of forming the temporary (!) associations of defects. Blocking the kinks on dislocations in this case occur due to Kulon′s electrostatic interaction with such associations or separate charge point defects, e.g. vacances.

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On the temporality of such associations a partial weakening of material evidences when a source of radiation is removed. Such a softening occurs during a time which close to time of electrical resistance relaxation.

In favour of stated presentations evidences the results of [9] on alkali-galloid crystals, where anomalous hysteresis was observed. It was explained by processes of "sweeping" by dislocations of cation vacancies. Charged point defects, which are produced in our case by irradiation, are responsible not only for inverse hysteresis under great amplitudes, as well as decreasing characteristic ADIF under small amplitudes. About it the measurements of electrical resistance evidence, which is increased at an initial moment of cyclic deformation and irradiation, both (fig. 2).

REFERENCES

1. V.L. Vinetsky, H.A. Holodar. *Radiation physics of semiconductors*. Kiev: “Naukova dumka”. 1979, p.336.
2. N.Ya. Rokhmanov, A.K. Gnap. Systems of information processing, Military University, Kharkov, 2003, v.1 p.110.
3. I.I. Soloshenko, A.A. Kryskov. *Mechanisms of internal friction in semiconducting and metallic materials*. Moskow: “Nauka”, 1972, p.31.
4. S.A. Ammer, B.M. Darinsky, A.I Drozhzhyn, A.G. Moskalenko. *Mechanisms of internal friction in solids.* Moskow: “Nauka”, 1976, p.54.
5. R.I. Garber, I.I. Soloshenko, I.A. Charkina // *Fizika tverdogo tela.* 1973, v.15, No.10, p.3088.
6. E.B. Malec, I.I. Soloshenko, A.V. Kamyshan. *Internal friction in semiconductors, dielectrics and ferromagnetics.* Moscow: Nauka: 1978, p.114.
7. V.I. Bendikov, R.I. Garber, A.K. Gnap at al. // *Radiation defects in semiconductors.* BGU, Minsk, 1972, p.203.
8. P.I. Baranski, V.P. Klotskov, I.V. Potykevich. *Semiconductor electronics*. Kiev: “Naukova dumka”, 1975, p.704.
9. K.V. Sapozhnikov, S.B. Kustov //*Fizika tverdogo tela.* 1995, v.37, No.9, p.2819.

РАДИАЦИОННОЕ РАЗРУШЕНИЕ И ВНУТРЕННЕЕ ТРЕНИЕ В МОНОКРИСТАЛЛАХ КРЕМНИЯ

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Методом внутреннего трения и электрического сопротивления изучено образование радиационных дефектов в монокристаллах кремния различной ориентации. При механическом исследовании применяли метод низкочастотного (f~5 Гц) упругого воздействия на образцы, облучаемые α-частицами. Были обнаружены убывающие кривые и аномальный инвертированный эффект гистерезиса обратной амплитуды циклической деформации. Результаты можно объяснить процессами взаимодействия инфракрасных лучей с заряженными дислокационно-точечными ассоциатами.

РАДІАЦІЙНЕ РУЙНУВАННЯ І ВНУТРІШНЄ ТЕРТЯ В МОНОКРИСТАЛАХ КРЕМНІЮ

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Методом внутрішнього тертя та електричного опору вивчене утворення радіаційних дефектів в монокристалах кремнію різної орієнтації. При механічному дослідженні застосовували метод низькочастотного (f~5 Гц) пружного впливу на зразки, що опромінювалися α-частками. Були виявлені спадаючі криві й аномальний інвертований ефект гістерезису зворотної амплітуди циклічної деформації. Результати можна пояснити процесами взаємодії інфрачервоних променів із зарядженими дислокаційно-точковими асоціатами.