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Pressure-induced shift of T_c and structural transition in "122" type pnictide superconductor $Ca_{0.34}Na_{0.66}Fe_2As_2$

Sijia Zhang,[1,a] Kan Zhao,[1] Xiaohui Yu,[1,2] Jinlong Zhu,[3] Qingqing Liu,[1] Xiancheng Wang,[1] Shaomin Feng,[1] Zhiqiang Chen,[4] Yusheng Zhao,[2] and Changqing Jin[1,a]

[1]*Institute of Physics, Chinese Academy of Sciences, Beijing100190, China*
[2]*Los Alamos Neutron Science Center (LANSCE), Los Alamos National Laboratory, Los Alamos, New Mexico 87545, United States*
[3]*High Pressure Science and Engineering Center, University of Nevada, Las Vegas, Nevada 89154, United States*
[4]*National Synchrotron Light Source, Brookhaven National Laboratory, Upton, New York 11973, United States*

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The effect of pressure on superconductivity of "122" type $Ca_{1-x}Na_xFe_2As_2$ (x=0.66) single crystal is investigated through the temperature dependence of resistance measurement. Optimal Na doped $(Ca_{0.34}Na_{0.66})Fe_2As_2$ shows a superconducting transition with $T_c \sim 33$ K at ambient pressure. With application of pressure, T_c decreases nearly linearly with $dT_c/dP \sim -1.7$K/GPa at pressures lower than 2 GPa, and disappears gradually at higher pressure. The disappearance of superconductivity is also companied with the recovery of standard Fermi liquid behaviors of the normal-state transport properties. Moreover, $(Ca_{0.34}Na_{0.66})Fe_2As_2$ exhibits a tetragonal (T) to collapsed-tetragonal (cT) transition at about 3 GPa. The evolution of non-Fermi liquid behaviors and superconductivity under pressure are both related to the interband fluctuations. [http://dx.doi.org/10.1063/1.4958873]

INTRODUCTION

The superconductivity of $LaO_{1-x}F_xFeAs$[1] with $T_c \sim 26$K has attracted much attention in high temperature superconductor research field as the transition temperature (T_c) is only second to the high T_c cuprates, and many pnictide superconductors were investigated from then on.[2–9] Similar to "1111" parent compounds, $CaFe_2As_2$ with tetragonal $ThCr_2Si_2$-type structure exhibits a spin-density wave (SDW) transition at about 165K, accompanied with a structural phase transition from high temperature tetragonal phase to low temperature orthorhombic phase.[10,11] Similar anomalies were observed in $BaFe_2As_2$[12] and $SrFe_2As_2$[13] as well.

Chemical substitution and pressure can both initiate or increase T_c for pnictide parent compounds. For instance, substituting Ba or Sr by K in $BaFe_2As_2$ or $SrFe_2As_2$ induces superconductivity at 38 K[6] and 35 K,[14] respectively. A superconductivity transition with T_c of ~26 K[15] for $(Ca_{0.6}Na_{0.4})Fe_2As_2$ or 20 K[11] for $(Ca_{0.5}Na_{0.5})Fe_2As_2$ has been reported by the chemical substitution at the Ca site subsequently. A higher $T_c \sim 33$ K in $(Ca_{0.34}Na_{0.66})Fe_2As_2$[16,17] or $T_c \sim 34$ K in $Ca_{0.32}Na_{0.68}Fe_2As_2$ has also been reported,[18] with the two-thirds Na doping at the Ca site, so-called optimal doping. Furthermore, the pressure-tuned superconductivity has been reported in some "1111-", "122-", "111-", or "11"-type pnictide compounds as well.[19–27] For some compounds, the superconductivity can be initiated by pressure and the T_c can be pushed to a maximum with initial compression, whereas for some other compounds the T_c is suppressed by application of pressure monotonously. It has been explained that the T_c of pnictide superconductors is closely related to the

[a]Author to whom correspondence should be addressed. Electronic mail: sjzhang@iphy.ac.cn, jin@iphy.ac.cn

geometric change of the $FeAs_4$ tetrahedron as well as the anion height from Fe layer,[28,29] which is also experimentally confirmed.[30,31]

