ELECTRIC PROPERTIES OF InSb CRYSTAL GROWING UNDER MICRO- AND SUPER-GRAVITY CONDITIONS

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I. INTRODUCTION

In recent years, the growth of crystal at microgravity intrigues many scientists[1-3]. In space microgravity environment, gravity-induced natural convection and buoyancy in melts diminish. The sedimentation of matters, which exists at normal gravity on earth owing to different density, is absent. It is much easier to control the process of mixing different materials and there is an increasing static stability of molten zones. The transport of matter in liquid mainly depends on diffusion. However, many new physical phenomena at microgravity are still not very clear, the basic researches of space physics as well as the characteristics of space materials need further study. Meanwhile, in order to investigate the influence of gravity-driven convection on the crystal growth, the super-gravity environment was simulated by centrifuger, the crystal growth experiments were done and the convection state in melts was studied by Müller et al. This note studies the electric properties of InSb crystal grown under different gravity levels and discusses the influence of gravity on crystal growth.

II. EXPERIMENT

The InSb crystals for this experiment have been remolten and re-grown at different gravity levels by normal solidification. First, Zn-doped (about $10^{16}/cm^3$) single crystal grown on earth along <111> direction was cut into several rods of 50mm in length. Then each of them was put into a clean quartz ampoule which was evacuated to 1.33×10^{-3} Pa prior to sealing. The sealed ampoules were used for experiments of remelting and regrowing crystals at variable gravity levels. Experiment at microgravity was performed on a "Recoverable"

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Satellite which was launched on August 5, 1987[5]. It is estimated that the microgravity level is lower than $2\times10^{-4}g_0$ when materials were processed in space. Before the "crystal processing furnace" had been mounted on the "Satellite", $1g_0$ sample was obtained at normal gravity level on earth. The supergravity environment was simulated by using centrifuger on which the "crystal processing furnace" had been mounted. The speed of the centrifuger was first up to 22 r/min and centrifugal acceleration was $3g_0$. Then the speed of the centrifuger was added to 31 r/min and the centrifugal acceleration increased to $6g_0$. The samples were processed at $3g_0$ and $6g_0$ separately. It was necessary to point out that when the samples were processed at different gravity levels, the temperature conditions were similar. In addition, in the period of material processing, the axis of furnace and the direction of temperature gradient were always parallel to the centrifugal force. So, the samples grown at different gravity levels were obtained.

In this experiment, Hall-effect measurments were carried out by Van De Pauw technique on slices with 1 mm in thickness cut from each sample. The experimental temperature ranges from 80K to 400K. Furthermore, for analysing atomic segregation of In and Sb in samples, the percentage contents of In and Sb were measured by JEM-1200ES TEM. Also dislocations and defects in each sample were observed using metallograph.

III. The Results and Discussions

Fig. 1 shows the relationship between Hall coefficient R_H and temperature.

At low temperature, the sign of the Hall coefficient (R_H) of each sample was positive

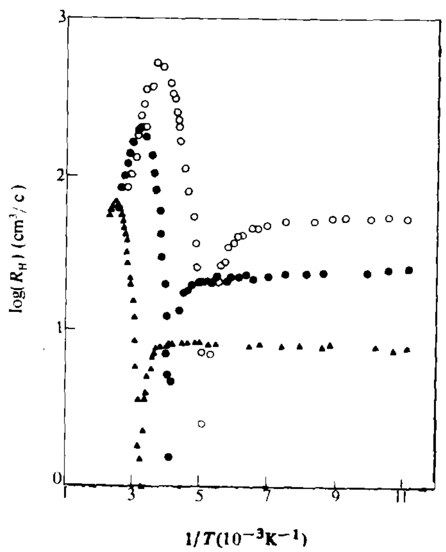

Fig. 1. Relationship between R_H and temperature. ○, space sample; ●, $1g_0$ sample; △, $6g_0$ sample.

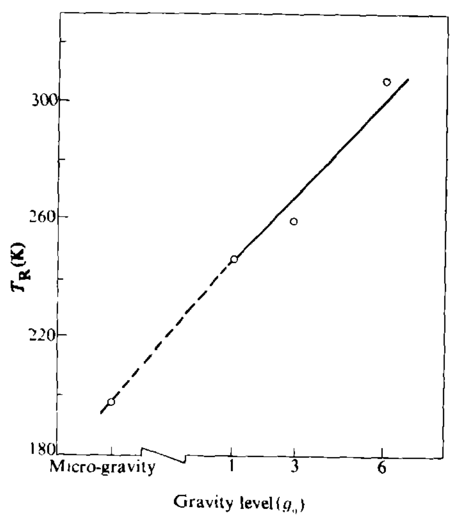

Fig. 2. The relationship between T_R and gravity level g_0.

and the samples presented hole conductivity. With rising temperature, the sign of the R_H changed from positive to negative, the inversion temperatures T_R were 198K, 248K and 308K for space, $1g_0$ and $6g_0$ samples respectively. The samples changed from impurity excited state to intrinsic state. The electron conductivity played a main role in samples because electron mobility is much larger than hole mobility at high temperature. The inversion temperature T_R increased with rising gravity levels, just as shown in Fig. 2.

The above results indicate that there were much more defects and impurities in $6g_0$ sample which made the intrinsic excited temperature increase and the R_H of samples decrease with the increase of gravity increasing.

