Superconductivity in 4d and 5d transition metal layered pnictides BaRh₂P₂, BaIr₂P₂ and SrIr₂As₂

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Abstract

Bulk superconductivity was discovered in BaRh₂P₂ ($T_c = 1.0$ K), BaIr₂P₂ ($T_c = 2.1$ K) and SrIr₂As₂ ($T_c = 2.9$ K), which are isostructural to (Ba,K)Fe₂As₂, indicative of the appearance of superconductivity over a wide variety of layered transition metal pnictides. The electronic specific heat coefficient in the normal state, 9.75, 6.86 and 7.03 mJ/(molK²) for BaRh₂P₂, BaIr₂P₂ and SrIr₂As₂ respectively, indicate that the electronic density of states of these three compounds are moderately large but smaller than those of Fe pnictide superconductors.

Key words:

BaRh₂P₂, BaIr₂P₂, SrIr₂As₂, Superconductivity, ThCr₂Si₂-type

1. Introduction

Recent discovery of superconductivity in Fe pnictides has provided fresh impetus to the exploration of novel superconductors with a high transition temperature. After the first report on superconductivity in LaFeAs(O,F)[1], the maximum superconducting transition temperature T_c of Fe pnictides quickly reached 55 K for SmFeAs(O,F)[2] by replacing La with the other rare earth elements. Further work has revealed that not only REFeAs(O,F) with ZrCuSiAs-type structure but also a variety of iron-based compounds with squared lattices of tetrahedrally coordinated Fe show superconductivity at relatively high temperatures, including (Ba,K)Fe₂As₂ ($T_c = 38$ K)[3] with ThCr₂Si₂-type structure, LiFeAs ($T_c = 18$ K) with CuSb₂-type structure and FeSe ($T_c = 8$ K)[5] with α -PbO-type structure. The exploration of new superconductors, triggered by the discovery of LaFeAs(O,F), has concentrated mostly on Fe based pnictides. A variety of non-Fe pnictides, isostructural to Fe pnictide superconductors, have been known for a long time but not yet fully explored in terms of possible superconductivity. The limited number of non Fe pnictide superconductors known to date. Further exploration of non-Fe pnictide superconductors is important for understanding the key factors in realizing the high transition temperature in the Fe pnictides and, if T_c is reasonably high, it will enhance the potential of pnictides substantially as untapped reservoir for discovering new superconductors. In this work, we present new Ir and Rh pnictide superconductors, isostructural to BaFe₂As₂, BaRh₂P₂, BaIr₂P₂ and SrIr₂As₂, with $T_c = 1.0$, 2.1 and 2.9 K, respectively.[6] The existences of BaRh₂P₂ and BaIr₂P₂ have been known since the early report by Wurth et al.[7] and Löhken et al.[8]

2. Experimental

Samples were synthesized from appropriate mixtures of powdered Ir (99.9%) or Rh (99.9%), Ba (99.9%) or Sr (99.99%) and P (99.999%) or As (99.999%) by conventional solid state reaction. The mixtures were pressed into a pellet, and placed in an alumina crucible and sealed under vacuum in a quartz tube. The tube was heated initially at 400 °C for 16 h and then at 1000 °C for 12h. In order to improve sample purity, the polycrystalline samples of SrIr₂As₂ was reground and sintered at 1150 °C for 48 h. The obtained samples were characterized by power X-ray diffraction with Cu K α radiation.

3. Results and Discussion

The XRD pattern was refined reasonably well with a space group $I4/mmm$, indicating that BaRh₂P₂, BaIr₂P₂ and SrIr₂As₂ crystallize in ThCr₂Si₂-type structure. The lattice constants are summarized in Table 1.

The evidence for superconductivity in BaRh₂P₂, BaIr₂P₂ and SrIr₂As₂ can be found in the resistivity and the magnetization data at low temperatures, as shown in Fig. 1. Around 1.0, 2.1 and 2.9 K for BaRh₂P₂, BaIr₂P₂ and SrIr₂As₂, respectively, a very clear resistance drop to zero resistance state was observed on cooling, accompanied by a large diamagnetic signal indicative of superconductivity. As shown in Fig. 1(b), the zero-field cooling (ZFC) and field cooling (FC) magnetizations for BaIr₂P₂ corresponds to 110 and 50% of the perfect diamagnetism, respectively, evidencing that the superconductivity occurs in bulk. Further support for the bulk superconductivity was obtained from the temperature dependent specific heat $C(T)/T$. At low temperatures, a clear jump is observed at each T_c , as shown in Fig. 2.

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Figure 1: (a) Temperature dependence of electric resistivity of BaRh₂P₂, BaIr₂P₂ and SrIr₂As₂ in zero applied field. (b) Temperature dependence of magnetic susceptibility of BaIr₂P₂ (open triangle) and SrIr₂As₂ (open circle) and real part of AC magnetic susceptibility of BaRh₂P₂ (filled square).

Table 1: Lattice constants and superconducting parameters of BaRh₂P₂, BaIr₂P₂ and SrIr₂As₂

	BaRh ₂ P ₂	BaIr ₂ P ₂	SrIr ₂ As ₂
<i>a</i> -axis (Å)	3.939(1)	3.946(1)	4.0680(1)
<i>c</i> -axis (Å)	12.576(2)	12.572(2)	11.794(3)
<i>T_c</i> (K)	1.0	2.1	2.9
<i>H_{c2}</i> (T)	0.07	0.14	1.4
<i>γ</i> (mJ/molK ²)	9.75	6.86	7.03
<i>ΔC/γT_c</i>	0.87	1.53	0.91

The electronic specific heat coefficient estimated from the specific heat $C(T)/T$ in the normal state for BaRh₂P₂, BaIr₂P₂ and SrIr₂As₂ indicates a modest electronic density of state at the Fermi level, not as large as those for FeAs superconductors. The normal-state $C(T)/T$ can be fitted well with $C(T)/T = \gamma + \beta T^2$, giving γ values of 9.75, 6.86 and 7.03 mJ/(molK²) for BaRh₂P₂, BaIr₂P₂ and SrIr₂As₂, respectively. These γ values are typical of transition metal intermetallics but substantially smaller than those reported for high-*T_c* FeAs superconductors, for example, $\gamma = 23$ mJ/(molK²) for (Ba,K)Fe₂As₂. [9]

We report superconductivity in BaRh₂P₂, BaIr₂P₂ and SrIr₂As₂ with ThCr₂Si₂-type structure. This discovery demonstrates the presence of superconductivity over a surprisingly broad range of transition metal compounds with ThCr₂Si₂-type structure from Fe to Ir. This flexibility of superconductivity against transition metal elements provides us with a unique opportunity to explore many new superconductors.

Figure 2: Electronic specific heat divided by temperature $C_e(T)/T$ vs temperature at zero applied field in BaRh₂P₂ (filled square), BaIr₂P₂ (open triangle) and SrIr₂As₂ (open circle).

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