Superconducting transition in quasi-one-dimensional sulfide $A_xV_6S_8$ ($A=$In,Tl) under magnetic field

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Abstract

Superconducting phase transitions of quasi-one-dimensional compound have been studied by the measurement of AC magnetic susceptibility $\chi'$. The $\chi'$ of powdered sample decreased stepwise, which was characterized by two transition temperatures $T_{C1}$ and $T_{C2}$. The $T_{C1}$ is considered to be the transition within the grains, and $T_{C2}$ is the inter-grain transition. Under the magnetic field, $T_{C2}$ shifted to the lower temperature. The magnetic field dependence of $T_{C2}$ is presented.

Key words: Superconducting transition; Nb$_3$Te$_4$ type structure; Quasi-one-dimensional structure; Inter-grain transition

$A_xV_6S_8$ which belongs to Nb$_3$Te$_4$ type structure (space group P6$_3$) has a quasi-one-dimensional structure with the V-V zigzag chains running along the c-axis[1]. Superconductivity of $A_xV_6S_8$($A=$In,Tl) was found in resistivity measurements by Bensch et al.[2]. Recently, we have confirmed the superconductivity in these sulfides by the measurements of $\chi'$, and have newly observed the superconductivity in KV$_6$S$_8$, RbV$_6$S$_8$ and CsV$_6$S$_8$[3]. The $\chi'$ of the powdered samples showed stepwise decrease characterized by two transition temperatures $T_{C1}$ and $T_{C2}$[4]. The higher transition temperature $T_{C2}$ is considered to be the intra-grain transition temperature, and $T_{C2}$ corresponds to the inter-grain transition temperature. In the present study, we have investigated the behavior of $T_{C2}$ by applying the external magnetic field.

The procedures of sample preparations are described in Ref. 3. The powdered sample consists of small rod-like single crystals with 10~30 $\mu$m in length and 2~6 $\mu$m in diameter. The sample was packed in a copper cylinder with 5 mm in height and 3 mm in diameter with the pressure of 1700 MPa for 3 min. in order to make adequate contact between grains, and then a cap was screwed into the cylinder. The sample cell was thermally connected to the mixing chamber of a dilution refrigerator. The 16 Hz-AC-magnetic susceptibility was measured employing a SQUID as a null detector, and AC magnetic field produced by primary coil was $\sim$10$^{-6}$ T. A permalloy case was attached outer the saddle magnet for external field so that the residual DC field at sample position was reduced to $\sim$10$^{-7}$ T.

Fig. 1 shows the temperature variations of $\chi'$ of sintered InV$_6$S$_8$ observed at $10^{-7}$ T, $2\times10^{-3}$ T, $5\times10^{-3}$ T and $10^{-2}$ T. The $\chi'$ decreased quite sharply at 3.5 K, and the transition temperature was not influenced by the magnetic field. In the next stage, the same sintered InV$_6$S$_8$ sample was crushed into powders and packed by pressing. Fig. 2 shows the temperature variations of $\chi'$. The powdered sample showed two steps, and the step at higher temperature was not influenced by the application of external field. On the other hand, the inflection point which is denoted as $T_{C2}$ shifted to the lower temperature as the increase of magnetic field.

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Fig. 1. Temperature variations of $\chi'$ for sintered InV$_6$S$_8$ under various magnetic fields.

Fig. 2. Temperature variations of $\chi'$ for powdered InV$_6$S$_8$ under various magnetic fields.

The temperature variations of $\chi'$ are explained by following consideration. As the temperature decreases, the energy of Josephson coupling between grains becomes to exceed the thermal energy, and thus the inter-grain superconducting transition would occur at $T_{C2}$. Above $T_{C2}$, the AC magnetic field produced by primary coil penetrates the surface of each grains even at zero external field. Below $T_{C2}$, the penetration volume becomes negligibly small since the shielding current flows the surface of the packed sample. Fig. 3 shows the temperature dependence of $\chi'$ of powdered In$_{0.71}$V$_6$S$_8$ under various magnetic fields. The values of $\chi'$ were not varied for the zero field cooling and the field cooling measurements in all samples.

The similar intra-grain and inter-grain superconducting transitions have been reported for high $T_C$ ceramic superconductor (YBCO) and BaPb$_{1-x}$Bi$_x$O$_3$ (BPBO) [5-7]. According to Ref. 7, the magnetic field dependence of $T_{C2}$ is represented as follows,

$$ H = H_0 \left(1 - \frac{T_{C2}}{T_0}\right)^n $$  \hspace{1cm} (1)

where $H$ is applied magnetic field, $H_0$ is constant and $T_0$ is the inter-grain transition temperature at $H=0$. The values of $n$, $T_0$ and $H_0$ are respectively 0.5, 56 K and 5x10$^{-2}$ T for YBCO, and are respectively 1.5, 7.65 K and 0.3 T for BPBO [7]. Fig. 4 shows the magnetic field dependence of $T_{C2}$/$T_0$ for InV$_6$S$_8$ and In$_{0.71}$V$_6$S$_8$. The obtained values of $n$, $T_0$ and $H_0$ are respectively 6.1, 1.97 K and 9.1 T for InV$_6$S$_8$ and are respectively 5.8, 0.37 K and 0.26 T for In$_{0.71}$V$_6$S$_8$. The shape of $H$-$T_{C2}$ curve shown in Fig. 4 is concave upward similar to BPBO. However, the value of $n$ is large compared with BPBO, and the shift of $T_{C2}$ is remarkable at low magnetic field. In order to analyze more precisely the effect of magnetic field on $T_{C2}$, it is necessary to investigate the effect in other AV$_6$S$_8$ samples.

References