INFLUENCE OF INTERFACIAL PHASES ON THERMAL AND ELECTRICAL CONDUCTIVITY IN GaSb-CrSb EUTECTIC SYSTEM

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GaSb-CrSb eutectic alloys were prepared by the vertical Bridgman method. By investigating of microstructure of GaSb-CrSb eutectic composite by electron microscope, it has been established that the interfacial zone between the semiconductor matrix and metallic inclusions is generated. In computations of effective electrical and thermal conductivity of the composite were taken into account the role of these interfacial zones.

Keywords: Eutectic composite, SEM and EDX analysis, thermal and electrical conductivity, thermoelectrics, interfacial zone.
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INTRODUCTİON

Diluted magnetic semiconductor materials based on III-V compounds and 3d-metals eutectic composites, having a stable composition and properties, are promising materials for spintronic devices [1-3]. GaSb-CrSb eutectic composite, where CrSb antiferromagnetic needles are distributed in GaSb matrix is of significant interest.

Previously, by X-ray diffraction analysis it was confirmed that the GaSb-CrSb composite has a two-phase structure, and enthalpy of fusion and specific heat were determined. Heat flow and specific heat capacity studies for GaSb-CrSb eutectic composite have been made in the 293-1273K temperature range. The initial and final points of melting temperature are determined as 943K and 965K, respectively. The peaks observed on the specific heat capacity curves possibly due to magnetic transitions [4]. It has been shown that in calculation of the heat and electrical conductivity, the inter-phase zones should be taken into consideration.

EXPERİMENTAL

GaSb-CrSb eutectic composites were prepared by using the vertical Bridgman method as described in detail in ref. [5,6]. Samples for electric measurement were prepared in a parallelepiped form with size (2×4×10)cm^3. On both the lateral sides of the samples, four contact probes were attached to measure the electrical conductivity (σ), thermal power (α) using the compensation method and the thermal conductivity (K) was measured by the absolute stationary heat flow method [7,8].

RESULTS AND DİSCUSSİON

An investigation of the temperature dependences of the electrical conductivity in the direction of the growth of crystallization, electric current, and magnetic field in the temperature range 80-300K shows that the short-circuit effect of metallic inclusions leads to anisotropy of these parameters.

