PIEZORESISTANCE EFFECT IN PbTe MICROWIRES

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Abstract

In physics of narrow-gap semiconductors, much attention is paid to A^4B^6 semiconductors, because they can be used to prepare a broad class of microconverters of physical quantities into electric signals. The multiellipsoidal band structure makes it possible to design piezoelectric converters based on these materials.

The technique of measuring the strain gauge factor **K** of a microwire (MW) is as follows. One end of the sample with a length of about 15 mm is attached, using glue BF-2, to the metal block connected to a microscrew, which enables it to move in a horizontal plane. The motion of the block is registered using a dial gauge. The other end of the sample is attached to another block connected to another microscrew, which gives it the possibility to move in a circumferential direction. The bending of the sample is measured using an indicator with a scale interval of 0.01 mm.

The relative strain of the MW was calculated by the formula

$$\varepsilon = 3/2\ (\mathrm{d\ h} / l^2),$$

where h is the bending deflection of the MW, mm; d is the diameter of the MW, mm; and l is the sample length, mm.

The strain gauge factor of the sample was defined as

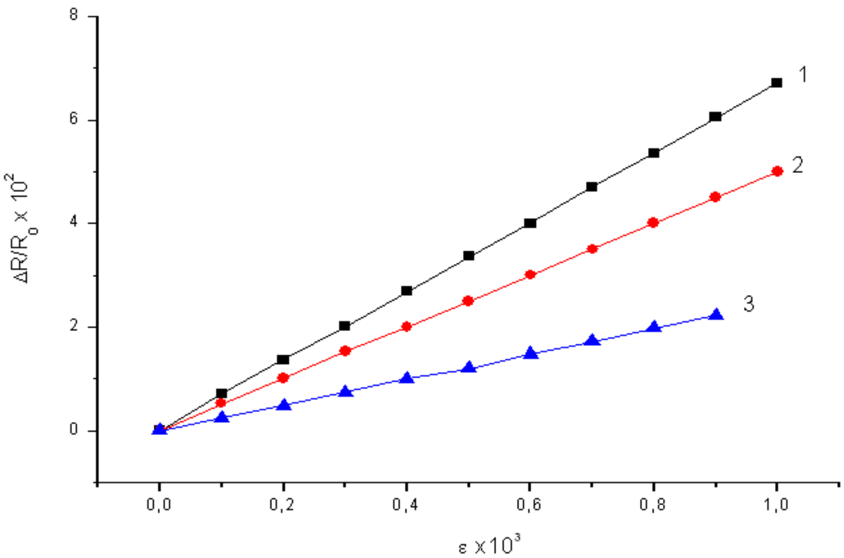
$$K = \Delta R / (R_0\ \varepsilon),$$

where R_0 is the initial resistance of the sample, ohm; ΔR is the change in resistance due to deformation, ohm .

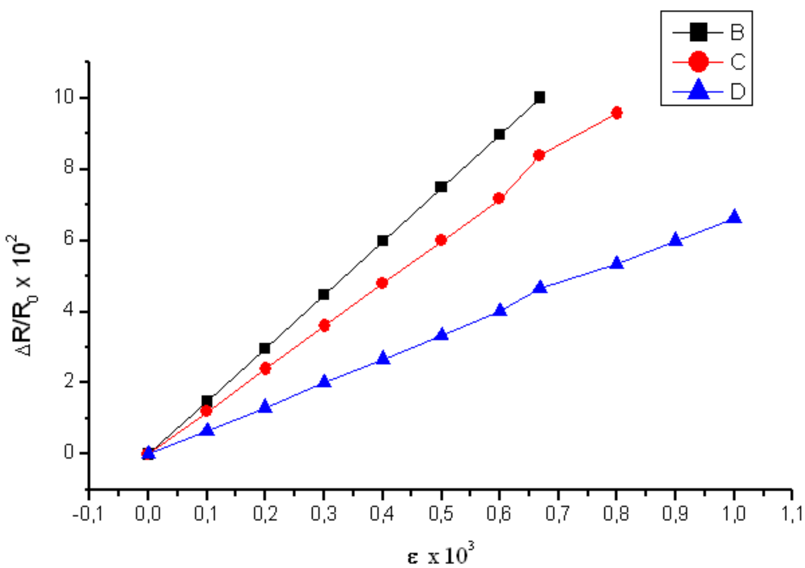
The strain effect or piezoresistance of A^4B^6 materials for bulk crystals were analyzed in a number of studies [1, 2]. According to these studies, piezoresistance is the result of superposition of two effects: a change in the population of isoenergetic ellipsoids located at the L points of the k-space along the <111> axes and a change in the parameters of the effective mass.

