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非晶态和亚稳中间相 InSb 的输运性质

TRANSPORTATION PROPERTIES OF AMORPHOUS STATE InSb AND ITS METASTABLE MIDDLE PHASE

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摘　要

低温凝聚 InSb 膜，底板温度的改变可以诱导金属-半导体转变。金属型非晶 InSb 以电子导电为主，半导体型非晶 InSb 则以空穴导电为主。金属型非晶 InSb，在液氦温度和 0.1T 磁场下呈现出电子-电子相互作用行为。金属型非晶 InSb 的结构弛豫，不仅可以导致近程有序度的提高，而且可能导致电子结构的变化。第一电导跃变主要起源于电子迁移率的大幅度增加，系统由类液非晶态弛豫到类点阵非晶态。金属型非晶 InSb 中，不同的结晶相变类型表现出不同的输运行为。金属型非晶 InSb 和亚稳中间相是载流子浓度（$n_0 \sim 10^{18}\text{cm}^{-3}$）最低的超导体系之一，且亚稳中间相的超导 T_c 与态密度有关，高的 T_c 值对应于高的态密度。准二维的层状结构对超导电性有利。

TRANSPORTATION PROPERTIES OF AMORPHOUS STATE InSb AND ITS METASTABLE MIDDLE PHASE

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ABSTRACT

The variation of the substrate temperature induces the metal-semiconductor transition in the condensation InSb films at low temperature. The electron conduction is dominant in the metal-type amorphous InSb and the hole in semiconductor-type one. In the metal-type amorphous InSb the electron-electron is correlated under the field above 0.1T in the temperature region of liquid nitrogen. The structure relaxation leads to not only the increase of the short range order but also the change of electron structure in metal-type amorphous InSb. The first conductance jump originates mainly from the increase of Hall mobility of the carrier, i.e. the increase of the short range order, and the system relaxes from the liquid-like to the lattice-like amorphous state. The three types of the crystallization phase transition for the metal-type amorphous InSb present obviously different transportation behaviours. Both metal-type amorphous state and metastable middle phase of InSb all is one of superconducting system with the lowest carrier concentration ($n_0 \sim 10^{18}\mathrm{cm}^{-3}$). Superconducting T_c of the metastable middle phase is related to the state density near Fermi surface, i.e. the higher T_c corresponds to the higher state density. The quasi-two-dimensional structure is favourable to superconductivity.

INTRODUCTION

The systematic researches on the crystallization phase transition and superconductivities of the metal-type amorphous InSb have been made[1~6]. It has been well known that the first jump of the conductance takes place spontaneously at the condensation temperature for the metal-type amorphous InSb and sample relaxes from liquid-like to lattice-like amorphous state. When the annealing temperature, T_a, rises to near 200 K, the phase transition of crystallization which is called the second jump of the conductance, takes place and a conductance peak which corresponds to a crystallization metastable metallic phase is reached at 210 K. However, the phase transition of crystallization without the striking second jump of the conductance can occur under certain conditions[2,5]. When the temperature rises continuously, the metastable metallic phase transforms into the crystalline semiconductor phase. We have also known that the metal-type amorphous InSb is a new superconductor and its superconducting T_c is variable with the change of the temperature of the substrate. The metastable middle phase corresponding to the peak of the second jump of the conductance is also a superconductor and its superconducting T_c is 4.18 K. In the process of the phase transition from the metastable middle phase to the semiconductor one, superconducting T_c reduces step by step and the transition width, ΔT_c, increases obviously. An abnormal superconducting phase transition appears after certain annealing temperature was reached. It has been explained by a mixture phase model[4,6].

The study on the transportation properties of the materials in the normal state is an important respect to consider the structure phase transition and the mechanism of superconductivity. In this paper, on the base of the studies of the crystallization phase transition and superconductivity, we report systematically the transportation properties of InSb in amorphous state and metastable metallic phase which exists in the process of the crystallization phase transition by studing the metal-semiconductor transition, the structure relaxation in the metal-type amorphous InSb and Hall effects of both amorphous state and metastable middle phase etc. The correlation between the transportation property and superconductivity is discussed briefly.

