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Physical Chemistry

Influence of Radiation Defects on Internal Friction Spectra of SiGe Crystals

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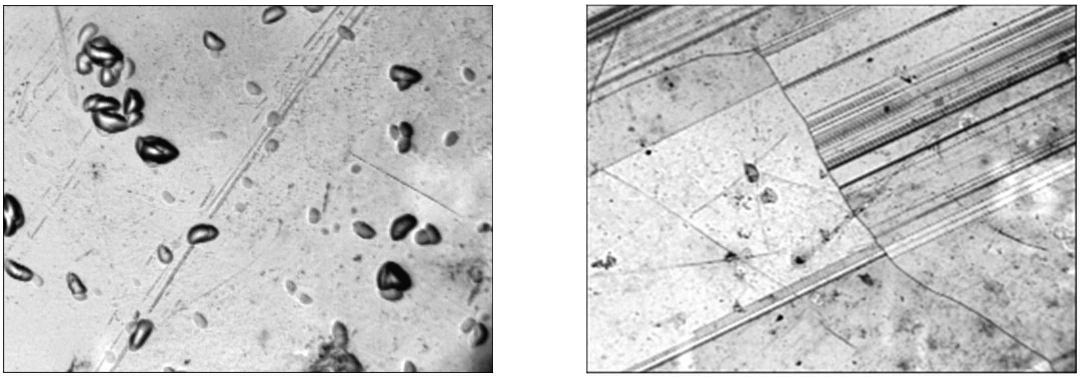
ABSTRACT. Influence of irradiation by 12 Mev energy electrons on structural-sensitive physical-mechanical properties of monocrystalline silicon and coarse-grained $Si_{0.98}Ge_{0.02}$ alloy is studied. The tendency to decrease of current carriers holes mobility is revealed in samples irradiated by ~ 10^{13} cm^{-2} fluence electrons. Relaxation maxima in temperature areas of 100 and 300^0C are revealed in internal friction temperature spectra of both crystals. Frequency factor of defects participating in relaxation is 10^{12}-$10^{13}s^{-1}$, and the values of activation energy are 1.0 and 1.4 eV respectively for the relaxation processes revealed at 100 and 300^0C temperatures. Possible mechanisms of pointed relaxation processes are proposed: reverse motion of vacancy pairs in temperature area of 100^0C and reverse motion of vacancy-oxygen atom pairs in area of 300^0C in external periodic stress field. The increase of the values of critical strain amplitude are revealed on the curves of strain amplitude dependent internal friction and dynamic shear modulus. The obtained results reveal hardening of Si and $Si_{0,98}Ge_{0,02}$ alloy irradiated by high energy electrons under the impact of radiation defects. *© 2018 Bull. Georg. Natl. Acad. Sci.*

Key words: internal friction, radiation defects, SiGe crystals

Semiconducting SiGe alloys are characterized by wide application prospects in microelectronic and optoelectronic devices. Regulation of structure and impurities state gives possibility to create controllable materials and devices on their base. Effective implementation of research works in this direction is possible using radiation technologies. In particular, formation of structural defects subsystem, change of its composition and concentration, and, therefore, the targeted control of physical characteristics is possible in semiconducting materials by radiation impacts.

At present, significant results were obtained in radiation defects studies of the bulk SiGe crystals and epitaxial structures using electrophysical and optical methods [1,2]. Influence of thermal and irradiation on the defects subsystem formation, motion activation and physical characteristics in SiGe alloys structure is insufficiently studied by acoustic spectroscopy and identation methods [3-5].

