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MAGNETIC AND ELECTRICAL PROPERTIES OF GaSb-CrSb EUTECTIC SYSTEM

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The magnetic and electrical properties of the GaSb-CrSb eutectic composite synthesized by the Bridgman method have been studied. By investigating GaSb-CrSb eutectic composite microstructure by electron microscope, it has been established that there are the interfacial zones between the semiconductor matrix and metallic inclusions. The role of these interfacial zones was taken into account in computation of effective electrical and thermal conductivity of the composite. The Neel temperature and the Curie-Weiss asymptotic temperature is determined as T= 680K and Θp =-300K, respectively.

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1. Introduction

In optoelectronic and biomedical applications it has been now widely used eutectic systems, in particular, eutectics based on diluted magnetic semiconductor materials of III-V compounds and 3d-metals composites, which have stable composition and properties [1-6].

GaSb-CrSb eutectic composite, in which 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]. In the present study, the magnetic and electrical characteristics (magnetization, magnetic susceptibility and electrical conductivity) of the GaSb-CrSb composite are investigated in a wide temperature range.

2. Experimental

GaSb-CrSb eutectic composites were prepared by using the vertical Bridgman method as described in detail in ref. [7-9]. 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 [11]. A small amount of GaSb-CrSb composite (0.5g) was placed in cooled

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vacuum a quartz ampoule. In the 100 ÷ 1000K temperature range for 0 - 1.0Tl magnetic field magnetisation and magnetic susceptibility were investigated by the pondemotor method.

3. Results and discussion

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.

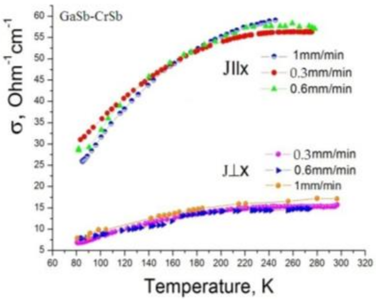

Fig.1. Temperature dependence of electric conductivity for GaSb-CrSb composite.

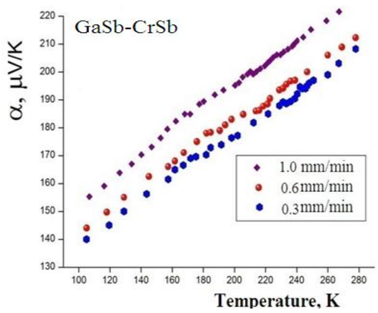

Fig. 2. Temperature dependence of thermopower for GaSb-CrSb composite.

As seen from Fig. 1, the electrical conductivity in the I||x direction is significantly larger than that in the I⊥x direction due to short-circuiting action by needle-shaped inclusions. The coefficient of conductivity anisotropy at 80 K is $\sigma_{\parallel}/\sigma_{\perp}=3.2$ and decreases with increasing temperature: $\sigma_{\parallel}/\sigma_{\perp}=3$ 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) were 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 $\alpha_{\perp}/\alpha_{\parallel}=2.4$.

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 metallic inclusions contain Cr = 27.8 wt% ,Sb = 72.3 wt%

(Fig.3, spectrum 2), and the interfacial phases contain Cr = 31.4 wt%, Sb = 64.4 wt%, Ga = 4.2wt% (Fig.3, spectrum 3).

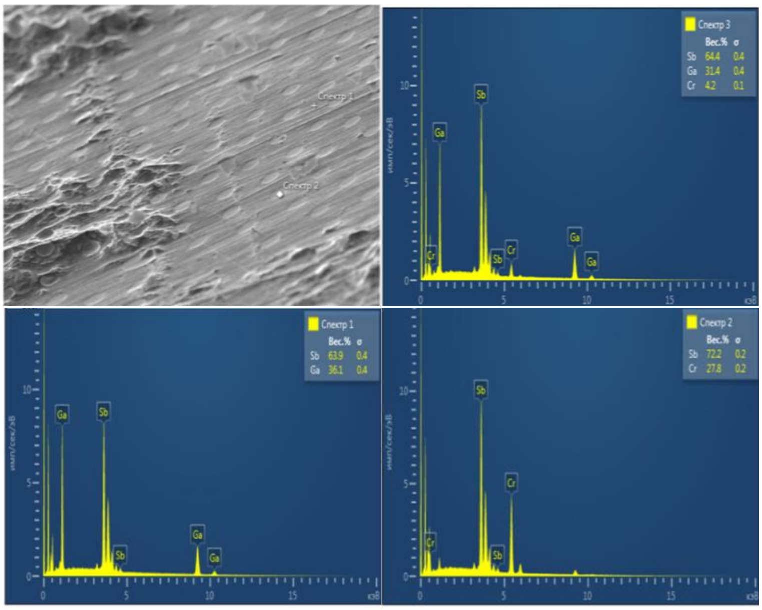

Fig. 3. X-ray spectra of GaSb–CrSb obtained with SEM–EDX from the needle and matrix phases along the lateral directions of the specimens.

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 ($\sigma_{\parallel}$) and perpendicular to it ($\sigma_{\perp}$) was calulated by the following expressions [11-13]:

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

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 (Fig. 4).