$CaFe_2As_2$ is somehow different from $BaFe_2As_2$ or $SrFe_2As_2$ as due to its reduced unit cell volume and c lattice parameter, which is very close to collapsed tetragonal (cT) phase. So it is very sensitive to external pressure and chemical pressure (doping). A pressure-induced tetragonal-to-collapsed tetragonal structure phase transition was observed in $CaFe_2As_2$ above 0.35 GPa at 50 K.[32] We focus on $(Ca_{0.34}Na_{0.66})Fe_2As_2$ in this work since it shows the highest T_c of ~ 33 K for $(Ca_{1-x}Na_x)Fe_2As_2$. The high-pressure resistance measurements and the high-pressure X-ray diffraction experiments for optimal doped $(Ca_{0.34}Na_{0.66})Fe_2As_2$ are performed. We mainly discussed the influence of T to cT phase transition on the superconductivity. The resistance changes its low-energy behavior from $\rho \propto T^{1.3}$ in the T phase to $\rho \propto T^2$ in the cT phase, with the disappearance of superconductivity. The interplay of superconductivity and collapsed tetragonal phase suggests the essential role of magnetic fluctuations in the emergence of superconductivity.

EXPERIMENTAL DETAILS

The $(Ca_{0.34}Na_{0.66})Fe_2As_2$ single crystals were synthesized using the solid-state reaction method. The detailed conditions and process of synthesis were described in Refs. 16 and 33.

The pressure-induced evolution of T_c in $(Ca_{0.34}Na_{0.66})Fe_2As_2$ single crystal was investigated by four-probe electrical resistance measurement methods at variant pressures. The experiments were performed using both piston-cylinder-type pressure cell with liquid transmitting medium silicone oil and diamond anvil cell (DAC) with solid transmitting medium hexagonal boron nitride (h-BN). In piston-cylinder-type pressure cell, the silicone oil was used as pressure-transmitting medium to measure the temperature dependence of resistance under different hydrostatic pressures. The size of the sample was about 1.5 x 0.9 x 0.05 mm^3. All the pressure values quoted in this paper were measured at room temperature. For DAC experiment, pressure was generated by a pair of diamonds with 500-μm-diameter culet. The stainless steel gasket was pre indented from 250 μm to ~40 μm thickness with a 250-μm hole in the center that serves as the sample chamber. The sample size was about 100 μm × 100 μm × 30 μm. The pressure was determined by ruby fluorescence method at room temperature before and after each cooling down. The DAC experiments were performed twice with two different samples.

The X-ray diffraction experiments at high pressure with synchrotron radiation were done at the National Light Synchrotron Source (NSLS) of the Brookhaven National Laboratory with a wavelength 0.407 Å using a symmetric Mao Bell diamond anvil cell at room temperature. The crystal structures were refined using GSAS package.[34]

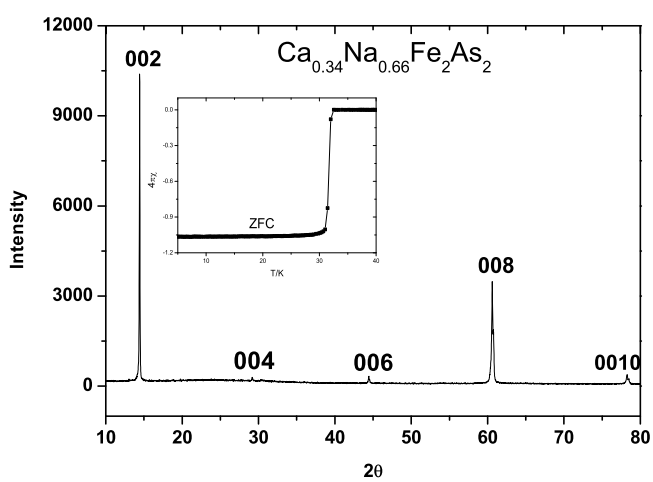


FIG. 1. The X-ray diffraction of $(Ca_{0.34}Na_{0.66})Fe_2As_2$ single crystal. Inset: Temperature dependent magnetization of $(Ca_{0.34}Na_{0.66})Fe_2As_2$ superconductors at ZFC conditions with H=30Oe.

RESULTS AND DISCUSSION

The $(Ca_{0.34}Na_{0.66})Fe_2As_2$ single crystals used in the high pressure experiments has a single-phase nature.[16] Fig. 1 shows the X-ray diffraction pattern of $(Ca_{0.34}Na_{0.66})Fe_2As_2$ single crystal with (00l) peaks. The magnetization curve shows sharp superconducting transition around 33K with full shielding fraction, which indicates the good quality of the sample. Fig. 2(a) shows the in-plane resistance R_{ab} of $(Ca_{0.34}Na_{0.66})Fe_2As_2$ as a function of temperature at different pressures up to 2.4 GPa using piston-cylinder-type pressure cell. Above 2 GPa, the width of superconducting transition increases apparently, from 0.5 K at pressures lower than 2 GPa to 3 K at 2.4 GPa. Because of the limitation of pressure in piston-cylinder-type pressure cell, we also perform the high-pressure resistance experiments using DAC cell, the results of two times are shown in Fig. 3. The width of superconducting transition increases rapidly with increasing pressure so that the zero-resistance disappears above 2 GPa, and the superconducting transition disappears completely at higher pressures. The values of T_c at variant pressures are determined from the intersection of two extrapolated lines, which extract from the experimental curve before and after transition as shown in Fig. 2(b). The T_c–pressure phase diagram of $(Ca_{0.34}Na_{0.66})Fe_2As_2$ from piston-cylinder-type pressure cell is

