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Magnetic properties of $Ce(Fe_{1-x}Co_x)_2$ under high pressure

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Abstract

We have studied the magnetic properties of $Ce(Fe_{1-x}Co_x)_2$ with $x = 0$ and 0.05 by magnetization measurements under high pressure. In both compound, the remarkable suppression of the magnetization is observed below T^* in the ferromagnetic (FM) state under 1.2 GPa. T^* shifts to lower temperature with increasing the magnetic field, and the extrapolated value to the zero magnetic field is estimated to be 95 and 123 K. These high pressure and magnetic field effects are probably due to the enhancement and the suppression of the AFM spin fluctuation, respectively.

Keywords: $Ce(Fe_{1-x}Co_x)_2$; Magnetic phase transition; High pressure; Antiferromagnetic spin fluctuation; Magnetic frustration

1. Introduction

The compound $CeFe_2$ with the C15 cubic Laves-phase ($MgCu_2$-type) structure is a unique ferromagnet with the lowest Curie temperature $T_C = 230$ K and the smallest saturation moment $M_s = 2.3\,\mu_B$/f.u. at 4.2 K among RFe_2 (R: rare earth metal) compounds. By a small amount of substitution of Co for Fe, the ferromagnetic (FM) ground state changes into the antiferromagnetic (AFM) state [1,2]. This substitution does not come from the change in the magnetic state of the Ce sublattice, but comes mainly from the instabilities of the magnetic state of the Fe sublattice [3].

Paolasini et al. have probed the Fe magnetic instability in $CeFe_2$ with neutron scattering experiments [4,5]. They observed that the AFM spin fluctuation with a propagation vector $q = [1/2, 1/2, 1/2]$ and an energy of ∼1 meV exists below about 100 K even in the FM state. They also revealed that the AFM spin fluctuation with the same q vector exists in the FM state for $Ce(Fe_{0.93}Co_{0.07})_2$, and that it changes into a typical AFM spin wave in the AFM state at low temperatures. The AFM spin fluctuation and the AFM spin wave observed by them are associated with the Fe spins. They also showed that the AFM state of $Ce(Fe_{0.93}Co_{0.07})_2$ is not a simple collinear AFM structure but a non-collinear one. Fujiwara et al. performed the neutron diffraction experiments of single crystal $CeFe_2$ under high pressure [6]. These results showed that the Fe static magnetic moment along the [1 1 1] at 1.5 GPa shrinks below about 110 K, and that the AFM spin fluctuation is enhanced by applying pressure. From magnetization measurements using a $CeFe_2$ single crystal, Fukuda et al. revealed that the magnetization along the [1 1 1] direction at 5 K is anisotropically suppressed by applying hydrostatic pressure [7]. According to their conclusion, such the anisotropic suppression of the magnetization originates from the anisotropic Ce 4f–Fe 3d hybridizations with the strong magnetoelastic effect.

Magnetization measurements under high pressure are useful methods to obtain the information on the hybridization effects between electron states. Quite recently, we reported magnetization measurements of $Ce(Fe_{1-x}Co_x)_2$ with $x = 0$, 0.05 and 0.1 under high pressure, and found that the remarkable suppression of magnetization under high pressure at lower temperatures [8]. In this paper, we will present the

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results of magnetization measurements of the polycrystalline samples of $Ce(Fe_{1-x}Co_x)_2$ with $x = 0$ and 0.05 under 1.2 GPa in the magnetic field up to 1 T in detail, which is discussed considering the AFM spin fluctuation.

2. Experimental

The polycrystalline samples of $Ce(Fe_{1-x}Co_x)_2$ with $x = 0$ and 0.05 were prepared by arc-melting the constituent metals with nominal 99.99% purity in an Ar flow atmosphere. The ingots were annealed in an evacuated quartz tube at 1123 K for one week. By the powder X-ray diffraction measurement at room temperature, the samples were confirmed to be a single phase of the C15 cubic structure except for a very weak Ce oxide phase.

Temperature dependence of the magnetization in the magnetic field up to 1 T under 1.2 GPa was measured by a SQUID magnetometer (Quantum Design). We used a handmade miniature cell made of a Cu–Be alloy. In this study, the magnetization was measured in heating process.

