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Doping and pressure studies on YbBiPt

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The compound YbBiPt exhibits an extremely large low-temperature C/T ($\gamma \sim 8 \text{ J K}^{-2} \text{ mol}^{-1}/\text{Yb}$) which, if due solely to a renormalized effective mass, would make this material the heaviest correlated electron system known to date. In the Kondo model, the very large γ corresponds to a small characteristic energy scale that is expected to be pressure dependent. We have studied the effect of chemical pressure on YbBiPt single crystals by heat-capacity measurements on Y and Lu-doped samples. We have also made preliminary low-temperature measurements under hydrostatic pressure of the heat capacity ($300 \text{ mK} < T < 2 \text{ K}$, up to 8 kbar) and resistance ($30 \text{ mK} < T < 1 \text{ K}$, at 16 kbar).

I. INTRODUCTION

Among Yb-based rare-earth (RE) compounds, the compound YbBiPt has attracted considerable attention due to its unusual heavy-fermion (HF) properties. The extraordinarily large Sommerfeld coefficient ($\gamma \sim 8 \text{ J K}^{-2} \text{ mol}^{-1}$, below 400 mK) places YbBiPt as the largest effective mass HF compound known to date.¹ Further, a cusp around 400 mK in the ac susceptibility¹ and a kink in the resistance at around 400 mK indicate that as with some selected cerium HF compounds, YbBiPt may be situated at the boundary between magnetic and HF states. Recent μ^+ SR experiments² in crushed powder samples of YbBiPt show evidence of spatially inhomogeneous magnetism below 500 mK. However, the question remains whether the observed inhomogeneous magnetism is caused by the sample quality (crushed powder) or is an intrinsic property of YbBiPt.

With respect to the transport properties, recent resistance experiments³ on the series REBiPt indicate that a gradual evolution from semiconducting toward semimetallic behavior occurs as the RE varies from Nd to Yb. Hall coefficient measurements on YbBiPt give a carrier count of about 0.04/formula unit, typical of a semimetal.

In view of the controversy involving the role of inhomogeneity and/or disorder in the physical interpretation of thermodynamic and transport properties of YbBiPt, in this paper we report on investigations of the effect of chemical ($\text{Yb}_x\text{Y}_{1-x}\text{BiPt}$) and hydrostatic pressure at low temperatures on single crystals and crushed-powder samples.

II. MATERIALS AND EXPERIMENTAL TECHNIQUES

YbBiPt is face-centered-cubic material with the MgAgAs structure.⁴ Single crystals of $\text{Yb}_x\text{Y}_{1-x}\text{BiPt}$ (and

$\text{Yb}_z\text{Lu}_{1-z}\text{BiPt}$) were grown out of Bi flux⁵ and characterized by powder x-ray diffraction. The pressed-pellet samples of YbBiPt used for the heat-capacity experiments under pressure were prepared by crushing single crystals, mixing them with a small amount of GE7031 varnish, and pressing at roughly 9 kbar at room temperature to obtain densities approaching 80% of the theoretical.

The high-temperature electrical resistance under high hydrostatic pressure ($1.5 \text{ K} < T < 300 \text{ K}$, up to 16 kbar) has been measured using a four-probe technique with the sample placed in a piston-cylinder self-clamping beryllium-copper cell.⁶ At low temperatures (below 1 K) the pressure cell was attached to the bottom of the mixing chamber of a dilution refrigerator. Heat-capacity measurements on single crystals of $\text{Yb}_x\text{Y}_{1-x}\text{BiPt}$ (and $\text{Yb}_z\text{Lu}_{1-z}\text{BiPt}$) were carried out using a quasiadiabatic thermal-relaxation technique in the temperature range $1.5 \text{ K} < T < 20 \text{ K}$. Finally, low-temperature heat-capacity experiments under hydrostatic pressure ($300 \text{ mK} < T < 2 \text{ K}$, up to 8 kbar) were carried out at Lawrence Berkeley Laboratory.⁷

III. RESULTS AND DISCUSSION

Figure 1(a) shows the high temperature ($1.5 \text{ K} < T < 300 \text{ K}$) resistance of a single crystal of YbBiPt under hydrostatic pressure (to roughly 17.5 kbar). As the temperature decreases below 300 K, the resistance decreases from the room temperature value, exhibiting an inflection point near 80 K (T_Δ). The temperature where the inflection point occurs (T_Δ) remains almost unchanged as we apply pressure [inset of Fig. 1(a)]. Indeed, inelastic neutron scattering experiments⁸ in a polycrystalline sample of YbBiPt reported a low-energy crystal-field excitation at approximately 6 meV, essentially at the same order of magnitude as T_Δ . Association of the anomaly in the resistance at T_Δ with the crystal-field splitting is therefore rather suggestive. In other words, dT_Δ/dP , which is small, could be of the same order of magnitude as the pressure-dependent Kondo-like scattering within this crystal-field doublet.⁹ Qualitatively, a very small ($\sim -0.5 \text{ K/kbar}$)

