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Low-temperature thermal expansion of CeBiPt

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Abstract

CeBiPt is a low-carrier-density semimetal which exhibits antiferromagnetic ordering below $T_N = 1.1\,K$. We measured the thermal expansivity α down to 0.3 K in zero and applied magnetic field $B = 1\,T$. In $B = 0$, a peak in $\alpha(T)$ indicates the antiferromagnetic phase transition. Antiferromagnetic ordering is suppressed in low fields. With increasing field Zeeman splitting of the ground state appears. The low-energy thermal exitations are seen as a minimum in the temperature dependence of the longitudinal thermal expansivity. The magnetostriction, i.e. the relative length change $\Delta L(B)/L(0)$ as a function of B, reaches a large value of 4×10^{-4} at $B = 8\,T$.

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Keywords: CeBiPt; Low-carrier-density semimetal; Thermal expansion coefficient; Antiferromagnetic ordering

Investigations of ternary rare-earth compounds continue to be an active topic of research because of their intriguing magnetic properties. The equiatomic ternary RBiPt intermetallic compounds (R = rare − earth elements) crystallize in the cubic MgAgAs-type structure (space group F$\bar{4}$3m) [1]. This structure consists of three fcc sublattices shifted by ($\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{4}$) along the body diagonal with their origins at (0 0 0), ($\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{4}$), and ($\frac{3}{4}$, $\frac{3}{4}$, $\frac{3}{4}$), respectively. A rich variety of ground-state properties is observed ranging from superconductivity (for R = La) over semimetallic (R = Ce) and small-gap semiconducting behavior (R = Nd) [2] to the heavy fermion-like behavior in YbBiPt with one of the highest measured specific-heat coefficients $\gamma = C/T = 8\,J/mol\,K^2$ [3]. Till date, however, there is only limited knowledge on the electronic, superconducting, and magnetic properties of these materials. Especially, the influence of the 4f moments on the electronic properties remains to be clarified.

Here, we present a study of the thermal expansivity α of CeBiPt down to 0.3 K in zero

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and applied magnetic field $B = 1\,\mathrm{T}$. CeBiPt is a semimetal with very low-charge-carrier concentration and, consequently, very small Fermi surfaces [4]. CeBiPt orders as a simple commensurate antiferromagnet below $T_N = 1.1\,\mathrm{K}$ with magnetic moments ordered along the cubic fcc axes [5]. Magnetic ordering is also evidenced by sharp maxima in specific heat, susceptibility, and magnetization measurements [6]. The susceptibility follows a Curie–Weiss law at higher temperature ($T > 100\,\mathrm{K}$) with an effective magnetic moment close to the free Ce^{3+} moment of $2.47\mu_B$. At lower T, the effective moment becomes significantly reduced. A fit $\chi^{-1} \propto (T - \Theta_{CW})/\mu_{eff}^2$ to the susceptibility data below 5 K yields $\mu_{eff} = 2.1\mu_B$ and $\Theta_{CW} = -1\,\mathrm{K}$.

The magnetic behavior supports a local character of the 4f electrons. Ce^{3+} ions form a $^2F_{5/2}$ ground state with $J = \frac{5}{2}$ according to Hund's rules. The sixfold-level degeneracy is lifted by the cubic crystal symmetry into a doublet and a quartet state. Therefore, either a twofold or a fourfold degeneracy of the crystal field ground state of CeBiPt is expected. An entropy analysis of the specific-heat data suggests the quartet state being the ground state.

Single crystals of CeBiPt were grown by use of the Bridgman technique in hermetically sealed Mo crucibles at Hiroshima University. Thereby, first CePt were prepared by argon-arc melting. Then the appropriate amount of Bi was added for the single-crystal growth. An almost cube-shaped sample of length $L_{RT} = 3.347\,\mathrm{mm}$ along the [1 0 0] direction was cut from the ingot and the thermal expansion coefficient $\alpha = (1/L) \times (\partial L/\partial T)_p$ was measured at Amsterdam University between 0.35 and 5.5 K with a parallel-plate capacitance dilatometer in a ^{3}He cryostat. The closed symbols in Fig. 1 show α versus T in zero magnetic field. $\alpha(T)$ is positive in the whole T range and the broad transition at T_N with $\Delta\alpha > 0$ is clearly visible. Since the thermal expansion coefficient and the specific heat are closely related via simple thermodynamic relations, the increase in $\Delta\alpha$ matches nicely the increase in the specific-heat discontinuity ΔC_p [6]. The ratio $\Delta\alpha_v/\Delta C_p$ can be related to the hydrostatic pressure dependence of T_N, $\mathrm{d}T_N/\mathrm{d}p$, by the Ehrenfest relation $\mathrm{d}T_N/\mathrm{d}p = T_N V_{mol} \Delta\alpha_v/\Delta C_p$, the approximately concordant behavior of both discontinuities indicates a slowly varying but positive $\mathrm{d}T_N/\mathrm{d}p \approx +0.1\,\mathrm{K/GPa}$.