3. Results and discussion

Fig. 1 shows the temperature dependence of the magnetization of $CeFe_2$ in the various magnetic fields up to 1 T under 1.2 GPa [8]. The data at $B = 0.8$ T under ambient pressure (0.1 MPa) is also shown in this figure for comparison with the behavior under 1.2 GPa. $CeFe_2$ shows a typical ferromagnetic behavior with Curie temperature of $T_C = 230$ K under 0.1 MPa. T_C decreases by applying pressure, and is estimated to be 209 K at 0.1 T under 1.2 GPa. Furthermore, the remarkable suppression of magnetization under 1.2 GPa is observed below $T^* = 80$ K at 0.5 T and $T^* = 65$ K at 1.0 T, respectively. Here, we cannot estimate T^* at 0.1 T, because the temperature dependence of the magnetization is also affected by the magnetic anisotropy in the magnetization measurement using the polycrystalline at low magnetic field.

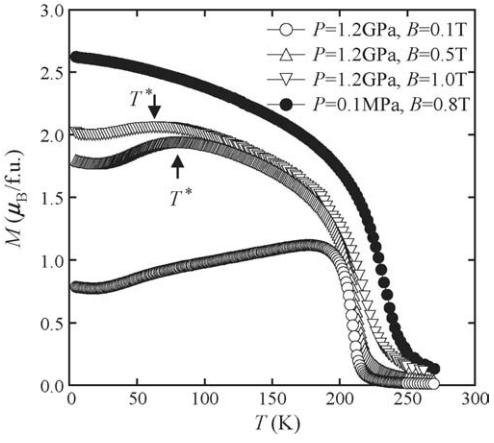

Fig. 1. Temperature dependence of the magnetization of $CeFe_2$ in the various magnetic fields up to 1 T under 1.2 GPa. The closed circles indicate the data at $B = 0.8$ T under 0.1 MPa.

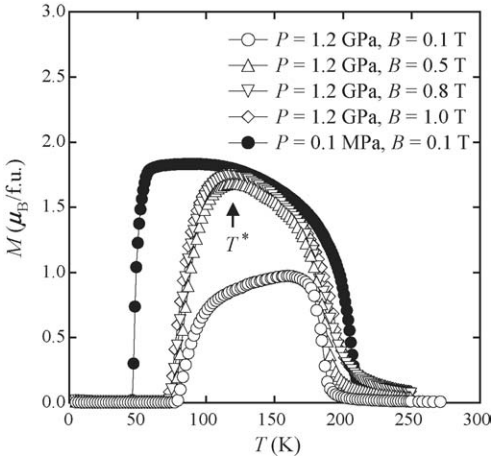

Fig. 2. Temperature dependence of the magnetization of $Ce(Fe_{0.95}Co_{0.05})_2$ in the various magnetic fields up to 1 T under 1.2 GPa. The closed circles indicate the data at $B = 0.1$ T under 0.1 MPa.

Fig. 2 shows the temperature dependence of the magnetization of $Ce(Fe_{0.95}Co_{0.05})_2$ in the various magnetic fields up to 1 T under 1.2 GPa. The data at $B = 0.1$ T under 0.1 MPa is also shown in this figure. With increasing temperature under 0.1 MPa, the AFM ground state abruptly changes into the FM state at transition temperature $T_A = 49$ K, and then the FM state changes into the paramagnetic (PM) state at $T_C = 209$ K. By applying pressure of 1.2 GPa, T_A increases to 83 K at 0.1 T, whereas T_C decreases to 183 K at 0.1 T. On the contrary to this, with increasing the magnetic field under 1.2 GPa, T_A slightly decreases, whereas T_C slightly increases. In addition, we can see that the magnetization in the FM region under 1.2 GPa begins to suppress below $T^* \sim 120$ K at 0.5, 0.8 and 1.0 T with decreasing temperature.

