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Anisotropic superconducting properties in $Sc_5Ir_4Si_{10}$

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Abstract

We have studied the anisotropic superconducting properties of $Sc_5Ir_4Si_{10}$ single crystalline sample by magnetic measurements. The upper critical field, H_{c2}, for H parallel to the c-axis is larger than that for H parallel to the ab-plane, with the anisotropic parameter of about 2.3, indicating that $Sc_5Ir_4Si_{10}$ is a quasi-one-dimensional superconductor. The magnetic penetration depths are estimated as $\lambda_c(0) = 840$ Å and $\lambda_{ab}(0) = 2100$ Å. The anisotropy of H_{c2} is also confirmed in randomly oriented powder samples.

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Keywords: Anisotropy; Upper critical field; $Sc_5Ir_4Si_{10}$

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1. Introduction

Since the discovery of high temperature superconductivity in an intermetallic compound MgB_2 with $T_c \sim 39$ K [1], much attention has been directed towards intermetallic compounds containing light elements with high phonon frequencies. Very recently, Emery et al. discovered superconductivity with $T_c \sim 11.5$ K in the graphite intercalation compound, CaC_6 [2]. However, these compounds have problems, such as high melting temperature in borides or unstable nature in air in carbon compounds. Thus, we directed our attention to the next candidates, silicides. It has been known that a class of intermetallic compounds $R_5Ir_4Si_{10}$ (R = Dy–Lu and Y) exhibit the coexistence of charge density wave (CDW) with magnetism or superconductivity [3–9]. In general CDW orderings have been observed in low-dimensional compounds which have anisotropic Fermi surfaces with small curvature that is favorable for nesting. These silicides crystallize in the $Sc_5Co_4Si_{10}$-type structure, where R atoms occupy three different sites. The R1 site form a chainlike structure along the c-axis that is embedded in a network of closely bonded R2, R3, and Ir atoms. Mostly probably, the chains of R1 atoms are responsible for the quasi-one-dimensional electronic band structure and the CDW occurs along it, opening a partial gap on the Fermi surface [5,6]. Superconductivity in such a system is expected to be anisotropic.

The related compounds $Sc_5Ir_4Si_{10}$, with the highest superconducting transition temperature ($T_c = 8.4$ K) does not exhibit the CDW. Therefore, it is of great importance to investigate the origin of the absence of CDW transition and the high transition temperature, and its anisotropic superconducting properties in single crystal of $Sc_5Ir_4Si_{10}$. We have measured the anisotropic magnetization properties of single crystalline $Sc_5Ir_4Si_{10}$. The upper critical fields and the magnetic penetration depths have been determined from a variation of the magnetization with magnetic field at several temperatures and the magnetization as a function of temperature at various applied fields. The anisotropy parameter has also been evaluated.

2. Experimental

The ingots of $Sc_5Ir_4Si_{10}$ are prepared by arc melting a 5:4:10 stoichiometric mixture of Sc, Ir and Si in an Ar environment. The ingots are then used to prepare the feeding and seed rods for the floating-zone method to grow single

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crystals. Single crystals are grown with a growth rate of 2 mm/h in an Ar environment with a flow rate of 1 l/min. The rods are rotated in the opposite directions at 20 rpm.

Magnetization as a function of temperature and magnetic field is measured using a SQUID magnetometer (MPMS-XL5, Quantum Design). Details of the crystal structure are characterized by X-ray diffraction using a four-circle diffractometer. The typical dimensions of the single crystal are $1.5 \times 1.0 \times 0.5$ mm^3. Resistivity is measure by the conventional four-probe method using a resistance bridge (LR-700, Linear research).

3. Results and discussion

The critical temperature of single crystalline $Sc_5Ir_4Si_{10}$ is determined from zero-field-cooled magnetization at 10 Oe. As shown in the inset of Fig. 1a, the onset of superconductivity is 8.4 K with the transition width of 0.4 K. The inset of Fig. 1b shows the temperature dependence of the resistivity for current along the *ab*-plane (ρ_{ab}). The absolute value of ρ_{ab} at room temperature in $Sc_5Ir_4Si_{10}$ is comparable to that in $Lu_5Ir_4Si_{10}$ [5]. However, due to the absence of the CDW transition in $Sc_5Ir_4Si_{10}$, ρ_{ab} just above T_c is much smaller than that in $Lu_5Ir_4Si_{10}$. Fig. 1a and b show the temperature dependence of magnetization in the single crystal of $Sc_5Ir_4Si_{10}$ for fields parallel to the *c*-axis and the *ab*-plane, respectively. Both H^c_{c2} and H^{ab}_{c2} are determined by the onset of diamagnetism for each field. As shown in the Fig. 4, it is clear that H^c_{c2} is larger than H^{ab}_{c2}, with the value of the anisotropy parameter $\gamma = H^c_{c2}/H^{ab}_{c2} = 2.3$. Hence, $Sc_5Ir_4Si_{10}$ is classified into the quasi-one-dimensional superconductors like $Lu_5Ir_4Si_{10}$. The anisotropy of γ in $Lu_5Ir_4Si_{10}$ is reported as 1.5 from the upper critical field measurements [10].

