Transport properties and magnetic-field-induced localization in the misfit cobaltite \([\text{Bi}_{2}\text{Ba}_{1.3}\text{K}_{0.6}\text{Co}_{0.1}\text{O}_{4}]^{\text{RS}}[\text{CoO}_{2}]_{1.97}\) single crystal

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Abstract

Resistivity under magnetic field, thermopower and Hall coefficient are systematically studied for the \([\text{Bi}_{2}\text{Ba}_{1.3}\text{K}_{0.6}\text{Co}_{0.1}\text{O}_{4}]^{\text{RS}}[\text{CoO}_{2}]_{1.97}\) single crystal. In-plane resistivity \((\rho_{ab}(T))\) shows metallic behavior down to 2 K with a \(T^2\) dependence below 30 K, while out-of-plane resistivity \((\rho_c(T))\) shows metallic behavior at high temperature and a thermal activation semiconducting behavior below about 12 K. The striking feature is that magnetic field induces a \(\ln(1/T)\) diverging behavior in both \(\rho_{ab}\) and \(\rho_c(T)\) at low temperature. The positive magnetoresistance (MR) could be well fitted by the formula based on multiband electronic structure. The \(\ln(1/T)\) diverging behavior in \(\rho_{ab}\) and \(\rho_c(T)\) could arise from the magnetic-field-induced 2D weak localization or spin density wave.

1. Introduction

Triangular cobaltites have attracted significant interest for their promising application prospect as thermo-electrical materials and their complex physical properties as strongly correlated electron systems \([1-4]\). The complex physical properties include the unconventional superconductivity in water-intercalated \(\text{Na}_{0.35}\text{CoO}_{2}\) \([5]\), temperature-dependent Hall effect \([3, 6]\), large negative magnetoresistance (MR) in \((\text{Bi, Pb})_2\text{M}_2\text{Co}_2\text{O}_y\) \((\text{M} = \text{Sr and Ca})\) and \(\text{Ca}_3\text{Co}_4\text{O}_9\) \([2, 6, 7]\), large thermopower (TEP) with low resistivity \([1, 2]\), complicated magnetic structure \([8-10]\), etc. These triangular cobaltites have the common structural unit of a \(\text{CdI}_2\)-type hexagonal [CoO\(_2\)] layer, which is composed of edge-sharing CoO\(_6\) octahedra. Among them, the so-called misfit cobaltites \(\text{Bi}_2\text{M}_2\text{Co}_2\text{O}_y\) \((\text{M} = \text{Ca, Sr and Ba})\) \([11]\) and \(\text{Ca}_3\text{Co}_4\text{O}_9\) \([2]\) are constructed by the alternative stacking rock-salt-type blocks and [CoO\(_2\)] layers. The two sublattices share common \(a\)- and \(c\)-lattice parameters, but possess different \(b\)-lattice lengths, causing a misfit along the \(b\)-axis with a misfit ratio \(b_{\text{RS}}/b_{\text{H}}\) \((b_{\text{RS}}\) and \(b_{\text{H}}\) are the \(b\)-lattice parameters for RS and hexagonal sublattices, respectively). In \(\text{Bi}_2\text{M}_2\text{Co}_2\text{O}_y\) \((\text{M} = \text{Ca, Sr and Ba})\), the quadruple RS block is composed of two deficient [BiO] layers sandwiched by two [M0] layers \([11]\). For \(\text{M} = \text{Ba}\), commensurate modulation along \(b\)-axis between RS and hexagonal sublattices with \(b_{\text{RS}}/b_{\text{H}} = 2.0\) was found \([12]\), in contrast to the incommensurate modulation in other misfit cobaltites. Metallicity increases with increasing ionic radii from Ca to Ba \([6, 7, 12]\), and the MR at low temperature also changes sign from negative in Ca and Sr compounds \([6, 7]\) to positive in Ba compounds \([12]\). It has been found by us that there coexist large negative and positive contributions to the nonmonotonic magnetic-field-dependent MR in Pb-doped \(\text{Bi}_2\text{Sr}_2\text{Co}_2\text{O}_y\) \([13]\). Spin-dependent charge transport has been taken into account for understanding the large negative MR in Sr and Ca compounds, but the large positive MR in Ba compounds has not been fully understood. In a polycrystalline \(\text{Bi}_2\text{Ba}_2\text{Co}_2\text{O}_y\) sample, Hervieu et al reported that the positive isostructural MR exhibits a linear \(H\) dependence. They compared the behavior in Ba compounds with MR in \(\text{Sr}_2\text{RuO}_4\) and heavy-fermion-like oxide \(\text{LiV}_2\text{O}_4\) to
understand the positive MR [12]. However, the origin of large positive MR was not settled; further work, especially on single crystals, is required to understand this anomalous positive MR.

