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LOW TEMPERATURE PERFORMANCES OF DOPED GASB WHISKERS

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Abstract. Temperature dependencies of n-type GaSb whisker resistance are measured in the temperature range of 1,5–300 K and in the magnetic field up to 14 T. The peculiarities of whisker resistance in the low temperature range (a sharp drop in the whisker resistance at about 4,2 K) are observed. Superconductivity in the whiskers is caused by the appearance of weak antilocalization, which leads to the emergence of negative magnetoresistance. The magnetoconductivity of these whiskers in the low field regime turns out to be well described by a two-dimensional (2D) weak antilocalization (WAL) model.

Key words: magnetoresistance, magnetoconductivity, n-type GaSb whiskers, weak antilocalization.

1. Introduction

GaSb is an important material as a substrate for lasers, high speed electronic and optoelectronic devices [1, 2]. To take full advantage of the potential and functionality of GaSb-based devices, it is necessary to grow the lattice-matched semiinsulating-substrate epitaxial layers or QDs [3, 4]. However, the influence of the substrate substantially restricts the advantages of the material. GaSb ingots [5], free-standing nano- and microwhiskers growth results in avoiding these shortcomings. [6]. Recently, it has been suggested that GaSb nanowires can be used as building blocks for lasing devices [7]. GaSb nanowires attract considerable attention due to their high hole mobility and scalable dimensions [8, 9]. At the same time, these high-performance p-type GaSb nanowires can also be potentially integrated into n-type InSb, InAs or InGaAs NW devices applying different nanowire transfer techniques to facilitate the III-V complementary metal-oxide-semiconductor [8, 10]. Nevertheless, GaSb whiskers have poorly been studied so far.

The aim of the paper is research into resistance and magnetic susceptibility of n-type GaSb whiskers in the temperatures ranged between 1,6–300 K and in the magnetic field up to 14 T.

2. Experiment

N-type GaSb microcrystals with various Te concentrations are selected as the objects of this research. The whiskers are grown by a chemical vapour deposition (CVD) method in the closed system. The results of the whiskers investigation by using the ion mass spectroscopy have shown that GaSb microcrystals have Te concentration that corresponds to a dielectric side of MIT, which ranges from 10^{18}cm^{-3} to 5 10^{18}cm^{-3}. Electric contacts are created at the opposite ends of the whiskers. This method provides ohmic contacts to the samples in the temperature range of 4,2–300 K. As a result, ohmic I-V curves are obtained. The results of the whiskers investigation by using the ion mass spectroscopy show that n-type GaSb microcrystals (ρ300K = 0,0113-0,0137 Ohm × cm) have Te concentration that corresponds to the dielectric side of MIT. The samples are cooled down to 4,2 K in a helium cryostat. Special equipment with a bifilar microfurnace is used to heat the samples to the room temperature. While measuring, the regulated electric current of 100 μA-1mA produced by the current source Keithley 224 is used. The digital microvoltmeters Keithley 2000 and Keithley 2010 with simultaneous automatic data registration via a parallel port of PC are used to measure voltage on potential contacts of the samples, output signals from a thermocouple and a magnetic field sensor. The accuracy is up to 1×10-6 V. A Bitter magnet is used to study the effect of strong magnetic fields on the samples. The induction of the magnet is 14 T, the deflection time is 1,75 T/min at 4,2 K.

3. Experimental results

The temperature dependencies of GaSb whisker resistance are measured in the temperature range of 1,5–300 K. With temperature changing, the whisker resistance changes, that is typical for metals. A sharp drop in the whisker resistance observed at about 4,2 K is indicative of electron localization in the crystal (Fig. 1).

To find out the origin of electron localization, one can suppose that superconductivity exists in the whiskers taking into account paper [11].

The source of superconductivity in the whiskers is not evident. It cannot be a supeconductive Ga-Au contact, since the Curie temperature for this alloy is much lower. The superconductivity in the whiskers may be the result of weak antilocalization leading to the emergence of negative magnetoresistance.

