Specific heat study of magnetic superconductor $ErNi_2B_2C$ single crystal under magnetic fields

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Abstract

Specific heat C_p of an $ErNi_2B_2C$ single crystal was measured. In the absence of a magnetic field, both antiferromagnetic and weak ferromagnetic transitions were observed as a peak and a kink in C_p at $T_N \sim 6$ K and $T_{WF} \sim 2.3$ K, respectively. Under magnetic fields parallel to the [110] direction, T_N monotonically decreases with increasing field, while T_{WF} increases at low fields and decreases above 1 T. This reentrant behavior of T_{WF} is reasonably explained by assuming the competition between magnetocrystalline anisotropy and the weak ferromagnetism arising from the magnetic moment at the antiferromagnetic domain boundary.

Key words:
Borocabide;Magnetic Superconductor;$ErNi_2B_2C$;Specific Heat

1. Introduction

A borocarbide magnetic superconductor $ErNi_2B_2C$ has been extensively studied because of the coexistence of superconductivity and weak ferromagnetism [1]. In the absence of a magnetic field, $ErNi_2B_2C$ becomes superconducting below $T_c \sim 10.5$ K. Magnetic moments of Er order into incommensurate antiferromagnetic state (AF) below $T_N \sim 6$ K [2] and show weak ferromagnetism (WF) below $T_{WF} \sim 2.3$ K [1]. Under magnetic fields, magnetic phase transitions strongly depend on the field direction because Er moments have strong magnetocrystalline anisotropy. Easy axis of magnetization is parallel to the [010] direction [1]. Because of this, magnetic phase diagram under magnetic fields parallel to the *a*-*b* plane is very rich, while magnetic fields along the [001] direction have little effect on magnetic phase transitions. To date, strong suppression of T_N and several metamagnetic phase transitions were observed under magnetic fields parallel to the *a*-*b* plane [3,4]. However, detailed nature of these metamagnetic phase transitions and their relation with WF are still unclear. To examine this issue, we measured the specific heat C_p of an $ErNi_2B_2C$ single crystal under magnetic fields.

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2. Experimental

A single crystal of $ErNi_2B_2C$ was grown by floating zone method and was annealed at 1100 °C in vacuum for 10 days. Superconducting transition temperature was determined to be 10 K. Specific heat was measured by thermal relaxation method. Magnetic fields were applied parallel to the [110] direction which is inclined 45 degrees from the easy axis of magnetization, [010] .

3. Results and Discussion

Specific heat C_p under various magnetic fields are shown in Fig. 1. Because of the large spin entropy of Er,

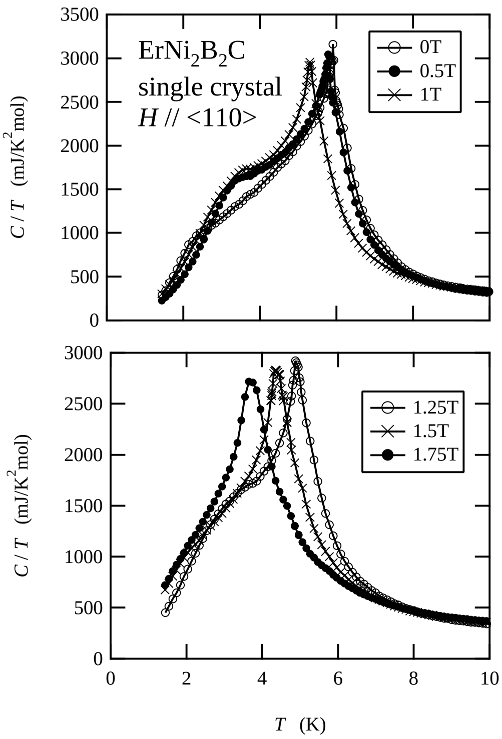

Fig. 1. Temperature dependence of C_p at various fields.

a large part of C_p is magnetic in origin. In the absence of a magnetic field, both AF and WF transitions were observed as a peak and a kink in C_p at $T_{\rm N} \sim 6$ K and $T_{\rm WF} \sim 2.3$ K, respectively. These temperatures are in good agreement with the previous reports [1,5].

Under magnetic fields, a λ-type peak at $T_{\rm N}$ decreases monotonically with increasing magnetic field. On the other hand, a kink at $T_{\rm WF}$ depends on magnetic fields in a complicated manner. Below 1 T, $T_{\rm WF}$ increases with increasing field as shown in the upper panel of Fig. 1. After taking maximum around 3 K, $T_{\rm WF}$ decreases with increasing field (lower panel of Fig. 1). At the same time, the kink at $T_{\rm WF}$ becomes broader and is smeared out above 1.5 T. Namely, $T_{\rm WF}$ shows reentrant behavior.

In Fig. 2, $T_{\rm N}$ and $T_{\rm WF}$ are plotted on the field-temperature plane together with the metamagnetic transition fields reported in Refs. [2] and [3]. The AF transition line is in good agreement with the previous result in Ref. [2]. The WF transition line we determined apparently agrees with one of the metamagnetic transition lines. Although we measured the detailed magnetic field dependence of C_p, we could not observe other metamagnetic transition lines. Considering that the C_p is a measure of the entropy change, major change in the spin configuration should be occurred at the reentrant-type transition line which connects to

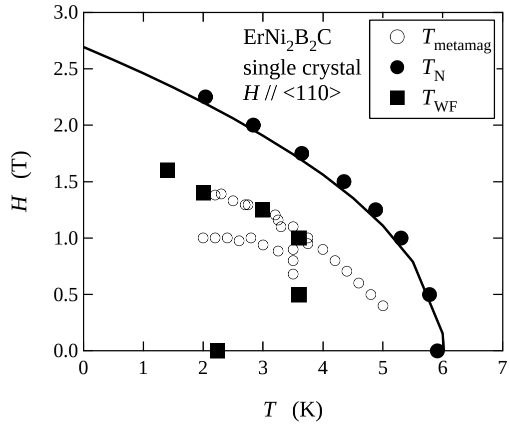

Fig. 2. Magnetic phase diagram. Solid circles - $T_{\rm N}$, solid square $T_{\rm WF}$, open circles - metamagnetic transition [3], solid line - $T_{\rm N}$ [2].

the WF transition in the absence of a magnetic field.

The origin of reentrant behavior of $T_{\rm WF}$ can be explained as follows. Since application of magnetic fields tends to align magnetic moments unidirectionally, increase in $T_{\rm WF}$ with increasing magnetic field below 1 T can be naturally understood. To understand the behavior at higher fields, spin structure and magnetocrystalline anisotropy must be taken into account. It is reported that WF originates from moments at the domain boundary among AF domains with periodicity of $20a$ [6]. WF moments are aligned to the [010] direction [1]. Large magnetocrystalline anisotropy forces Er moments to align along the [010] direction or nearly equivalent [100] direction [1]. Therefore, when strong magnetic field is applied along the [110] direction, as in the present case, part of Er moments should be aligned to the [100] direction through metamagnetic transition. In such a situation, AF domain structure is modified and the domain boundary, which is a source of WF, should be largely affected. As a result $T_{\rm WF}$ decreases in high magnetic field region. Namely, the reentrant behavior of $T_{\rm WF}$ can be understood in terms of the competition between magnetocrystalline anisotropy and WF arising from the magnetic moment at the AF domain boundary.

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