In this paper, a K-doped Bi$_2$Ba$_2$CoO$_5$ single crystal was grown through the flux method. The single crystal shows metallic resistivity in the ab plane down to 2 K, while it exhibits a weak thermal activation behavior along the c-axis at low temperature. Magnetic field induces a ln(1/T) diverging behavior at low temperature in $\rho_{ab}(T)$ and $\rho_c(T)$. The positive MR can be interpreted by the multiband electronic structure. The ln(1/T) diverging behavior in $\rho_{ab}(T)$ may be ascribed to the magnetic-field-induced 2D weak localization or spin density wave (SDW).

2. Experimental procedures

Bi–Ba–Co–O single crystals were grown by the solution method using K$_2$CO$_3$–KCl fluxes. Starting materials Bi$_2$O$_3$, BaCO$_3$ and Co$_3$O$_4$ were mixed in a proportion of Bi:Ba:Co = 2:2:2 with a total weight of 4 g. The powders were heated at 800 °C for 10 h. Then the prepared Bi$_2$Ba$_2$CoO$_5$ was mixed with a mixture of KCl and K$_2$CO$_3$ with a molar proportion of 1:4 (20.5 g), which was loaded in an aluminum crucible having 30 ml volume. The solute concentration was about 1.5 mol%. A lidded crucible was used to prevent the solution from evaporating and to grow crystals under stable conditions. The mixture was melted at 950 °C for 20 h, and then slowly cooled down to 600 °C at a rate of 5 °C h$^{-1}$. The single crystals were separated from the melt by washing with distilled water. The crystals were large thin platelets and black in color. Typical dimensions of the crystals are 5 × 5 × 0.05 mm$^3$.

Single crystals were characterized by electron diffraction (ED) and x-ray diffraction (XRD) using Cu Kα radiation, respectively. The actual chemical composition of the single crystals was determined by the inductively coupled plasma (ICP) atomic emission spectroscopy (AES) (ICP-AES) technique and the x-ray energy dispersive spectrum (EDS). The obtained results from ICP-AES and EDS were almost consistent, Bi:Ba:K:Co = 2:1:3:0.6:2:1.

Suscptibility was measured using a SQUID magnetometer (MPMS-7XL, Quantum Design). Electrical transport was measured using the alternating current (ac) four-probe method with an ac resistance bridge system (Linear Research; LR-700P). The Hall effect is measured by the four-terminal ac technique. To eliminate the offset voltage due to the asymmetric Hall terminals, the magnetic field was changed from −5 to 5 T and the Hall voltage was calculated to be $V(H) − V(−H))/2$, where $V$ is the voltage between the Hall probes. The dc magnetic field for MR measurements is supplied by a superconducting magnet system (Oxford Instruments). Thermoelectric power (TEP) was measured using the steady-state technique.

