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Distribution of Radiation Defects on Thickness of IV-VI Thin Films at a-Irradiation

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Irradiation of materials by easy particles with energy 0.1-10 MeV plays an important role at creation of semiconductor devices. Exactly defects in undoped films of lead chalcogenides and tin are responsible for their semiconductor properties.

For analysis of damages profile it is possible to use the method which is based on the change of electrical resistance of thin sample. Thus, to define the degree of damages with depth for weakening of flood foils of different thickness are putted.

The calculation of profiles of ionization loss and damages of crystalline lattice under the action of monoenergetic α-particle beam is actual for the tasks of modification of properties of semiconductor materials; for development, choice of the regimes of exploitation and radiation firmness of detectors of ionizing radiation.

For the purpose of reception of a primary information about the distribution of electrically active defects in samples is applied the method witch connected with measuring of bulk resistance of films of different thickness. The spatial distribution of ionization and nuclear loss of energy by fast α-particles in $A^{IV}B^{VI}$ semiconductors was calculated.

Key words: thin films, radiation defects, α-irradiation, lead chalcogenides, profiles of ionization loss.

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Introduction

An ionization loss of charged particles in semiconductor is mainly spent for formation electron-hole pairs. Knowledge of size of concentration of generating non-equilibrium charge carriers is necessary at use of semiconductors for the detectors of radiation [1,2]. Also ionization loss are mainly determine free path of a charged particle. Such data, especially for compounds, are often absent or them theoretical estimation is rather rough, or for a calculation are needed a difficult programs which use the method of Monte Carlo.

I. Experimental dependences of electro-physical values from the thickness of PbTe film

Experimental dependences of relative specific electrical conductivity of PbTe films from thickness at different floods of irradiation are shown in Fig.1. The general law is that on curves in region of films thickness about 20-25 microns are observed considerable sensitivity of conductivity to an irradiation. The increase

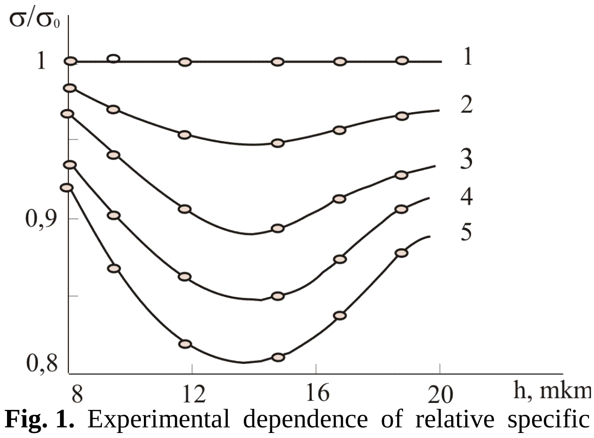

Fig. 1. Experimental dependence of relative specific conductivity σ/σ_0 of p-PbTe films from thickness h: 1 – initial data and after irradiation by α-particles flood of $\Phi\times10^{-12}$ cm^{-2}: 2 – 0.3; 3 – 0.6; 4 – 0.9; 5 – 1.2. Points – experiment, lines – calculation.

of integral flood of irradiation causes to more noticeable change of relative conductivity from thickness.

Obtained experimental data can be explained by Gaussian distribution of defects in material at plane-parallel flood of α-particles with taken into account isotropy of radiation of plane source. As a specific resistance is measured at transmission of current in parallel a film surface, then

$$\rho(x) = \rho_0 + k\,\Phi\,F(x), \qquad (1)$$

where ρ_0 – initial specific resistance, Φ – flood of particles, k – coefficient of change of specific resistance on unit of size of flood, F(x) – distribution of defects on depth.

For chosen geometry of experiment F(x) will be:

$$F(x) = \frac{2}{\sqrt{2\pi}\delta}\int_0^1 e^{-\frac{(x/\cos\theta - x_0)^2}{2\delta}}\, d\cos\theta\ , \qquad (2)$$

where θ – angle of incidence of particles on surface of sample: x_0 and δ – average depth and standard deviation for Gaussian profile of defects distribution.