1 EXPERIMENTAL METHODS

For the Ⅲ-V group semiconductors, including InSb and GaAs etc, amorphous state can not be prepared yet by liquid quench, but it has been obtained by the technique of vapour condensation at low temperature. The samples are prepared in an apparatus which allow in situ of low temperature condensation and measurement[7]. The condensation substrate is a polishing glass piece and its temperature can be controlled conveniently. The vacuum is about 10^{-6}torr during the condensation. The resistance and Hall effect of the sample all is measured by standard four probe method. During Hall effect measurement, the ohm voltage which is caused by the nonsymmetry between two Hall terminals and the stray potentials are compensated to zero by a electronic circuit[8]. A calibrated copper-contantan couple is applied in the measurement of the temperature. The magnetic field is produced by a water cooling solenoid.

2 EXPERIMENTAL RESULTS

2. 1 Transportation property of amorphous InSb.

2. 1. 1 Metal-semiconductor transition

The metal-nonmetal transition is an interesting field of the research. In particular, the study of superconductivity on one side of metal has the important valuable. The high T_c superconductivity is closely related to the lattice instability, for example, in the conventional superconductors Nb_3Si, and Nb_3Ge and in high T_c oxide superconductors etc.

For amorphous InSb condensed at low temperature, the crystalline semiconductor is always formed as the substrate temperature T_s is above 200 K; the amorphous InSb having the properties of semiconductor which is called the semiconductor-type amorphous state is formed for $T_s < 200$ K; however, when temperature of the substrate reduce to near 120 K, we find firstly that the variation of the temperature of the substrate induces the occurrence of metal-semiconductor transition. That is, when $T_s >$ 120 K, the semiconductor-type amorphous InSb is formed and its dependence of the conductance σ upon annealing temperature T_a , $\sigma(T_a)$, is shown in Fig. 1. It can be seen that there is very low conductance (about 10^{-6} S) in the condensation state. The conductance of the sample which is in thermodynamical metastable state changes rapidly when the annealing temperature T_a reaches to near 180 K, and a peak of the conductance is reached at 210 K. The conductance of the sample reduces quickly and the sample transforms into the stable crystalline semiconductor phase when the annealing temperature goes on. A new jump of the conductance takes place when the annealing temperature rises above the room temperature. The comparison with the condensation state (the point ⊙ in Fig. 1) shows that the conductance increases to 3. 5 order magnetude.

The large rate of the peak conductance in crystalline state to the conductance in amorphous state is an important feature of the crystallization phase transition in the semiconductor-type amorphous InSb. When the substrate temperature $T_s < 120$ K, the metal-type amorphous InSb film is formed, its crystallization phase transition in the process of rising temperature is shown in Fig. 2. Its striking features are that in comparison with the semiconductor-type amorphous InSb, it has much higher conductance, about 10^{-3} S; that a jump of the conductance which is called the first jump of the conductance takes place spontaneously at the condensation temperature, and the sample relaxes from liquid-like to liquid lattice amorphous state[10]. When the annealing temperature T_a rises to near 200 K, a new jump of the conductance which is called the second jump of the conductance occurs, and a peak of the conductance is reached at 210 K; The sample transforms gradually into stable crystalline semiconductor phase when annealing temperature goes on. The third jump of the conductance occurs above the room temperature. The X-ray diffraction has already shown that the third jump of the conductance is a result in which In-Sb solid solution collects gradually and constructs partially the electrical passageway in the boundary of the grains. In contrast with semiconductor-type amorphous InSb, the enhancement of the conductance from amorphous state to the peak of the second conductance jump is less than one order magnitude. The second jump of the conductance may not occur under some conditions in the process of crystallization phase transition of metal-type amorphous InSb. [2,5]

The detial experimental result on the dependence of both the transportation and the crystallization phase transition behaviour of low temperature condensation InSb upon the temperature of the substrate T_s has shown that 120 K is a boundary near which the metal-semiconductor transition occurs. For example, the metal-type amorphous InSb forms at $T_s = 119.5$ K while the semiconductor-type amorphous InSb forms at $T_s = 120$ K.

The temperature coefficient of the resistance for metal-type amorphous InSb is generally smaller than that for semiconductor-type one, although they all have a negative value. However, the distinction between both is no great near the boundary of metal-semiconductor transition, as shown in Fig. 3.

2.1.2 Hall effect in amorphous state

The state of metal-type amorphous InSb can be distinguished into two stages according to if the first jump of the conductance has took place. The measurement results on the resistivity and Hall effect is listed in Table 1. It can be seen that comparing after and before the occurrence of the first jump of the conductance, the resistivity reduces a half and Hall mobility increases to 14 times while the concentration of the carrier, n_c, decrease beyond six-times. From this, the first jump of the conductance is mainly caused by greatly sudden increase of Hall mobility. The increase of Hall mobility presents the enhancement of the short range order, while the variation of the concentration of the carrier represents the change of electron structure in amorphous state. Above experimental result has exactly shown that the first jump of the conductance is a outcome of the structure relaxation from liquid-like to lattice-like amorphous state.

