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SUPERCONDUCTIVITY OF NON-STRAINED PbTe–PbS AND STRAINED PbTe–SnTe SUPERLATTICES *

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A comparative study of structural and superconductive properties of semiconductor epitaxial superlattices PbTe–SnTe and PbTe–PbS grown on (001) KCl has been carried out. It has been found that the superconductivity of the PbTe–SnTe superlattices is caused by the stretching strain in the SnTe layers and it may be connected with the relative positions of L_6^+ and L_6^- terms of PbTe and SnTe, respectively in the heterojunction. In contrast to the PbTe–SnTe superlattices, the superconductivity of the PbTe–PbS superlattices is found to be associated with regular misfit dislocation grids which are generated at the interfaces.

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Superconducting semiconductor superlattices having the critical temperature much higher than that of bulk semiconductors [1, 2] are of special interest to those who are interested in the high temperature superconductivity models. Such materials as PbTe, PbSe and PbS are not superconductors, and SnTe is a superconductor at 0.22 K. Therefore, it may be supposed that the superconductivity of the superlattices made of those materials is connected with some pecular electron

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states existing at the interfaces. Mironov et al. [2] have demonstrated that the superconductivity of the superlattices based on PbTe, PbSe and PbS is caused by a special structure of the interface, namely by a regular grid of misfit dislocations at the interface.

The aim of the present work is to investigate the influence of the interface structure on superconductive properties of PbTe–SnTe superlattices and to compare the results with the previous ones obtained for the PbTe–PbS superlattices. It should be mentioned that in comparison to PbTe and PbS, the band structure of SnTe is "inverted", i.e. the ordering of the L_6^+ and L_6^- is reversed, if the strain is neglected. For our experiments two series of strained and partially strained PbTe–SnTe superlattices with different periods have been grown on a PbS buffer layer and on (001) cleaved KCl substrates by vacuum deposition. Periodicity of these superlattices has been evaluated from the presence of the satellites on the X-ray diffractograms [3]. The first series consists of superlattices with thick and thereby unstrained PbTe layers and thin stretched SnTe layers. The superlattices of the second series have thick SnTe layers and thin compressed PbTe layers. For electron microscopy investigations of the interface structure we have prepared several two-layer samples of PbTe–SnTe with various thickness of the SnTe layers, such as $d_{\mathrm{PbTe}} \gg d_{\mathrm{SnTe}}$ with $d_{\mathrm{PbTe}} = \mathrm{const}$. That allows considering the PbTe layer as a substrate and neglecting its deformation. Thus, it is assumed that only the SnTe layers are deformed. Results of the electron microscopy investigations are shown in Fig. 1. As may be concluded from Fig. 1b, the critical thickness d_{cr} of the pseudomorphic growth of SnTe on PbTe is about 10 nm. If the thickness of the SnTe layer is smaller than d_{cr}, the lattice mismatch 2% is accomodated by deformation of the SnTe layer, and if the thickness of the SnTe layer becomes larger than d_{cr} the pseudomorphic strained layer structure transforms to dislocation structure relaxing partly the strain. On the basis of the investigations the minimum period of the misfit dislocation grid d_{MD} in the PbTe–SnTe system may be estimated to be 32 nm. In comparison with the PbTe–PbS system [2] having $d_{\mathrm{MD}} = 5.2$ nm, the regularity of the misfit dislocation grid in the PbTe–SnTe system is decreased because of the large distance between the dislocations, and consequently, weaker interactions between them. Moreover, the regularity of the misfit dislocation grid is limited by the dimensions and orientation of the blocks of the KCl substrate. With the preparation method it is possible to change structure of the PbTe–SnTe interface in a wide range to obtain strained, partly strained and dislocation superlattices.

