საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 3, №2, 2009
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 3, no. 2, 2009

Physical Chemistry

Amplitude Dependence of Internal Friction and Shear Modulus of Tin-Doped Monocrystalline Silicon

George Darsavelidze*, Ia Kurashvili, Guram Bokuchava**, Tengiz Mkheidze***, Ekaterine Sanaia*, Leonti Gabrichidze***

* *F. Tavadze Institute of Metallurgy and Materials Science*
** *Sokhumi I.Vekua Institute of Physics and Technology*
*** *Georgian Technical University*

(Presented by Academy Member G. Tsintsadze)

ABSTRACT. Internal friction and shear modulus amplitude dependences of tin-doped monocrystalline silicon were investigated. Values of critical strain amplitudes of dislocation segments breakaway, absolute shear modulus and elastic limit were determined. Internal friction, shear modulus and elastic limit are measured. Internal friction and shear modulus hysteretic type variations mechanism were analyzed. *© 2009 Bull. Georg. Natl. Acad. Sci.*

Key words: *silicon, internal friction, shear modulus, elastic limit, dislocation.*

The physical-mechanical properties of silicon-based materials are strongly influenced by interaction between dislocation and point defects, particularly impurities atoms[1]. A study of this interaction in silicon and its alloys is very important considering that these materials are widely used in optoelectronics and microelectronics devices. The nature of dislocation-point defects interaction can be investigated by the amplitude dependence of internal friction (IF), which allows investigating the aspects of the material property change in accordance with external thermal and mechanical influence.

In the present work some data on amplitude dependence internal friction and dynamic shear modulus of isovalent metal tin-doped silicon as function of strain amplitude are obtained. Measurements of the logarithmic decrement of damping and frequency of torsional oscillations were carried out in the range of strain amplitude $5\cdot10^{-5}$–$5\cdot10^{-3}$ and oscillations 0.5–5.0Hz frequency. Massive Si:Sn monocrystalline specimens were grown along [111] direction by Czochralski method. The investigated specimens with sizes $0.5\cdot0.5\cdot(10–15)$ mm^3 were obtained by cutting on the diamond disk. The microstructure on the polishing (111) plane of the investigated Si:Sn monocrystals has been studied with optical microscope Neophot-21. Amplitude dependence internal friction was investigated with a torsion pendulum and the damping and oscillations frequency were measured by the free decay of oscillation at fixed temperatures. Hole concentration was measured by Hall effect in constant magnetic field.

The results of measurements of structure, electrophysical and mechanical characteristics of monocrystalline Si:Sn specimens with different content of tin are presented in Table 1. It is shown that with an increased doping metal concentration the density of the dislocations and their nonhomogeneous distribution increase. Values of absolute shear modulus and microhardness of monocrystalline Si doped with Sn decrease because around the substituted atoms of tin with atomic radius (1.4 Å) in crystalline lattice of Si interatomic distance increases and respectively interaction forces between atoms decrease.

Table 1

Physical-Mechanical Characteristics of nondoped and tin-doped monocrystalline Si

Specimen	Hole concentration, cm^{-3}	Microhardness, kG/mm^2	Shear modulus kG/mm^2	I critical amplitude	II critical amplitude	I elastic limit, kG/mm^2	II elastic limit, kG/mm^2
Si [111]	$5\cdot10^{15}$	1250	4550	$3\cdot10^{-4}$	-	1.36	-
Si:Sn (0.05 at%) [111]	$2\cdot10^{16}$	1180	4400	$1\cdot10^{-4}$	$2\cdot10^{-3}$	0.44	8.8
Si:Sn (0.1 at%) [111]	$5\cdot10^{16}$	1100	4320	$0.7\cdot10^{-4}$	$0.8\cdot10^{-3}$	0.30	3.45

IF and shear modulus amplitude dependences of undoped and tin-doped monocrystalline Si of p-types conductivity, with [111] crystallographic direction, have been studied. Measurements have been carried out at 400^0C. An increase of the mobility of dislocations takes place at this temperature in monocrystalline Si.

Critical value of the strain amplitude has been revealed on the curves of IF and shear modulus amplitude dependences of undoped Si. Doping with tin causes the decrease of critical values of strain amplitude; simultaneously the absolute value of shear modulus also weakly decreases.

Cyclic torsion deformation (å~$5\cdot10^{-3}$) causes a slight decrease of shear modulus and critical strain amplitude. Annealing of the deformed specimen at 750^0C temperature, for 3h, causes an increase of the initial values of the mechanical characteristics. At different temperatures in the range 20-750^0C in the IF and shear modulus amplitude dependences, of undoped monocrystal, only one value of critical strain amplitude has been revealed. Tin-doped monocrystalline Si is characterized by two values of critical strain amplitude.

From the results, shown in Fig 1. it may be concluded that internal friction versus strain amplitude curve results from the superposition of three processes. One-at low strains, in which the damping remains constant or slightly increases with increasing oscillatory strain amplitude, the second one gives a linear rise of internal friction at intermediate amplitudes and the third increases sharply with strain at high strain amplitudes.

