CURRENT CARRIER SCATTERING IN EPITAXIAL PbSe FILMS

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The dependence of the current carrier mobility in the epitaxial PbSe films deposited on the mica substrates on the film thickness within the interval 0.1—2.0 μm and at temperatures 77—300 K has been studied. A contribution to the mobility caused by the current carrier scattering by the surface has been calculated. The residual mobility and the dominating mechanisms of the current carrier scattering at various film thicknesses have been determined.

1. The films of lead selenide are used in detectors of radiation and sources of emission in the IR range of the optical spectrum [1, 2]. We note that the parameters of thin-film active elements are determined to a great extent by dominating mechanisms of current carrier scattering. In the range of small film thicknesses, the scattering mechanisms are known [3] to differ substantially from those inherent to massive specimens, i.e. crystals. In particular, in the former case in addition to the scattering by thermal vibrations of the lattice and ionized centers [4], one has to take into account the scattering by the surface, mismatch dislocations, and solidification fronts [5].

In this work, by comparing theoretical calculations of the current carrier mobility with experimental results, the dominating mechanisms of current carrier scattering in PbSe films possessing various thicknesses have been determined within the temperature range 77—300 K.

2. The films were grown in vacuum on mica (001) chips by the method of molecular beams [6]. The evaporation temperature was about 920 K and the deposition one $T_d = 300 \div 720$ K. The film thickness d was governed by the deposition time and varied within the limits $d = 0.1 \div 2.0$ μm. The carrier concentration in all specimens was $(1 \div 3) \times 10^{18}$ cm^{-3}.

The Hall mobility was determined on the basis of the Hall emf measured in constant electric and magnetic fields at temperatures 77—300 K.

According to the data of electron diffraction and electron microscopy, the films presented the epitaxial structures, whose $\{111\}$ planes and $\langle 1\bar{1}0 \rangle$ directions were oriented in parallel to the (001) plane and to the $\langle 100 \rangle$ and $\langle 010 \rangle$ directions of mica crystals, respectively. The dimensions of crystallites amounted to $0.1 - 0.5$ μm, and the angle of azimuthal off-orientation was up to $5°$.

The dependences of the current carrier Hall mobility in PbSe films on the film thickness measured at various temperatures are depicted in Fig. 1. One can see that, in the whole temperature interval under investigation, the current carrier mobility increases with the film thickness. In so doing, the especially substantial variation of the mobility is characteristic of the low temperature range (77 K). At film thicknesses of about 2 μm, typical is the tendency to the mobility saturation. Higher measurement temperatures result in the reduction of the mobility (Fig. 1); it is also true for massive specimens.

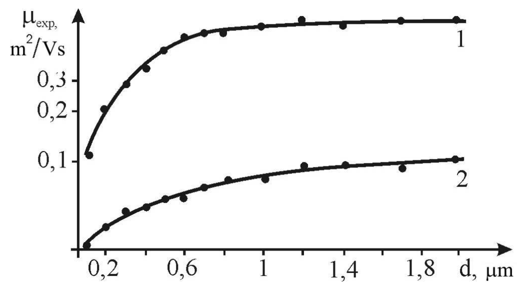

Fig. 1. Dependences of the effective mobility $\mu_{\rm exp}$ of current carriers in PbSe films on the film thickness d at various temperatures $T = 77$ (*1*) and 300 K (*2*)

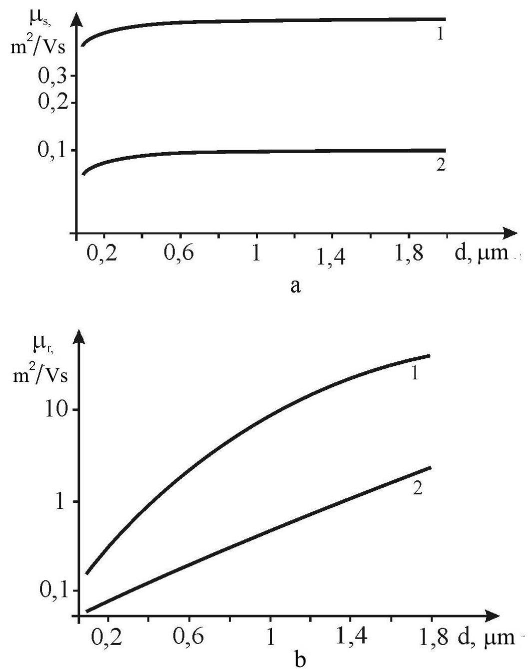

Fig. 2. Dependences of the (*a*) surface, μ_s, and (*b*) residual, μ_r, mobilities of current carriers in PbSe films on the film thickness d at temperatures 77 (*1*) and 300 K (*2*)

3. According to the Matthiessen rule [4, 5], several contributions can be singled out from the effective mobility $\mu_{\rm exp}$ measured in experiments:

$$\frac{1}{\mu_{\rm exp}} = \frac{1}{\mu_s} + \frac{1}{\mu_r} + \frac{1}{\mu_v}, \qquad (1)$$

where μ_s is the mobility of current carriers related to the scattering by the surface (surface mobility), μ_v the current carrier mobility in a massive specimen (bulk mobility), and μ_r the mobility that takes into account the scattering by mismatch dislocations at the heterostructure interface, intergrain scattering, and scattering by growth defects (residual mobility).