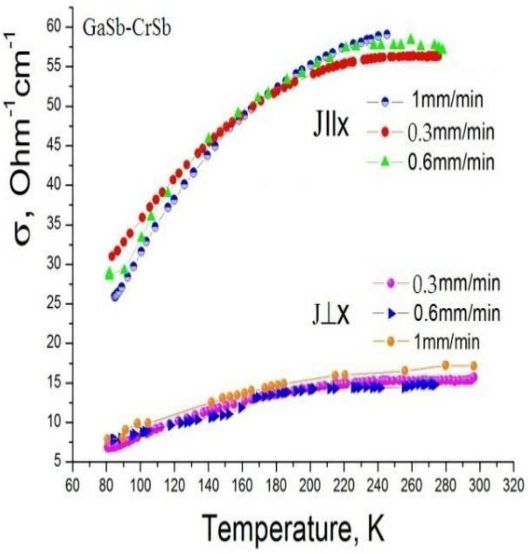

Fig.1. Temperature dependence of electric conductivity for GaSb-CrSb composite

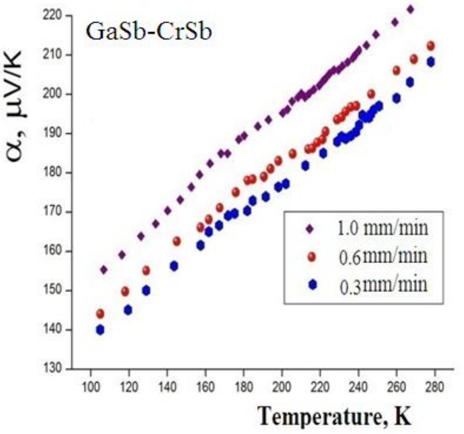

Fig.2. Temperature dependence of thermopower for GaSb-CrSb composite

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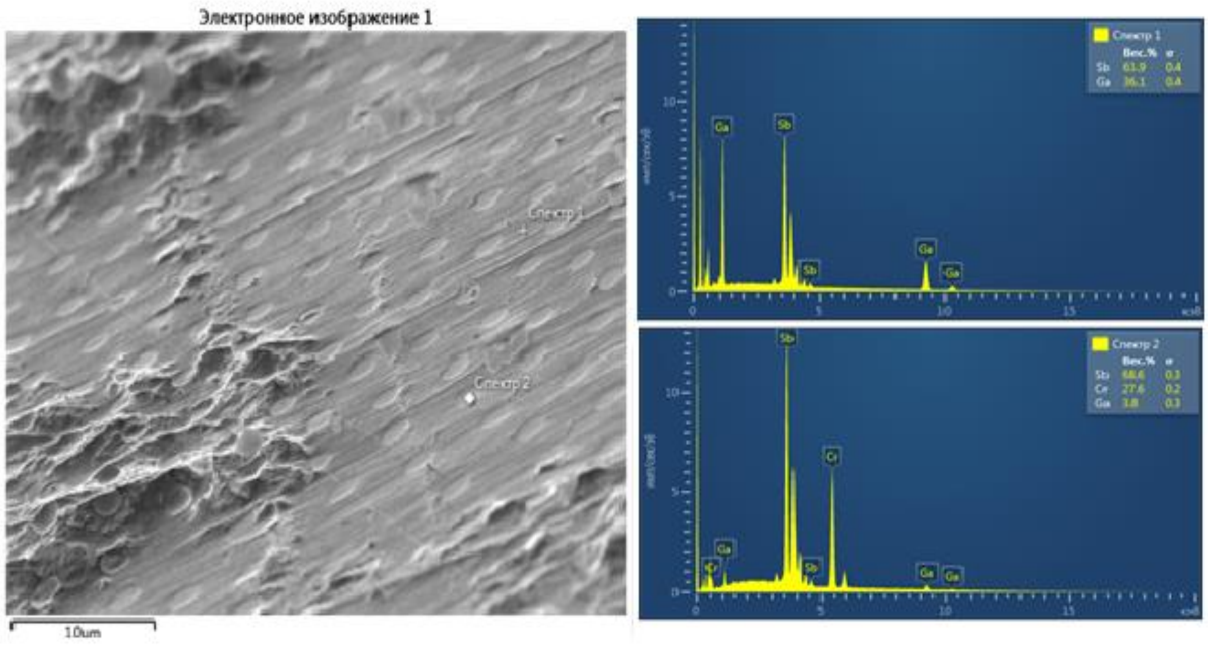

Fig.3. X-ray spectra of GaSb–CrSb obtained with SEM–EDX from the needle and matrix phases along the lateral directions of the specimens

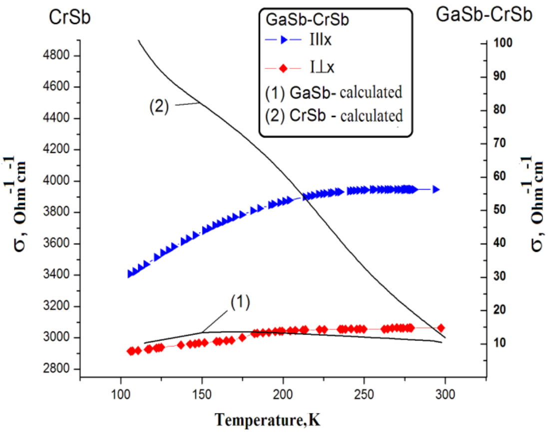

Fig.4. Temperature dependence of electric conductivity for GaSb-CrSb composite curves 1 and 2 are calculated from the formula (1)

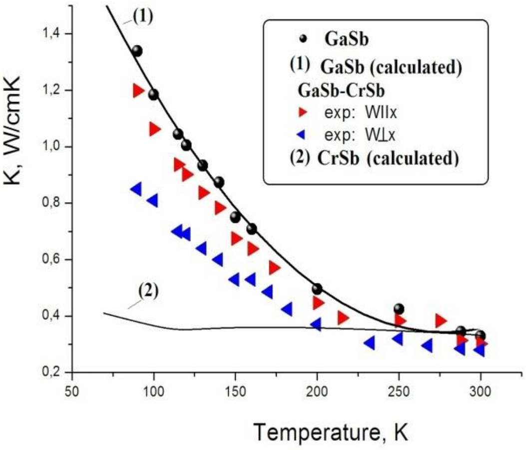

Fig.5. Temperature dependence of thermal conductivity for GaSb-CrSb composite curves 1 and 2 are calculated from the formula (2)

As seen from Fig.1, due to short-circuiting action by needle-shaped inclusions, the electrical conductivity in the I||x direction is significantly larger than that in the I⊥x direction. The coefficient of conductivity anisotropy at 80 K is $\sigma_{\|}/\sigma_{\perp}=3.2$ and decreases with increasing temperature: $\sigma_{\|}/\sigma_{\perp}=3$ at 300K.

