Size Effects in Transport Properties of PbSe Thin Films

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Due to the intensive development of nanophysics and nanotechnology, detailed studies of size effects are of special interest. There are two types of size effects: classical and quantum ones. The former are associated with an increasing contribution of the surface to the conductivity under decreasing film thickness (*d*), the latter represent a manifestation of the energy spectrum size quantization when at least one dimension of a system becomes comparable to the de Broglie wavelength.

Earlier [1-3], in the thin films with different charge carrier concentrations obtained by thermal evaporation in vacuum of stoichiometric *p*-type and nonstoichiometric *n*-type PbSe crystals and of *n*-PbSe crystals doped with chlorine, we observed non-monotonic character of the *d*-dependences of transport properties and attributed it to the manifestation of size effects.

The goal of the present work was to carry out a detailed analysis of our experimental results on the thickness dependences of the transport properties with a view to establishing some general regularities, as well as physical mechanisms and factors that determine the character of the size effects manifestation in PbSe thin films.

It is found that only in the films obtained from stoichiometric *p*-PbSe crystals does a change in the conductivity type occur under changing film thickness, and in a certain range of *d,* the conductivity type changes periodically with increasing *d.* We attribute this phenomenon to a high sensitivity of the electron subsystem to any external effect at *d*'s close to the conductivity sign inversion point. It is shown that the inversion of the conductivity type under changing *d* makes it possible to study quantum size effects caused by energy spectra quantization both of the electrons and holes. For all PbSe films, in a certain *d* range, an oscillatory behavior of the dependences of transport properties on *d* is observed and attributed to quantum size effects. For all films the oscillation periods calculated within the framework of a model of a rectangular quantum well with infinitely high walls taking into account the *d*-dependence of the Fermi energy and contribution to the kinetic coefficients by all energy subbands located below the Fermi level were in good agreement with the experimentally observed oscillation periods. In all the cases, under increasing *d*, the *d*-dependences of the kinetic coefficients exhibit an oscillatory behavior in the range of smaller thicknesses and then the coefficients change monotonically. The experimental dependences of the electrical conductivity and Seebeck coefficient are well described within the framework of the Fuchs-Sondheimer theory, which indicates the manifestation of classical size effect. It follows from the obtained experimental results that studying the *d*-dependences of the transport properties, one can differentiate between quantum and classical size effects and that the model of a rectangular quantum well with infinitely high walls and the classical Fuchs-Sondheimer theory describe the experimental data rather accurately.

References

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