Thermal expansion and magnetostriction in CeRh$_3$B$_2$

T. Takeuchi$^{a,b,*}$, A. Thamizhavel$^c$, T. Okubo$^c$, M. Yamada$^c$, Y. Inada$^c$, A. Galatanu$^d$, E. Yamamoto$^d$, Y. Ōnuki$^{c,d}$

$^a$Low Temperature Center, Osaka University, Toyonaka, Osaka 560-0043, Japan
$^b$KYOKUGEN, Osaka University, Toyonaka, Osaka 560-8531, Japan
$^c$Graduate School of Science, Osaka University, Toyonaka, Osaka 560-0043, Japan
$^d$Advances Science Research Center, Japan Atomic Energy Research Institute, Tokai, Ibaraki 319-1195, Japan

Abstract

Thermal expansion and magnetostriction measurements have been performed on a single crystal CeRh$_3$B$_2$ with an unusually high Curie temperature $T_C \sim 120$ K. The thermal expansion coefficients show a weak anomaly at $T_C$ and characteristic positive and negative peaks around 150 K for [0 0 0 1] and [10 0] respectively. The magnetostriction at 4.2 K for the field along the basal plane is very small, with an order of $10^{-5}$, suggesting a localized nature of Ce – 4f moments.

Keywords: CeRh$_3$B$_2$; Thermal expansion; Magnetostriction

CeRh$_3$B$_2$ has been attracting a great deal of interest because of its unusual ferromagnetic properties [1]. It crystallizes in the hexagonal CeCo$_3$B$_2$-type structure and shows a ferromagnetic ordering below a Curie temperature $T_C \sim 120$ K, which is the highest magnetic ordering temperature of any Ce compound with nonmagnetic constituents and even two orders higher than $T_C \sim 1$ K expected from the de Gennes scaling of $T_C \sim 90$ K for GdRh$_3$B$_2$. In spite of the high ordering temperature, the magnetization at 4 K shows only $\sim 0.5 \mu_B$/Ce at 7 Koe [2]. From these facts, it was suggested that the ferromagnetism in CeRh$_3$B$_2$ is itinerant in nature [1]. However, the X-ray spectroscopy [3] and substitution experiments [4] indicate that the ferromagnetism is not due to itinerant 4f-electrons but due to the local Ce moments. Subsequent NMR experiments also show that the magnetic moment of 0.4 $\mu_B$ is localized at the Ce site below $T_C$ [5]. The $c$ lattice parameter (3.09 Å) is, however, smaller than $\alpha$-Ce and decreases further with decreasing temperature, while the $a$ lattice parameter increases with decreasing temperature [6]. These lattice strains might enhance the evolution of direct overlap between atomic wave functions of neighboring Ce atoms, which will cause the unusual magnetic properties.

In this work, we grew a single crystal of CeRh$_3$B$_2$ and performed precise thermal expansion and magnetostriction measurements.

Fig. 1 shows the temperature dependence of the thermal expansion $\Delta/\ell$ along [000 1] and [1010]. $\Delta/\ell$ for [1010] shows a gradual increase of about $1.7 \times 10^{-3}$ with decreasing temperature. In contrast, $\Delta/\ell$ along [000 1] decreases largely with decreasing temperature, and a total change amounts to about 1% between 4.2 and 300 K. These features are consistent with the previous reports [6,7]. For both directions, there is a weak kink at $T_C \sim 120$ K in the thermal expansion. This anomaly can be seen more clearly in the temperature dependence of the thermal expansion coefficient $\alpha$, as shown in the inset of Fig. 1. In addition to this anomaly at $T_C$, broad positive and negative peaks centered at about 150 K were observed for $\alpha||[0 0 0 1]$ and [1010],

$^*$Corresponding author. Low Temperature Center, Osaka University, Toyonaka, Osaka 560-0043, Japan. Tel.: +81-6-6850-6691; fax: +81-6-6850-5288.
E-mail address: takeuchi@reem.osaka-u.ac.jp (T. Takeuchi).

0304-8853/$-$ see front matter © 2003 Published by Elsevier B.V.
respectively. The reason of this peak is not clear at present, but this might indicate a characteristic energy scale, such as a crystalline electric field excitation.

The field dependence of the longitudinal magnetostriction and magnetization at 4.2 K for $H \parallel [10\bar{1}0]$ (easy-axis) are shown in Fig. 2. The magnetostriction increases gradually up to about 1 T, where the magnetization reaches a saturation value of about 0.45 $\mu_B$. Above 1 T, the magnetostriction starts to decrease linearly with increasing magnetic field. These features of magnetostriction will be explained by a simple ferromagnetic domain orientation during the magnetization process. In fact, the magnetostriction shows a monotonical small change of $10^{-6}$ above $T_C$ for all the principal axes.

In general, mixed valence and Kondo compounds exhibit a very large and nonlinear magnetostriction at low temperatures due to the unstable 4f state. In such systems, the large spontaneous magnetostriction appears below the ordering temperature, reflecting the temperature variation of the magnitude of local moments. In CeRh$_3$B$_2$, the anomaly at $T_C$ is very weak and the spontaneous magnetostriction below $T_C$ is also rather small, as shown in Fig. 1. In addition, the value of the field dependence of magnetostriction is relatively small, i.e., $10^{-5}$ at 4.2 K. Considering these facts, the Ce moments seem to have a localized nature even below $T_C$.

This work was supported by the Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology.

References