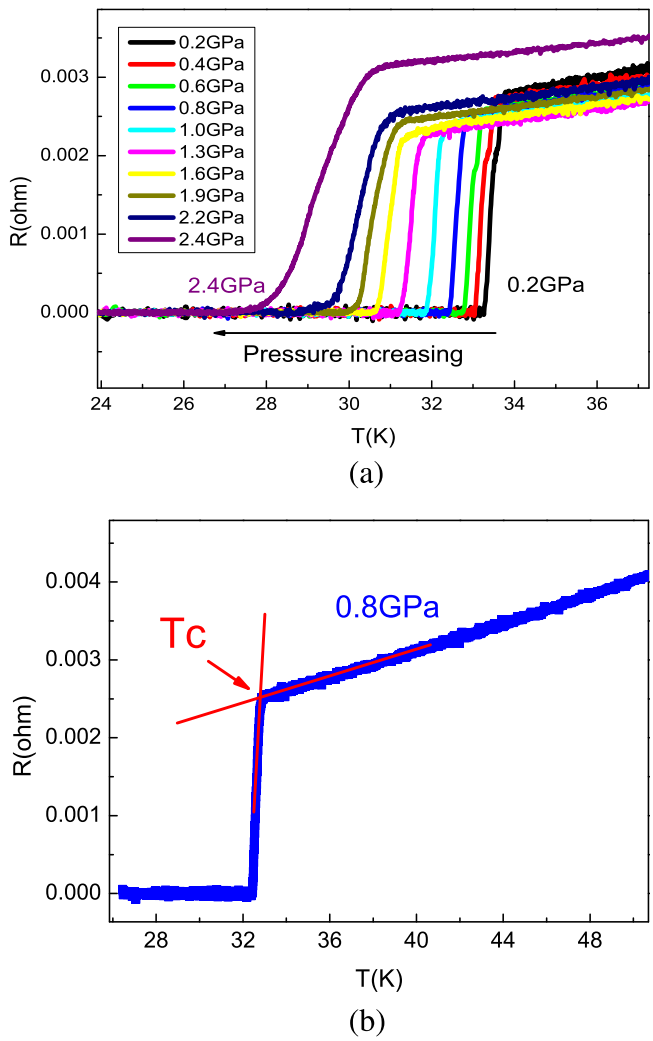


FIG. 2. (a) The temperature dependence of in-plane resistance R_{ab} for $(Ca_{0.34}Na_{0.66})Fe_2As_2$ single crystals at variant pressures up to 2.4 GPa using piston-cylinder-type pressure cell; (b) The definition of T_c: two extrapolated lines are drawn through the resistance curve before and after superconducting transition. The T_c is determined from the intersection of two lines.