Magnetic hysteresis curves at various temperatures for $H\|c$ and $H\|ab$ are shown in Fig. 2, respectively. There is a clear peak effect at lower temperatures ($T \leqslant 6$ K) as shown in the inset of Fig. 2a and b. The H_{c2} values are estimated by the field where the *M–H* curves change their slopes. The temperature variations of H^c_{c2} and H^{ab}_{c2} are also shown in Fig. 4. We have evaluated the equilibrium magnetization M_{eq} using $M_{eq}(H) = (M_+(H) + M_-(H))/2$ for all temperatures, where $M_+(H)$ and $M_-(H)$ are magnetizations for increasing and decreasing field, respectively. Using $\frac{dM^c_{eq}}{d(\ln H)} = \frac{\Phi_0}{32\pi^2\lambda^2_{ab}}$ and $\frac{dM^{ab}_{eq}}{d(\ln H)} = \frac{\Phi_0}{32\pi^2\lambda_{ab}\lambda_c}$ [11], where Φ_0 is the flux quantum, we estimated the magnetic penetration

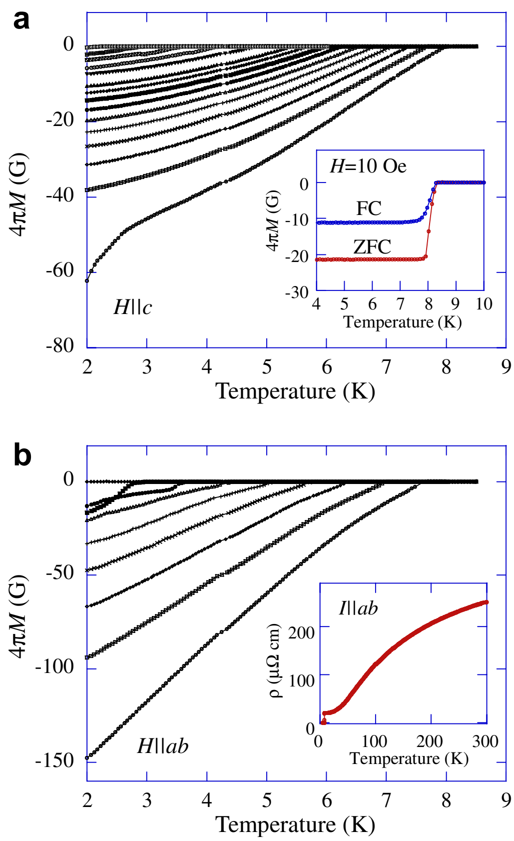

Fig. 1. Field-cooled magnetization as a function of temperature in $Sc_5Ir_4Si_{10}$ for (a) for $H\|c$ from 1 to 10 kOe with intervals of 1 kOe, from 12 to 20 kOe with intervals of 2 kOe, and (b) for $H\|ab$ form 1 to 9 kOe with intervals of 1 kOe. The inset of (a) shows the temperature dependence of field cooled (FC) and zero field cooled (ZFC) magnetizations at 10 Oe. The inset of (b) shows the temperature dependence of resistivity for current along the *ab*-plane.

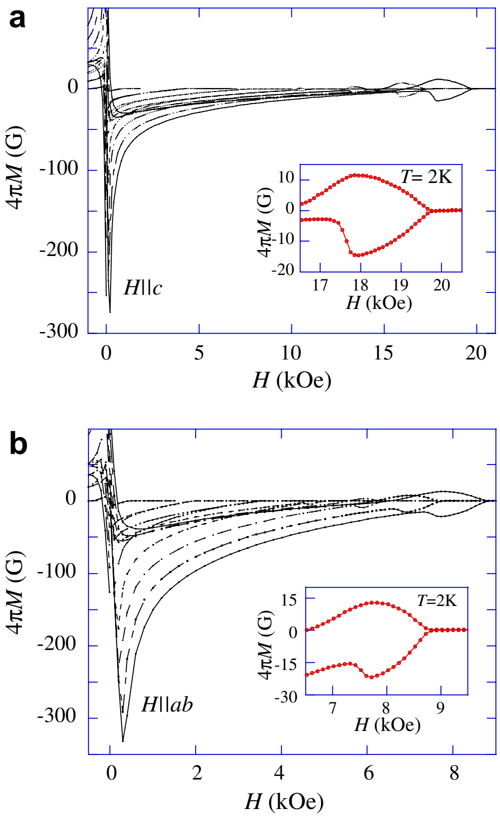

Fig. 2. Magnetic Hysteresis curves of $Sc_5Ir_4Si_{10}$ at temperatures, from 2 K to 8 K for (a) $H\|c$ and for (b) $H\|ab$. The inset of (a) and (b) shows the peak effect region at 2.0 K for $H\|c$ and $H\|ab$, respectively.