The electrical conductivity (Fig.1.) and thermopower(Fig.2.) of the samples taken with different crystallization speeds (1mm/min, 0.6mm/min, 0.3mm/min) was measured. The temperature dependence of thermo power at the mutual directions of current, magnetic field and inclusions between of 80K and 300K have been investigated. Strong anisotropy is also observed in the temperature dependence of the thermoelectric power (Fig.2).

The short-circuiting of V_α potential by metallic inclusions in ΔT||x direction is caused by a decrease in the thermo power with anisotropy degree of $\alpha_{\perp}/\alpha_{\|}=2.4$.
The observed change in electrical conductivity and thermopower at different crystallization rates, associated with changes in the size of the inclusions, indicates the possibility of controlling the parameters of the material under study [9].

Based on SEM examinations (Fig.3), the needle-shaped metallic inclusions with a diameter of about 0.9-1.6 μm, a length of 20÷50 μm and a density of $\sim 6\cdot 10^4$ mm^{-2} are uniformly and parallel distributed in the GaSb matrix. It was found that the matrix contains Ga = 36.1wt%, Sb = 63.9 wt% (Fig.3, spectrum 1), the inclusion are contained Cr = 27.8 wt%, Sb = 68.6 wt%, Ga = 3.8wt% (Fig.3, spectrum2).

Different models were proposed in order to determine composite physical parameters. In the present study, heat and electrical conductivity of the GaSb-CrSb eutectic composite was calculated based on the theory of effective ambient.

The effective electrical conductivity in the direction of crystallization ($\sigma_{\|}$) and perpendicular to it ($\sigma_{\perp}$) was calulated by the following expressions [10,11]:

$$\sigma_{\perp} = \frac{(\sigma_1-\sigma_2)\left(1-\sqrt{\frac{c}{1+c}}\right)+\sigma_1\sqrt{\frac{1+c}{c}}}{1+\left(\frac{\sigma_2}{\sigma_1}\right)\sqrt{\frac{1+c}{c-1}}}, \quad \sigma_{\|} = \sigma_1\frac{1}{1+c} + \sigma_2\frac{c}{1+c} \qquad (1)$$

here σ_1 and σ_2 are the electrical conductivity of the matrix and metal phase, and c is the volume fraction of the metal inclusions.

The following formula is used for the effective thermal conductivity in parallel ($K_{\|}$) and perpendicular ($K_{\perp}$) to the metal needles [12]:

$$\left.\begin{aligned} K_{\|} &= K_2 + (1-c)(K_1-K_2) \\ K_{\perp} &= K_2 + \frac{2K_2(1-c)(K_1-K_2)}{2K_2+c(K_1-K_2)} \\ c &= \frac{V_i N_i}{1-V_i N_i} \end{aligned}\right\} \qquad (2)$$

here K_1 and K_2 are the thermal conductivity of the matrix and metal phase, respectively, N_i is the density of the metal phase, V_i is the volume of the metal needles. The influence of the inclusions on the thermal conductivity is negligible due to their low volume fraction.

The temperature dependence of thermal conductivity K(T) of GaSb-CrSb eutectic composite are presented on the fig. 6. Thermal conductivity up to 200K depends on temperature as $\sim T^{-0.8}$. Two features are observed in the temperature dependence: the anisotropy in K(T) in parallel and perpendicular directions of metallic inclusions to the solidification front and additional thermal conductivity. At 80 K, anisotropy degree is 1.27 with temperature increasing it reduces and at room temperature disappears. The calculations have shown that free path length of the long-wavelength phonons is the same order as the transverse dimensions of metallic inclusions, which indicates the relationship of the observed anisotropy to the long-wavelength phonons scattering at the boundary inclusions.

The heat transfer mechanisms have been investigated in the framework of Callaway model. The total thermal conductivity of the composite is calculated taking into account contributions of the electron and phonon parts.