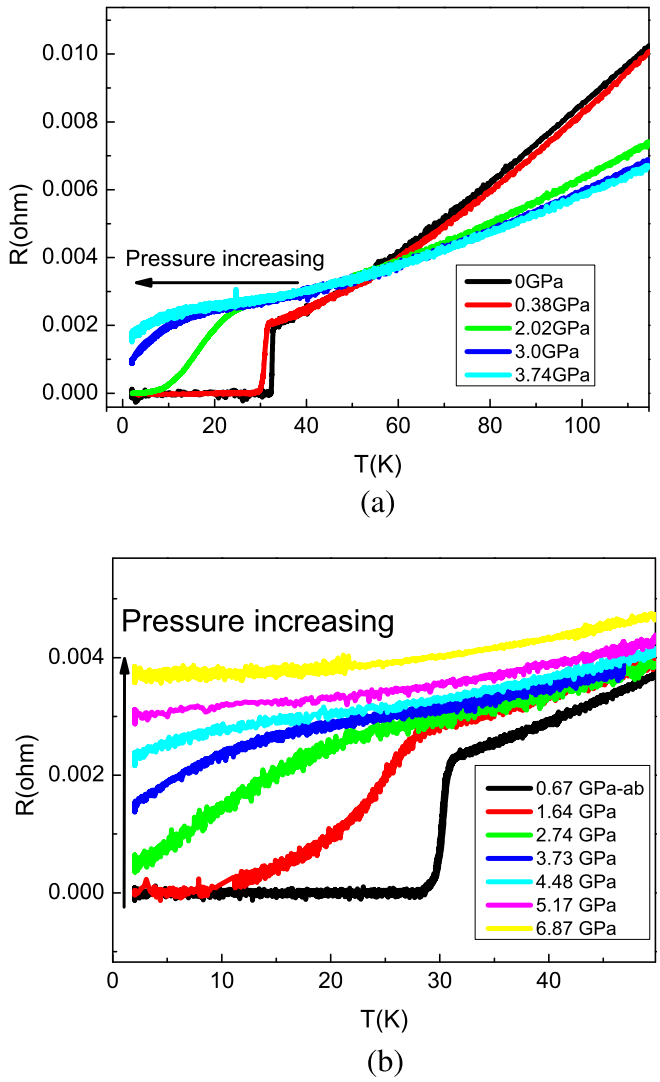


FIG. 3. (a) The temperature dependence of in-plane resistance R_{ab} for $(Ca_{0.34}Na_{0.66})Fe_2As_2$ single crystals at variant pressures up to 3.7 GPa using DAC cell; (b) The second experiment using DAC cell at variant pressures up to 6.9 GPa.

shown in Fig. 4. It is noteworthy that T_c decreases linearly as the pressure increases with a slope $dT_c/dP = -1.7$ K/GPa. The T_c evolution behavior with pressure is closely related to the change of strong Fermi surface nesting between hole and electron sheets through tuning the As-Fe-As bond angles and the anion height from Fe layer directly by pressure.[28,29] So pressure probably makes the structure distort away from optimal position so that T_c decreases with increasing pressure in $(Ca_{0.34}Na_{0.66})Fe_2As_2$.

To investigate the normal-state transport properties of $(Ca_{0.34}Na_{0.66})Fe_2As_2$, the formula $R(T) = R_0 + AT^{\alpha}$ is used for fitting the low-temperature part of R-T curve beyond transition temperature, the result is shown in Fig. 5. It exhibits an approximate T-linear dependence in a wide temperature range ($T_c < T < 130$ K) at 0.2 GPa, which suggests a strong similarity to the non-Fermi-liquid (non-FL) behaviors governed by quantum fluctuations in strongly correlated electron systems. Similar anomalous T-linear behaviors that deviate from the standard Fermi-liquid (FL) properties have been reported in several Fe-pnictides.[35–41] With increasing pressure, α increases and the FL behavior recovers gradually. The width of superconducting transition of $(Ca_{0.34}Na_{0.66})Fe_2As_2$ also increases rapidly with the recovery of FL behavior. The Fermi surface structure with interband nesting plays an important role for superconductivity in Fe-pnictides. Thus there must be a large

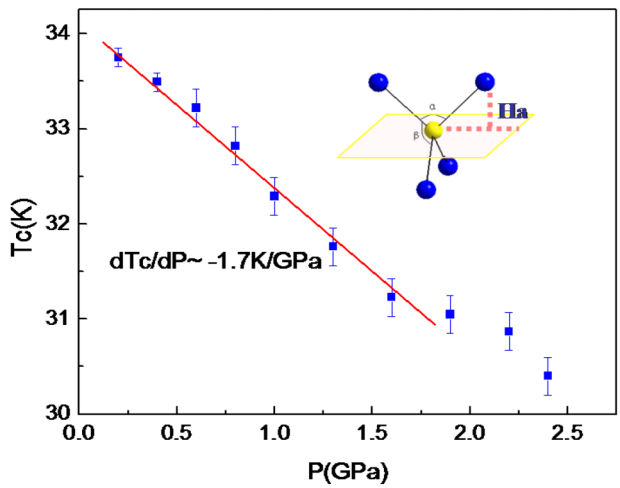


FIG. 4. The $T_c - P$ phase diagram of $(Ca_{0.34}Na_{0.66})Fe_2As_2$ obtained from resistance measurements. Experimental data are the points with error bar. The pattern of As-Fe-As bond angles and anion height from Fe layer is also given, the blue spheres are As atoms (all around), and the yellow sphere is Fe atom (middle).

change of Fermi surface nesting between the hole and electron sheets induced by pressure, which resulting the non-FL to FL transition.[39]

