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ANISOTROPIC MICROWAVE ABSORPTION IN HIGH-T_c LIKE SEMICONDUCTOR SUPERCONDUCTING SUPERLATTICES (001) PbTe–PbS

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The anisotropic microwave absorption in the presence of alternative magnetic field has been studied for the first time in superconducting superlattices based on PbTe–PbS, which are layered anisotropic systems similar to high T_c superconductors. A new method of study has been used. The microwave response was detected under broad-band conditions and compared with the results of synchronous detection. All the features which have been observed in high T_c materials are clearly seen here.

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The use of new systems with structure properties similar to high temperature superconductors (HTSC) has great importance for explaining the mechanism of superconductivity in these systems [1]. The lead chalcogenides (PbTe, PbSe and PbS) are narrow-gap semiconductors which exhibit superconductivity at $T < 2.0$ K when heavily doped with Tl acceptors [2]. Superconducting semiconductor superlattices (SL's), having the critical temperature much higher than that of bulk semiconductors, are of special interest to those who are interested in the high temperature superconductivity models [3, 4]. Semiconducting superlattices PbTe–PbS with misfit dislocation networks (MDN) have been found to be close structural and physical HTSC analogs [5–7]. We chose materials such as PbTe, PbSe and

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PbS which are not superconductors without Tl doping. Therefore, it may be supposed that the superconductivity of the SL made of those materials is connected with some peculiar electron state existing at the interfaces [3, 4]. The SL of lead chalcogenides with regular MDN at layer interfaces is a new type of semiconductor SL with new galvanomagnetic properties in comparison with bulk materials A^4B^6.

Regular square networks of edge MD's forming at the interfaces during epitaxial growth in the (001) orientation can be considered as models of CuO_2 planes in HTSC structure.

One of the most informative methods of investigation of superconductive peculiarities of various systems is to study the microwave properties in the presence of an alternative magnetic field H. These methods are successfully applied to investigations of both HTSC materials [1, 11] as well as hysteretic effects in the microwave response of superconductive SL's [9, 10]. Experiments were performed with an ESR ($\nu = 9.4$ GHz) superheterodyne spectrometer without rf modulation of the magnetic field. The spectrometer was modified so that the static magnetic field H could be swept from a negative value $(-H)$ through $H = 0$ to a positive value $(+H)$. We used both the field configuration $H \neq H_{\rm mw}$ ($H_{\rm mw}$ is the microwave field) which is the customary configuration for the ESR method and the configuration $H \parallel H_{\rm mw}$. In the latter case, the cryostat with the microwave cavity was removed from the electromagnet of the spectrometer and housed in magnetic shield and H was swept over a small interval by means of Helmholtz coils positioned at the throat of the cryostat inside the magnetic shield. The microwave-response signals were detected on an oscilloscope directly from the help of a low frequency (50 Hz) modulation of the field H. The test samples were positioned at the antinode of the field $H_{\rm mw}$ of the spectrometer cavities.

It was found that the dependence of the modulated magnetic field phase shift is relative to modulation magnetic field phase. In the present work, quantitative analysis of the observed effect of transition from in-phase response signal to $\pi/2$-phase is fulfilled when the modulation amplitude increases.

These SL's are single crystals with mosaic blocks of size 10–100 μm which are similar to mosaic block configurations on the KCl substrate. The block boundaries are weak links which lead to the appearance of Josephson interaction between blocks. It is manifested in the Meissner effect field dependencies and in the sharp decrease in critical currents at magnetic field as low as 1–10 Oe [8].

The microwave response signal (MRS) in SL PbTe–PbS at various modulation magnetic field amplitudes $H_{\rm m}$ is shown in Fig. 1. It is seen that the MRS is in phase with the modulation field at low $H_{\rm m}$ and the phase shift tends to $\pi/2$ as $H_{\rm m}$ increases. Quantitatively the value of phase shift φ as a function of $H_{\rm m}$ is presented in Fig. 2.