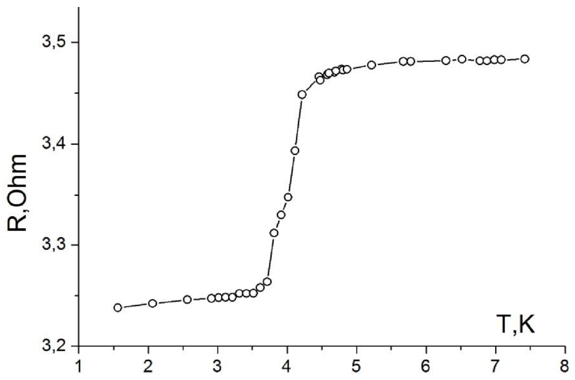

Fig. 1. Temperature dependence of resistance for GaSb whiskers at low temperatures.

Classical magnetoresistance at low (helium) temperatures is known to be absent in semiconductors and semiconductor structures with two-dimensional (2DEG) and one-dimensional electron gas (1DEG) [12]. The emergence of either positive or negative magnetoresistance depends on the electron wave interference during the spin-orbit interaction. In particular, a singlet state of the interfering electron waves with the total spin J = 0 leads to an increase in the conductivity (antilocalization effect).

The quantum coherence length for the GaSb whiskers is $L_f \sim 540$ nm at T = 4,2 K [13] that is much less than the sample dimensions (~20μm in diameter). So we should use a 2D or 3D model of weak antilocalization (WAL) [14] to describe magnetoresistance at low temperatures in the whiskers. The theoretical dependence of magnetoresistance in the magnetic field for two-dimensional electron gas [15] has the following form:

$$\frac{\Delta s\,(B)}{G_0}=\frac{s\,(B)-s\,(0)}{G_0}=f\left(\frac{B}{H_{so}+H_j}\right)+ +\frac{1}{2}f\left(\frac{B}{2H_{so}+H_j}\right)-\frac{1}{2}(1+b\,)\,f\left(\frac{B}{H_j}\right), \qquad (1)$$

where B represents the magnetic field, $G_0=e^2/2ph$, b are the factor determining the value of Maxi-Thompson correction. Later, we shall consider $b\to 0$.

The function $f(x)$ is determined by the digamma function $\Psi(z)$:

$$f(z)=\Psi\left(\frac{1}{2}+\frac{1}{x}\right)+\ln(x). \qquad (2)$$

The parameter H_j is related to the dephasing time t_j of the wave function of electron because of inelastic scattering caused by an electron-electron or electron-phonon interaction:

$$H_j=\frac{\mathbf{h}c}{4eDt_j}, \qquad (3)$$

The parameter H_{so} is related to the dephasing time τ_{so}, caused by a spin-orbit interaction of the electrons:

$$H_{so}=\frac{\mathbf{h}c}{4eDt_{so}}, \qquad (4)$$

where c denotes the velocity of light, D stands for the diffusion coefficient.

The conductivity change $\Delta s\,(B)$ in the magnetic field, normalized by the amount of G_0, was determined from the experimental dependencies of GaSb whiskers magnetoresistance in a magnetic field in the following way:

$$\frac{\Delta s\,(B)}{G_0}=\frac{s\,(0)}{G_0}\left(\frac{\Delta R(B)}{R(0)}+(mH)^2\right), \qquad (5)$$

where m is the Hall mobility, H stands for the magnetic field intensity. The temperature dependences of mobility for these microcrystals are presented in [16].

The dependences $\Delta s\,(B)$ obtained in this way (Fig. 2) were matched with the theoretical ones (1) to find the parameters H_j and H_{so}.