3. Experimental results

3.1. Structural characterization

XRD pattern shown in figure 1(a) indicates that the single crystals have perfect c-orientation with the c-axis lattice parameter of 15.55 Å, larger than that in the undoped polycrystalline sample (15.44 Å) [12], consistent with the substitution of the larger K$^+$ for the Ba$^{2+}$ ion ($r_{K^+} = 1.38$ Å, $r_{Ba^{2+}} = 1.36$ Å) [14]. The [001] ED pattern shown in figure 1(b) is similar to that of the undoped sample reported by Hervieu et al [12] except that the reflection of (020)$_{H}$ visibly separates from that of (040)$_{RS}$ (where H and RS refer to the hexagonal and RS sublattices, respectively). In-plane lattice parameters can be estimated from the [001] ED pattern. The a and b parameters of the RS sublattice are larger than those in the undoped polycrystalline sample. $a_{RS}$ and $b_{RS}$ are 4.905 and 5.640 Å for the undoped polycrystalline sample, while 5.031 and 5.683 Å for the present single crystal, respectively. This is due to the substitution of the larger K$^+$ for the Ba$^{2+}$ ion. Along the a axis, we obtain $a_{RS} = \sqrt{3}(a_{H} = 2.907$ Å), indicating that the RS and H subsystems share a common a-axis lattice parameter. Along the b axis, however, an incommensurate modulation with the misfit ratio $b_{RS}/b_{H} = 1.97 (b_{H} = 2.88$ Å) can be obtained, indicating that $b_{RS}$ and $b_{H}$ axes are collinear but aperiodic. This is in contrast to the incommensurate modulation along the b direction in the undoped polycrystalline sample ($b_{RS}/b_{H} = 2$) [12]. Therefore, the structural formula of the present compound could be written as [Bi$_2$Ba$_{1.3}$K$_{0.6}$Co$_{1.0}$O$_{4.7}$]$^{2+}$[CO$_{2}$O$_{4}$]$_{1.97}$.

3.2. Magnetic susceptibility

The temperature dependences of the magnetic susceptibility ($\chi$) recorded at $H = 1000$ Oe with H perpendicular to the
Figure 2. The temperature dependence of the magnetic susceptibility and its inverse, collected at 0.1 T with $H$ parallel to the $c$-axis. Inset shows the inverse magnetic susceptibility for $H$ parallel to both the $c$-axis and the $ab$-plane, in which a downturn from the high-temperature linear part can be observed, just as in the main pattern.

$ab$ plane and its inverse ($\chi^{-1}$) are shown in Figure 2. The high-temperature linear $\chi^{-1}$ indicates a paramagnetic state. Below about 30 K, however, there exists an abnormal decrease in $\chi^{-1}$, suggesting a short-range magnetic order. Another interpretation for the deviation of $\chi^{-1}$ at 30 K could be the formation of an SDW. As in previous reports for $\text{Bi}_2\text{Ca}_2\text{Co}_2\text{O}_y$ (structurally, $[\text{Ca}_2\text{Bi}_1.7\text{Co}_{0.3}\text{O}_4][\text{CoO}_2]_{1.67}$) [7, 10], the temperature where the low-temperature $\chi^{-1}$ deviates down from the high-temperature linear part is almost the same as that where the SDW begin to form as detected by $\mu$SR. Therefore, the downturn of $\chi^{-1}$ at about 30 K from the high-temperature linear part in the present crystal may suggest the appearance of the SDW. But Sugiyama et al [10] reported that there is no SDW down to 1.8 K in the undoped polycrystalline sample, so the $\mu$SR experiment is required to confirm whether there exists an SDW in the present crystal. The curves registered at $H = 50$ kOe with $H$ both parallel and perpendicular to the $ab$ plane are shown in the inset. The deviation from the high-temperature linear $\chi^{-1}$ still exists around 30 K.