Unknown parameters were found from approximation of experimental values of conductivity (Fig.1.) by dependence:

$$\sigma\ /\ \sigma_0 = \frac{1}{h}\int_0^h \frac{\rho_0 dx}{\rho(x)}, \qquad (3)$$

by least squares method.

As a result were obtained such values x_0 = 18 mkm, δ = 2 mkm, k = 10^{13} Om × cm^3. Distribution F(x) on

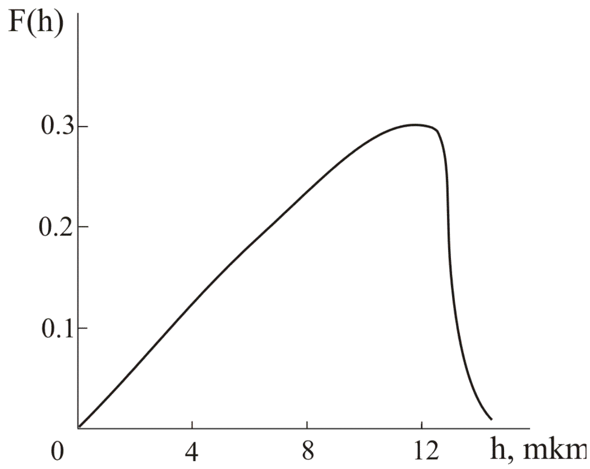

Fig. 2. Calculated profile of distribution of defects on depth of a film at α-irradiation by isotropic floods.

depth of a film at α-irradiation with obtained parameters is shown in Fig. 2. Notice that curves of approximation are in good agreement with experimental data. It testifies about possibility of definition of profile of radiation defects in offered way.

II. Ionization and nuclear energy loss of α-particles in $A^{IV}B^{VI}$

2.1. Path of α-particles in $A^{IV}B^{VI}$

In [3] is shown empirical calculation formula of path of α-particles:

$$R_\alpha = 0.1E_\alpha(E_\alpha A)^{\frac{1}{2}}, \qquad (4)$$

where R_α measure in mg/cm^2, E_α – MeV, A – atomic number. In Fig. 3. is shown plots of dependence of free path from energy of particle in Pb, Te, Sn, Se. Path of α-particles with energy 5.5 MeV, that also were presented in Fig.3., were taken from tables [4]. Deviations in data from two sources are less then 5%.

Path of particle in compound AB find from formula [4]:

$$R_{AB} = (A_A + A_B)/(A_A/R_A + A_B/R_B). \qquad (5)$$

Dependences of path values from energy of particles with taken into account densities of compounds are

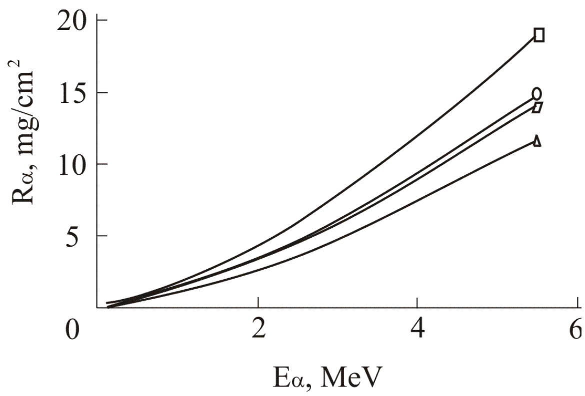

Fig. 3. Path of α-particles calculated from empirical formula and that taken from tables in dependence from initial energy in Se – 1, Sn – 2, Te – 3 i Pb – 4.

shown in Fig.4.

To confirm shown above path of α-particles R_α with energy E_α in dense condensed medium use another empirical formula [5]:

$$E_\alpha = \alpha\left(\frac{m_\alpha}{m_p}\right)^{1-n} Z_\alpha^{2n} R_\alpha^n, \qquad (6)$$

where parameters of dependence, for photoemulsion α = 0.25 , n = 0.58, m_α/m_p = 4, z_α = 2 —characteristics of