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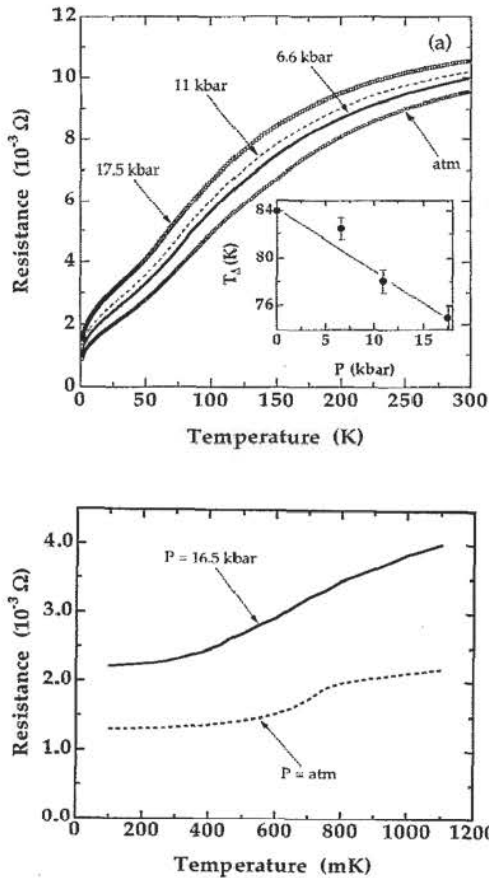


FIG. 1. (a) Resistance as a function of temperature for a single crystal of YbBiPt. The inset shows the pressure dependence of T_{Δ} (see the text). (b) Low temperature resistance of YbBiPt at 16.5 kbar.

and negative dT_{Δ}/dP is observed. We also believe that thermal expansion experiments will be a very important probe to investigate the crystal-field splitting of YbBiPt.

As the temperature is lowered below T_{Δ} , the resistance decreases, but with a slope close to half the slope found for $T > T_{\Delta}$. At around 5 K a very fast drop in the resistance is observed. Our preliminary results of low-temperature resistance experiments under pressure are shown in Fig. 1(b). The fast drop in $R(T)$ continues until another inflection point is observed at roughly 500 mK for the high-pressure data [Fig. 1(b) shows the resistance at low temperature]. The resistance at 16 kbar shows only a small variation when compared with the zero-pressure results. The interesting point is that the inflection point in the data collected at ambient pressure occurs at around the same temperature as the peak in ac susceptibility (χ_{ac}) in a single crystal.¹ Due to the small variation of $R(T,P)$ at low temperatures when compared with χ_{ac} the following question remains: Is the kink in the resistance a signature of a magnetic phase transition?

To investigate in more detail the effect of pressure on REBiPt materials, a series of resistance, magnetic susceptibility, and heat capacity experiments have been performed over a wide temperature range¹⁰ on samples with substitution of Y or Lu for Yb. In Fig. 2 we show the effect of chemical pressure studied by heat capacity experiments

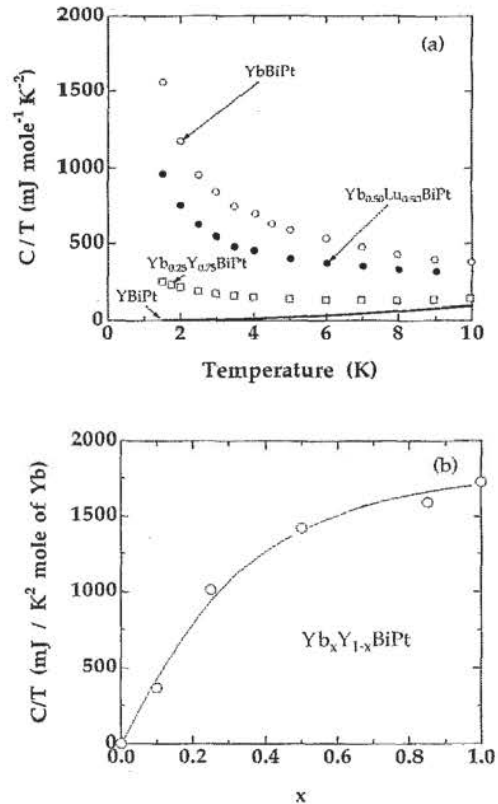


FIG. 2. (a) C/T as a function of temperature for selected alloys of $Yb_xY_{1-x}BiPt$, and $Yb_{0.50}Lu_{0.50}BiPt$. (b) C/T as a function of Y concentration (x).

on $Yb_xY_{1-x}BiPt$ and $Yb_2Lu_{1-x}BiPt$. Figure 2(a) shows C/T as a function of temperature for some selected single-crystal alloys. For pure YBiPt (and LuBiPt that is not shown) C/T at the lowest temperature investigated (1.5 K) amounts to around $1 \text{ mJ K}^{-2} \text{ mol}^{-1}$ for both compounds. As we increase the Yb concentration to about 25% [Fig. 2(b)] a very large C/T (comparable with YbBiPt) at very low temperatures (around 60 mK) is still observed.¹¹ The very large C/T for this reasonably large Y concentration is already an interesting result; this could mean that the large quasiparticle renormalization in YbBiPt (the large Sommerfeld coefficient) is essentially unaffected by the lattice inhomogeneity and positive chemical pressure caused by Y substitutions. In Fig. 2(b) we show the C/T (at 1.5 K) as a function of Yb content (x), as we can see, only with a large amount of Y ($\sim 50\%$) does the C/T at 1.5 K start to show considerable variations. Low-temperature heat-capacity experiments are currently in progress to study the phase diagram [Fig. 2(b)] in greater detail.