3.3. Resistivity, Hall coefficient and thermopower

Figure 3(a) shows the temperature dependence of the in-plane and out-of-plane resistivity ($\rho_{ab}(T)$ and $\rho_c(T)$) for the $[\text{Bi}_2\text{Ba}_{1.3}\text{K}_{0.6}\text{Co}_{2.1}\text{O}_y][\text{CoO}_2]_{1.97}$ single crystal. $\rho_{ab}(T)$ shows metallic behavior down to 2 K. This contrasts with the semiconducting behavior below 80 K in the undoped polycrystalline sample [12]. It suggests that K doping on the Ba sites induces excess charge carriers into the system. Figure 4(a) indicates that the metallic in-plane resistivity below 30 K follows $T^2$-dependence, indicative of strong electron correlation in the crystal. Such behavior is similar to that observed in $\text{Na}_{0.7}\text{CoO}_2$ [4]. However, out-of-plane resistivity shows a weak semiconducting behavior below 12 K. Figure 4(b) indicates that the weak semiconducting behavior obeys thermal activation behavior with an activation energy of 0.013 meV. At high temperature, the out-of-plane resistivity shows metallic behavior up to room temperature. No incoherent-to-coherent behavior is observed in this crystal, contrasting with the Pb-doped $\text{Bi}_2\text{Ba}_2\text{Co}_2\text{O}_y$ [15], in which $\rho_{ab}(T)$ is metallic down to 2 K, while $\rho_c(T)$ shows...
Figure 4. (a) $T^2$ dependence of the in-plane resistivity below 50 K; (b) plot of ln($\rho$) versus $1/T$ for the [Bi$_2$Ba$_{1.3}$K$_{0.6}$Co$_{0.4}$O$_4$]$^{RS}$[CoO$_2$]$_{1.97}$ single crystal.

Figure 5. Temperature dependence of the Hall coefficient for the [Bi$_2$Ba$_{1.3}$K$_{0.6}$Co$_{0.4}$O$_4$]$^{RS}$[CoO$_2$]$_{1.97}$ single crystal. (b) The square $T$ dependence of the Hall coefficient.
and then decreases with decreasing temperature. This maximum is much larger than the obtained maximum of $Q$ in Bi$_2$Ca$_2$Co$_2$O$_y$ ($\approx 3.2 \times 10^{-4}$ W m$^{-1}$ K$^{-2}$) and Ca$_3$Co$_2$O$_9$ ($\approx 2.1 \times 10^{-2}$ W m$^{-1}$ K$^{-2}$) single crystals [19]. This indicates that the [Bi$_{2.3}$K$_{0.6}$Co$_{0.1}$O$_{4.19}$]$_{0.97}$ single crystal has a better thermoelectric performance than the Bi$_2$Ca$_2$Co$_2$O$_y$ and Ca$_3$Co$_2$O$_9$ single crystals [19].

But the thermoelectric performance of the [Bi$_{2.3}$K$_{0.6}$Co$_{0.1}$O$_{4.19}$]$_{0.97}$ single crystal is lower than those observed in Na$_x$CoO$_2$ ($x \geq 0.70$) according to the data reported by Lee et al [18].

**3.4. Magnetotransport**

Figure 7 shows the temperature dependence of in-plane resistivity under different magnetic fields ($H$) varying from 0 to 14 T. A striking feature is observed that magnetic field leads to a transition from metallic to semiconductor-like behavior at low temperature with $H$ both perpendicular and parallel to the $ab$ plane. The minimum resistivity appears in $\rho_{ab}(T)$ and obvious positive MR is observed. As shown in figure 9, the temperature corresponding to the minimum resistivity shifts to high temperature with increasing magnetic field. At 2.5 K and 8 T, the positive MR reaches 4% when $H$ lies in the $ab$ plane and 6% when $H$ is along the $c$-axis, respectively. These values are much lower than that observed in the undoped polycrystalline sample, where about 10% of MR was observed at 2.5 and 7 T [12]. The effect of $H$ on $\rho_{ab}(T)$ is stronger with $H \parallel ab$ plane than with $H \perp ab$ plane. As shown in figure 8, a similar effect of $H$ on $\rho_{c}(T)$ is also observed. Although the upturn of $\rho_{c}(T)$ at low temperature follows a thermal activation behavior without magnetic field, external magnetic field leads to a change of low-temperature resistivity from a thermal activation behavior to a $\ln(1/T)$ diverging behavior with $H$ both perpendicular and parallel to the $ab$ plane. This suggests that $\rho_{ab}(T)$ and $\rho_{c}(T)$ show the same temperature dependence under $H$ at low temperature, although they show contrasting behavior (metallic in $\rho_{ab}(T)$ and semiconducting in $\rho_{c}(T)$) without $H$.

