

Quantum size effects and thermoelectric properties of IV–VI-based 2D-nanostructures

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Electron confinement in low-dimensional (LD) structures leads to a radical change in physical properties of these systems as compared with bulk crystals and introduces new ways for controlling the properties. At present, the study of LD systems is one of the leading directions in the physics of thermoelectricity and thermoelectric (TE) materials science, which is connected with the great potential of those objects for TE applications. The interest in studying TE properties of 2D-structures has grown significantly since the possibility of a substantial increase in the TE figure of merit ZT in quantum wells (QWs) under decreasing the QW width was predicted theoretically and confirmed experimentally [1]. In QWs, charge carrier motion is confined in one direction, which results in the quantization of the electron quasi-momentum in this direction. For thin film applications in thermoelectricity, it is necessary to take into account the quantum size effects (QSEs), which can drastically change TE properties under thin film thickness d decreasing.

Narrow-gap IV–VI semiconductor compounds are well known as promising materials for TE applications. The development of nanophysics and nanotechnologies stimulates studies of these materials in thin-film state. One of the possible manifestations of the QSEs in 2D-structures is an oscillatory behavior of the thickness dependences of the transport properties. Quantum oscillations of TE properties in IV–VI thin films first were observed in [2] and attributed to the QSEs.

The present status of our studies (see, for example, [2–5]) on the TE properties of thin film nanostructures with QWs based on IV–VI semiconductor compounds (IV = Pb, Sn, Ge; VI = Te, Se, S) as a function of the QW width ($d = 2\text{--}500$ nm) will be reviewed.

The methods of preparation of IV–VI-based 2D structures, their characterization by electron microscopy, X-ray diffraction techniques, the growth mechanisms on different substrates, and the methods of transport properties measurements will be described. Particular attention will be given to the effect of near-surface oxidation on the transport properties of freshly prepared IV–VI thin films exposed to air at room temperature without a protective passivation layer.

It was established that the experimental values of the oscillation period are in good agreement with the results of the theoretical calculations. These calculations were conducted using the effective mass approximation and a model of a rectangular potential well with infinitely high walls or a model of a finite barrier height and taking into account the dependence of the Fermi level on thin film thickness and availability subbands below Fermi level.

The influence of various factors (type of barriers and substrates, energy band and structural parameters, layer growth mechanisms, the degree of structural perfection, temperature, n - or p -type doping for shifting the Fermi level and others) on the observed oscillatory phenomena will be analyzed. The effect of the size quantization on the TE figure of merit of thin film structures will be considered. Intercomparisons between the behaviors in the various IV–VI compounds will be made. For thin film applications in thermoelectricity, it is necessary to take into account the QSEs which can drastically change TE properties under decreasing thin film thickness.

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