Physica C 471 (2011) 600-602

Contents lists available at ScienceDirect

Physica C

journal homepage: www.elsevier.com/locate/physc



Superconductivity of the platinum doped 122 iron arsenide $SrFe_{2-x}Pt_xAs_2$

S.B. Zhang^{a,*}, Y.F. Guo^a, J.J. Li^{b,c}, X.X. Wang^{b,c}, K. Yamaura^{b,c,d}, E. Takayama-Muromachi^{a,c,d}

^a International Center for Materials Nanoarchitectonics (MANA), National Institute for Materials Science, Tsukuba, Ibaraki 305-0044, Japan
 ^b Superconducting Materials Center, National Institute for Materials Science, 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan
 ^c Department of Chemistry, Graduate School of Science, Hokkaido University, Sapporo, Hokkaido 060-0810, Japan
 ^d JST, Transformative Research-Project on Iron Pnictides (TRIP), Tsukuba, Ibaraki 305-0044, Japan

ARTICLE INFO

Article history: Accepted 5 January 2011 Available online 13 May 2011

Keywords: Iron based-superconductor Doping

ABSTRACT

Pt doped 122 iron arsenide $SrFe_{1-x}Pt_xAs_2$ ($0 \le x \le 0.4$) was successfully synthesized. The tetragonal unitcell volume and the lattice constant *a* increase with increasing the Pt content, while *c* decreases, suggesting that the Fe ions are indeed replaced by Pt ions. By the Pt doping, the magnetic order of the parent phase is suppressed, and superconductivity emerges at approximately x = 0.15. T_c reaches the maximum of 16 K at x = 0.2. The compounds series can be a suitable subject to investigate role of the doped 5*d* state in the superconducting 3*d* Fe–As layer.

© 2011 Elsevier B.V. All rights reserved.

1. Introduction

In the past several years, the Fe-based superconductor has attracted broad attentions. Superconductivity (SC) has been reported one after another for the family members, like *RE*FeAsO_{1-x}F_x (*RE* = rare-earth metal) [1–3], doped AEFe₂As₂ (*AE* = Ca, Sr, Ba) [4–7], *A*FeAs (*A* = Li, Na) [8,9], FeSe_x [10,11], and Sr₄V₂O₆Fe₂As₂ [12]. All of them have a common structure piece, the Fe–As layer, which is directly responsible for the SC.

In the materials system, AEFe₂As₂ has several advantages for investigating nature of the FeAs layer [1]; there is no complication caused by oxygen nonstoichiometry [2]. AEFe₂As₂ widely accepts chemical doping to the AE, Fe, or As sites [4–7]. Some doped elements eventually induce the SC [3]. Besides, applied pressure can also induce the SC; CaFe₂As₂ indeed shows crossover to the SC at 12 K at pressure as low as 0.4 GPa [13–15] as does SrFe₂As₂ at 27 K at 3 GPa and BaFe₂As₂ at 29 K at 3.5 GPa [16].

In this paper, we report SC induced by replacing Fe of $SrFe_2As_2$ with the 5*d* element Pt. The doped compound crystallizes into the ThCr₂Si₂-type structure with the space group *I*4/*mmm* as well as the host compound. The lattice parameters variation over the Pt substitution demonstrates that Fe is successfully replaced by Pt up to 20 at.%. The spin-density-wave (SDW) transition of the parent compound is suppressed gradually with the Pt doping, and the SC emerges. A comparable feature was observed for the Pt doped $SrFe_2As_2$ by other independent groups very recently [17,18]. Single-crystal and polycrystal samples of Pt-doped $SrFe_2As_2$ had been

* Corresponding author. Address: National Institute for Material Science (NIMS), International Center for Materials Nanoarchitectonics (MANA), 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan. Tel.: +81 29 851 3354x8024; fax: +81 29 860 4674.

E-mail address: ZHANG.Shoubao@nims.go.jp (S.B. Zhang).

studied, separately. The maximum T_c is about 17 K in our samples, which is almost same as in above two works. There is an interesting phenomenon that the T_c is almost independent with Pt doping content in Ref. [18]. However, the T_c is dependent Pt doping content strongly in our work and Ref. [17]. Stoichiometry and homogeneity of Pt element should been the key point for this behavior.

2. Experiments

Polycrystalline sample was prepared by a solid-state reaction method with two steps. First, SrAs and FeAs were prepared by the method from Sr pieces (99.9%, Strem Chemicals), Fe powder, and As grains (99.999%, High Purity Chem.). Second, they were mixed with Pt (99.9%, Strem Chemicals) and Fe powder (99.9%, 100 mesh, Rare Metallic Co.) with the proportions of $SrFe_{2-x}Pt_xAs_2$ (x = 0, 0.1, 0.15, 0.2, 0.3, 0.4). The mixture was pressed into a Ta capsule. The capsule was sealed in an evacuated quartz tube, followed by heating at 1000 °C for 48 h. The weighing, grounding, and pressing were processed in a glove box, which was constantly maintained under a protective argon atmosphere.