For $(Ca_{0.34}Na_{0.66})Fe_2As_2$, the width of superconducting transition of R-T curve increases and zero-resistance disappears above 2 GPa. The phenomena indicate that the sample is no longer a single phase. To further investigate the evolution of structure of $(Ca_{0.34}Na_{0.66})Fe_2As_2$ under high pressure, we perform the high pressure X-ray diffraction experiments. Fig. 6(a) shows the synchrotron X-ray diffraction pattern for a wide angle range from ambient pressure up to 5.1GPa at room temperature. Each peak is labeled with the corresponding (hkl). The GSAS program software package is used to obtain the lattice parameters at each pressure, which is listed in Fig. 6(b). With increasing pressure, the *c* axis shrinks and *a* axis slightly expands, between 2.3GPa and 3.1 GPa, there is a rapid reduction as large as ~6% of the c axis whereas the a axis expands by ~1%, indicating the T to cT phase transition, which has been reported in the parent $CaFe_2As_2$ under pressure.[32,42,43] With further increasing pressure, both *a* axis and *c* axis smoothly decrease. Because of the destruction of interband nesting in cT phase, the lack of magnetic fluctuations could be responsible for the recovery of FL behaviors and the absence of superconductivity.

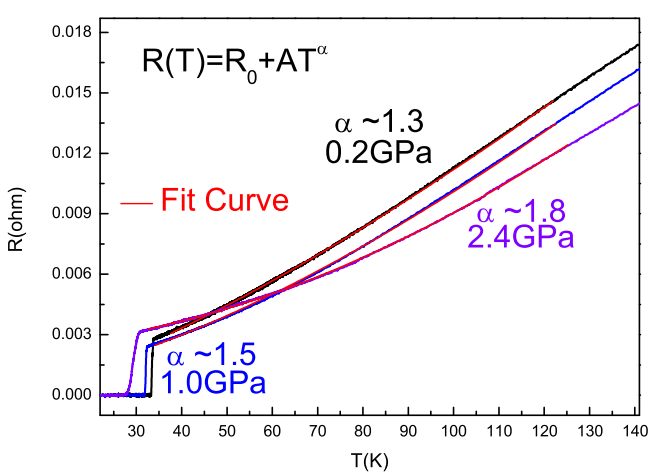
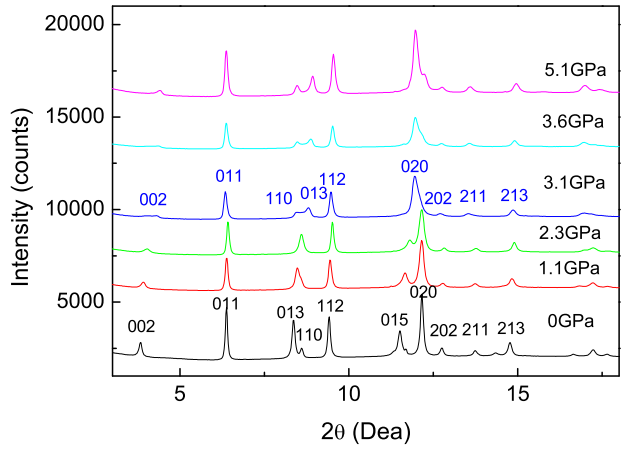
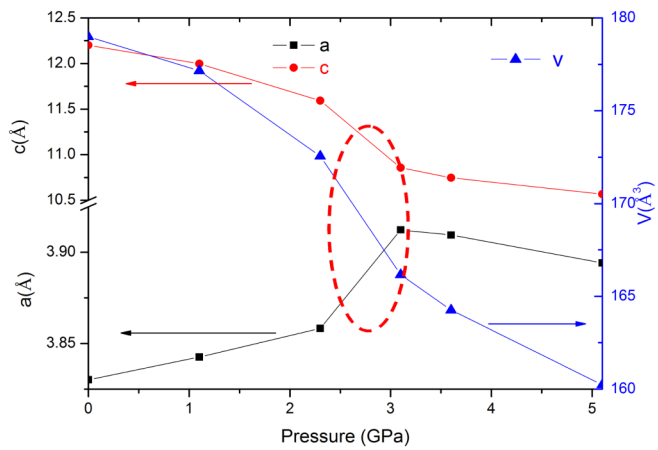


FIG. 5. The low-temperature part of R-T curves ($T_c < T < 130$ K) can be fitted by the formula as shown in the figure, which exhibits a change from approximately T-linear to T-square dependence of resistance.



(a)



(b)

FIG. 6. (a) The synchrotron X-ray diffraction pattern for a wide angle range from ambient pressure up to 5.1GPa at room temperature. Each peak is labeled with the corresponding (hkl) at 0 GPa and 3.1 GPa respectively; (b) Pressure dependence of crystal parameters a, c and volume, which shows a T to cT phase transition.