Table 1

State of sample	ρ (10^{-3} Ωcm)	R_H (10^{-7} m^3/AS)	μ_H (cm^2/VS)	n_c (10^{18} cm^{-3})	Temperature for measurement (K)
Before jump	3.52	<|-1.83|	<52.0	>34.1	87
After jump	1.71	-12.4	725	5.04	85

Hall coefficient of the semiconductor-type amorphous InSb is always a positive value about $+1.80\sim+2.60\times10^{-7}$ m^3/AS. This implies that the hole conduction is dominant in semiconductor-type amorphous InSb.

2.1.3 Structure relaxation in metal-type amorphous InSb

The study on the structure relaxation of amorphous materials provides an unique insight in the dynamics and stability of the modulation of the stress and the position of atoms on an atomic scale under heat annealing below the glass transition temperature T_g. The author apply for the first time the Hall effect method[11] to study the structure relaxation of metal-type amorphous InSb, including the structure relaxations for amorphous InSb without the second jump of the conductance in the process of crystallization phase transition.

Metal-type amorphous InSb with the second jump of conductance: The sample 86-2 which was condensed on the substrats at 80 K belongs to the type with the second jump of the conductance. The annealing temperature rises from the deposition temperature to 192 K by the rate of 3.6 K/min., then at once, the temperature was droped to liquid N_2 temperature quickly. The results measured at the liquid N_2 temperature are given in Table 2. It can be seen from Table 1 that as a result of structure relaxation, the resistivity of the sample reduces lightly, Hall coefficient does not change essentially, but the mobility increases lightly. This means that the decrease of the resistivity origins from the increase of the mobility. This show that the primary result of structure relaxation was to increase the order degree of amorphous state in the short range.

Table 2

State of sample (K)	ρ ($\mu\Omega$cm)	R_H (10^{-9} m^3/AS)	μ_H (cm^2/AS)
80	373	−3.08	8.28
191	352	−3.03	8.61

Metal-type amorphous InSb without the second jump of the conductance: The sample 85-5 which was deposited on the substrate at 80 K is one of the metal-type amorphous InSb without the second jump of the conductance. The sample underwent two annealing processes: The annealing temperature, T_a, rose from the deposition temperature to 167 K, then at once, it was droped to 80 K; T_a rose again from 80 K to 198 K, then, at once, it was droped to 80 K again. The rate of rising temperature is all 4 K/min. The measurements were carried out at 80 K. The experimental results are given in Table 3 and Fig. 4. The dependences of the resistivity upon the temperature T for above mentioned two states are also in Fig. 5. They have same negative temperature coefficients.

It can be seen from Table 3 and Fig. 4 that as compared with the measurement value in the deposited state, the resistivities which was respectively in the state at 167 K and 198 K reduce 5.3 % and 6.3 %. However the absolute values of their Hall coefficient increase respectively 108.8 % and 211 %, Hall mobility increases 119.5 % and 230.8 % respectively. These show that the changes of Hall effect parameters are much larger than one of resistivities by tens time in the process of structure relaxation. On the other hand, we can see from above experimental results that structure relaxation is not only to change the order degree of amorphous state in the short range, but can lead to change of the electron structure in the metal-type amorphous InSb. At least, it is done for the systems of some amorphous materials, for example, InSb system in this paper. By the way, above experimental results indicate already that the Hall effect measurement is a available method to study the structure relaxation in amorphous materials.

Table 3

State of Sample (K)	ρ ($\mu\Omega cm$)	R_H ($10^{-7}\ m^3/AS$)	μ_H (cm^2/VS)
80	398	−1.55	390
167	377	−3.23	856
198	373	−4.82	1290

2.1.4 The anomalous Hall effect

In Fermi electron gas, the electrons are believed to be Fermions without interactions between each other, because they have very great mobile kinetic energy. However, when there are electron-electron interactions, they are dealt with as Fermi liquid[12] The electron-electron interaction and even Wignerlattice of the electrons[13] can appear in the system having very low carrier concentration and in the disordered system at low temperature when a high magnetic field is applied. The magnetic field causes the mobile kinetic energy to reduce enormously. Thus the coulomb interaction between electrons can manifest itself. The so called "high magnetic field" (a critical magnetic field at which electron-electron interaction occurs) is different for different materials, and it depends mainly on the carrier concentration, n_0 [2].

