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ANOMALOUS TEMPERATURE DEPENDENCE OF THE RESISTIVITIES IN n-InSb BELOW 100 mK

Seizo Morita, Tetsuo Fukase*, Yoshimasa Isawa,
Shuichi Ishida**, Yosihisa Takeuti
and Nobuo Mikoshiba

Research Institute of Electrical Communication,
Tohoku University, Katahira, Sendai, Japan
*The Research Institute for Iron, Steel and Other Metals,
Tohoku University, Katahira, Sendai, Japan
**Department of Physics, Faculty of Science,
Osaka University, Toyonaka, Osaka, Japan

The resistivities of n-InSb in the metallic impurity conduction region were investigated down to 20 mK and up to 100 G. We observed a new logarithmic temperature dependence and a strong positive magnetoresistance below 100 mK.

I. Introduction

Since the energy scale of shallow impurity levels in semiconductors is small, this system is very sensitive to the small change in impurity concentration, the randomness due to the distribution of impurities, the degree of compensation, etc.. Therefore, many interesting phenomena have been observed in semiconductors in the metallic impurity conduction region at very low temperatures[1]-[5]. In n-InSb , a logarithmic temperature dependence and a negative magnetoresistance(MR) have been reported above 0.1 K, and they have been explained by an s-d model in semiconductors[2]-[3] which was first discussed by Toyozawa[6] by assuming d-like localized electrons brought about by the inhomogeneities. Similar phenomena found in Ge:Sb and Si:P[4] have also been interpreted by this model[7]. However, on the interpretation of the logT dependence of resistivity in a Si-MOS inversion layer by the s-d model, some doubts have been cast by Kawaguchi et al.[5] from their experimental results that the negative MR comes only from the component of magnetic field perpendicular to the surface. Recently, a logT dependence of resistivity has been found also in dirty metallic wires[8]. Therefore, it seems to us that the logT dependence was observed in 1, 2, and 3 dimensional(D) systems.

In order to investigate the true origin of the logT dependence and the anomalous MR in n-InSb, we have carried out the measurements down to 20 mK and up to 100 G.

II. Experimental

Temperature and magnetic field dependences of resistivity were measured between 4.2 K and 0.02 K below 100 G for the samples of n-InSb with high mobility, having N_D-N_A=9.0-25x10^{13}/cm^3 in the metallic impurity conduction region[9].

As shown in Fig.(1), in zero magnetic field, a new logT dependence of resistivity is found in the low N_D-N_A sample(67S) below 1 K, while the resistivities in the high N_D-N_A samples(C2-511, 210-4) in the present measurement take the maximum values at about 0.2 K. The coefficient of logT in the low N_D-N_A sample has the sign opposite to

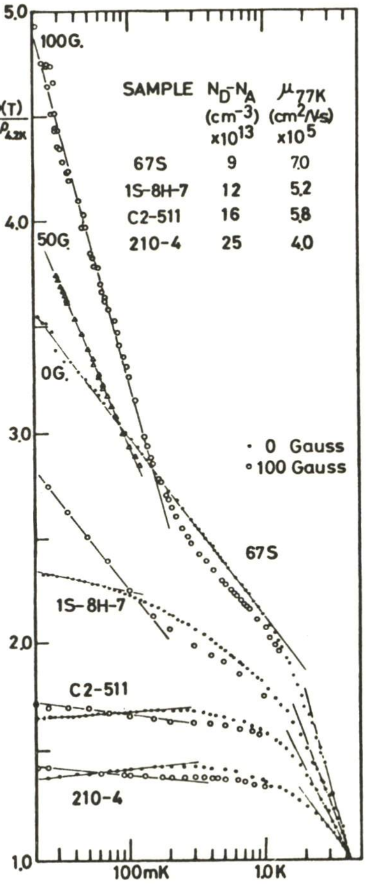

Fig.1 Temperature dependence of the resistivity

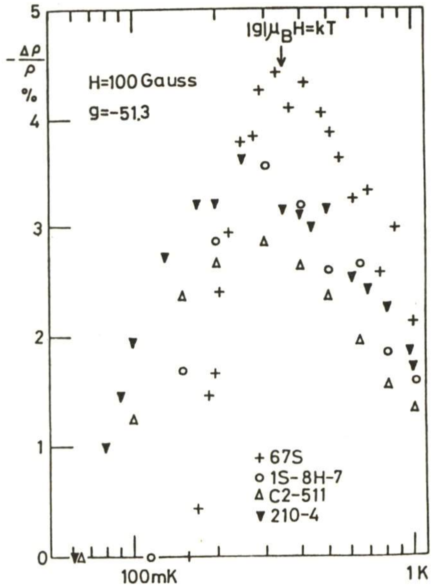

Fig.2 Temperature dependence of the magnetoresistance

that of Ge:Sb and Si:P, but has the same sign as that of the Si-MOS inversion layer. It is not clear whether the temperature dependence below 0.2 K in the high N_D-N_A samples is logarithmic or not.