The present paper deals with the investigations of inelastic properteis of p-type monocrystalline Si and $Si_{0.98}Ge_{0.02}$ alloys grown by Czochralski



a b

Fig.1. Microstructure of SiGe crystals, x200.

a. Monocrystalline Si after electrons irradiation; b. Coarse-grained $Si_{0.98}Ge_{0.02}$ alloy after electrons irradiation.

method. Irradiation by high energy electrons was conducted by Varian Clinac 2100iX device (electrons energy- 12MeV, fluence~$8 \cdot 10^{12}$cm^{-2}). Microstructure was investigated by the optical microscope NMM-80RF/TRF. Chemical etching was performed in $1HNO_3+2H_2SO_4+3HF$ solution for revealing defects on mechanical polished surfaces. Investigations of temperature dependent internal friction and dynamic shear modulus were carried out in vacuum 10^{-4} Torr on the laboratory device by registration of logarithmic decrement of torsion oscillation damping in the ranges of 0.5-5.0Hz frequency and 1.10^{-5}–5.10^{-3} strain amplitude. Electrophysical characteristics were determined on the Ecopia HMS-3000 device by Hall Effect measurements in the constant magnetic field of 0.5 Tesla induction.

Chaotic distribution of etching figures of different sizes is revealed in the microstructure of initial Si. Some of them have distorted forms. Concentration of etching figures on (111) planes in Si structure changes in a range of $1 \cdot 10^3$-$5 \cdot 10^4$ cm^{-2}.

The microstructure of $Si_{0.98}Ge_{0.02}$ alloys is coarse-grained. The size of the grains is 1-3 mm. Separating boundaries of large blocks , as well as planar defects in their internal structure are free from the point defects and dispersive inclusions. Concentration of small size etching pits has been noticeably increased (~10^4cm^{-2}) in the microstructure of monocrystalline Si alloys after electrons irradiation [Fig.1,a]. Numerous small black etching figures are formed on the separating boundary of planar defects and blocks in $Si_{0.98}Ge_{0.02}$ alloy structure (Fig.1,b). There are also visible light spots of small size, that confirms the existence of dislocations free from impurities. It is possible to conclude, that density of free dislocations as well as blocked by dispersive inclusions has been increased in the microstructure of Si and $Si_{0.98}Ge_{0.02}$ alloys irradiated by high energy electrons.

Table 1

Electrophysical characteristics of Si and $Si_{0.98}Ge_{0.02}$ alloys irradiated by electrons

Materials	Dislocation density, cm^{-2}	Holes concentration, cm^{-3}	Holes mobility, cm^2.V.s^{-1}	Resistance, ohm.cm
p-Si, [111], initial state	~3.10^3	$2.4.10^{15}$	275	9.8
p-Si, [111], after electrons irradiation	1.10^4	6.10^{15}	205	0.6
p-$Si_{0.98}Ge_{0.02}$, initial state	5.10^3	7.10^{15}	195	0.46
p-$Si_{0.98}Ge_{0.02}$ after electrons irradiation	$3 \cdot 10^4$	$2 \cdot 10^{16}$	130	0.5

Electrophysical characteristics of mono-crystalline Si and coarse-grained $Si_{0.98}Ge_{0.02}$ alloys in initial state and after electrons irradiation were determined at the room temperature. The obtained results are presented in Table 1.

Defects in initial Si stipulate low values of holes mobility, that is further reduced after electrons irradiation. This is due to increasing holes scattering on dislocations existing in initial structure and defects formed by electrons irradiation. After electrons irradiation tendency to decrease holes mobility was revealed also in p-$Si_{0.98}Ge_{0.02}$ alloys.

It is established by the analysis of the obtained experimental results that irradiation by high energy electrons with $8{\cdot}10^{12}cm^{-2}$ fluence stipulates significant changes in dislocation structure of silicon, in particular, density of dislocations pinned by dispersive phases and impurities increases. The tendency to increase dislocation density is more clearly revealed in the micristaructure of $Si_{0,98}Ge_{0,02}$ alloys. Changes implemented in the structural defects subsystem by electrons irradiation stipulate increase of the holes concentration and decrease of their mobility.

Internal friction (Q^{-1}) and shear modulus (f^2) spectra of monocryatlline Si and $Si_{0.98}Ge_{0.02}$ alloys before and after high energy electrons irradiation were studied in temperature range of 20-400^{0}C.