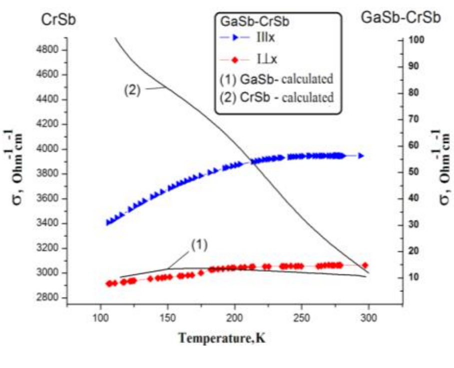

Fig. 4. Temperature dependence of electric conductivity for GaSb-CrSb composite; curves 1 and 2 are calculated from the formula (1).

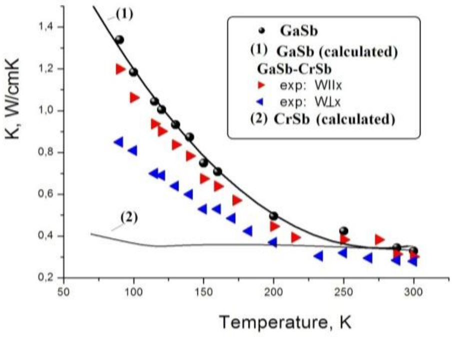

Fig. 5. Temperature dependence of thermal conductivity for GaSb-CrSb composite; curves 1 and 2 are calculated from the formula (2).

The following formula is used for the effective thermal conductivity in parallel ($K_{\parallel}$) and perpendicular ($K_{\perp}$) to the metal needles [13]:

$$K_{\parallel} = K_2 + (1-c)(K_1 - K_2) \quad K_{\perp} = K_2 + \frac{2K_2(1-c)(K_1-K_2)}{2K_2 + c(K_1-K_2)}, \; c = \frac{V_i N_i}{1 - V_i N_i} \qquad (2)$$

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 (Fig. 5.). The influence of the inclusions on the thermal conductivity is negligible due to their low volume fraction [15].

The results of conducted measurements for special magnetization of CrSb compound and GaSb-CrSb composite in B = 0.86Tl magnetic field are shown in Fig. 6.

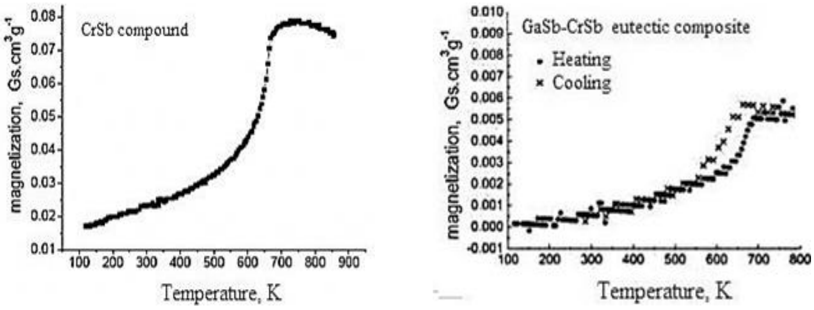

Fig. 6. Temperature dependence of special magnetization for GaSb-CrSb composite [10].

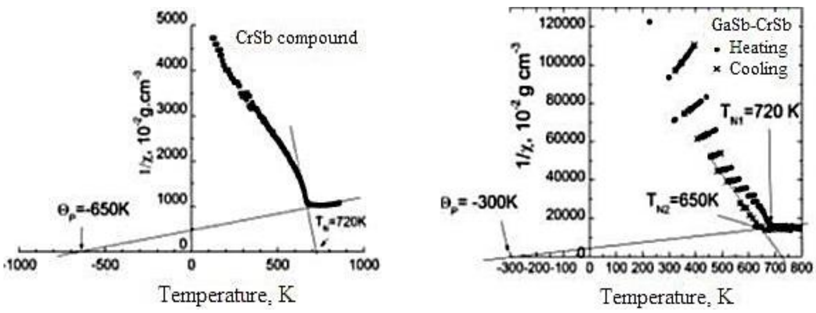

Fig. 7. Temperature dependence of magnetic susceptibility for GaSb-CrSb composite[10].

It is seen from the figure that M = f (T) has a antiferromagnetic character and that in the 650 - 700K interval the paramagnetic transition takes place. As it is obvious from Fig. 6. hysteresis is observed near the magnetic phase transition. The Neel temperature and the Curie-

Weiss asymptotic temperature is determined as T= 680K and Θp=-300K, respectively for the GaSb-CrSb eutectic (Fig. 7). The investigation shows that the specific magnetization for the GaSb-CrSb composite is smaller than that of the CrSb compound. The decrease in special magnetism during composite formation is due to the weakening of the magnetic exchange between ferromagnetic constants [14].

4. Conclusions

The observed change in electrical conductivity and thermo power 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. By studying magnetic properties the GaSb-CrSb composite, it has been shown to be antiferromagnetic. The Neel temperature and the Curie-Weiss asymptotic temperature is determined as T= 680K and Θp =-300K, respectively.

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