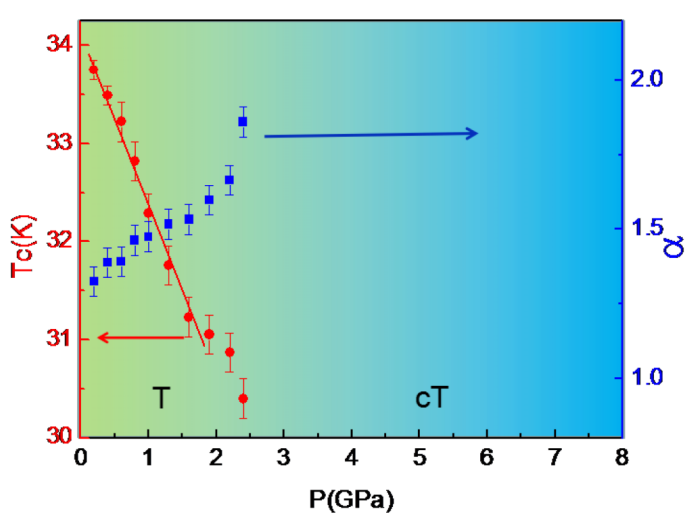


FIG. 7. The pressure-temperature phase diagram of $(Ca_{0.34}Na_{0.66})Fe_2As_2$.

Similar with $(Ca_{0.34}Na_{0.66})Fe_2As_2$ in cT phase, both the absence of superconductivity and the recovery of FL behaviors have also been observed in cT phase of $CaFe_2As_2$ or doped Ca122 Fe pnictides.[39,44–47]

In summary, we have shown that the T_c of $(Ca_{0.34}Na_{0.66})Fe_2As_2$ decreases nearly linearly with a slope $dT_c/dP \sim -1.7$ K/GPa with increasing pressure. Anomalous non-FL behaviors of R-T curves are also observed at lower pressures in $(Ca_{0.34}Na_{0.66})Fe_2As_2$, whereas the recovery of FL transport properties corresponds to the disappearance of superconductivity. Meanwhile, $(Ca_{0.34}Na_{0.66})Fe_2As_2$ exhibits a tetragonal (T) to collapsed-tetragonal (cT) transition at about 3GPa according to high pressure synchrotron X-ray diffraction experiments. The pressure–temperature phase diagram is shown in Fig. 7. The results strongly suggest that the superconductivity and the observed non-FL transport properties are both closely related to the interband-associated strong spin and orbital fluctuations in Fe pnictides.