Low frequency $Q^{-1}(T)$ spectra of monocrystalline Si and $Si_{0.98}Ge_{0.02}$ samples are presented on Fig.1. $Q^{-1}(T)$ spectrum of monocrystalline Si contains low intensity background, that is characterized by weak linear increase up to 300^{0}C temperature. Its further change at high temperatures is exponential. Intensity of $Q^{-1}(T)$ spectrum in $1{\cdot}10^{-5}$-$1{\cdot}10^{-4}$ range of strain amplitude is practically unchanged.

$Q^{-1}(T)$ spectrum of Coarse-grained $Si_{0.98}Ge_{0.02}$ alloy in 20-250^{0}C temperature range changes similarly to the spectrum of Si. At the same temperatures background intensity of $Q^{-1}(T)$ spectrum is significantly high (Fig.2). Also $Q^{-1}(T)$ background of coarse-grained $Si_{0.98}Ge_{0.02}$ alloy does not change in a wide range of strain amplitude up to 300^{0}C temperature.

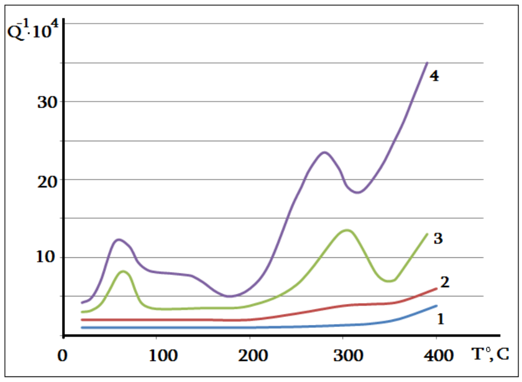


Fig. 2. Internal friction versus Temperature in Si and $Si_{0.98}Ge_{0.02}$ crystals.
1.Initial state, Si, [111], fo=1.3 Hz, 2.Initial state, $Si_{0.98}Ge_{0.02}$, fo=1.5 Hz,
3. Si, [111], irradiated by electrons, fo=1.2 Hz, 4. $Si_{0.98}Ge_{0.02}$, irradiated by electrons, fo=1.4 Hz.

Two maxima were revealaed in $Q^{-1}(T)$ spectra at 100 and 300^{0}C tempertures in monocrystalline Si after irradiation by 12 MeV energy electrons (Fig.2). They are characterized by large width that indicates the existence of relaxation time spectrum of defects participating in energy scattering process.

$Q^{-1}(T)$ spectra of initial monocrystalline p-Si and coarse grained p-$Si_{0,98}Ge_{0,02}$ alloys are characterized by low intensity background weakly dependent on temperature. After electrons irradiation its value is higher by 2-3 times and reveals noticeable exponential growth in a temperature range of 300-400^{0}C. In initial state Si and $Si_{0,98}Ge_{0,02}$ alloys squared frequency factor practically does not change up to 400^{0}C. In $Q^{-1}(T)$ spectrum of investigated crystals irradiated by high-energy electrons sharp exponential raise of background intensity and two wide maxima are revealed.

In $Q^{-1}(T)$ spectrum of $Si_{0.98}Ge_{0.02}$ alloys in a range of 100-130^{0}C plateau appears. Temperature of both maxima changes by changing oscillations frequency in 0.5-5.0Hz range, that shows their relaxation nature. Activation characteristics of

Table 2

Activation characteristics of relaxation processes in SiGe crystals

Materials	Temperature of maxima, ^{0}C	Activation energy, eV	Frequency factor, s^{-1}
p-Si, [111]	100	1.0	$1\cdot10^{13}$
	310	1.4	$3\cdot10^{13}$
p-$Si_{0.98}Ge_{0.02}$	90-130	0.8-0.9	$8\cdot10^{12}$
	280	1.30	$2\cdot10^{13}$

oscillation energy scattering processes were determined based on relaxation maxima temperature dependence on oscillation frequency [5]. Obtained results are presented in Table 2.