The relationship between resistivity and temperature of each sample has also been measured. At low temperature, with increasing temperature, the resistivity of space sample increased, $1g_0$ and $3g_0$ samples were almost constant and $6g_0$ sample slightly decreased. In the middle temperature range, with increasing temperature, the resistivities of all samples increased. The value of the resistivity of space sample reached to the highest point at 200K, while $1g_0$, $3g_0$ and $6g_0$ samples to their highest points at 250K, 270K and 300K. Over these temperatures, the resistivities of samples decreased quickly with temperature continuously increasing. The value of the resistivity of $6g_0$ sample is the lowest and that of space sample is the largest at the same temperature. At 150K, the relationship between resistivity of samples and gravity levels is shown in Fig. 3.

According to the equation of $\mu_H = \sigma R_H$, Hall mobility μ_H can be obtained. From the

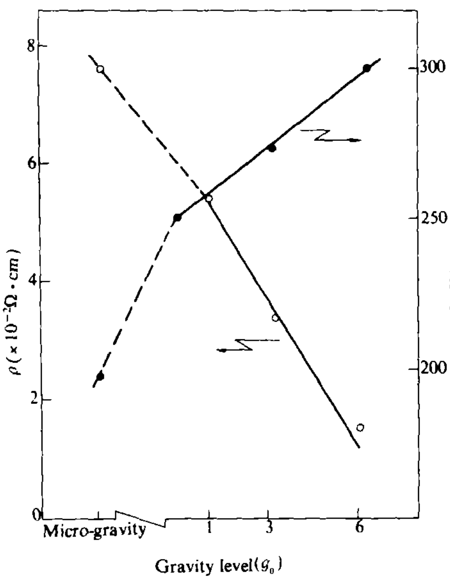

Fig. 3. The relationship between ρ (150K), T_R and gravity levels.

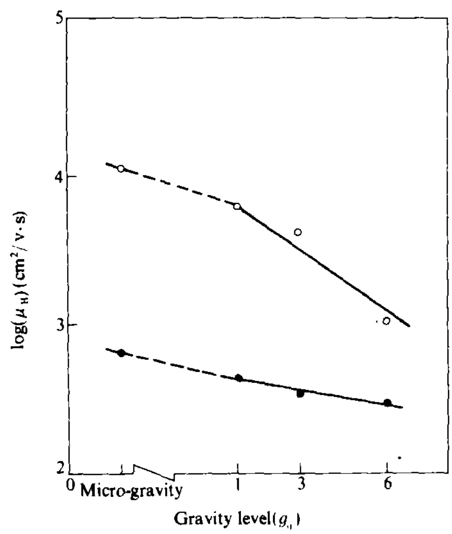

Fig. 4. The values of mobility of each sample at 100K and 350K. ○, 350K; ●, 100K.

experimental results of R_H and ρ, we can conclude that, when temperature is lower than 150K, the conduction of impurity reached saturation and the mobility is the hole one. But beyond 310K, quantities of electrons were excited and the samples brought into intrinsic state. At high temperature, because electron mobility was much larger than hole mobility in InSb material, the main conducting carriers were electrons and obtained mobility was mainly the electron one. The values of mobility at 100K and 350K are shown in Fig. 4.

From Fig. 4, we know that at the same temperature, μ_H decreases with gravity level increasing. The μ_H of space sample is the largest which indicates that there are much less impurities and defects in space sample.

The dislocations and etched pits of all samples were observed by metallograph. The etched pits were much more in $6g_0$ sample than that in other samples. Furthermore, atomic segregations of each sample were measured by means of energy analysis using JEM – 1200ES TEM. The result indicats that there were more In than Sb atoms in samples and the atomic segregation of $6g_0$ sample was 7 times as much as that of the space sample. The average segregation scale of samples is shown in Table 1.

Table 1

Segregation Scale of Samples

Samples	Space	$1g_0$	$3g_0$	$6g_0$
Segregation scale	0.16%	0.44%	0.75%	1.2

These results show that the ratio of contents of In and Sb in space sample was nearer to theoretical value, while there were many In separations in $6g_0$ sample which produced a lot of negative centers. All these In separations and negative centers played impurity roles. So, the electric properties of $6g_0$ sample was the worst and that of space sample was the best in these samples.

It is known that the existence of gravity can cause convections in melts when growing crystal and there are different convective states at different gravity levels. In space micro-gravity, the convection in melt is steady and the streamline is parallel to the surface of the melt[6] which lead to the fact that the rate of crystal growth is steady. So the structure of crystal is perfect and the segregation of atoms in space sample is small. When crystal grew at normal gravity level on earth, the gravity-induced natural convection yields periodic oscillation which results in the temperature oscillation at the interface between liquid and solid[6]. This phenomenon further leads to the rate of growth oscillation and distribution of impurity inhomogenity. The doped striations had been observed in earth sample[5]. At supergravity condition, there exists not only centrifugal force, which is parallel to temperature gradient, but also gravity which is perpendicular to temperature gradient. So the convection in melt is complicated and disordered. Not only turbulence but also eddy occurs in melt. The convective direction is not parallel to temperature gradient which leads to the unsteady growth rate, the inhomogenity of component distribution and unperfection of structure. But Müller et al. observed that striations would be suppressed by applying large accelation during crystal growth. We have not obtained this result. This phenomenon needs further study.

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