Under the condition of diffusion scattering by the surface, the surface mobility can be calculated according to the formula [5]

$$\mu_s = \frac{\mu_v}{(1 + \lambda/d)}. \qquad (2)$$

Here, λ is the average mean free path of a current carrier. Note that, in the case of thin films, the manifestations of dimensional effects – with respect to the average mean free path and the Debye screening length – are possible. For lead chalcogenides, both the lengths amount to 25—50 nm [5, 7]. Since these values are much smaller than the nominal thickness of the researched films (0.1 μm), the influence of the dimensional phenomena on the current carrier mobility is improbable.

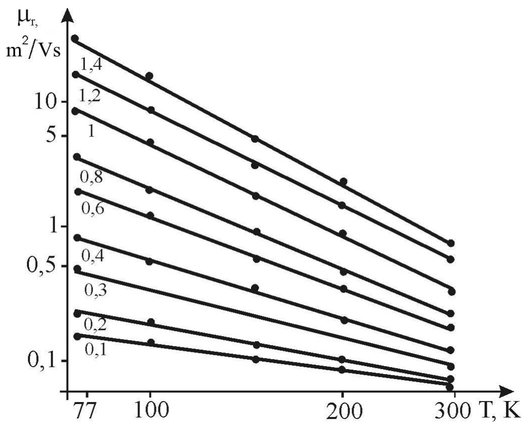

Fig. 3. Dependences of the residual mobility μ_r on the temperature T for PbSe films of various thicknesses d (indicated in microns near the relevant curves)

The calculated dependences of the surface mobility on the film thickness for films where $\lambda = 50$ nm are presented in Fig. 2,*a*. The bulk mobility μ_v of current carriers in single crystals were calculated according to the method developed in [7] and taking into account their scattering by the screened Coulomb and short-range potentials of vacancies, deformation potentials, acoustic and optical phonons, the polarization potential of optical phonons, and making also allowance for the interaction between current carriers. The following results were obtained: $\mu_v = 0.103$ and 0.691 m^2/(V×s) for the temperatures $T = 300$ and 77 K, respectively.

The dependences for the residual mobility μ_r, which were calculated by relation (1) on the basis of the known values of $\mu_{\rm exp}$, μ_s, and μ_v, are presented in Fig. 2,*b*. One can see that, as the thickness of the film increases within the researched interval, μ_r grows by two orders of magnitude.

4. In order to determine the dominating mechanism of current carrier scattering, the temperature dependences of their residual mobility $\mu_r(T)$ in films with various thicknesses were analyzed (Fig. 3). For a film with the thickness d, this dependence can be written down as follows [5]:

$$\mu_r = \mu_0(d) T^{-n(d)}, \qquad (3)$$

where $\mu_0(d)$ is a constant which is defined by material parameters and depends on the film thickness, and $n(d)$ is a parameter which is defined by the prevailing

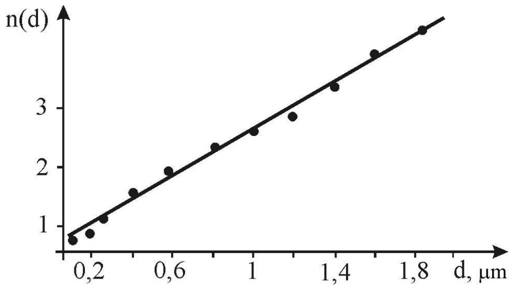

Fig. 4. Dependence of the power exponent n, which enter into the analytical temperature dependence of the current carrier mobility in PbSe films, on the film thickness d

mechanism of scattering in the film of a definite thickness. For perfect enough lead chalcogenide films, where the scattering by long-wave acoustic phonons dominates, taking into account the temperature dependence of the effective mass results in $n \approx 2.5$. In the case of surface scattering, $n \approx 0.5$. The value $n = 0.8$ is related to the scattering by growth defects, and n=1.5—2.0 for the scattering by dislocations [7–9].

The calculated values of the power exponent n for the films of various thicknesses are plotted in Fig. 4. It turned out that the dependence $n(d)$ can be approximated by a straight line, the analytical expression of which is

$$n(d) = 0.76 + 1.89d, \quad (4)$$

where the film thickness d is measured in microns.

Thus, the dislocation mechanism of current carrier scattering (n=1.5÷2.0) is realized in films, whose thickness is 0.4—0.6 μm. For thinner films, dominating is the scattering by growth defects and the surface, while for thicker ones by acoustic phonons.

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РОЗСІЯННЯ НОСІЇВ ЗАРЯДУ В ЕПІТАКСІЙНИХ ПЛІВКАХ PbSe

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Р е з ю м е

Досліджено залежність рухливості носіїв заряду від товщини плівки (0,1—2,0 мкм) в епітаксійних плівках PbSe на сколах слюди при температурах 77—300 К. Розраховано внесок у рухливість, зумовлений розсіянням на поверхні. Визначено залишкову рухливість і домінуючі механізми розсіяння носіїв заряду для плівок різної товщини.