Figure 9 shows the magnetic field dependence of the temperature corresponding to the minimum resistivity ($\rho_{ab}(T)$)
We tried to fit the $\rho_T$ of $T$ to be pointed out that $\ln c$ certain temperature [2, 6, 7], while with $M$ semiconducting resistivity can usually be observed below a positive MR has been found in clearly understood. In the previous reports, no such obvious magnetic ordering transitions, while the positive MR is not dependent transport at temperatures below or close to the negative MR has been explained to be related to the spin-MR has been observed in a polycrystalline sample [12]. The $\ln$ (the minimum resistivity $\rho$ and $[\ln c]$). It indicates that the temperature corresponding to the minimum resistivity ($T_{\text{min}}$) increases with increasing $H$, suggesting that the localization is enhanced by $H$. It should be pointed out that $T_{\text{min}}$ in $\rho_s(T)$ is enhanced slightly with increasing magnetic field, contrasting to the strong dependence of $T_{\text{min}}$ in $\rho_{\text{ab}}(T)$.

Negative MR is a common feature in $\ln$ and $\ln$ (Bi, Pb)$_2$M$_2$Co$_2$O$_y$ ($M = \ln$ Sr and Ca), in which semiconducting resistivity can usually be observed below a certain temperature [2, 6, 7], while with $M = \ln$ Ba large positive MR has been observed in a polycrystalline sample [12]. The negative MR has been explained to be related to the spin-dependent transport at temperatures below or close to the magnetic ordering transitions, while the positive MR is not clearly understood. In the previous reports, no such obvious positive MR has been found in metallic triangular cobaltites: either $\ln$SrCoO$_3$ or $\ln$Na$_3$CoO$_2$. $\ln$Na$_{0.75}$CoO$_2$ is an exceptional case; the spin density wave (SDW) has been taken into account for interpreting the anomalously large positive MR in it [20]. We tried to fit the $\rho_{\text{ab}}(T)$ at $H = 8$, 11 and 14 T below $T_{\text{min}}$ with a variety of functional forms. It turned out that the resistivity at low temperature under $H$ cannot be fitted by formulae including thermal activation ($\ln \rho \sim -1/T$, various types of variable range hopping (VRH) conduction ($\ln \rho \sim -T^{-\alpha}$ with $\alpha = \frac{1}{3}$, $\frac{1}{4}$ and $\frac{1}{3}$) and power law ($\ln \rho \sim \ln T$). Instead, the data at high magnetic field with $H$ both perpendicular and parallel to the $ab$ plane exhibit a $\ln(1/T)$ divergence ($\rho \sim \ln(1/T)$) as shown in figures 7(c), (d) and 8. Such magnetic-field-induced localization has not been observed in the triangular layered cobaltites previously.

The in-plane and out-of-plane isothermal MRs were measured at 5 and 10 K with $H$ varying from 0 to 14 T as shown in figure 10. All the MRs are positive and increase with lowering temperature. The value of MR with $H \parallel ab$ is larger than that with $H \parallel c$ at a fixed temperature. The MR does not follow the classical $H^2$ law or Kohler's law (i.e. collapsing to a single curve in the Kohler plot, $\delta \rho / \rho$ versus $H / \rho_0$). The MRs do not follow a linear relationship to $H$, as claimed by Hervieu et al in the undoped polycrystalline sample [12]. These unusual positive MRs may be related to the magnetic-field-induced localization as indicated in figures 7 and 8.

