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Doping dependence of magnetic and transport properties in single crystalline Co-doped $BaFe_2As_2$

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ABSTRACT

We report the doping dependence of transport and magnetic properties in Co-doped $BaFe_2As_2$. With increasing Co concentration x, structural and magnetic transitions are suppressed and superconductivity emerges in the range of $0.3 < x < 0.15$. T-linear resistivity is observed at the optimally doped composition $x = 0.075$ and the temperature exponent of the resistivity increases with x. Critical current density J_c at low temperatures and low fields obtained from bulk magnetization is reasonably large and the doping dependence shows a maximum at $x \sim 0.07$ similar to T_c. The values of J_c at low temperatures reach about 1×10^6 A/cm^2 around the optimally doped region, which is potentially attractive for technological applications.

1. Introduction

Since the discovery of the high-T_c iron-based oxypnictide superconductor $LaFeAsO_{1-x}F_x$ with $T_c \sim 26$ K [1], other iron-based superconductors have attracted great interest. Following this discovery, oxygen-free iron-arsenide $AFe_2As_2 (A = Ba, Sr, Ca)$ was discovered. These materials show superconductivity with the substitution of alkali metals, such as Na, K, and Cs, for A resulting in the introduction of holes in the $(FeAs)^-$ layers [2], or Co for Fe resulting in the introduction of electrons [3]. Among them, Co-doped $BaFe_2As_2$ has attracted much attention because the superconductivity induced by the substitution in the conducting layers strongly compares well with a drastic suppression of T_c in cuprates [4] and may suggest a possibility of novel superconducting state. We report here the doping dependence of transport and magnetic properties in Co-doped $BaFe_2As_2$ in order to investigate normal and superconducting properties. With increasing Co concentration x, structural and magnetic transitions are suppressed and superconductivity occurs in the range of $0.03 < x < 0.15$. T-linear resistivity is observed at the optimally doped composition near $x = 0.075$ and temperature exponent of resistivity crosses over to T^2 in the overdoped region. Critical current density J_c at low temperatures and low field obtained from bulk magnetization is relatively large and shows a doping dependence similar to T_c. The values of J_c reach about 1×10^6 A/cm^2 at 2 K around the optimally doped region.

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2. Experiments

Single-crystalline samples of $Ba(Fe_{1-x}Co_x)_2As_2$ were grown by the FeAs/CoAs self-flux method. FeAs and CoAs were prepared by placing mixtures of As pieces and Fe/Co powder in a silica tube and reacting them at 1065 °C for 10 h after heating at 700 °C for 6 h. A mixture with a ratio of Ba: FeAs/CoAs = 1:5 was placed in an alumina crucible. The whole assembly was sealed in a large silica tube, and heated up to 1150 °C for 10 h followed by slow cooling down to 800 °C at a rate of 5 °C/h, which is slightly different from the synthesis reported before [5]. After cleaving, we can obtain shiny samples. The typical dimensions of the resulting crystals is $4 \times 4 \times 0.1$ mm^3. Co concentrations were determined by energy dispersive X-ray spectroscopy measurements. Magnetization was measured by a commercial SQUID magnetometer (Quantum Design MPMS–XL5) and resistivity measurement was performed by a four-contact method.

3. Results and discussion

Fig. 1 shows the temperature dependence of in-plane resistivity ρ_{ab} for $Ba(Fe_{1-x}Co_x)_2As_2$. For $BaFe_2As_2, x = 0$, the sharp decrease of ρ_{ab} associated with the structural and magnetic transition [2,6] is observed at 134 K. With increasing x, temperature of the resistive anomaly is suppressed monotonically. For $x \geqslant 0.038$, superconductivity is observed and disappear at $x \gtrsim 0.15$. At $x = 0.075, T_c$ shows a maximum of $\sim$24 K and very sharp transition within $\Delta T_c < 1$ K is observed in the resistivity and magnetization as shown in the right inset of Fig. 1. We find T-linear resistivity at the optimally doped composition $x = 0.075$ and the temperature