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[1] Y. Kamihara, T. Watanabe, M. Hirano, and H. Hosono, J. Am. Chem. Soc. **130**, 3296 (2008).
[2] Z. A. Ren, J. Yang, W. Lu, W. Yi, X. L. Shen, Z. G. Li, G. C. Che, X. L. Dong, L. L. Sun, F. Zhou, and Z. X. Zhao, Europhys. Lett. **82**, 57002 (2008).
[3] X. H. Chen, T. Wu, G. Wu, R. H. Liu, H. Chen, and D. F. Fang, Nature **453**, 761 (2008).
[4] H. H. Wen, G. Mu, L. Fang, H. Yang, and X. Y. Zhu, Europhys. Lett. **82**, 17009 (2008).
[5] G. F. Chen, Z. Li, D. Wu, G. Li, W. Z. Hu, J. Dong, P. Zheng, J. L. Luo, and N. L. Wang, Phys. Rev. Lett. **100**, 247002 (2008).
[6] C. Wang, L. J. Li, S. Chi, Z. W. Zhu, Z. Ren, Y. K. Li, Y. T. Wang, X. Lin, Y. K. Luo, S. Jiang, X. F. Xu, G. H. Cao, and Z. A. Xu, Europhys. Lett. **83**, 67006 (2008).
[7] M. Rotter, M. Tegel, and D. Johrendt, Phys. Rev. Lett. **101**, 107006 (2008).
[8] X. C. Wang, Q. Q. Liu, Y. X. Lv, W. B. Gao, L. X. Yang, R. C. Yu, F. Y. Li, and C. Q. Jin, Solid State Commun. **148**, 538 (2008).
[9] F. C. Hsu, J. Y. Luo, K. W. Yeh, T. K. Chen, T. W. Huang, P. M. Wu, Y. C. Lee, Y. L. Huang, Y. Y. Chu, D. C. Yan, and M. K. Wu, Proc. Natl. Acad. Sci. USA **105**, 14262 (2008).
[10] N. Ni, S. Nandi, A. Kreyssig, A. I. Goldman, E. D. Mun, S. L. Bud'ko, and P. C. Canfield, Phys. Rev. B **78**, 014523 (2008).
[11] G. Wu, H. Chen, T. Wu, Y. L. Xie, Y. J. Yan, R. H. Liu, X. F. Wang, J. J. Ying, and X. H. Chen, J. Phys. Condens. Matter **20**, 422201 (2008).
[12] M. Rotter, M. Tegel, D. Johrendt, I. Schellenberg, W. Hermes, and R. Pöttgen, Phys. Rev. B **78**, 020503 (2008).
[13] J.-Q. Yan, A. Kreyssig, S. Nandi, N. Ni, S. L. Bud'ko, A. Kracher, R. J. McQueeney, R.W. McCallum, T. A. Lograsso, A. I. Goldman, and P. C. Canfield, Phys. Rev. B **78**, 024516 (2008).
[14] G. F. Chen, Z. Li, G. Li, W. Z. Hu, J. Dong, X. D. Zhang, P. Zheng, N. L. Wang, and J. L. Luo, Chin. Phys. Lett. **25**, 3403 (2008).
[15] P. M. Shirage, K. Miyazawa, H. Kito, H. Eisaki, and A. Iyo, Appl. Phys. Express **1**, 081702 (2008).
[16] K. Zhao, Q. Q. Liu, X. C. Wang, Z. Deng, Y. X. Lv, J. L. Zhu, F.Y. Li, and C. Q. Jin, J. Phys. Condens. Matter **22**, 222203 (2010).
[17] K. Zhao, Q. Q. Liu, X. C. Wang, Z. Deng, Y. X. Lv, J. L. Zhu, F.Y. Li, and C. Q. Jin, Phys. Rev. B **84**, 184534 (2011).
[18] S. Johnston, M. Abdel-Hafiez, L. Harnagea, V. Grinenko, D. Bombor, Y. Krupskaya, C. Hess, S. Wurmehl, A. U. B. Wolter, B. B¨uchner, H. Rosner, and S.-L. Drechsler, Phys. Rev. B **89**, 134507 (2014).
[19] H. Takahashi, K. Igawa, K. Arii, Y. Kamihara, M. Hirano, and H. Hosono, Nature **453**, 376 (2008).
[20] N. Takeshita, A. Iyo, H. Eisaki, H. Kito, and T. Ito, J. Phys. Soc. Jap **77**, 075003 (2008).
[21] W. Yi, L. L. Sun, Z. Ren, W. Lu, X. L. Dong, H. J. Zhang, X. Dai, Z. Fang, Z. C. Li, G. G. Che, J. Yang, X. L. Shen, F. Zhou, and Z. X. Zhao, EPL **83**, 57002 (2008).
[22] M. S. Torikachvili, S. L. Bud'ko, N. Ni, and P. C. Canfield, Phys. Rev. Lett. **101**, 057006 (2008).
[23] A. Mani, N. Ghosh, S. Paulraj, A. Bharathi, and C. S. Sundar, EPL **87**, 17004 (2009).
[24] K. Igawa, H. Okada, H. Takahashi, S. Matsuishi, Y. Kamihara, M. Hirano, H. Hosono, K. Matsubayashi, and Y. Uwatoko, J. Phys. Soc. Jpn. **78**, 025001 (2009).
[25] S. J. Zhang, X. C. Wang, R. Sammynaiken, J. S. Tse, L. X. Yang, Z. Li, Q. Q. Liu, S. Desgreniers, Y. Yao, H. Z. Liu, and C. Q. Jin, Phys. Rev. B. **80**, 014506 (2009).
[26] S. J. Zhang, X. C. Wang, Q. Q. Liu, Y. X. Lv, X. H. Yu, Z. J. Lin, Y. S. Zhao, L. Wang, Y. Ding, H. K. Mao, and C. Q. Jin, EPL **88**, 47008 (2009).
[27] Y. Mizuguchi, F. Tomioka, S. Tsuda, T. Yamaguchi, and Y. Takano, Appl. Phys. Lett. **93**, 152505 (2008).
[28] C. H. Lee, A. Iyo, H. Eisaki, H. Kito, M. T. Fernandez-Diaz, T. Ito, K. Kihou, H. Matsuhata, M. Braden, and K. Yamada, J. Phys. Soc. Jpn. **77**, 083704 (2008).
[29] Y. Mizuguchi, Y. Hara, K. Deguchi, S. Tsuda, T. Yamaguchi, K. Takeda, H. Kotegawa, H. Tou, and Y. Takano, Supercond. Sci. Technol. **23**, 054013 (2010).
[30] J. G. Zhao, L. H. Wang, D. W. Dong, Z. G. Liu, H. Z. Liu, G. F. Chen, D. Wu, J. L. Luo, N. L. Wang, Y. Yu, C. Q. Jin, and Q. Z. Guo, JACS **130**, 13828 (2008).