Electronic thermal conductivity is calculated by the formula Wiedemann-Franz, and phonon thermal conductivity is for relaxation model of Callaway [13]:

$$K_f = \frac{k}{2\pi^2 v}\left(\frac{k}{\eta}\right)^3 T^3 \int_0^{\theta/T} \frac{\tau_c z^4 e^z}{\left(e^z-1\right)^2} dz$$

$$K_1 = K_{el} + K_f, \qquad (3)$$

here θ is the Debye temperature, $z = \frac{\eta\omega}{k_0 T}$, ω is the phonon frequency, τ_c is the generalized relaxation time.

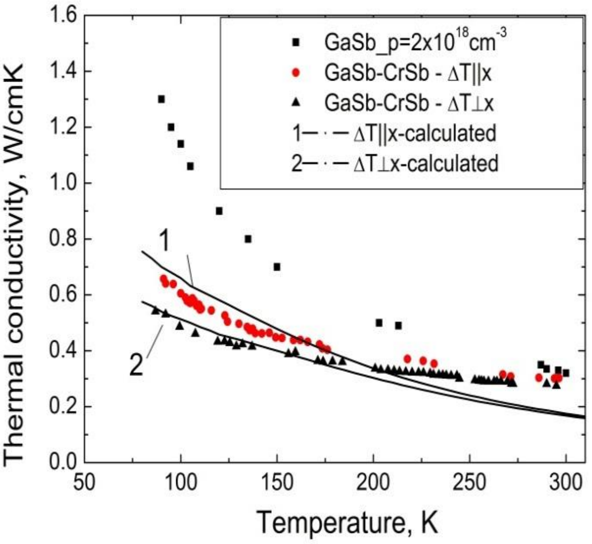

Fig.6. Thermal conductivity of GaSb and GaSb-CrSb composite, curves 1 and 2 are calculated from the formula (3)

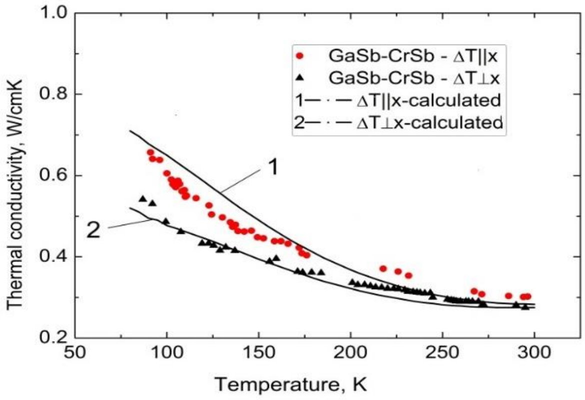

Fig.7. Thermal conductivity of GaSb and GaSb-CrSb composite, curves 1 and 2 are calculated from the formula (4)

As can be seen from Fig.6, above 200K the calculated curve is below the experimental one due to the additional thermal conductivity which is 30% of the total at 300K. Most likely, in this region there are the other mechanisms of heat transfer. Such mechanisms can be magnon and photon thermal conductivity. However, calculations show that in this region, their parts in thermal conductivity are negligible. According to Koshino and Ando model [14] the resonance energy transfer can be the dominant mechanism in thermal conductivity increasing. It is known that 3d-transition metal impurities may produce the deep and shallow impurity levels in the III-V group compounds [15]. When the excited electron from a deep local level in the band gap moves into the conduction band, other conduction electron returns to the shallow level. At thermal gradient, ionization energy is transferred to the cold edge of the sample. As seen from fig.1 electrical conductivity of GaSb-CrSb eutectic composite in the range of 80÷300K prevails over the extrinsic conductivity and in this region the resonance energy transfer is expressed as follows [13]:

$$K_2 = K_{el} + K_f + K_R \qquad (4)$$

Here ε_∞ is the dielectric constant, k_B is the Boltzmann constant, n_d is the local level concentration, E_d is the energy of the local level, m_0 is the mass of the

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electron, we have assumed ε_∞=16 and E_d=0.02eV. The total thermal conductivity calculatied by formula (4) well agrees with the experimental data (Fig. 6).

CONCLUSİONS

It has been shown that the role of the interphase zone in anisotropy of electric and thermal conductivity of eutectic compositions of the semiconductor-metal type is substantial and that it is necessary to take into account volume fractions of the interphase zone in computation of effective thermal conductivity in the framework of the effective medium theory. The influence of the inclusions on the thermal conductivity is negligible due to their low volume fraction. The heat transfer mechanisms have been discussed in the framework Callaway model. The thermal conductivity calculated with taken into account the role of the charge curriers transfer, point defects, three-phonon normal and three-phonon umklapp processes and the mechanism of resonance transfer of ionization energy.

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