Phase identification was carried out by an X-ray diffraction (XRD) method in Philips X'pert PRO X-ray diffractometer using a θ -2 θ scan with Cu K α radiation at room temperature. Structural refinement was performed by a standard Rietveld technique [19]. Electronic resistivity measurements were conducted in physical property measurements system, Quantum Design, by a standard four-probe method. DC magnetization measurements were done in magnetic property measurements system, Quantum Design.

3. Results and discussion

Fig. 1 shows the XRD patterns of the $SrFe_{2-x}Pt_xAs_2$ samples at x = 0, 0.1, 0.15, 0.2, 0.3 and 0.4. Obvious impurity peaks were



^{0921-4534/\$ -} see front matter @ 2011 Elsevier B.V. All rights reserved. doi:10.1016/j.physc.2011.05.005

undetected, indicating that all the samples are of single phase. We indexed all peaks with a tetragonal lattice model [I4/mmm; Sr 2a (0, 0, 0), Fe/Pt 4d (0.5, 0, 0.25), As 4d (0.25, 0, 0.3608)] [17] by a standard Rietveld method. As a representative, fit to the pattern for SrFe_{1.85}Pt_{0.15}As₂ is shown in Fig. 2. The lattice constants *a*, *c*, a/c and the unit-cell volume *V* obtained by the fits are shown in Fig. 3. It reveals that the lattice constants *a*, a/c, *V* increase with the Pt content, while *c* decreases. Distance between the Fe–As layers is slightly shortened, however the increase of unit-cell volume indicates a negative chemical pressure is actually introduced by the Pt-doping.

Fig. 4 shows the temperature dependence of the electrical resistivity of $SrFe_{2-x}Pt_xAs_2$ at x = 0, 0.1, 0.15, 0.2, 0.3 and 0.4. It can be seen that the parent compound $SrFe_2As_2$ exhibits a clear anomaly at 210 K, which corresponds to the SDW transition [17]. The SDW transition temperature decreases by the Pt doping; 143 K at x = 0.1, 94 K at x = 0.15, and the anomaly disappears at x = 0.2and higher. Meantime, SC appears at x = 0.1 and higher. The zero resistivity was observed at x = 0.15, 0.2 and 0.3, but not at x = 0.4. The x = 0.4 sample is probably in the "over doped" region. It is noteworthy that coexistence of SC and SDW was observed for the samples at x = 0.1 and 0.15. Because the coexistence directly reflects nature of the unusual SC, further investigation of the samples is in progress.

Fig. 5a–f. show temperature dependence of the magnetic susceptibility for all the samples of $SrFe_{2-x}Pt_xAs_2$ (x = 0-0.4) measured in a magnetic field of 3 kOe at zero field cooling (ZFC) and field cooling (FC) conditions. Inset to Fig. 5a is an expanded view focusing on the anomaly at 210 K. Other insets to Fig. 5b–f. show additional data measured at 10 Oe below 30 K.

The 3 kOe data indicate that all of the samples are paramagnetic-like. The small gap in the ZFC and FC curves at x = 0.1, 0.2, 0.3 indicate magnetic contributions from undetected impurities, masking the SC diamagnetism. In fact, such the magnetic contributions are often observed for many iron-based superconducting compounds [20]. We thus conducted the measurements in a much weak field of 10 Oe.

As shown in the inset to Fig. 5a, a small anomalous peak was observed at 210 K, which is likely due to the SDW transition. With increasing the Pt content, the SDW gradually disappears. For the x = 0.1 sample, a weak downturn feature in the ZFC curve was detected, while the samples at x = 0.15, 0.2, 0.3 show much larger diamagnetic signals below 12 K, 16.5 K and 16 K, respectively. Because the temperatures are comparable with the zero resistivity temperature, it is reasonable to attribute the large diamagnetic signals to the SC. At the maximum Pt concentration x = 0.4, the SC is suppressed probably due to the over doped carriers.



Fig. 1. X-ray diffraction patterns of $SrFe_{2-x}Pt_xAs_2$ (*x* = 0, 0.1, 0.15, 0.2, 0.3 and 0.4).



Fig. 2. X-ray diffraction pattern of $SrFe_{1.85}Pt_{0.15}As_2$. Crosses indicate the experimental data and the calculated data is the continuous line overlapping them. The lowest curve shows the difference between experimental and calculated patterns.



Fig. 3. Pt-substitution dependence of lattice constants *a*, *c*, *a*/*c* and unit cell volume V.



Fig. 4. Temperature dependence of resistivity for $SrFe_{2-x}Pt_xAs_2$ with x = 0, 0.1, 0.15, 0.2, 0.3 and 0.4 at zero magnetic field.