Up to now, the experimental studies of the electron-electron interaction were all carried out in the doped narrow-gap semiconductors under high magnetic field and at low temperature[12~16].

In our experimental study of Hall effect of the metal-type amorphous InSb, the anomalous Hall effect was observed for the first time. It characterizes the occurrence of the magnetic-frozen out phenomena in amorphous metals. It took place at the temperature about 80 K and a field near 0. 1T. Comparising with norrow-gap semiconductors in which a similar phenomenon appears, its temperature is much higher and the field is much lower. It is related to the localization induced by disorder.

The sample was prepared by vapour-condensation method. Pure InSb was deposited on the substrate at low temperature. Its resistivity is about 10^{-3} Ωcm[6].

The dependence of Hall voltage V_H upon the magnetic field B is shown in Fig. 6. It can be seen that there is a starting magnetic field, B_H , at which the Hall voltage begin to appear. Its value is about 0. 08T. The value will be 0. 11T if it is defined to be the intercept of the linear extrapolation of the curve V_H vs B with the abscissa. And a saturation Hall voltage was reached at a magnetic field between 0. 3T and 0. 35T.

The dependence of the carrier concentration, n_e ,upon the magnetic field, B , is shown in Fig. 7. It can be seen directly that the carrier concentration decreases with the increase of the magnetic field, i. e. the conduction electrons are localized or magnetic-frozen out. The zero mobility of the carriers below B_H can be a result of the lattice disordering which leads to Anderson localization.

It is also seen from Fig. 2 that the carrier concentration increases slightly with the increase of the magnetic field in the high field region. We believe that it should be related to the enhancement of the effective mass of the electron. As a consequence of the electron-electron interaction, the effective mass of the electron would be changed.

2. 2 Transportation properties of Metastable middle phase.

For following mention and discussion, the brief describing the structure analysis[17,18] in both metal-type amorphous InSb and its process of crystallization phase transition is need to be done. The X-ray diffraction shows that the sample is always in amorphous state before the occurrence of the second jump of the conductance, as shown in Fig. 8. The sample crystallizes into the hexagonal InSb phase$(InSb)_H$ which is in layered structure and corresponds to a high pressure InSb phase under 125×10^8 Pa. The conductance of $(InSb)_H$ exhibits the typical metallic behaviours and it is a superconductor with $T_c=4.18$ K.

The intensity of X-ray diffraction of $(InSb)_H$ phase decreases and the peaks of X-ray diffraction of both the centred tetragonal (InSb)4μ corresponding to one of InSb under 26×10^8 Pa and the face central cubic(InSb)8F appear, i. e. there are three crystalline phases when the annealing temperature T_a just leap over the peak of the second conductance jump. Along with the rise of annealing temperature T_a, the phases of $(InSb)_H$ and (InSb)4μ decrease and disappera gradually, while the phase of (InSb)8F increases gradually. Above results indicate that $(InSb)_H$ and (InSb) 4μ are the metastable middle phase and (InSb)8F is a stable crystalline semiconductor phase. It should be also noticed that the peaks of X-ray diffraction of In and Sb appear and enhance gradually in rear of the peak of the second jump of the conductance. The quick collection of In-Sb solid solution on the boundary of InSb grains leade to the occurrence of the third jump of the conductance above room temperature[2,5].

The systematic study of the crystallization phase transition of metal-type amorphous InSb has shown that the appearances of three type crystallization phase transition are related to deviation of the composition from stoichiometric InSb[10]. When the deviation is no large, the typical crystallization phase transition occurs, i. e. there is the second jump of the conductance; when the deviation of the composition is large, the crystallization phase transition without the second jump of the conductance appears; when the deviation of the composition is repeated along the thickness of the film, the first jumps of the conductance appear by many step jumps.

2. 2. 1 Crystallization phase transition type with the second jump of the conductance

The crystallization phase transition the Hall coefficients, and the Hall mobility at some characteristic points of the crystallization phase transition is given in Fig. 8a, b, and c,respectively. The results are measured on same sample. The R_H and μ_H of them are the measurement value at the temperature which is reduced from the characteristic point of the phase transition to the temperature of the liquid nitrogen. The "." and "+" represents the Hall coefficient R_H to be negative and positive, respectively. For comparison, in Fig. 8 give simultaneously relevant parameters in amorphous state.