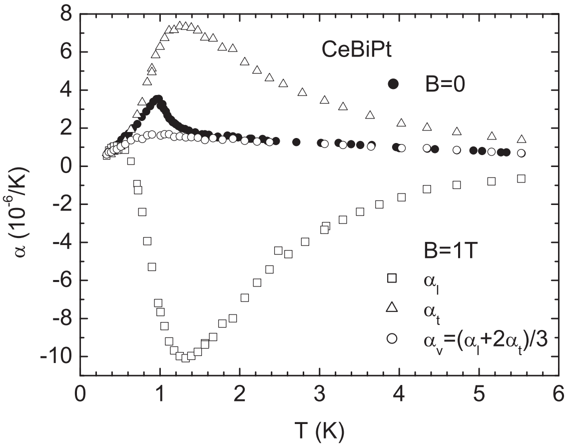

Fig. 1. Thermal expansivity α versus T of CeBiPt in zero and applied magnetic field $B = 1\,\mathrm{T}$.

Applying a magnetic field has two effects: at first, it suppresses magnetic ordering, and, secondly, it breaks the cubic crystal symmetry. The applied field can be considered as a uniaxial pressure which compresses the crystal in the transversal direction and elongates it in the longitudinal direction. Therefore, we measured $\alpha(T)$ at $B = 1\,\mathrm{T}$ in the transversal ($\alpha_t, B \perp \Delta L$) and longitudinal direction ($\alpha_l, B \parallel \Delta L$) shown as open symbols in Fig. 1. A huge Schottky-like anomaly appears in α_t and α_l, respectively. The anomaly is most likely caused by Zeeman splitting of the degenerate crystal-field level. No discontinuity is left in an applied magnetic field $B = 1\,\mathrm{T}$ in the volume expansion coefficient α_v obtained from $\alpha_v = (\alpha_l + 2\alpha_t)/3$ in line with the thermodynamic measurements [6].

The longitudinal magnetostriction $\Delta L(B)/L(0)$ with $B \parallel \Delta L$ was determined at three different temperatures above and below T_N (see Fig. 2). No significant difference was observed above and below T_N besides a reduction of the relative length change with increasing temperature. The magnitude of the magnetostriction at maximum field reaches relatively large values of $\approx 4 \times 10^{-4}$. In summary, we have presented measurements of the thermal expansivity of the antiferromagnet CeBiPt

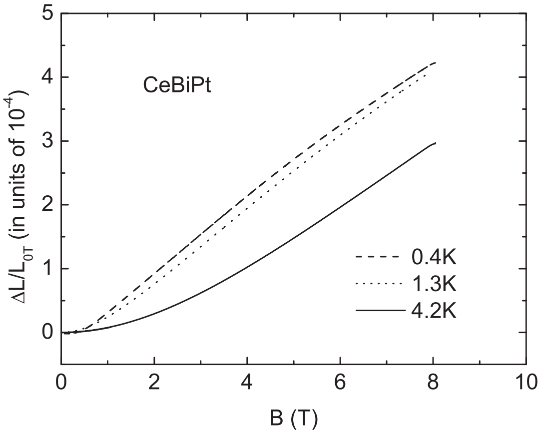

Fig. 2. Longitudinal magnetostriction $\Delta L(B)/L(0)$ of CeBiPt for $T = 0.4$, 1.3, and 4.2 K.

in zero and applied magnetic field. The result gives support to a local character of the 4f electrons and the importance of crystal-field effects. A detailed analysis of the data to higher temperatures and higher magnetic field will be published elsewhere.

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