In summary, Pt doped 122 iron arsenide $SrFe_{1-x}Pt_xAs_2$ was successfully synthesized up to x = 0.4. The structure, electric transport, and magnetic properties were investigated. With increasing the Pt content, the SDW transition of the parent phase is gradually suppressed and SC emerges at a doping level of approximately x = 0.15. Although the Pt doping eventually applies a negative



Fig. 5. (a–f) Temperature dependence of magnetic susceptibility for SrFe_{2–x}Pt_xAs₂ with x = 0, 0.1, 0.15, 0.2, 0.3 and 0.4 measured under a 3000 Oe magnetic field in ZFC and FC models. The inset of (a) is the magnification of the $\chi(T)$ between 180 K and 250 K. And the insets of (b–f) show the $\chi(T)$ measured under a 10 Oe magnetic field in ZFC and FC models below 30 K.

chemical pressure, which usually works against SC, T_c reaches the maximum of 16 K at x = 0.2. Perhaps, the 5*d* state in the Fe–As layer alters the electrical carrier density effectively, overcoming the pressure effect. Additional studies focusing on nature of the doped 5*d* state in the superconducting 3*d* Fe–As layer are in progress.

Acknowledgments

This research was supported in part by the World Premier International Research Center (WPI) Initiative on Materials Nanoarchitectonics from MEXT, Japan; the Grants-in-Aid for Scientific Research (20360012, 22246083) from JSPS, Japan; and the Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program) from JSPS.

References

- [1] Y. Kamihara, T. Watanabe, M. Hirano, H. Hosono, J. Am. Chem. Soc. 130 (2008) 3296.
- [2] Z.A. Ren, W. Lu, J. Yang, W. Yi, X.L. Shen, Z.C. Li, G.C. Che, X.L. Dong, L.L. Sun, F. Zhou, Z.X. Zhao, Chin. Phys. Lett. 25 (2008) 2215.
- [3] C. Wang, L. Li, S. Chi, Z. Zhu, Z. Ren, Y. Li, Y. Wang, X. Lin, Y. Luo, S. Jiang, X. Xu, G. Cao, X. Zhu'an, Europhys. Lett. 83 (2008) 67006.
- [4] M. Rotter, M. Tegel, D. Johrendt, Phys. Rev. Lett. 101 (2008) 107006.
- [5] G.F. Chen, Z. Li, G. Li, W.Z. Hu, J. Dong, X.D. Zhang, P. Zheng, N.L. Wang, J.L. Luo, Chin. Phys. Lett. 25 (2008) 3403.
- [6] M.S. Torikachvili, S.L. Bud'ko, N. Ni, P.C. Canfield, Phys. Rev. Lett. 101 (2008) 057006.
- [7] K. Sasmal, B. Lv, B. Lorenz, A.M. Guloy, F. Chen, Y.Y. Xue, C.W. Chu, Phys. Rev. Lett. 101 (2008) 10700.
- [8] X.C. Wang, Q.Q. Liu, Y.X. Lv, W.B. Gao, Y.X. Yang, R.C. Yu, F.Y. Li, C.Q. Jin, Solid State Commun. 148 (2008) 538.
- [9] J.H. Tapp, Z.J. Tang, B. Lv, K. Sasmal, B. Lorenz, C.W. Chu, A.M. Guloy, Phys. Rev. B 78 (2008) 060505.
- [10] 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, M.K. Wu, Proc. Natl. Acad. Sci. USA 105 (2008) 14262.
- [11] S.B. Zhang, Y.P. Sun, X.D. Zhu, X.B. Zhu, B.S. Wang, G. Li, H.C. Lei, X. Luo, Z.R. Yang, W.H. Song, J.M. Dai, Supercond. Sci. Technol. 22 (2009) 015020.
- [12] X.Y. Zhu, F. Han, G. Mu, B. Zeng, P. Cheng, B. Shen, H.H. Wen, Phys. Rev. B 79 (2009) 024516.
- [13] W. Schnelle, A. Leithe-Jasper, R. Gumeniuk, U. Burkhardt, D. Kasinathan, H. Rosner, Phys. Rev. B 79 (2009) 214516.
- [14] A. Leithe-Jasper, W. Schnelle, C. Geibel, H. Rosner, Phys. Rev. Lett. 101 (2008) 207004.
- [15] N. Ni, A. Thaler, A. Kracher, J.Q. Yan, S.L. Bud'ko, P.C. Canfield, Phys. Rev. B 80 (2009) 024511.
- [16] P.C. Canfield, S.L. Budko, Ni Ni, J.Q. Yan, A. Kracher, Phys. Rev. B 80 (2009) 060501.
- [17] K. Kirshenbaum, S.R. Saha, T. Drye, J. Paglione, Phys. Rev. B 82 (2010) 44518.
 [18] Y. Nishikubo, S. Kakiya, M. Danura, K. Kudo, M. Nohara, J. Phys. Soc. Jpn. 79
- (2010) 095002. [19] L.B. McCusker, R.B. von Dreele, D.E. Cox, D. Louër, P. Scandi, J. Appl. Cryst. 32
- (1999) 35.
 [20] S.B. Zhang, H.C. Lei, X.D. Zhu, G. Li, B.S. Wang, L.J. Li, X.B. Zhu, W.H. Song, Z.R. Yang, Y.P. Sun, Physica C 469 (2009) 1958.