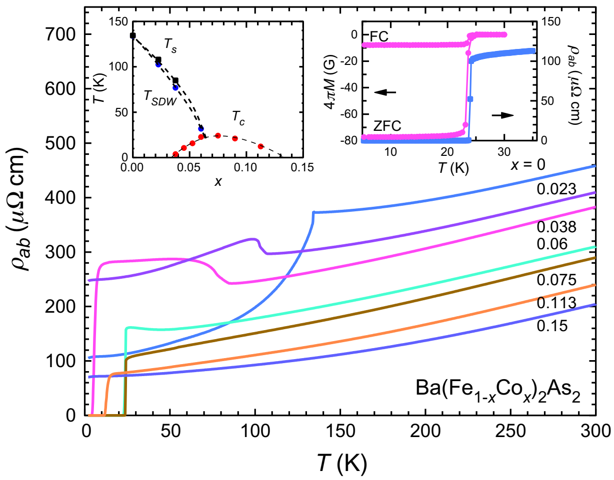

Fig. 1. Temperature dependence of the in-plane resistivity ρ_{ab} for $Ba(Fe_{1-x}Co_x)_2As_2$, $x = 0$, 0.023, 0.038, 0.06, 0.075, 0.113, and 0.15. The right inset shows the temperature dependence of ρ_{ab} and zero-field-cooled (ZFC) and field-cooled (FC) magnetization for $x = 0.075$. The left inset shows the phase diagram for $Ba(Fe_{1-x}Co_x)_2As_2$. T_s and T_{SDW} were by the temperature derivative of resistive anomaly and T_c is determined by the onset of diamagnetism. Dashed lines are guides for the eye.

exponent of the resistivity increases with x. At $x = 0.15$, T^2-behavior is observed below 40 K, which indicates the non-Fermi-liquid to Fermi-liquid crossover with increasing x. The doping dependence of resistivity for $Ba(Fe_{1-x}Co_x)_2As_2$ are very similar to those reported by Refs. [7,9]. The Left inset of Fig. 1 shows the phase diagram of $Ba(Fe_{1-x}Co_x)_2As_2$ obtained from the transport and magnetization measurements, where structural transition temperature T_s and spin-density wave transition temperature T_{SDW} were determined by the temperature derivative of resistive anomaly and T_c is determined by the onset of diamagnetism, which is consistent with the previous study reported in Ref. [8].

The inset of Fig. 2 shows the field dependence of magnetization for $x = 0.045$, 0.06, 0.075, and 0.113 at several temperatures. For $x = 0.045$ and 0.113, corresponding to under- and over-doped region, respectively, a maximum at zero field is very sharp. By contrast, for $x = 0.06$ and 0.075 near the optimally doped region, a peak at zero field is broadened and the irreversible magnetization is much larger than those for $x = 0.045$ and 0.113. For $x = 0.075$, prominent fish-tail magnetization is observed at 15 K [5] while for $x = 0.045, 0.06$, and 0.113, the fish-tail effect is not observed in the present temperature and field range.

Fig. 2 shows the field dependence of critical current density J_c for $x = 0.045, 0.06, 0.075$, and 0.113. J_c is obtained from hysteresis loop in the magnetization shown in each inset using the Bean model,

$$J_c = 20\frac{\Delta M}{a(1 - a/3b)}, \tag{1}$$

where ΔM is $M_{down} - M_{up}, M_{up}$ and M_{down} are the magnetization when sweeping fields up and down, respectively, and a and b are the sample widths ($a < b$). For $x = 0.075$, non-monotonious field dependence of J_c at high temperatures above 10 K reflecting the fish-tail magnetization is observed. On the other hand, for

