Transport Properties of In_2Bi and InBi Single Crystals

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Abstract

Specific heat and thermoelectric power measurements were carried out for In_2Bi and InBi using single crystals. Applying an external field at the specific heat measurement of In_2Bi enabled us to estimate a magnitude of the specific-heat discontinuity between the normal and superconducting states at a transition temperature. Debye temperatures were estimated to be 92(±8) K for In_2Bi and 120(±15) K for InBi below 5 K. Thermoelectric power of InBi was found to be anisotropic against the crystallographic axes.

Key words: In_2Bi, InBi, specific heat, thermopower

1. Introduction

Indium and bismuth are known to form three kinds of intermetallic compounds: InBi, In_5Bi_3 and In_2Bi. Whereas In_5Bi_3 and In_2Bi show superconductivity at ambient pressure [1][2], InBi only undergoes a superconducting transition with an externally applied pressure [3]. This work aims to compare transport properties between InBi and In_2Bi to find a hint why In_2Bi is a superconductor, but InBi is not. The specific heat of InBi has been studied in detail [4]. Present results of InBi will be compared with the previous ones to find a suitable way of data analysis.

2. Results and discussion

Samples were prepared by melting high quality (more than 5N grade) constituents together in a pyrex glass tube in vacuum. A polycrystalline ingot in the glass tube was passed through a Bridgeman furnace to be grown into a single crystal. The residual resistance ratios of the resultant samples were approximately 110 for InBi and 45 for In_2Bi. Both the compounds exhibited diamagnetism in the temperature range from 2 to 300 K with fields up to 7 T at measurements by SQUID. Magnetization of In_2Bi at the c-axis showed de Haas-van Alphen oscillations with a frequency of about 80(±2) T, which consistents with the previous report [5].

Fig. 1 shows temperature dependence of the specific heat,C, of InBi measured by an adiabatic heat-pulse method. The inset in Fig. 1 displays a $C/T\ vs.\ T^2$ curve, which appears to slightly deviate from a linear relation between C/T and T^2.

On the basis of the Debye model, the low-temperature specific heat is approximated as $C = \gamma T + \alpha T^3$, implying a constant Debye temperature, θ_D, where γ denotes the electronic specific heat coefficient. It is widely accepted, however, that the effective value of θ_D varies with temperature, having a minimum between $\theta_D/2$ and $\theta_D/50$ [6]. This kind of variation of θ_D has been observed in InBi, in which a minimum θ_D of about 100 K was found around 9 K [4].

We attempted, therefore, to fit the $C/T\ vs.\ T^2$ data to a quadratic equation, instead of a linear function. The best fit was found at $\gamma = 4$ (± 3) mJ/mole·K^2 and $\theta_D = 120(\pm\ 15)$ K. The extracted value of θ_D is close to the previously reported one: 139.8 K [4].

Experimental results of specific heat of In_2Bi is illustrated in Fig. 2. There is a small peak originated in

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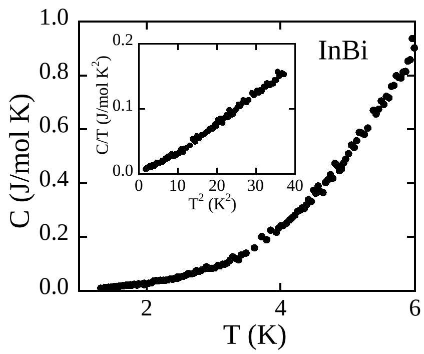

Fig. 1. $C\,vs.\,T$ curve, and $C/T\,vs.\,T^2$ curve (inset) of InBi.

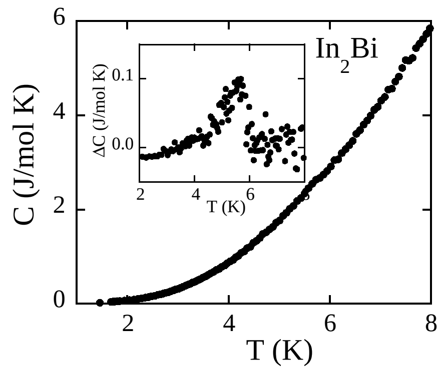

Fig. 2. $C\,vs.\,T$ curve of In$_2$Bi without field. The inset presents a result of subtracting C with field of 0.5 T from C without field; $\Delta C = C(0T) - C(0.5T)$.

a superconducting transition at 5.9 K (=T_C). The inset in Fig. 2 shows differences of specific heat between the superconducting, C_S, and normal, C_n, states ; C_n were obtained from the specific heat acquired under an external field of 0.5 T which is higher than the critical field: $B_{C2} = 0.2$ T [7]. A jump of the specific heat at the transition was estimated as $\Delta C(T = T_C) = C_S - C_n$ = 0.1 J/mol·K. The same data, C_n, were used to deduce γ and θ_D values: $\gamma = 8(\pm 7)$ mJ/mol·K^2 and θ_D = 92($\pm$8) K. In$_2$Bi feels relatively soft, as opposed to quite brittle InBi at room temperature. Thus, It is reasonable that the θ_D value of In$_2$Bi is lower than that of InBi.

Using the extracted value of γ, a magnitude of the specific heat discontinuity, $\Delta C/\gamma T_C$, is calculated to be 2.1. The BCS theory predicted $\Delta C/\gamma T_C = 1.43$, and the two-fluid model calculation resulted in $\Delta C/\gamma T_C =$ 2 [8]. Experimental values of the magnitude have been observed between 1 and 3.

Thermopwer, S, were measured applying temperature gradient along the crystallographic axis directions as shown in Fig. 3(a) and 3(b). Since InBi and In$_2$Bi show diamagnetism, main contributions to S would be brought about by a diffusion process described by the Mott expression: $S_d = (\pi^2 k^2 T/3e)(\partial \ln\sigma/\partial\epsilon)_{E_F}$ [9]. All the data lines of S seem to roughly follow the Motto relation; S values decreased toward zero as temperature was lowered. S of InBi indicated that a majority carrier at the a-axis was electrons, and that at the c-axis was holes.

In conclusion, the present results of InBi and In$_2$Bi did not exhibit pronounced differences in C and S. This work is extending to In$_5$Bi$_3$ to study further In-Bi series.

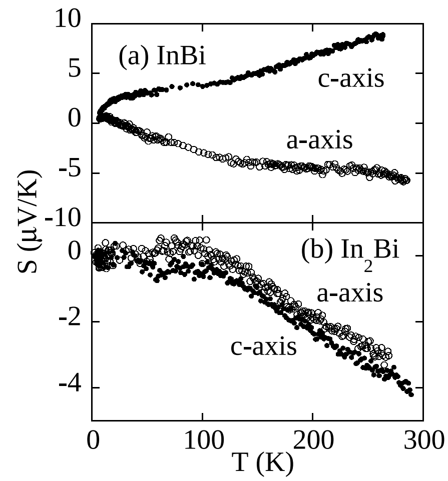

Fig. 3. Thermopower of InBi (a) and In$_2$Bi (b) along the crystallographic axis directions.

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