High values of frequency factors of relaxation maxima (10^{13}-$10^{14}s^{-1}$) indicates, that they are connected with the motion of strong localized relaxation centers, in particular, with migration of vacancies, oxygen and carbon atoms or their complexes in external mechanical stress field. In temperature areas of 100 and 300^{0}C relaxation maxima do not exist in $Q^{-1}(T)$ spectra of initial Si and $Si_{0.98}Ge_{0.02}$ crystals. They appear only after irradiation by high energy electrons.

It is supposed that relaxation maxima revealed in $Q^{-1}(T)$ spectra of Si and $Si_{0.98}Ge_{0.02}$ crystals are stipulated by motion of radiation defects. Considering the literature data [3] it is assumed, that relaxation process in temperature area of 100^{0}C is caused by reverse motion of the divacancy, formed by electrons irradiation, and relaxation observed at 300 ^{0}C temperature is connected to migration of vacancy-oxygen atom pairs in external mechanical stress field. Intensity of the both relaxation processes significantly decreases at 320-350^{0}C temperatures during 0.5hrs. Further annealing at 450^{0}C temperature for 1 hr. completely suppresses both relaxation processes. This circumstance clearly confirms their connection with radiation defects generated by high energy electrons irradiatin in crystalline lattice of Si and $Si_{0,98}Ge_{0,02}$ alloys.

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ფიზიკური ქიმია

რადიაციული დეფექტების გავლენა SiGe კრისტალების შინაგანი ხახუნის სპექტრებზე

ი. ყურაშვილი*, გ. დარსაველიძე*, გ. ბოკუჩავა*, გ. ჩუბინიძე*, ი. ტაბატაძე*, გ. არჩუაძე*

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შესწავლილია 12 მევ ენერგიის ელექტრონებით დასხივების გავლენა (111) კრისტალოგრაფიული ორიენტაციის სილიციუმისა და მსხვილმარცვლოვანი $Si_{0,98}Ge_{0,02}$ შენადნობის სტრუქტურულად მგრძნობიარე ფიზიკურ-მექანიკურ თვისებებზე. ~ 10^{13} სმ$^{-2}$ ფლუენსის ელექტრონებით დასხივებულ ნიმუშებში გამოვლენილია დენის მატარებელი ხვრელების ძვრადობის შემცირების ტენდენცია. ორივე კრისტალის შინაგანი ხახუნის ტემპერატურულ სპექტრში გამოვლენილია რელაქსაციური მაქსიმუმები 100 და 300^0C ტემპერატურათა არეებში. რელაქსაციაში მონაწილე დეფექტების გადაადგილების სიხშირის ფაქტორი 10^{12}-10^{13}წმ$^{-1}$ შეადგენს, ხოლო აქტივაციის ენერგიის სიდიდეებია 1,0 და 1,4 ევ, შესაბამისად 100 და 300^0C ტემპერატურებზე. შემოთავაზებულია აღნიშნული რელაქსაციური პროცესების შესაძლებელი მექანიზმები: ვაკანსიების წყვილების შექცევადი მოძრაობა 100^0C ტემპერატურის არეში და ვაკანსია-ჟანგბადის ატომის წყვილების შექცევადი მოძრაობა 300^0C ტემპერატურის რაიონში გარეშე მექანიკური ძაბვის ველში.

შინაგანი ხახუნისა და ძვრის დინამიკური მოდულის დეფორმაციის ამპლიტუდაზე დამოკიდებულების გრაფიკებზე გამოვლენილია კრიტიკული დეფორმაციის სიდიდეების ამაღლება. მიღებული შედეგები ავლენენ მაღალი ენერგიის ელექტრონებით დასხივებული Si-ისა და $Si_{0,98}Ge_{0,02}$ შენადნობის განმტკიცებას რადიაციული დეფექტების გავლენით.

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