THE INVESTIGATION OF THE PECULARITIES OF THE INTERNAL FRICTION AND THE SHEAR MODULUS IN THE LEAD TELLURIDE MONOCRYSTAL

O. DAVARASHVILI, M. ENUKASHVILI, N. KEKELIDZE
The Tbilisi State University name of Javakhishvili,
380128б Tbilisi, Chavchavadze ave., 1

G. DARSAVELIDZE, L. GABRICHIDZE, E. KUTELIYA
Institute of metallurgy and materiology name of A.Tavadze, AS of Georgia,
380060, Tbilisi, Kazbegi str., 15

V.P. ZLOMANOV, O.I. TANANAEVA
The Moscow State University name of M.V. Lomonosov

N. AHMEDZADE
Institute of Physics of Academy of Sciences of Azerbaijan
Baku - 1143, H.Javid av. 33

L. TECER
Karaelmaz University, Zonguldak, Turkey

T. MAMEDOV
Gazi University, Ankara, Turkey

The internal friction and the shear modulus have been investigated in PbTe crystals, undopped and dopped by chromium till the temperature 650°C. It has been established at the first time, that the shear modulus increases at the room temperature in the dopped PbTe almost in 2,5 times, and the elastic limit increases in 5-6 times.

The lead telluride, belonging to the narrow-band semiconductor materials, is widely used in the modern semiconductor technique for the production of lasers and photodetectors in the infrared-ray spectrum region, and also for the production of the high-effective thermoelectric transducers. The investigation of the types of the structural defects and their thermal stability, their influence on the structural-sensitive mechanical properties will cause the expansion of the possibilities of their use in many respects.

Such kind of the investigation can be carried out successfully with the use of the acoustic spectroscopy methods, allowing us to define the absolute values of elastic constants, to estimate activation parameters of the different defects and their contribution in the formation of the mechanical properties.

As the last investigations show [1], these questions are very actual in the compound and solid solutions of $A^{IV}B^{VI}$ in the connection with the diffusion error in the heterostructures and the inelastic phenomena, connected with them.

In the present paper for the solution of such kind of problems the method of the low-frequency internal friction at the torsional oscillations has been used. The method has the high sensitivity to the change of the crystal elastic properties, allows us to carry out the measurements in the wide ranges of the temperature change and the amplitudes of the vibrational deformation. The choice of this method is also caused by the fact, that it differs by the high sensitivity to the different defects of the crystal lattice (planar and point defects). The relaxation times of the processes, connected for example with the dislocation defects, interacting with the vacancies or atoms of the impurities, can have the values, which are close to the period of oscillation of the torsion pendulum. This allows us to get the information about the nature of the relaxation processes of the dissipation of energy of the mechanical oscillations, caused by the real structure of crystals.

The PbTe crystals (~ 0,1at. %) undopped and dopped by chromium, are chosen as the objects of the investigation. Earlier in the samples, dopped by chromium at T=80K, the increase of the elastic constants more than in two times with the comparison of the undopped PbTe, was revealed [2].

The measurements of the internal friction and dynamic shear modulus are carried out in the vacuum on the installation of the internal friction with the direct torsion pendulum at the oscillation frequency 1-5 Hc in the temperature interval from the room temperature till 650C. The samples' sizes are $0.5 \cdot 0.5 \cdot (10\text{-}15) mm^3$, the velocity of the temperature change is 2 grad/min. The amplitude vibrational deformation was changing in the interval $5 \cdot 10^{-5}$-10^{-3}.

The value of the internal friction was defined by the formula [3]:

$$Q^{-1} = \ln (A_n / A_{n+N}) / \pi N \quad , \qquad (1)$$

where N is the number of the free-damped oscillations at the decrease of the light deflection amplitude on the optical scale from A_n till A_{n+m}. The precision of estimation of the value is IF~5%. The absolute value of the shear modulus at the room temperature was defined by the method of the comparison

with the etalon sample (aluminum of high purity) of identical sizes by the formula

$$G = G_{et} f^2/f^2_{et}, \quad (2)$$

where G and f, G_{et} and f_{et} are values of the shear modulus and oscillation frequency of the investigated and etalon samples correspondingly. At the construction of the curves of the shear modulus, its proportionality to the square of oscillation frequency: $G \sim f^2$ was used.

The activation energy was defined by the Verta-Marx method on the known values of the temperature T_{max} and oscillation frequency f_{max} from the experiment at the maximum of the relaxation internal friction [3]:

$$H = RT_{max} \ln(KT_{max} / hf_{max}), \quad (3)$$

where K and h are Bolzman and Plank constants correspondingly, R is the gas constant.

The relative deformation was defined at the torsional oscillations by the formula:

$$r = NL / lR, \quad (4)$$

where r is the radius of the circumscribed circle of the sample cross- section, l is the sample length, R is the distance from the sample till the optical reference system, L is the deflection of the light ray on the optical scale .

The temperature spectrum IF of the monocrystal undopped sample PbTe at the oscillation frequency ~5Hc characterizes by the maximums at the temperatures 240 and 340K (fig.1).