It can be seen from Fig. 8 that there is a sudden reduce of R_H value, i. e. a sudden increase of the carrier concentration and that the Hall mobility μ_H increases about twice at the peak of the second jump of the conductance. These experimental results show that the occurrence of the second jump of the conductance is a consequence of the simultaneous increase of both the carrier concentration and the mobility, but the increase of the mobility is dominant. The increase of both the carrier concentration and the mobility is a consequence in which the sample has transformed from amorphous state into the metastable metallic phase. In particular,the formation of the quasi-two-dimensional layered structure[18] at the peak of the second jump of the conductance leads to enhancement of order degree to become the main origin of the increasing the Hall mobility.

It can be also seen from Fig. 8 that, in rear of the peak of secend jump of the conductance, R_H increases rapidly, i. e. the carrier concentration reduce quickly, and the sign of R_H changes from negative to positive in the certain stage of crystallization phase transition. This phenomenon indicates the sample to transform from the metastable metallic phase into the crystalline semiconductor phase and to be a p-type semiconductor in the stable crystal state. The reduce of the mobility in the rear of the peak of the second jump of the conductance is related to the disappearance of the quasi-two-dimension structure. In the rear, the sample transforms from the homogeneous metallic phase with the layered structure into the mixture phase consisted of the metallic phase and semiconductor phase, then into the polycrystalline semiconductor. The appearance of both the mixture phase and the polycrystal leads to the enhancement of the scattering effect, thus reducing the mobility.

After the third jump of the conductance occurs(see Fig. 8a), the sign of the Hall coefficient R_H changes again from positive to negative, the carrier concentration increases rapidly, but the change of mobility is no large. We can conclude from this that the third jump of the conductance attributes mainly to the increase of the carrier concentration. However, the great increase of the carrier concentration can not attribute to the grains of crystalline semiconductor phase to grow up. It is obviously a consequence of the collection of In-Sb solid solution phase on boundary of the InSb grains and the electron conduction is dominant. There is higher carrier concentration in In-Sb solid solutions.

2.2.2 Crystallization phase transition type without the second jump of the conductance

Comparing with above one type, the feature of the crystallization phase transition for the metal-type amorphous InSb without the second jump of the conductance is that there is not the second jump of the conductance in the temperature region over 200~220 K. Its crystallization phase transition (see Fig. 9a), the Hall coefficient R_H (see Fig. 9b) and the mobility μ_H (see Fig. 9c) during crystallization phase transition is shown in Fig. 9. It can be seen that the great reduce of Hall coefficient or the great increase of the concentration, although there is not the second jump of the conductance in the temperature range of 200~220 K. Obviously, it is caused by the phase transition from amorphous state to the metastable metal phase. The origin in which the second jump of the conductance does not occur is because the variations of the conductance led by both the reduce of the mobility and the increase of the carrier concentration are compensated each other. Therefore, what the second jump of the conductance does not occur does not imply that the sample has transformed directly from amorphous state to the crystalline semiconductor phase[6].

2.2.3 Many step jumps of the conductance

The many step jumps of the conductance appeared below 200 K used to be put under the first jump of the conductance. Here, we should further prove above conclusion to be right through the study of its transportation properties. Its crystallization phase transition (see Fig. 10a), the Hall coefficient (see Fig. 10b) and the mobility (see Fig. 10c) have been shown in Fig. 10. It can be seen that the transportation property before and after the occurrence of the first jump of the conductance is distinguished, and it resemble to the conclusion in (1)and (2).

In the process from the first jump of the conductance at the temperature of deposition to the occurrence of the second jump of the conductance before, the conductance of the sample is in the process of the step jump whose degree is not equal, as shown in Fig. 10a, the Hall coefficient R_H and the mobility μ_H decrease gradually by large amplitude, as shown in Fig. 10b, and 10c. They show that above many step jumps of the conductance originate from the increase of the carrier concentration. It is striking contrast to the structure relaxation in both metal-type amorphous InSb with and without the second jump of the conductance. Therefore, these step jumps of the conductance to belong actually to the first or the second jump of the conductance become again a problem. In order to clarify it, we have studied the conductance as function of temperature after many step jumps of the conductance have been finished but before the second jump has not yet been occurred, as shown in Fig. 11. It has been well known that the metal-type amorphous InSb has always a negative temperature coefficient of the resistance, but the metastable metal phase formed after the occurrence of the second jump of the conductance has always an positive one[3,5]. It can been seen from Fig. 11, the temperature coefficient of the resistance is also a negative value after the sample undergo many step jumps of the conductance. Therefore, it can be said that the many step jumps of the conductance belongs still to the first jump of the conductance.