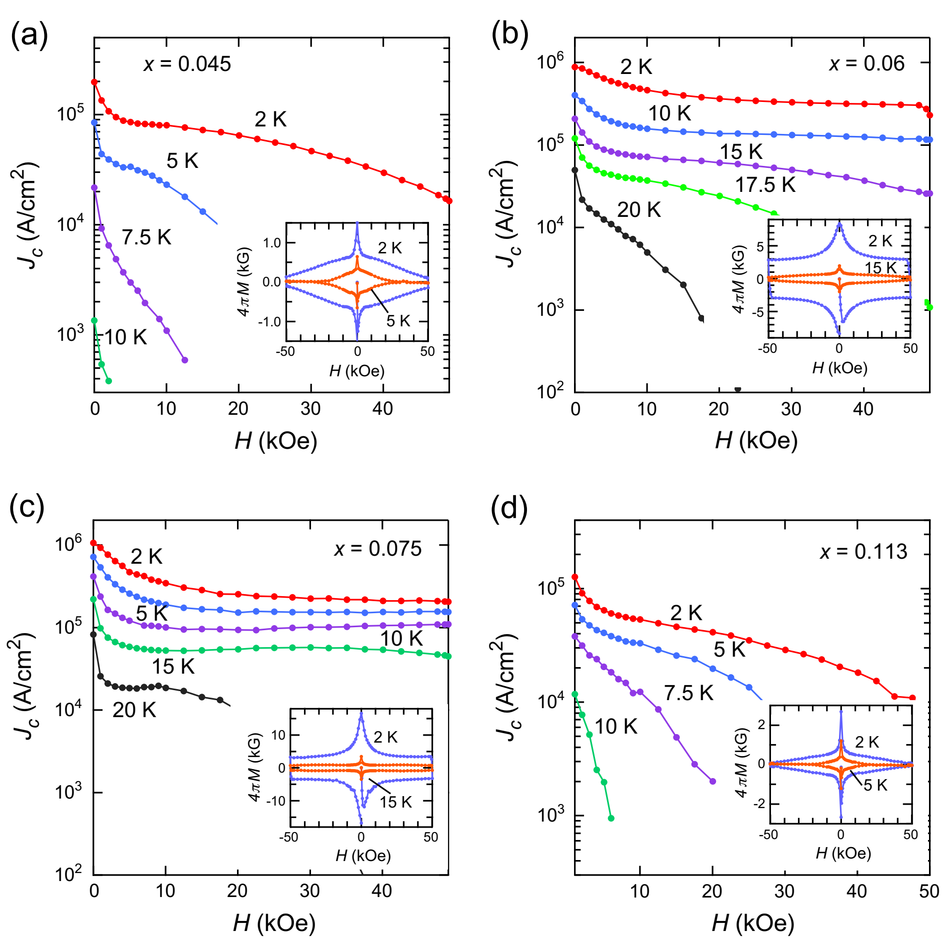

Fig. 2. Field dependence of critical current density for $Ba(Fe_{1-x}Co_x)_2As_2$, (a) $x = 0.045(330 \times 415 \times 30\ \mu m^3)$, (b) 0.06 $(410 \times 520 \times 35\ \mu m^3)$, (c) 0.075 $(600 \times 1200 \times 20\ \mu m^3)$ and (d) 0.113 $(410 \times 540 \times 10\ \mu m^3)$ obtained from magnetization using the Bean model. Inset shows the field dependence of magnetization at several temperatures.

$x = 0.045, 0.06$, and 0.113, J_c decreases monotonically with increasing field. The values of J_c at 2 K reach about 1×10^6 A/cm^2 for $x = 0.06$ and 0.075 around optimally-doped region, which is relatively high and potentially attractive for technological applications. It should be noted that further enhancement of J_c by heavy-iron irradiation has been demonstrated [10].

In summary, we study the doping dependence of transport and magnetic properties in Co-doped $BaFe_2As_2$. With increasing Co concentration, structural and magnetic transitions are suppressed and superconductivity emerges in the range $0.03 < x < 0.15$. T-linear resistivity is observed only near the optimally doped composition $x = 0.075$ and the temperature exponent of the resistivity increases with x. J_c at low temperatures and fields reaches about 1×10^6 A/cm^2 around optimally doped region, which is potentially attractive for technological applications.

References

[1] Y. Kamihara, T. Watanabe, M. Hirano, H. Hosono, J. Am. Chem. Soc. 130 (2008) 3296.

[2] M. Rotter, M. Tegel, D. Johrendt, Phys. Rev. Lett. 101 (2008) 107006.

[3] A.S. Sefat, R. Jin, M.A. McGuire, B.C. Sales, D.J. Singh, D. Mandrus, Phys. Rev. Lett. 101 (2008) 117004.

[4] H. Fujishita, M. Sato, Solid State Commun. 72 (1989) 529.

[5] Y. Nakajima, T. Taen, T. Tamegai, J. Phys. Soc. Jpn. 78 (2009) 023702.

[6] Q. Huang, Y. Qiu, Wei Bao, M.A. Green, J.W. Lynn, Y.C. Gasparovic, T. Wu, G. Wu, X.H. Chen, Phys. Rev. Lett. 101 (2008) 257003.

[7] L. Fang, H. Luo, P. Cheng, Z. Wang, Y. Jia, G. Mu, B. Shen, I.I. Mazin, L. Shan, C. Ren, H.H. Wen, Phy. Rev. B 80 (2009) 140508.

[8] N. Ni, M.E. Tillman, J.-Q. Yan, A. Kracher, S.T. Hannahs, S.L. Bud'ko, P.C. Canfield, Phys. Rev. B 78 (2008) 214515.

[9] F. Rullier-Albenque, D. Colson, A. Forget, H. Alloul, Phys. Rev. Lett. 103 (2009) 057001.

[10] Y. Nakajima, Y. Tsuchiya, T. Taen, T. Tamegai, S. Okayasu, M. Sasase, Phys. Rev. B 80 (2009) 012510.