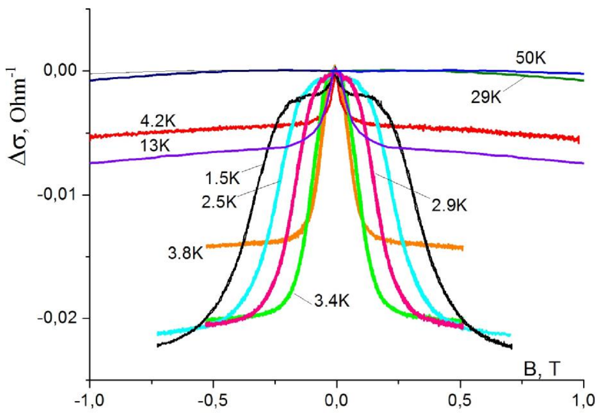

Fig. 2. Change in magnetoconductivity in a magnetic fields at different temperatures for a 20mm GaSb whiskers.

The temperature dependences L_j and L_{so} are calculated by using the following relations:

$$L^2{}_j=Dt_j=4\frac{e}{\mathbf{h}c}H_j \qquad (6)$$

$$L^2{}_{so}=Dt_{so}=4\frac{e}{\mathbf{h}c}H_{so} \qquad (7)$$

where L_j is the coherence length L_{so} represents the spin-orbit interaction length. The temperature curves $L_j(T)$ and $L_{so}(T)$ are shown in Fig. 3.

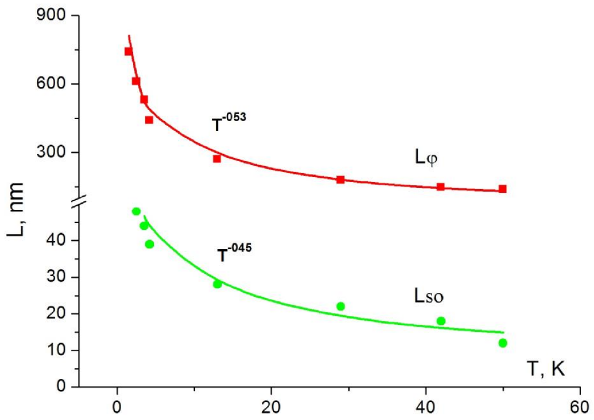

Fig. 3. L_j and L_{so} as functions of temperatures obtained from the fitting with the 2D localization theory

It is well-known that the coherence length L_j is proportional to $T^{-1/3}$ for the one dimensional system and to $T^{-1/2}$ for the two dimensional one [12]. Fig.3 shows that coherence length L_j and spin-orbit length L_{so} for 20 µm whiskers are proportional to $T^{-0.53}$ and $T^{-0.46}$ respectively, which are very close to the exponent $T^{-1/2}$ characteristic for the two-dimensional system.

4. Conclusions

Resistance and magnetoresistance of n-type GaSb whiskers are measured in the temperatures ranged between 1,6–300 K and in the magnetic field up to 14 T. The obtained sharp drop in the resistance indicates in the possible localization of electron gas in the whiskers. The source of the localization consists in the inducing of superconducting state in the whiskers at low temperatures (up to 4,2 K). The possible reason for the superconductivity in the whiskers can be weak antilocalization which in turn leads to the emergence of positive magnetoresistance. The magnetoconductivity of these whiskers in the low field regime can be well described by a two-dimensional (2D) weak antilocalization (WAL) model, where the dephasing length of electrons corresponds to $T^{-1/2}$ dependence.

The obtained results show that the GaSb whiskers have potential applications in cryogenic engineering.

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НИЗЬКОТЕМПЕРАТУРНІ ХАРАКТЕРИСТИКИ ЛЕГОВАНИХ НИТКОПОДІБНИХ КРИСТАЛІВ АНТИМОНІДУ ГАЛІЮ

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Проведено вимірювання температурних залежностей опору ниткоподібних кристалів (НК) GaSb n-типу в температурному діапазоні 1,5–300 К та магнітному полі до 14 Тл. Спостерігалось різке (стрибкоподібне) падіння опору в НК за температури 4,2 К. Можливою причиною появи надпровідного стану в ниткоподібних мікрокристалах може бути виникнення слабкої анти локалізації та відповідно негативного магнетоопору. Встановлено, що магнетоопір досліджуваних НК можна описати двовимірною моделлю слабкої антилокалізації в магнітному полі.

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