Let us now emphasize the importance of the sample quality in the physics of YbBiPt. In Fig. 3 we show the low-temperature heat-capacity data for two different samples of YbBiPt. The first sample (S1) is a single crystal for which C/T at low temperatures ($40 \text{ mK} < T < 400 \text{ mK}$) is $\gamma \sim 8 \text{ J K}^{-2} \text{ mol}^{-1}$; in addition, a well-defined maximum in the heat capacity near 400 mK is present.¹ The second sample (S2) was obtained by forming a pressed pellet from

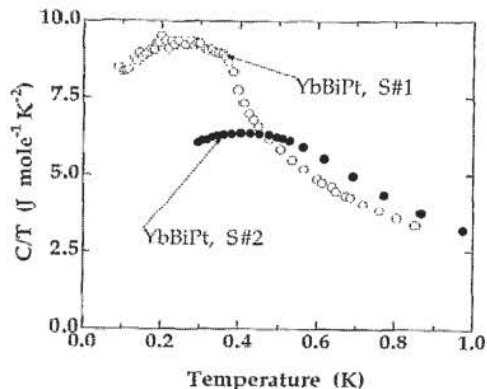


FIG. 3. C/T as a function of temperature of YbBiPt, single crystal (S1) and pressed pellet (S2).

crushed single-crystal fragments (details about S2 are described in Sec. II). The data presented in Fig. 3 reveal a striking difference between the single-crystal (S1) and the pressed-pellet (S2) samples. The features in C/T for the S1 sample are completely smeared out for the S2 sample which displays only a smooth maximum near 400 mK. Nonetheless, the Sommerfeld coefficient for the S2 sample is still quite high ($\gamma \sim 6 \text{ J K}^{-2} \text{ mol}^{-1}$). Despite the large γ for the S2 sample, the shape and intensity of the transition are very different when compared to the S1 results. For the high-temperature regime (above 1 K), S1 and S2 present the same heat-capacity values. We want to point out that since YbBiPt seems to be strain sensitive, we also measured an annealed (750 °C for 10 days) single crystal of YbBiPt and the heat-capacity results were essentially similar to that found for the S1 sample, indicating that there is no significant strain in the as-grown single crystals. Very recently, similar strain dependence on C/T has been observed in the HF compound CeAl_3 .¹²

Keeping the basic differences between single-crystalline and pressed-pellet heat-capacity results in mind, we now consider C measurements on a pressed pellet under pressure (see Fig. 4). The heat capacity has been measured at 2, 6, and 8 kbar. The first striking result is the very small pressure dependence of the heat capacity. The heat capac-

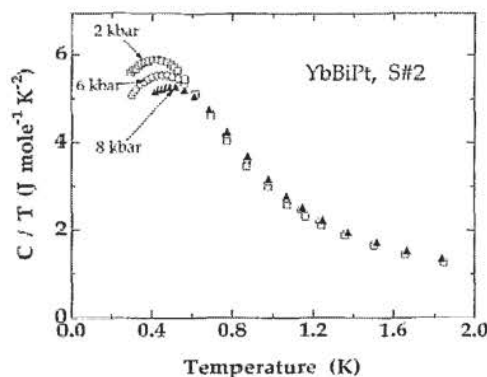


FIG. 4. Pressure dependence of the heat capacity as a function of temperature for sample S2.

ity at zero pressure (not shown) is only about 5% higher than the 2 kbar data. As we increase pressure, the maximum in C/T situated near 400 mK at zero pressure shifts to roughly 550 mK at 8 kbar and above 600 mK, C is independent of pressure. Another HF compound with very low characteristic temperatures (below 1 K) and displaying a qualitatively similar pressure dependence of the heat capacity is CeAl_3 . For CeAl_3 , the C is most strongly pressure dependent for $P < 1$ kbar.¹³ For YbBiPt, further measurements of both heat capacity under pressure and thermal expansion on single crystals must be done to try to elucidate the thermodynamics of this compound via scaling theories and a Grüneisen analysis.

To summarize, we have measured thermodynamic and transport properties of YbBiPt at low temperatures under hydrostatic pressure. The HF state of this compound seems to be unchangeable by a relatively large amount of nonmagnetic doping (Y or Lu). The heat-capacity experiments under pressure in pressed-pellet samples reveal a small pressure dependence when compared with some selected HF compounds. Finally, the drastic difference between the heat-capacity signatures of single-crystal and pressed-pellet specimens clearly indicates the importance of examining single-crystal samples when attempting to elucidate the unique physical properties of YbBiPt.

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