Superconductivity in the novel semiconducting superlattices

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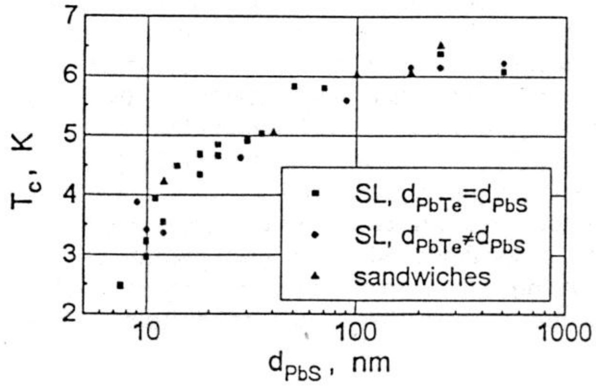
Novel superconducting superlattices (SL) with transition temperature 4-6 K consisting only of semiconducting materials are discovered. Among them there are multilayers containing ferromagnetic chalcogenide EuS. Single films of the semiconducting materials constituting SL do not reveal superconductivity, and it appears only in multilayered systems. It is shown that superconductivity is confined to the interfaces between two semiconductors. The possible correlation between superconductivity and interfacial regular grids of misfit dislocations is discussed.

The first attempts to fabricate artificial superlattices consisting of alternating thin layers of superconductor and some isolating material were connected with the expectation to obtain high transition temperature due to excitonic mechanism of superconductivity. The great body of experimental data showed that T_c of artificial multilayers as a rule do not exceed the transition temperature of superconducting films constituting superlattice [1]. As the single exception the semiconducting superlattices PbTe/PbS and PbTe/SnTe revealing T_c about 6 K [2-4] may be considered. Semiconducting compounds used in these multilayers are either superconductors with very low T_c<<1 K (SnTe) or non-superconducting materials if they are not doped with some specific impurities. Individual thin semiconducting films with thickness d=15-300 nm do not reveal superconductivity too.

Here we report about discovering of new "members" in the family of superconducting semiconducting SLs. Among them there is a composition including ferromagnetic semiconductor EuS.

All multilayers and three-layered sandwiches were grown epitaxially on the cleaved [100] face of KCl single crystals. All measurements have been carried out by a resistive method with the use of four probe geometry. The T_c values were determined in the middle point of the resistive transition ($R = 0.5\, R_n$). Some of the new semiconducting multilayers appeared to be very strained and unstable. For such compositions the low temperature measurements were possible only on three-layer sandwiches. For the possibility to compare superconducting T_c on SLs and sandwiches, the properties of stable system PbTe/PbS were investigated.

Figure shows the T_c dependence on the thickness d_{PbS} for the samples PbTe/PbS in the range 7.5-500 nm. In this figure the data for symmetric ($d_{PbTe}=d_{PbS}$) SLs, for asymmetric ($d_{PbTe}\neq d_{PbS}$, d_{PbTe}=12 nm) SLs, and three-layer sandwiches are presented. There is sharp increase of T_c in the d_{PbS} range 7.5 -- 20 nm. With the further increase of d_{PbS} transition temperature shows a tendency to the saturation, especially in the range above 100 nm. The transition temperatures for different types of samples



practically coincide. As for T_c dependence on PbTe layer thickness it was investigated on the series of multilayers with constant d_{PbS} = 12 nm in the shorter range of d_{PbTe} (up to d_{PbTe} = 70 nm). In this range there is no any dependence of T_c on d_{PbTe}.

Taking into account the results presented for PbTe/PbS system we investigated the properties of superlattices and sandwiches of different compositions with equal thicknesses of two constituting films $d_1 = d_2 = (100\pm10)$ nm.

The characteristics of the layered systems investigated are presented in a Table. The superconductivity is found in two new compositions of Pb chalcogenides. But more interesting seems the fact that SLs with combinations of narrow-gap semiconductor (PbTe) and wide-gap one (chalkogenides of rare earth metals) also reveal superconductivity. The superconductivity is absent if SL consists only of wide-gap semiconductors (see the Table). One of the wide-gap semiconductors (EuS) which is a component of superconducting SL has ferromagnetic ordering at $T_K \cong 16$ K.

Table

System	Misfit f, %	D_{dn}, nm	T_c, K
PbS/PbSe	3.16	13.5	4.29
PbTe/PbSe	4.8	8.6	6.02
PbTe/PbS	8.3	5.2	6.03
PbTe/SnTe	2.0	23.0	2.97
PbTe/YbS	13.0	3.3	5.93
PbTe/EuS	7.7	5.7	5.01
YbS/YbSe	3.83	10.6	no super-
YbS/EuS	5.3	7.7	conductivity

From the investigations of critical magnetic fields and dimensional crossover it became clear that in PbTe/PbS SLs superconductivity is confined to the interfaces between two semiconductors (superstructure period defined from crossover field on symmetric Sls appeared to be 2 times less than that determined by X-ray small-angle diffractometry; it means that on every interface there is superconducting layer) [4].

According to structural data in SLs studied the interface areas are saturated with regular grids of misfit dislocations with the grid parameter D_{dn} depending on a misfit between crystal lattice parameters in two semiconductors. The semiconducting periodic multilayers considered belong to a specific class of three-demensional Sls with in-plane modulation of the structure which is due to periodic dislocation stress fields and with compositional modulation in the orthogonal to layers direction.

There is a fact pointing to the absence of superconductivity when dislocations on the interfaces are absent. On symmetric PbTe/PbS SLs at small wavelengths, when the thicknesses of individual semiconducting layers are less than critical thickness for formation of dislocation grids, superconductivity does not appear.

More detailed investigations are necessary for to find possible correlations between superconducting properties on the one hand, and the properties of individual semiconductors and interfaces between them, on the other hand. It is quite probable that there is close connection between superconductivity and dislocations, i.e. superconductivity itself may result from dislocation structures and specific interfacial electronic states. Further experiments are needed to clarify this question.

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