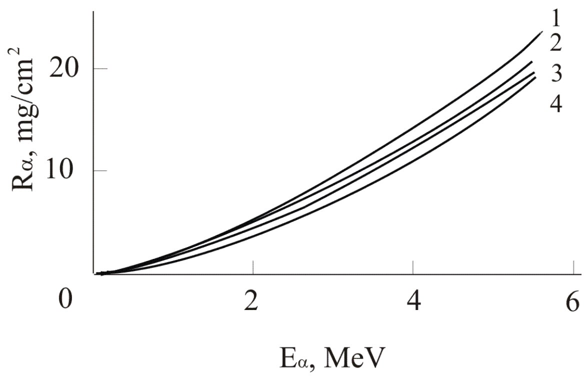

Fig. 4. Path of α-particles in dependence from initial energy of particles in SnTe – 1, PbSe – 2, PbTe – 3 and photoemulsion – 4.

particle. Path expresses by the formula:

$$R_\alpha = \left(\frac{E_\alpha}{4\alpha}\right)^{\frac{1}{n}}, \qquad \text{mkm } (7)$$

This dependence also is shown in Fig.4. We can see similarity of dependences and calculated values.

2.2. Ionization loss of α-particles in $A^{IV}B^{VI}$

In range of energies, when speeds of ions are compared to speeds of atomic electrons, theoretical consideration of ionization loss is absent. In this range of

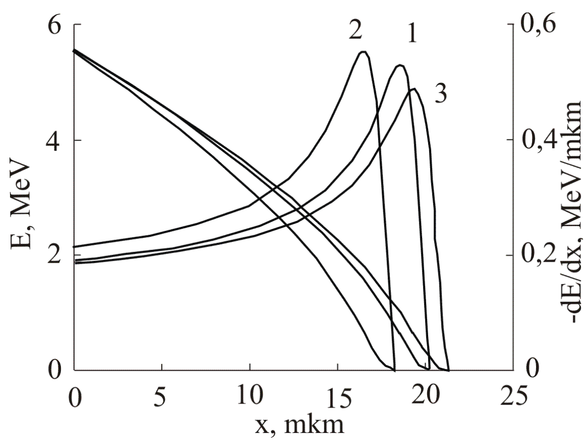

Fig. 5. Energies and ionization loss of α-particles along path for initial energy of particles 5.5 MeV of source Pu^{238} in PbSe – 1, PbTe – 2 and SnTe – 3.

speeds inelastic loss of energy have maximum. At calculations of transport of ions of intermediate energy in material often use cross-linking of values obtained from Linhard-Sharf formula [6] for low energies and Bethe-Bloch formula [7] for high energies.

However, loss of energy that calculated from formula (1)

$$\frac{-dE_\alpha}{dx} = \frac{2}{3}\left(\frac{A}{E_\alpha}\right)^{\frac{1}{2}}\frac{N}{N_\alpha}, \text{ MeV/mkm,} \qquad (8)$$

is monotone decreasing function of energy , where N – atom concentration. For α-particles maximum of stopping power is in range of energies, that intensively use experimentally, ~ 1 MeV. On base of a big amount of experimental data interpolation dependence [8]:

$$S_e = 0.235\, Z\, Z_\alpha^2\, T^{0.6}\, ln\big(b(T^2 + 0.01Z + 0.08)/(T + 0.003\, Z + 0.024)\big)/(T^{1.6} + a), \qquad (9)$$

$$\frac{-dE_\alpha}{dx} = S_e N \qquad (10)$$

where Z – order number of atom, T = $E_\alpha/4$, E_α energy of α-particles in MeV; a, b – changeable parameters, that in [8] selected so to provide optimal agreement with experiment. Cross section of stopping of α-particles in materials S_e is expressed in units 10^{-15} eV × cm^2/atom. Fitting parameters a and b for components of compounds are represented in table 1. Calculated (with using (7)) energies of α-particles and ionization loss along path for initial energy of particles 5.5 MeV are represented in Fig.5. From figure we see, that maximum of loss is in the end of path and in about 2 times exceeds loss in the beginning.