IF maximum of hysteresis type and sharp decrease of shear modulus have been revealed at the return curve registered from the second critical strain amplitude. Anomalous changing of the noticed characteristics has been revealed in heavily-doped monocrystalline Si.

Annealing in vacuum at 750^0C, for 3 h, causes decrease of hysteretic type IF maximum intensity, and increase of the values of both critical strain amplitudes. It also causes near hysteretic type IF maximum significant decrease of shear modulus defect.

According to the theory, in the interval independent from the first critical oscillatory strain amplitude the level of the IF intensity is determined by the oscillations of the segments, which are on the dislocations pinned with point defects. According to [2,3] in the second interval of the oscillatory deformation, increasing of intensity of IF and shear modulus defects results from the breakaway of oscillatory segments from the pinning points (vacancy, impurity atoms) and its oscillatory motion under the influence of the periodic stress field. This process is reversible, because after the end of stress action dislocation segments return to the initial state. In the interval of high oscillatory strain, with the existence of hysteresis type IF maximum, it is established that microplastic deformation in the structure of Si:Sn monocrystal takes place in local areas. It is the result of breakaway of geometric and kink pairs from the strong pinning centers distributed along dislocation lines. From the results it is possible to conclude that doping of Si with various concentrations of tin causes reduction of the values of the dynamic mechanical characteristics.

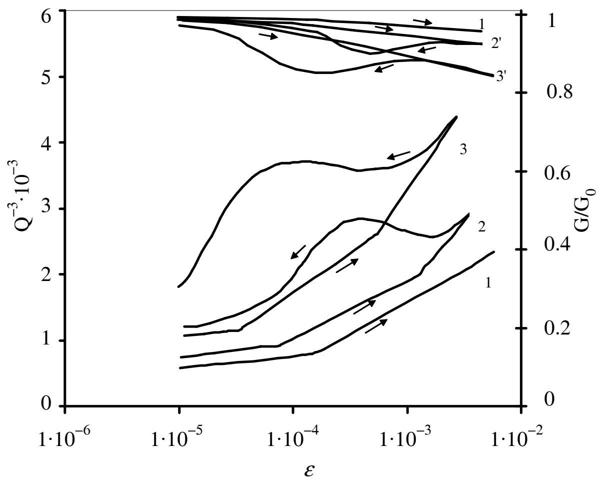

Fig. 1. Amplitude dependence internal friction (1,2,3) and relative shear modulus (1',2',3') of monocrystalline Si:Sn specimens:
1, 1'- undoped Si
2, 2'- Si:Sn (0.05at%)
3, 3'- Si:Sn (0.5 at%)

Variations of structural-sensitive physical-mechanical characteristics of tin-doped monocrystalline silicon are evidenced by changing interatomic bonding forces of the crystalline lattice. Tensile deformation near Sn atoms influences the thermal stability, diffusion activity and concentration of point defects. Simultaneously there occurs a decrease in the interaction of forces of dislocation-point defects. They cause a decrease of the potential barrier in the area of dislocation core. That causes decrease of the energy of dislocation motion and characteristics of mechanical properties of tin-doped monocrystalline silicon. According to the foregoing, by changing isovalent tin concentration it is possible to control the mechanical properties of monocrystalline Si.

ფიზიკური ქიმია

კალით ლეგირებული მონოკრისტალური სილიციუმის შინაგანი ხახუნისა და ძვრის მოდულის ამპლიტუდური დამოკიდებულება

გ. დარსაველიძე*, ი. ყურაშვილი, გ. ბოკუჩავა**, თ. მხეიძე***, ე. სანაია*, ლ. გაბრიჭიძე***

** ფ. თავაძის მეტალურგიისა და მასალათმცოდნეობის ინსტიტუტი, თბილისი*
*** სოხუმის ილია ვეკუას ფიზიკა-ტექნიკის ინსტიტუტი, თბილისი*
**** საქართველოს ტექნიკური უნივერსიტეტი, თბილისი*

შესწავლილია კალით ლეგირებული მონოკრისტალური სილიციუმის შინაგანი ხახუნისა და ძვრის მოდულის ამპლიტუდური დამოკიდებულება. განსაზღვრულია წერტილოვანი დეფექტებიდან დისლოკაციების მოწყვეტის კრიტიკული დეფორმაციის ამპლიტუდის, ძვრის მოდულისა და დრეკადობის ზღვრის მნიშვნელობები. გაანალიზებულია შინაგანი ხახუნისა და ძვრის მოდულის ჰისტერეზისული ტიპის ცვლილების მექანიზმები.

REFERENCES

1. *I. Yonenaga, T. Taishi, X. Huang, K. Hoshikawa* (2005), Journal of Crystal Growth, Cryst. Growth, **275,** issues 1,2, e501-e505.
2. *S.A. Antipov, A. Drozhzhin, A.M. Rosshchupkin* (1985), FTT.**27**, 7:2092-2094 (in Russian).
3. *R.De Batist* (1972), Internal Friction and Structural Defects in Crystalline Solids, Amsterdam, p.477.

Received February, 2009