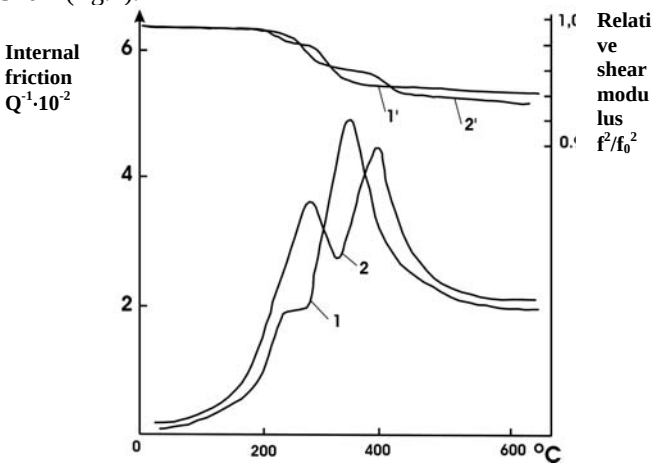

Fig.1. The temperature dependence of the internal friction and relative shear modulus (1,2) of monocrystallic PbTe. 1,1 - PbTe (undopped), 2,2 - PbTe:Cr.

They appear on the IF phone, the level of which increases strongly in the temperature region >400°C. The decrease of the shear modulus is observed in the neighborhood of the IF temperature maximums. The last one, excepting the given maximal wanes, decreases approximately linearly at the increase of the sample temperature. At the further measurement of the IF spectrums and shear modulus in the cooling process the significant changes were not observed with the comparison with the initial spectrums. In the repeated experiment, carried out on the heating and the cooling, the former characteristics of given temperature spectrums mainly conserved. This fact proves the thermal stability of the maximums and IF phone in the PbTe samples. It is need to notice, that spectrum of the temperature dependence are registered in the mode, when the internal friction Q^{-1} is the amplitude-independent.

According to the calculation by the formula (3), IF maximums at 240 and 340°C are characterized by the values of activation energy 1,23 and 1,49 eV correspondingly. From the exponential dependence of the frequency relaxation factor on the back absolute temperature $r^{-1} = r_0^{-1} exp(H/KT_{max})$ the frequency factors were equal $1{,}7\cdot10^{10}$ and $6\cdot10^{12} 1s^{-1}$, correspondingly. The equality at the maximum $2\pi f_{max} = r^{-1}$, where r is relaxation time is used at the calculation.

The absolute value of the shear modulus was equal $1.21\cdot10^{11}$ din/cm^2. It didn't change at the further experiments, carried out after the sample's heating till 650°C in the measurement process of IF and f^2. When $Q^{-1}(E)$ depends on the amplitude, then the separation of the dislocation segments from the fixed points begins in the case of the crystals with low potential barrier or the separation of the twists begins on the dislocations in the case of the crystals having high Payerls barrier. The interface of the amplitude-independent and -dependent regions of Q^{-1} is referred to the critical amplitude deformation. It is equal $9{,}3\cdot10^{-4}$ for the undopped PbTe (fig.2, table).

In the temperature IF spectrum of PbTe sample, dopped by chromium, measured at the frequency ~5Hc, the above mentioned maximums are revealed at the relative high temperatures 265 and 385°C. They appear on the phone, having the lowered intensity in the comparison with the undopped sample. And in this case IF maximums have the higher thermal stability, i.e. the extract at 600°C during 2,5 hours practically doesn't influence on their temperature position and intensity. The shear modulus decreases in the temperature region of IF maximums. Its decrease is higher in the region of the second maximum, characterizing by the relative high intensity. The absolute value of the shear modulus of the dopped sample is – $2{,}96\cdot10^{11}$din/cm^2.

Table.

Physic-mechanical characteristics of the lead telluride monocrystallic samples.

Sample's type	Shear modulus 10^{11} din/cm^2	Critical amplitude of deformation	Temperature of IF maximums, °C	Activation energy, eV	Frequency factor, s^{-1}
PbTe (andopped)	1,21	$9{,}3\cdot10^{-4}$	240	1,23	$1{,}7\cdot10^{10}$
			340	1,49	$6\cdot10^{12}$
PbTe: Cr	2,96	$2{,}9\cdot10^{-3}$	265	1,30	$3\cdot10^{10}$
			385	1,60	$2.8\cdot10^{13}$

The activation characteristics of IF maximums in the dopped sample also have the relative high values 1,3 eV and $1{,}3\cdot10^{10} s^{-1}$ for the maximum at 265°C and 1,6 eV and $2{,}8\cdot10^{10}$ s^{-1} for the second maximum at 385°C.