From the description of $\Delta\varphi(H_{\rm m})$ dependence we suggest that the modulated MRS ΔP registered as absorption has two components, one of which is in phase, and second one is shifted by $\pi/2$ as compared to the modulation field $H = H_{\rm m}\sin(\omega_{\rm m}t)$ ($\omega_{\rm m}$ is a modulation frequency)

$$\Delta P = A|\cos(\omega_{\rm m}t)| + B|\sin(\omega_{\rm m}t)|, \tag{1}$$

where A and B are coefficients of the above-mentioned components. In the interval

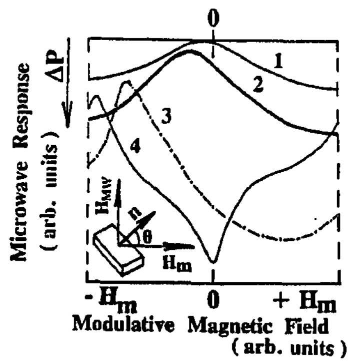

Fig. 1. Microwave response of SL PbTe–PbS in modulative magnetic field H_m (where $\omega_m/2\pi = 50$ Hz) with amplitudes H_m [Oe]: 1 — 0.05; 2 — 0.1; 3 — 0.4; 4 — 3.0. $T = 4.2$ K, $\theta = 45°$. Reciprocal orientation of H_m, H_{mw} (microwave field) and n normal to the SL plane is shown. The upper horizontal line corresponds to absorption level ΔP at $H_m = 0$; extrema of modulative field are indicated with dashed lines.

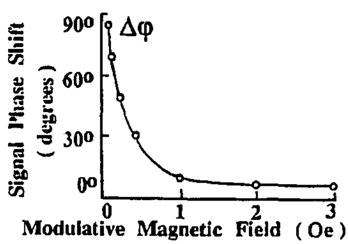

Fig. 2. Dependence of modulated microwave signal phase shift on H_m. Dots are experimental data taken from Fig. 1, $\Delta\varphi$ is calculated from $\varphi = \pi/2$, which corresponds to H_m extrema. Solid line is plotted via formula (2) with the fitted parameter $H^* = 0.23$ Oe.

$0 < \omega_m t < \pi/2$ the expression (1) may be written in the form

$$\Delta P = B\left(1 + \frac{H_m^2}{H^{*2}}\right)^{1/2} \cos\left[\omega_m t - \arctan(H^*/H_m)\right], \qquad (2)$$

where it is supposed that $A/B = H_m/H^*$, H^* is a fitted parameter which may be found from comparison with experiment. The full line in Fig. 2 is plotted via formula (2) at the value $H^* = 0.23$ Oe.

The good agreement of the suggested description with experiment permits us to make the conclusion that the modulated MRS has contributions from two mechanisms, one of them dominates at $H_m < H^*$, and the other at $H_m > H^*$.

It is shown in Ref. [10] that at low H_m the hysteretic MRS is dominating due to modulation of microwave losses at superconductive state due to magnetic field dependent Josephson inductance, involved parallel to the Josephson junctions active resistance [11]. At large H_m the main contribution to MRS microwave losses are due to destruction of the critical state of the superconductor by eddy currents, which arise at remagnetization of the sample by the modulation field. In the framework of this description the parameter H^* is defined by flux quantum value, which corresponds to the mean area quantization contour in the studies sample ($S = \Phi_0/H^*$), where H^* is a well-known state parameter of the sample. It is noted that in Ref. [10] the independent measurement of H^* value was found from the hysteresis curve 4 in Fig. 1. The value $H^* = 0.2 \pm 0.05$ Oe was found, which is in agreement with the above received result.

Therefore, microwave investigations of SL in alternating magnetic field showed that these structures as well as HTSC materials are Josephson media and their superconductive states may be easily destroyed by alternating magnetic field of insignificant value.

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