4. Discussion and conclusions

Magnetotransport behavior can usually be related to the Fermi surface [21]. For example, a square Fermi surface can lead to a linear MR due to the presence of sharp corners [21]. For systems with multiband electronic structure involving two types of charge carriers, the $H$ dependence of MR can be written as

$$\Delta \rho / \rho(0) = aH^2/(b + cH^2)$$

(1)

where $a$, $b$ and $c$ are positive, $H$-independent quantities determined by the relaxation rates of each type of charge carrier [22]. We tried to fit the MR data shown in figure 10 using equation (1). Surprisingly, the out-of-plane MR data can be well fitted using equation (1), as shown in figure 8. The in-plane MR data can also be roughly fitted. Therefore, the isothermal MR could suggest the multiband electronic structure in the $[\ln Bi_2Ba_{1.3}K_{0.6}Co_{0.1}O_4]^{RS}[\ln Co_2]_{0.97}$ single crystal. Local density approximation (LDA) calculations in NaCoO$_2$ predicted a large cylindrical Fermi surface centered about two-thirds of the way out on the $\Gamma-K$ and $A-H$ directions [23]. In Na$_2$CoO$_4$, however, no such satellite
Another point of view, because of the peculiar rhombohedral structure as $\text{Ca}_3\text{Co}_4\text{O}_9$, the SDW is a common spin ordered state [10]. Determining from zero or low field in undoped $\text{Bi}_2\text{Ba}_2\text{Co}_2\text{O}_7$ single crystal to be a (quasi-) 2D electronic system. From these results, it is also possible that field-induced 2D weak localization results in the logarithmically temperature-dependent resistivity. This is the reason why the in-plane MR data are roughly fitted with slight deviation based on the multiband electronic structure with two types of charge carriers.

In conclusion, the electrical transport properties have been systematically studied for the $[\text{Bi}_2\text{Ba}_1\text{K}_0\text{Co}_0\text{O}_4]\text{RS}[\text{CoO}_2]\_{1.97}$ single crystal. An anomalous behavior is observed in that there exists a contrasting behavior at low temperature in the in-plane resistivity ($\rho_{ab}(T)$) and out of plane ($\rho_c(T)$): metallic behavior down to 2 K with a $T^2$ dependence below 30 K in $\rho_{ab}(T)$; while a thermal activation semiconducting behavior below about 12 K in $\rho_c(T)$. Magnetic field leads to a $\ln(1/T)$ diverging behavior in both $\rho_{ab}$ and $\rho_c(T)$ at low temperature. The isothermal out-of-plane MR can be quite well fitted by taking into account the multiband electronic structure with two types of charge carriers. The $\ln(1/T)$ diverging $\rho_{ab}(T)$ in magnetic field could arise from the field-enhanced 2D weak localization or magnetic-field-induced spin density wave.