Many step jumps of the conductance have already led to the increase of the carrier concentration. It will be interesting, provided we can measure the superconductivity corresponding to each step jump of the conductance. Unfortunately, the instability during many step jumps of the conductance make the experiment can not be achieved.

Lastly, in order to understand the more respects on the transportation property of both amorphous and metastable middle phase InSb, to describe briefly their temperature coefficient of resistance[5] at the characteristic temperature in the crystallization phase transition will be favourable. It is a negative value in amorphous state, an positive one for metastable metal phase existed at the peak of the second jump of the conductance. In the rear of the peak, its positive value reduces gradually and continuously, changes the sign. The change of the temperature coefficient of the resistance indicates right the variation of the transportation property in amorphous state-metastable metal phase-crystalline semiconductor phase. The temperature coefficient of the resistance changes again from a negative value to a positive one after the third jump of the conductance occurs. It is a result in which the growth of the grains of semiconductor phase leads to the formation of connected networks consisted of In-Sb solution in the boundaries of the grains. The detail results have been reported in [5].

3 SUMMARY

1. The variation of the substrate temperature induces the occurrence of metal-semiconductor transition in amorphous InSb films condensed at low temperature. The temperature boundary of metal-semiconductor transition is at 120 K. The metal-type and semiconductor-type amorphous InSb has distinguished mechanism of the electrical conduction, the electron conduction is dominant for the former and the hole conduction is dominant for the latter.

2. I metal-type amorphous InSb, the first jump of the conductance and latter structure relaxation are a process to increase the short rang order and to lead to the change of electon structure. It indicates that the first jump of the conductances is a relaxation process from liquid-like to lattice-like amorphous state.

3. In the metal-type amorphous InSb, these electrons are correlated, i. e. the magnetic-frozen out in the temperature region of liquid nitrogen in the field above 0. 1 T occurs. In such high temperature and such low magnetic field, the appearrance of the electron correlation phenomenon is related to both low carrier concentration and localization led by the disorder.

4. The metal-type amorphous InSb with various type of crystallization phase transition shows different transportation behaviours. In the metal-type amorphous InSb with the second jump of the conductance, what there is only the small variation of both the carrier concentration and the Hall mobility indicates the higher stability of amorphous state. In metal-type amorphous InSb without the second jump of the conductance, the structure relaxation in amorphous state is more striking. Its Hall coefficient and mobility increase by above 200% although its variation of resistivity is no large. This implies that the stability in amorphous state is worse than former. In metal-type amorphous InSb with many step jumps of the conductance, the many step jumps of the conductance below 200 K still belongs to the first jump of the conductance and originates from the increase of carrier concentration.

5. There is maximum of the electron concentration, i. e. maximum of state density in the peak of the second jump of the conductance. For sample without the second jump of the conductance, the increase of carrier concentration indicates that there is still the metastable metal phase in the temperaturere region from 200 K to 220 K. What the second jump of the conductance does not occur or is not striking is because the variation of the conductance led by both the reduce of the mobility and the increase of the carrier concentration compensate each other. What both T_c (T_s)[5] and $\sigma(T_s)$

curves resemble each other in shape indicates that the high T_c corresponds to high state density and that the layered structure, i. e. the quasi-two-dimensional structure is favourable to superconductivity. Either metal-type amorphous state or metastable metal phase is one of superconducting system having the lowest carrier concentration.

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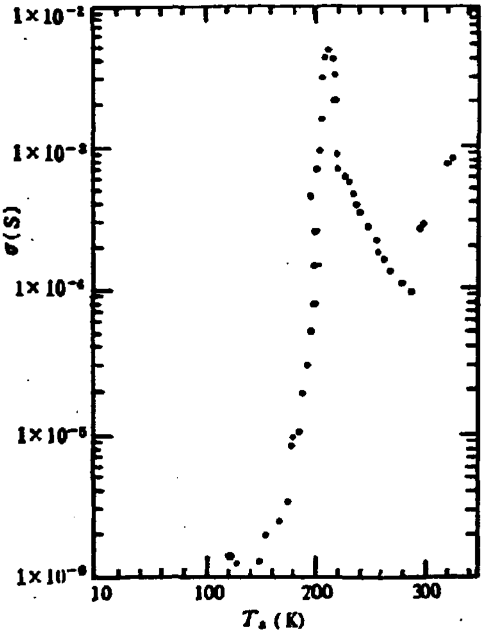

Fig. 1 The phase transition of the semiconductor-type amorphous InSb film.