The investigations of the galvanomagnetic properties of the PbTe–SnTe superlattices have been carried out in the temperature range from 300 K to 1.5 K at magnetic fields up to 15 kOe. It was found [4] that the superlattices with the period $D < 30$ nm show a transition to superconductivity at temperatures lower than 4 K. Murase et al. [1] consider lead inclusions and interactions between them as a reason of the superconductivity met also in their PbTe–SnTe superlattices. That may be confirmed by the two-stage character of the superconductive transitions. Similar explanation of the superconductivity observed in iron-doped HgSe showing inclusions of Hg was proposed by T. Dietl [8, 9]. On the contrary our superlattices are free of Pb precipitates and the superconductive transitions are

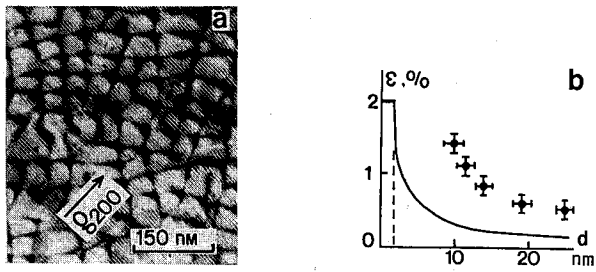

Fig. 1. (a) Transmission electron-microscope images of misfit dislocation grids at PbTe–SnTe heterocontact formed by a 40 nm PbTe layer and a 25 nm SnTe layer. (b) Deformation ε as a function of thickness d of a SnTe layer deposited on PbTe thick film. Points are experimental data obtained from the distance between the misfit dislocations p using the formula: $\varepsilon = f - |\boldsymbol{B}|/p$, where $\boldsymbol{B}$ is Burgers vector and f is the lattice mismatch. The curve is calculated on the basis of the theory proposed in [10].

not of the two-stage character. This means that our superlattices are not granular systems.

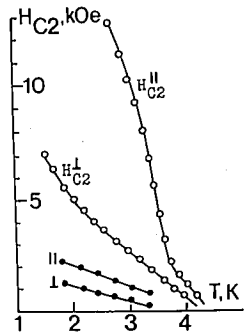

Fig. 2. Temperature dependences of the upper critical fields H_{C2} of the superlattices. Open circles: a PbTe–PbS superlattice with the PbTe layer of thickness 15 nm and the PbS layer of thickness 16 nm. Closed circles: a PbTe–SnTe superlattice with the PbTe layer of thickness 5.5 nm and SnTe layer of thickness 11 nm. $H^{\parallel}_{C2}$ and $H^{\perp}_{C2}$ are the magnetic fields oriented parallel and perpendicular to the superlattice layers, respectively.

The galvanomagnetic and structural studies show that the transition to superconductivity in our superlattices occurs for $d_{cr} \gg d_{SnTe} \ll d_{PbTe}$. It means that the SnTe layers are in a pseudomorphic stretched state. That may be confirmed by the absence of superconductivity in the superlattices of the second series with the thick SnTe unstrained layers. That fact may be connected with the mutual positions of the L_6^+ and L_6^- terms of PbTe and SnTe in the strained heterocontact [5–7]. The appearance of the misfit dislocations at the interfaces caused by the in-

crease of SnTe layer thickness leads to the suppression of superconductivity. That is manifested by the absence of the zero resistivity and increasing temperature-width of the superconductive transition.

Some differences can be noted when comparing the superconductive properties of the PbTe–SnTe and PbTe–PbS superlattices . Firstly there is no transition from the three-dimentional to the two-dimensional behaviour ("the crossover") on the temperature dependences of the upper critical fields in PbTe–SnTe superlattices (Fig. 2). Secondly the angle dependences of the upper critical fields obey Tinkham formula for a superconducting homogeneous thin film. From these angle dependences the thickness of a superconductive layer has been determined. The thickness appears to be equal to the superlattice thickness, i.e. it is of about 180 nm. From that it is concluded that superconductivity of the PbTe–SnTe superlattices is not of a quasi-two-dimensional character. Assuming that the stretched SnTe layers are responsible for the superconductivity of the SnTe–PbTe superlattices a strong bond between the SnTe layers across the PbTe layers is concluded.

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