2.3. Nuclear loss of a -particles in $A^{IV}B^{VI}$

For normalized nuclear stopping power is used analytical expression from works [6, 9]:

$$S'_n = 0.5\frac{\ln(1+1.1383\,\varepsilon)}{\varepsilon+0.01321\,\varepsilon^{0.21226}+0.1959\,\varepsilon^{0.5}}, \qquad (11)$$

where

$$\varepsilon = \frac{E_\alpha a_b M}{1.13\, Z Z_\alpha \left(Z_\alpha^{2/3}+Z^{2/3}\right)^{\frac{1}{2}} e^2 (M_\alpha+M)}, \qquad (12)$$

where a_b – Bohr radius. Value of stopping power in maximum is equal

$$S_n = 3.62 N a_b Z Z_\alpha M_\alpha \frac{e^2}{\left(Z_\alpha^{2/3}+Z^{2/3}\right)^{1/2}(M_\alpha+M)}, \text{ erg/cm} \qquad (13)$$

In Fig.6. are represented nuclear loss in sublattices of metal and chalcogen for PbSe, PbTe and SnTe. From picture we see, that maximums of loss are in order bigger than loss along all trajectory and that loss on more heavy elements of compound are closer to surface of sample.

Thus, ionization loss of α-particles in $A^{IV}B^{VI}$ are featured with using the dependence, that was presented in [8], with parameters selected by us, also was calculated nuclear loss. Nuclear loss, that responds for defect formation, on three orders less than ionization loss.

Was shown, that profile of distribution of radiation defects is the sum of Gaussian distributions for plane-parallel floods, which give isotropic flood. Parameters of Gaussian distribution are: average depth x_0 = 18 mkm, standard deviation δ = 2 mkm.

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[1] V.A. Nikerov. *Application of particles and radiations of high energies.* High school, M. 152 с. (1988).
[2] *Laboratory practical work on experimental methods of nuclear physics.* Under the editorship of K.G.Finogenova. — Energyatompublish, M. 432 с. (1986).
[3] K.G. Jafarov. *Radiation-stimulative diffusion in semiconductors.* Energyatompublish, M. 220 с. (1991).
[4] O.F. Nemec, Ju.V. Hoffmann. *Directory on the nuclear physics.* Science thuoght, Kiev. 414 с. (1975).
[5] K.N. Mukhin. *Introduction in the nuclear physics.* Science, M. 584 с. (1975).

[6] Ju.D. Lizunov, A.K. Ryazanov. Research of stopping charged particles and formation of dot defects. Pre-print. Institute of nuclear energy, M. 36 c. (1988).
[7] I.A. Ahiezer, L.N. Davydov. *Introduction in the theoretical radiating physics of metals and alloys.* Science thought, K. 250 c. (1975).
[8] N.N. Pucherov, T.D. Chesnokova. *Questions of a nuclear science and technics.* // **1**, 10-12 (1979).
[9] J.P. Biersack. Nuclear Instruments and Methods in Physics Research. // **B27**, 21-36 (1987).

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Розподіл радіаційних дефектів по товщині тонких плівок IV-VI при а-опроміненні

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Опромінення матеріалів легкими частинками з енергією 0,1-10 МеВ відіграє важливу роль при створенні напівпровідникових приладів. Вирішення проблеми керування властивостями напівпровідникового матеріалу α-опроміненням неможливе без розуміння механізму взаємодії опромінення з твердим тілом і впливу дефектів на його властивості. Саме дефекти в нелегованих плівках халькогенідів свинцю і олова відповідальні за їх напівпровідникові властивості.

При досить великих енергіях падаючих α- частинок, коли максимум профілю пошкоджень знаходиться на глибині кількох мікрон, для його аналізу можна використати метод, що базується на зміні електроопору тонкого зразка. При цьому для того, щоб визначити ступінь пошкоджень з глибиною ставлять для ослаблення потоку фольги різної товщини.

Обчислення профілів іонізаційних втрат та пошкоджень кристалічної гратки під дією моноенергетичного пучка α-частинок актуальне для задач модифікації властивостей напівпровідникових матеріалів; розробки, вибору режимів експлуатації та радіаційної стійкості детекторів іонізуючого випромінювання.

З метою одержання первинної інформації про розподіл електричноактивних дефектів у зразках застосовано метод, звя’заний з вимірюванням об’ємного опору плівок різної товщини. Розраховано просторовий розподіл іонізаційних і ядерних втрат енергії швидкими α-частинками в напівпровідниках $A^{IV}B^{VI}$.

Ключові слова: тонкі плівки, радіаційні дефекти, α-опромінення, халькогеніди свинцю, профілі іонізаційних втрат.