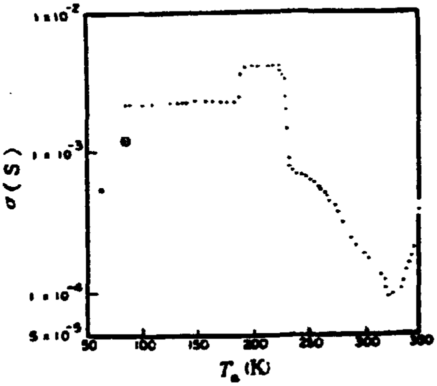

Fig. 2 The phase transition of the metal-type amorphous InSb film.

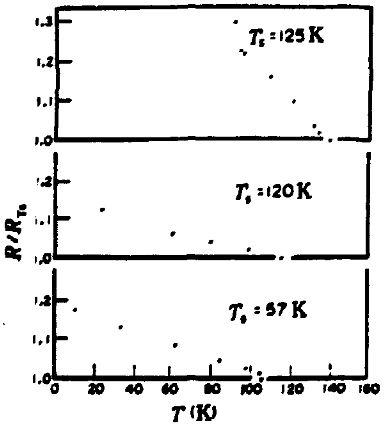

Fig. 3 The temperature coefficient of the resistance of amorphous InSb film condensed at the various temperature.

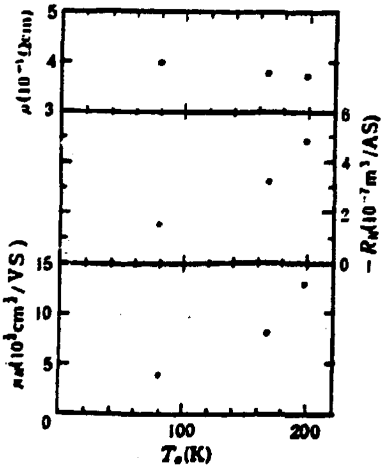

Fig. 4 The ρ, R_H and μ_H of the metal-type amorphous InSb in various state of structure relaxation measurement at 80 K.

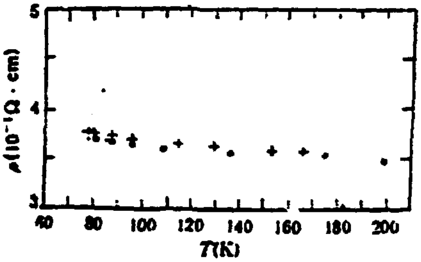

Fig. 5 ρ (T) relations of the metal-type amorphous InSb in various states of structure relaxation.

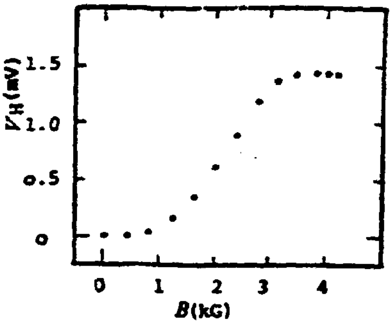

Fig. 6 An anomalous Hall effect in the metal-type amorphous InSb at 80 K.

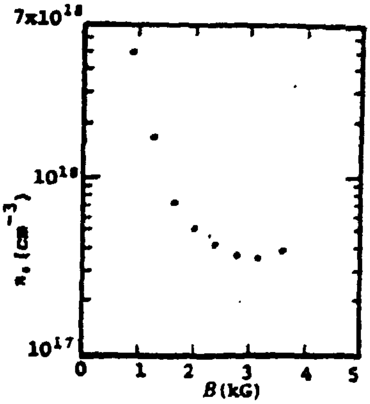

Fig. 7 The dependence of carrier concentration on the magnetic field.

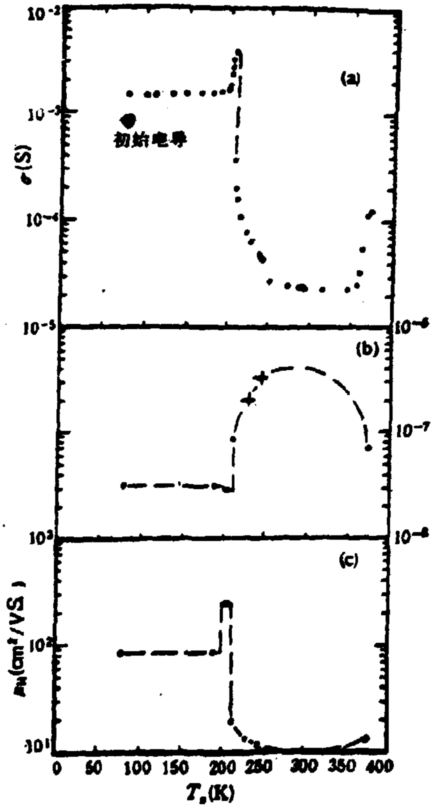

Fig. 8 Crystallization phase transition (a), Hall coefficient R_H(b) and Hall mobility μ_H(c)for metal-type amorphous InSb with the second jump of the conductance.