[31] Q. Q. Liu, X. H. Yu, X. C. Wang, Z. Deng, Y. X. Lv, J. L. Zhu, S. J. Zhang, H. Z. Liu, W. G. Yang, L. Wang, H. K. Mao, G. Y. Shen, Z. Y. Lu, Y. Ren, Z. Q. Chen, Z. J. Lin, Y. S. Zha, and C. Q. Jin, J. Am. Chem. Soc. **133**, 7892 (2011).
[32] A. Kreyssig, M. A. Green, Y. Lee, G. D. Samolyuk, P. Zajdel, J. W. Lynn, S. L. Bud'ko, M. S. Torikachvili, N. Ni, S. Nandi, J. B. Leão, S. J. Poulton, D. N. Argyriou, B. N. Harmon, R. J. McQueeney, P. C. Canfield, and A. I. Goldman, Phys. Rev. B **78**, 184517 (2008).
[33] J. S. Kim, K. Zhao, C. Q. Jin, and G. R. Stewart, Solid State Communications **193**, 34 (2014).
[34] A. C. Larson and R. B. Von Dreele, Los Alamos National Laboratory Report LAUR 86-748 (Los Alamos National Laboratory, Los Alamos, NM, 1994).
[35] R. H. Liu, G. Wu, T. Wu, D. F. Fang, H. Chen, S. Y. Li, K. Liu, Y. L. Xie, X. F. Wang, R. L. Yang, L. Ding, C. He, D. L. Feng, and X. H. Chen, Phys. Rev. Lett. **101**, 087001 (2008).
[36] M. Gooch, B. Lv, B. Lorenz, A. M. Guloy, and C.-W. Chu, Phys. Rev. B **79**, 104504 (2009).
[37] X. F. Wang, T. Wu, G. Wu, R. H. Liu, H. Chen, Y. L. Xie, and X. H. Chen, New J. Phys. **11**, 045003 (2009).
[38] S. Kasahara, T. Shibauchi, K. Hashimoto, K. Ikada, S. Tonegawa, R. Okazaki, H. Shishido, H. Ikeda, H. Takeya, K. Hirata, T. Terashima, and Y. Matsuda, Phys. Rev. B **81**, 184519 (2010).
[39] S. Kasahara, T. Shibauchi, K. Hashimoto, Y. Nakai, H. Ikeda, T. Terashima, and Y. Matsuda, Phys. Rev. B **83**, 060505(R) (2011).
[40] Y. M. Dai, B. Xu, B. Shen, H. Xiao, H. H. Wen, X. G. Qiu, C. C. Homes, and R. P. S. M. Lobo, Phys. Rev. Lett. **111**, 117001 (2013).
[41] Y. M. Dai, H. Miao, L. Y. Xing, X. C. Wang, P. S. Wang, H. Xiao, T. Qian, P. Richard, X. G. Qiu, W. Yu, C. Q. Jin, Z. Wang, P. D. Johnson, C. C. Homes, and H. Ding, Physi. Rev. X **5**, 031035 (2015).
[42] W. Yu, A. A. Aczel, T. J. Williams, S. L. Budko, N. Ni, P. C. Canfield, and G. M. Luke, Phys. Rev. B **79**, 020511(R) (2009).
[43] M. S. Torikachvili, S. L. Budko, N. Ni, P. C. Canfield, and S. T. Hannahs, Phys. Rev. B **80**, 014521 (2009).
[44] Masataka Danura, Kazutaka Kudo, Yoshihiro Oshiro, Shingo Araki, Tatsuo C. Kobayashi, and Minoru Nohara, J. Phys. Soc. Jpn. **80**, 103701 (2011).
[45] R. S. Dhaka, Rui Jiang, S. Ran, S. L. Bud'ko, P. C. Canfield, B. N. Harmon, Adam Kaminski, Milan Tomić, Roser Valentí, and Yongbin Lee, Phys. Rev. B **89**, 020511 (2014).
[46] K. Tsubota, T. Wakita, H. Nagao, C. Hiramatsu, T. Ishiga, M. Sunagawa, K. Ono, H. Kumigashira, M. Danura, K. Kudo, M. Nohara, Y. Muraoka, and T. Yokoya, J. Phys. Soc. Jpn. **82**, 073705 (2013).
[47] Y. Furukawa, B. Roy, S. Ran, S. L. Bud'ko, and P. C. Canfield, Phys. Rev. B **89**, 121109 (2014).