We studied n- and p-conductivity MW samples oriented along the <100> crystallographic axis. Figure 1 shows the dependences of change in the resistance of n- and p-conductivity crystals at T = 293 K. The data in Figs. 1a and 1b suggest:

1. The strain gauge factor is positive for both n- and p-conductivity (the resistance increases with increasing deformation).
2. In the elastic strain range for the p-conductivity samples, the dependence of relative resistance on strain is linear; and for the n-conductivity crystals, a certain deviation from linearity is observed.
3. A decrease in the MW diameter leads to an increase in the strain gauge factor.
4. The strain gauge factor **K** of the n-conductivity samples (K_n = 30–60) is less than the **K** values of the p-type MW samples (K_p = 70–150) by a factor of 2-2.5.



a)



b)

Fig. 1. Dependences of change in the relative resistance on relative strain for the PbTe MW samples (T = 293 K): (a) n-conductivity: (*1*) d = 36.3 mm, K_n = 63; (*2*) d = 60.0 mm, K_n = 53; (*3*) d = 139.5 m, K_n = 34 and (b) p-conductivity: (B) d = 36.3 mm, K_p = 150; (C) d = 50.0 mm, K_p = 120; (D) d = 115.3 m, K_p = 73.0.

The factor K of PbTe Lead Telluride wire crystals was estimated as described in [3]. According to this study, the factor K can be represented as follows:

$$K = K_L \cos 2\Theta + K_t \sin 2\Theta,$$

where K_L is the longitudinal strain gauge factor, K_t is the transverse strain gauge factor, and (Θ) Theta is the angle between the direction of the applied strain and the direction of the electric field.

The strain gauge factors K_L and K_t are expressed through piezoresistance coefficients (π_{11}, π_{12}, and π_{44}) as follows:

$$K_L = 1 + 2\nu + \pi_l\ Y,$$
$$K_t = \pi_t - 1,$$
$$\pi_l = \pi_{11} + 2(\pi_{44} + \pi_{12} - \pi_{11})\,F(l\,m\,n),$$
$$\pi_t = \pi_{12} + (\pi_{11} - \pi_{12} - \pi_{44})\,H(l\,m\,n),$$
$$F(l\,m\,n) = l_1^2 m_1^2 + m_1^2 n_1^2 + n_1^2 l_1^2,$$

where (π) PI, (ν) Nude, (Y) Y, l_1, m_1, and n_1 are the direction cosines between the axis of the cubic crystal and the longitudinal axis of the sample, and

$$H(l\,m\,n) = l_1^2 l_2^2 + m_1^2 m_2^2 + n_1^2 n_2^2,$$

where l_2, m_2, and n_2 are the direction cosines between the direction of the electric field and the direction of the applied strain. Substituting the direction cosines into the respective formulas for the case where (x, y, z) are perpendicular to the <100> axis and using the formula for Young's modulus and Poisson's ratio, after simple transformations, we obtain

$$F(l\,m\,n) = \cos^2\varphi \sin^2\varphi, \quad H(l\,m\,n) = 2\cos^2\varphi \sin^2\varphi.$$

where (φ) Phi is the angle between the direction of deformation on microwire cristal in a spherical coordinate system.

To compare the curves calculated from the above formulas and the experimental results, we give the K values for the case where the angle $\varphi = \pi/4$, i.e., where the functions F(l m n) and H(l m n) take the maximum values (F(l m n) = 1/4, H(l m n) = 1/2).

The required values for the piezoresistance constants of the PbTe crystals were taken from [4] and [5] for the p- and n-type samples, respectively; the compliance coefficient values were taken from [6]. For the p-conductivity crystals, we obtained

$$K_p = 105\cos^2\varphi - 6\sin^2\varphi;$$

for the n-type crystals, we have

$$K_n = -14\cos^2\varphi + 32\sin^2\varphi.$$

According to the resulting formulas, the maximum value of the factor **K** is 105 and 32 for the p- and n-conductivity MW samples, respectively. These values are 1.5–2 times lower than the strain gauge factor values derived by us for the MW.

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