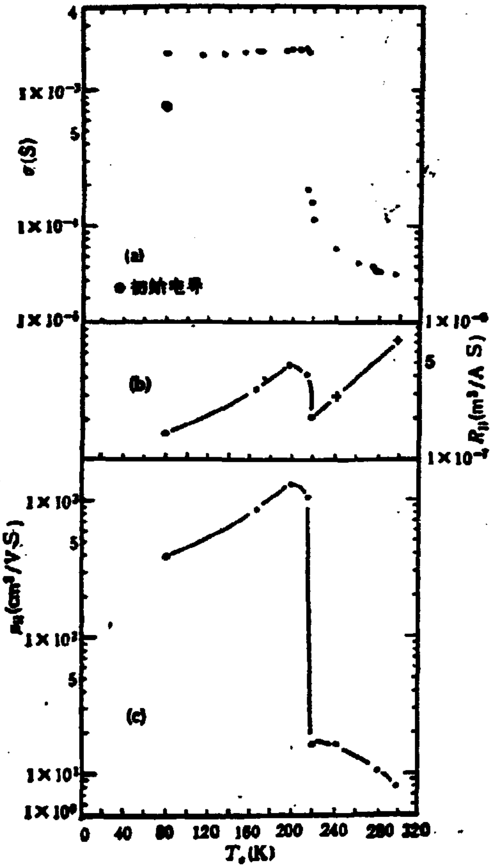

Fig. 9 Crystallization phase transition (a), Hall coefficient R_H (b) and Hall mobility μ_H (c) for metal-type amorphous without the second jump of the conductance.

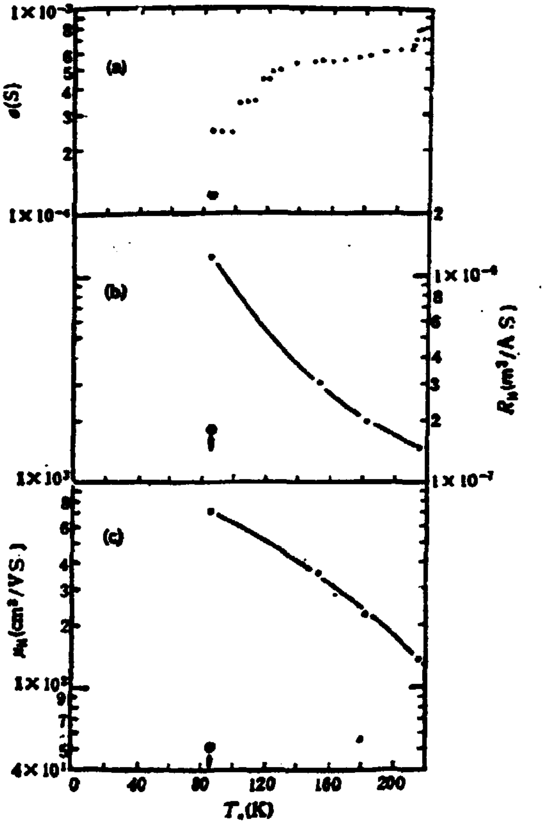

Fig. 10 Crystallization phase transition (a), Hall coefficient R_H(b) and Hall mobility (c) for metal-type amorphous InSb with many step jump of the conductance. ⊙ is the value before the jump of the conductance occurs. Arrow represents is smaller than ⊙.

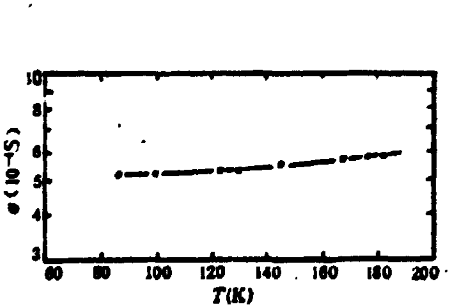

Fig. 1 σ (T) relation after the occurrence occurence of many step jump of the conductance and before the occurrence of the second jump of the conductance.

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