By recent neutron scattering experiments for $CeFe_2$, Paolasini et al. revealed that the AFM spin fluctuation with a propagation vector $q = [1/2, 1/2, 1/2]$ exists in the FM state below about 100 K [4]. They also observed that the AFM spin fluctuation with the same q vector exists in the FM state for $Ce(Fe_{0.93}Co_{0.07})_2$ [5]. In addition, Fujiwara et al. reported that the Fe static magnetic moment along [1 1 1] at 1.5 GPa shrinks below about 110 K for $CeFe_2$, and that the AFM spin fluctuation is enhanced by applying pressure [6]. Therefore, the remarkable suppression of magnetization below T^* for $CeFe_2$ and $Ce(Fe_{0.95}Co_{0.05})_2$ is probably due to the enhancement of the AFM spin fluctuation by applying high pressure.

Figs. 3 and 4 show the B–T magnetic phase diagrams under 1.2 GPa for $CeFe_2$ and $Ce(Fe_{0.95}Co_{0.05})_2$, respectively. T^* shifts to lower temperature with increasing the magnetic field in both compounds. The extrapolated value to the zero magnetic field is estimated to be 95 and 123 K, and the magnetic field dependence of T^* is obtained to be $d\ln T^*/dB = -0.31$ and $-0.061\ T^{-1}$ for $CeFe_2$ and $Ce(Fe_{0.95}Co_{0.05})_2$, respectively. The value of $d\ln T^*/dB$ of $Ce(Fe_{0.95}Co_{0.05})_2$ is smaller

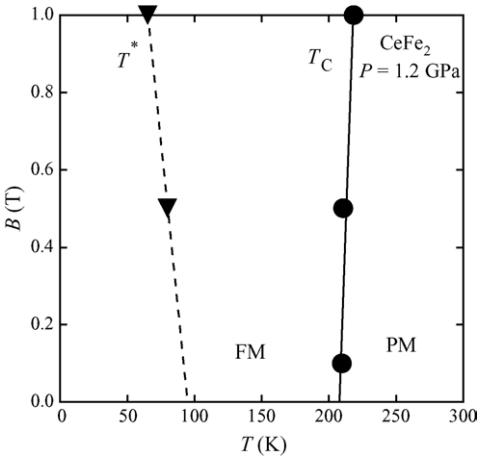

Fig. 3. B–T magnetic phase diagram for $CeFe_2$ under 1.2 GPa.

than that of $CeFe_2$. This may be due to the enhancement of the AFM correlation by the Co substitution.

Considering the previous reports of $Ce(Fe_{1-x}Co_x)_2$ [1–9], the Ce 4f–Fe 3d hybridization plays an important role in the intrinsic magnetic properties of $Ce(Fe_{1-x}Co_x)_2$ systems. It has supposed that this hybridization causes the AFM correlation on the Fe(Co)-sublattice. In addition, the AFM correlation probably induces the magnetic frustration effect, like YMn_2 compound [10], because the Fe(Co) atoms form a

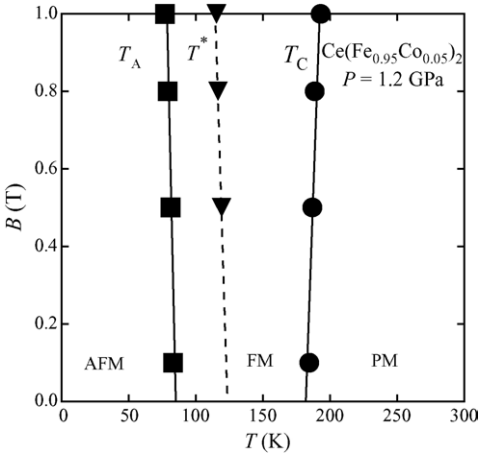

Fig. 4. B–T magnetic phase diagram for $Ce(Fe_{0.95}Co_{0.05})_2$ under 1.2 GPa.

three-dimensional network of corner-sharing tetrahedral in this compound. In Co doped compounds, the AFM correlation is enhanced, compared to that of $CeFe_2$. By applying pressure, the Ce 4f–Fe 3d hybridization is enhanced due to the lattice contraction, leading to the enhancement of the AFM correlation. Therefore, the AFM spin fluctuation due to the magnetic frustration effect is also enhanced by applying pressure. As a consequence, the magnetization is suppressed below T^* and the AFM state become more stable below T_A, whereas the FM state is suppressed by applying pressure. On the other hand, the FM state becomes stable by applying magnetic field, leading to the decrease of T^* and T_A, because the AFM spin fluctuation is suppressed.

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