In the magnetic field of 100 G, negative and positive MR are observed, roughly speaking, above and below 0.1 K, respectively. As shown in Fig.(2), the maximum values of negative MR take place at $|g|\mu_B H=k_B T$ where g=-51.3 is the g-factor for shallow donors. In the intermediate N_D-N_A sample(1S-8H-7), a new logT dependence that seems not to exist in H=0 G dominates the behaviour below 0.1 K in H=100 G. On the other hand, logT dependence is not seen clearly in the high N_D-N_A samples. A striking feature in the low N_D-N_A sample is the change in the coefficients of logT near $T=|g|\mu_B H/k_B$ (T=0.34 K, H=100 G).

MR for H $<$ 100 G is shown in Fig.(3) and (4). In general, the negative MR in low magnetic fields changes into the positive one in a certain magnetic field, whose value is larger at higher temperatures and/or in higher N_D-N_A samples. The low N_D-N_A sample which shows smaller negative MR in weak magnetic fields exhibits larger logT dependence and stronger positive MR when the magnetic field is increased. In a certain range of magnetic field below 100 G, the positive MR takes a linear dependence on H as shown in Fig.(4). The positive MR below 0.1 K in H=100 G in n-InSb resembles in a sense that of Ge:Sb and Si:P. However, in the latter case, the logT dependence is destroyed at the temperature where the positive MR is observed.

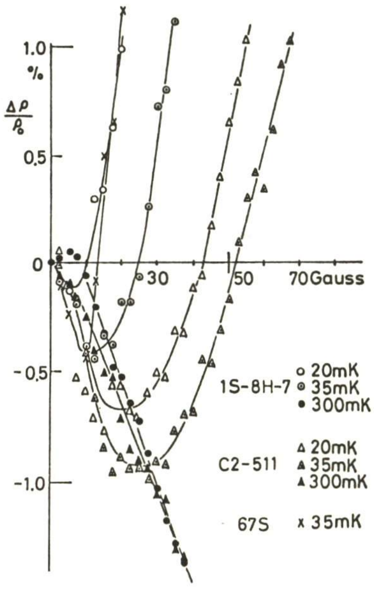

Fig.3 Magnetic field dependence of the magnetoresistance

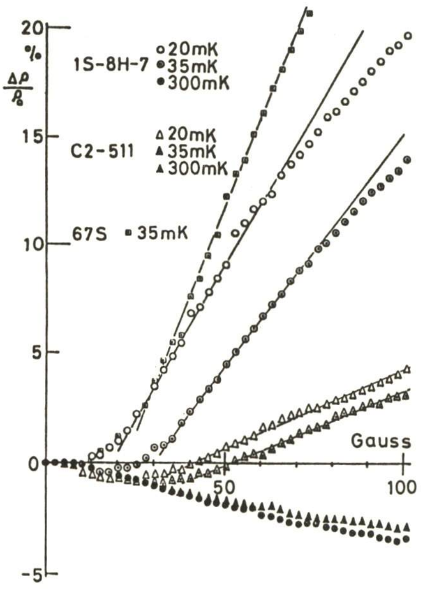

Fig.4 Magnetic field dependence of the magnetoresistance

On the other hand, the logT term in n-InSb is rather induced or enhanced by the magnetic field, and the positive MR originates from the coefficient of logT.

III. Discussion

Since negative MR takes the peak value at $|g|\mu_B H=k_B T$ as shown in Fig.(2), the MR seems to originate from the Zeeman effect of the shallow donor states whose g-value is -51.3. In H=0 G, the resistivity of the low N_D-N_A sample takes the logT form in the wide temperature range, 1 K > T > 0.02 K. In 100 G, the logT dependence is divided into two parts, separated by T=0.34 K which satisfies $k_B T=|g|\mu_B H$, with reduced and enhanced coefficients of logT at higher and lower temperature sides, respectively. This indicates that the origin of logT comes from the shallow donor states but not from the s-d interaction , which may lead to the saturation of logT for $|g|\mu_B H > k_B T$. The electron concentration where the logT dependence is observed is in the metallic conduction region irrespective of dimensionality[4],[5],[8]. The magnitude of logT term seems to become larger when coming closer to the non-metallic region. This may indicate that the logT dependence of resistivity is a peculiar phenomenon in the vicinity of the metal-nonmetal transition.

Recently, many interesting theoretical analyses have been done in relation to the Anderson localization[10]-[13]. According to these theories, the interruption of a coherence by the magnetic field results in the negative MR both for the 2-D system[14] and the 3-D system[15]. However, these theoretical results make a striking contrast with our experimental results at $|g|\mu_B H > k_B T$. Theories so far proposed to lead to the logT dependence are limited to the 2-D system[11],[12],

[16] and cannot be applied to n-InSb which is the 3-D system, because the logT term in the 2-D system can be derived from the 2-D momentum integration of the diffusion mode included in vertex correction due to impurity scattering. We would like to suggest a model where the localized states near the Fermi level act as trapping centers for the electrons in the impurity band[17].

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