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References

[1] Terasaki I, Sasago Y and Uchinokura K 1997 Phys. Rev. B 56 R12685
[2] Masset A C, Michel C, Maignan A, Hervieu M, Toulemonde O, Studer F and Raveau B 2000 Phys. Rev. B 62 166
[3] Wang Y Y, Rogado N S, Cava R J and Ong N P 2003 Nature 423 425 (Preprint cond-mat/0305455)
[4] Li S Y, Taillefer L, Hawthorn D G, Tanatar M A, Paglione J, Sutherland M, Hill R W, Wang C H and Chen X H 2004 Phys. Rev. Lett. 93 056401
[5] Takada K, Sakurai H, Takayama-Muromachi E, Izumi F, Dilanian R A and Sasaki T 2003 Nature 422 53
[6] Yamamoto T, Tsukada I, Takagi M, Tsunobue T and Uchinokura K 2001 J. Magn. Magn. Mater. 226–230 2031
[7] Yamamoto T, Uchinokura K and Tsukada I 2002 Phys. Rev. B 65 184434
[8] Maignan A, Hebert S, Hervieu M, Machel C, Pelloquin D and Khomskii D 2003 J. Phys.: Condens. Matter 15 2711
[8] Foo M L, Wang Y Y, Watauchi S, Zandbergen H W, He T, Cava R J and Ong N P 2004 Phys. Rev. Lett. 92 247001
[9] Wang C H, Chen X H, Wu T, Luo X G, Wang G Y and Luo J L 2006 Phys. Rev. Lett. 96 216401
[10] Sugiyama J, Brewer J H, Ansalido E J, Itahara H, Tani T, Mikami M, Mori Y, Sasaki T, Hebert S and Maignan A 2004 Phys. Rev. Lett. 92 017602
[11] Leligny H, Grebille D, Perez O, Masset A C, Hervieu M, Michel C and Raveau B 1999 C. R. Acad. Sci. Paris II 2 409
Leligny H, Grebille D, Perez O, Masset A C, Hervieu M, Michel C and Raveau B 2000 Acta Crystallogr. B 56 173
[12] Hervieu M, Maignan A, Michel C, Hardy V, Creon N and Raveau B 2003 Phys. Rev. B 67 045112
[13] Luo X G, Chen X H, Wang G Y, Wang C H, Li X, Miao W J, Wu G and Xiong Y M 2006 Eur. Phys. J. B 49 37
[14] Shannon R D 1976 Acta Crystallogr. A 32 751
Shannon R D and Prewitt C T 1969 Acta Crystallogr. B 25 925
[15] Valla T, Johnson P D, Yusof Z, Wells B, Li Q, Loureiro S M, Cava R J, Mikami M, Mori Y, Yoshimura K and Sasaki T 2002 Nature 417 627
Yusof Z, Wells B O, Valla T, Johnson P D, Fedorov A V, Li Q, Loureiro S M and Cava R J 2006 Preprint cond-mat/0610271
[16] Chen X H, Yu M, Ruan K Q, Li S Y, Gui Z, Zhang G C and Cao L Z 1998 Phys. Rev. B 58 14219
[17] Luo X G, Chen X H, Wang C H, Wang G Y, Xiong Y M, Song H B, Li H and Lu X 2006 Europhys. Lett. 74 526
[18] Lee M, Vicu L, Li L, Wang Y Y, Foo M L, Watauchi S, Pascal R A Jr, Cava R J and Ong N P 2006 Nat. Mater. 425 537
[19] Luo X G, Jing Y C, Chen H and Chen X H 2008 J. Cryst. Growth 308 309
[20] Motohashi T, Ueda R, Naujalis E, Tojo T, Terasaki I, Atake T, Karppinen M and Yamauchi H 2003 Phys. Rev. B 67 064406
[21] Pippard A B 1989 Magnetoresponse in Metal (Cambridge: Cambridge University Press)
[22] Ziman J M 1972 Principles of the Theory of Solids 2nd edn (Cambridge: Cambridge University Press)
[23] Singh D J 2000 Phys. Rev. B 61 13397
[24] Hasan M Z, Chuang Y D, Qian D, Li Y W, Kong Y, Kuprin A, Fedorov A V, Kimmerling R, Rotenberg E, Rossnagel K, Hussain Z, Koh H, Rogado N S, Foo M L and Cava R J 2004 Phys. Rev. Lett. 92 246402
[25] Mizokawa T, Tjung L H, Steeneker P G, Brookes N B, Tsukada I, Yamamoto T and Uchinokura K 2001 Phys. Rev. B 64 115104
[26] Ando Y, Boebinger G S, Passner A, Kimura T and Kishio K 1995 Phys. Rev. Lett. 75 4662
[27] Sun X F, Komiya S, Takeya J and Ando Y 2003 Phys. Rev. Lett. 90 117004
[28] Komiya S and Ando Y 2004 Phys. Rev. B 70 060503
[29] Luo X G, Chen X H, Liu X, Wang R T, Wang C H, Huang L, Wang L and Xiong Y M 2005 Supercond. Sci. Technol. 18 234
[30] Hidaka Y, Yamaji Y, Sugiyama K, Tomiyama F, Yamagishi A, Date M and Hikita M 1991 J. Phys. Soc. Japan 60 1185
[31] Hagen S J, Xu X Q, Jiang W, Peng J L, Li Z Y and Greene R L 1992 Phys. Rev. B 45 515
[32] Bergmann G 1984 Phys. Rep. 107 1