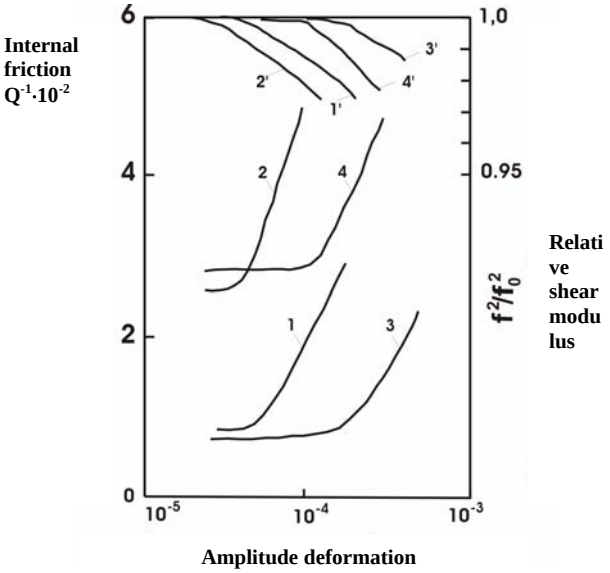

Fig.2. The amplitude dependence of the internal friction (1-4) and relative shear modulus (1-4)
PbTe (undopped): 1,1 -IF and shear modulus at the room temperature, 2,2 - at 300°C
PbTe:Cr3,3 - IF and shear modulus at the room temperature, 4,4 - at 300°C.

The initial spectrums of IF and shear modulus in the temperature interval from room till 650°C and in the case of chromium doping reveal the strong dependence on the oscillation amplitude (fig.2). The decrease of the value of the critical amplitude deformation, at which the strong increase of IF increase or the decrease of shear modulus, is observed on the amplitude dependences of IF and shear modulus at the increase of the temperature of their measurement. Such change of the critical amplitude is character for the thermoactivated process of the dislocation separation on the relative weak fixed points [4].

The calculations of the elastic limit by the formula $\sigma = 2C_{44} \cdot (3\text{-}4 \cdot C_{44}/C_{11})\cdot\varepsilon_{cur}$ show, that in PbTe sample, dopped by chromium, the elastic limit increases not the less, than in 5-6 times in the comparison with the undopped one. Here it is noted, that $C_{44} = G = 29{,}6\cdot10^{10}$ din/cm^2, $C_{11}=104\cdot10^{10}$ din/cm^2 [5] and $143\cdot10^{10}$ din/cm^2 for the undopped and dopped samples correspondingly. The existence of the lowered values of the critical amplitudes at the increased temperatures shows, that dislocation limit also decreases at the increase of the sample's temperature. According to the results of the measurements its decrease is significant at the temperatures >200°C. The annealing at 600°C during 2,5 hours insignificantly increases the value of the critical amplitude at the different temperatures. Therefore, the given thermal treatment practically doesn't influence on the absolute values of shear modulus and dislocation elastic limit, i.e. doesn't cause the significant changes of the real structure of the dopped sample.

[1] *O.I.Davarashvili, M.I.Enukashvili, N.P.Kekelidze etc.* Georgian Engineering News, 2002, 2, 7.
[2] *A.N. Vasilyev, Yu. P. Gaydukov, V.P. Zlomanov i dr.* Neorganicheskiye materiali, 1988, 19, 2, 237.(in Russian).
[3] *V.S. Postnikov*. Vnutrenneye treniye v metallakh. Moskow, Metallurgiya, 1974, 351s. (in Russian).
[4] *M.A. Krishtal, S.A. Golovin.* Analiticheskiye vozmojnosti metoda vnutrennego treniya. Moskow, Nauka, 1973, s.178-190. (in Russian).
[5] *A.A. Chudinov*. FTT, 1962, 4, 3, 755. (in Russian).

O.İ. Davaraşvili, M.İ. Enukaşvili, N.P. Kekelidze, Q.Ş. Darsavelidze, L.L. Qabriçidze, E.R. Kuteliya, V.P. Zlomanov, O.İ. Tananayeva, T.S. Mamedov, N.D. Əhmədzadə, L.N. Teser

PbTe MONOKRİSTALLARININ DAXİLİ SÜRTÜNMƏ VƏ SÜRÜŞMƏ MODULUNUN XÜSUSİYYƏTLƏRİNİN TƏDQİQİ

PbTe və xromlu kristallarının daxili sürtünmə sürüşmə modulu 650°C temperaturuna qədər tədqiq edilmişdir. Xromlu PbTe kristalında müəyyən edilmişdir ki, sürüşmə modulu otaq temperaturunda 2,5 dəfə, elastiklik sərhəddi isə 5-6 dəfə artır.

О.И. Даварашвили, М.И. Енукашвили, Н.П. Кекелидзе, Г.Ш. Дарсавелидзе, Л.Л. Габричидзе, Э.Р. Кутелия, В.П. Зломанов, О.И. Тананаева, Т.С. Мамедов, Н.Д. Ахмедзаде, Л.Н. Тесер

ИССЛЕДОВАНИЕ ОСОБЕННОСТЕЙ ВНУТРЕННЕГО ТРЕНИЯ И МОДУЛЯ СДВИГА В МОНОКРИСТАЛЛАХ ТЕЛЛУРИДА СВИНЦА

В нелегированных и легированных хромом кристаллах PbTe исследованы внутреннее трение и модуль сдвига вплоть до температур 650ºС. Впервые установлено, что модуль сдвига при комнатной температуре возрастает в легированном PbTe почти в 2.5 раза, а предел упругости- в 5-6 раз.

Received: 25.02.2005