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Comparative study of anisotropic superconductivity in CaAlSi and CaGaSi

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Abstract

In order to get some insight into the origin of the anomalous angular dependence of H_{c2} in a layered intermetallic compound CaAlSi, electronic, superconducting, and structural properties are compared between CaAlSi and CaGaSi. The angular dependence of H_{c2} in CaGaSi is well described by the anisotropic GL model. Parallel to this finding, the pronounced lattice modulation accompanying the superstructure along the *c*-axis in CaAlSi is absent in CaGaSi. A relatively large specific heat jump at the superconducting transition in CaAlSi compared with CaGaSi indicates the presence of strong electron–phonon coupling in CaAlSi, which may cause the superstructure and the anomalous angular dependence of H_{c2}.

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Keywords: Upper critical field; Anisotropy; Superstructure; CaAlSi; CaGaSi

1. Introduction

After the discovery of superconductivity in MgB_2 with $T_c = 39$ K [1], much attention has been directed towards the superconductivity in intermetallic compounds. In particular, superconductivity in structurally similar systems to MgB_2 has been explored extensively. A group of compounds with the general formula $A(M_{1-x}Si_x)_2$ (A = Ca, Sr, Ba, M = Al, Ga) turns out to have rich physics in various aspects of superconductivity [2–5]. Among these compounds, CaAlSi has the highest superconducting transition temperature, T_c of 7.7 K under ambient pressure [3], although $CaSi_2$ shows superconductivity as high as 14 K under extremely high pressure after the structural transition [6]. Band structure calculations equivocally show that the density of state at the Fermi level, $N(0)$, in

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CaAlSi is smaller than that in SrAlSi, although T_c in CaAlSi is much higher than in SrAlSi ($T_c = 4.9$ K) [7,8]. Specific heat measurements in CaAlSi and SrAlSi confirmed this reversed trend of T_c and $N(0)$, and the strong coupling nature of superconductivity in CaAlSi [4]. We have reported that the angular dependence of the upper critical field, $H_{c2}(\theta)$, in CaAlSi shows a cusp-like anomaly when the field is applied parallel to the superconducting plane despite its modest anisotropy $\gamma = 2$ (γ: anisotropy parameter) [5]. X-ray diffraction studies have also shown the presence of prominent superstructure along the c-axis [5]. CaAlSi is reported to have positive pressure dependence of T_c while it is negative in SrAlSi. All these experimental findings highlight anomalous nature of superconductivity in CaAlSi. In order to get some insight into the origins of the anomalies in CaAlSi, especially the anomalous $H_{c2}(\theta)$, we have made comparative studies between CaAlSi and CaGaSi. Despite their chemical and structural similarities, $H_{c2}(\theta)$ in CaGaSi can be fitted by anisotropic GL model with $\gamma \sim 1.5$. Parallel to this observation, superstructure along c-axis is absent in CaGaSi.

2. Experimental

Single crystals of CaAlSi and CaGaSi are grown by the floating-zone method using an image furnace in argon atmosphere [5]. Typical growth rate is 10 mm/h. The stating polycrystalline rods are prepared by melting pieces of starting elements in an arc furnace. Magnetization as a function of temperature and magnetic field is measured using SQUID magnetometer (MPMS, Quantum Design). The angular dependence of H_{c2} is determined by measuring magnetic field dependence of resistivity at various angles at constant temperatures. Resistivity is measured by the conventional four-probe method using AC-resistance bridge (LR-700, Linear Research). Four gold wires are attached to the pads on the sample surface formed by silver paste. Care is taken to pass the current homogeneously through the sample. Specific heat is measured by the relaxation method. The thermal relaxation curve is fitted assuming a single relaxation time. The crystal structure including the superstructure is characterized by X-ray diffraction using four-circle diffractometer (AFC-7PC, Rigaku).

3. Results and discussion

The upper critical fields H_{c2} for magnetic fields both parallel and perpendicular to the ab-plane are determined by the onset of diamagnetism in the field-cooled measurements. Thus determined H_{c2} in both CaAlSi and CaGaSi are anisotropic. The anisotropy parameter γ defined by the ratio of the upper critical fields is 2.0 and 1.6 for CaAlSi and CaGaSi, respectively. The angular dependences of H_{c2} in CaAlSi and CaGaSi are shown in Fig. 1(a) and (b). Here, $\theta = 0°$ corresponds to the field parallel to the ab-plane. We define H_{c2}

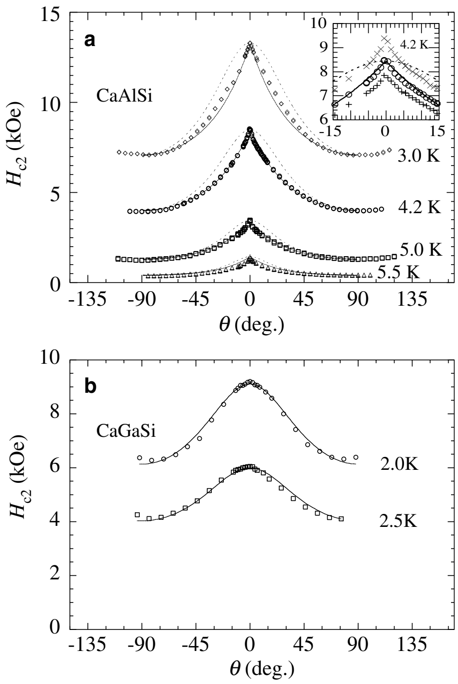

Fig. 1. Angular dependence of H_{c2} for (a) CaAlSi and (b) CaGaSi determined from the resistive transition with the criterion of $\rho = 0.5\rho_n$, where ρ_n is the normal state resistivity. Dotted and solid lines show fitting curves by the anisotropic GL model (Eq. (1)) and the Tinkham's model (Eq. (2)). Inset of (a) shows a blow-up of the small angle region including H_{c2} determined by different criteria $\rho = 0.1\rho_n$ (pluses) and $0.9\rho_n$ (crosses).