Superconductivity in Ti-doped Iron-Arsenide Compound Sr$_4$Cr$_{0.8}$Ti$_{1.2}$O$_6$Fe$_2$As$_2$

Xiyu Zhu, Fei Han, Gang Mu, Peng Cheng, Bing Shen, Bin Zeng, and Hai-Hu Wen

National Laboratory for Superconductivity, Institute of Physics and Beijing National Laboratory for Condensed Matter Physics, Chinese Academy of Sciences, P. O. Box 603, Beijing 100190, People’s Republic of China

Superconductivity was achieved in Ti-doped iron-arsenide compound Sr$_4$Cr$_{0.8}$Ti$_{1.2}$O$_6$Fe$_2$As$_2$ (abbreviated as Cr-FeAs-42622). The x-ray diffraction measurement shows that this material has a layered structure with the space group of $P4/nmm$, and with the lattice constants $a = b = 3.9003$ Å and $c = 15.8376$ Å. Clear diamagnetic signals in ac susceptibility data and zero-resistance in resistivity data were detected at about 6 K, confirming the occurrence of bulk superconductivity. Meanwhile we observed a superconducting transition in the resistive data with the onset transition temperature at 29.2 K, which may be induced by the nonuniform distribution of the Cr/Ti content in the FeAs-42622 phase, or due to some other minority phase.

Recently, superconductivity was observed in the iron-pnictide based systems, since $c_{\text{FeAs}}$ has been extended rapidly, and the physical properties as well as pairing mechanism of these superconductors have been investigated widely. Now it is known that for the iron-arsenide based systems, superconductivity can be induced by doping electrons or holes in the parent phases in various ways. By the end of 2008, a new Fd-As based system, Sr$_3$Sc$_2$O$_6$Fe$_2$As$_2$ (FeAs-32522), with the space group of $I4/mmm$ has been investigated widely. Recently, superconductivity was observed in the iron-nitride based system Sr$_3$Sc$_2$O$_6$Fe$_2$P$_2$ (FeP-42622) and also doped iron-arsenide compounds.

In this paper we present the structural and transport properties of a new iron-arsenide based superconductor in the FeAs-42622 phase, namely the Ti-doped Sr$_4$Cr$_{0.8}$Ti$_{1.2}$O$_6$Fe$_2$As$_2$. It is found that this material also has a rather large distance between neighboring conducting layers (FeAs-layers). Bulk superconductivity was confirmed by the clear diamagnetic properties and zero resistivity.

By using a two-step solid state reaction method, the polycrystalline samples were fabricated. In the first step, SrAs and FeAs powders were obtained by the chemical reaction method with Sr pieces, Fe powders and As grains. Then they were mixed with Cr$_2$O$_3$ (purity 99.9%), SrO (purity 99%), TiO$_2$ (purity 99%), Ti (purity 99%) and Fe powder (purity 99.9%) in the formula Sr$_4$Cr$_{0.8}$Ti$_{1.2}$O$_6$Fe$_2$As$_2$, ground and pressed into a pellet shape. The pellets were sealed in a quartz tube with 0.2 bar of Ar gas, followed by a heat treatment at 1000 °C for 40 hours. Then it was cooled down slowly to room temperature. All the weighing, mixing, grounding and pressing procedures were finished in a glove box under argon atmosphere with the moisture and oxygen below 0.1 PPM.

The X-ray diffraction (XRD) patterns of our samples were carried out by a Mac-Science MXP18A-HF equipment with $\theta - 2\theta$ scan. The ac susceptibility of the samples was measured on the Maglab-12T (Oxford) with an ac field of 0.1 Oe and a frequency of 333 Hz. The resistivity data were obtained using a four-probe technique on the Quantum Design instrument physical property measurement system (PPMS) with magnetic fields up to 9 T. The temperature stabilization was better than 0.1% and the resolution of the voltmeter was better than 10 nV.

The X-ray diffraction (XRD) pattern for the sample Sr$_4$Cr$_{0.8}$Ti$_{1.2}$O$_6$Fe$_2$As$_2$ is shown in Fig. 1. One can see that the sample was dominated by the phase of the tetragonal structure with the space group of $P4/nmm$. Some impurity phases were found to come from FeAs, SrO and Sr$_2$TiO$_4$. The lattice constants of our samples are shown in Fig. 1.

FIG. 1: (Color online) X-ray diffraction patterns for the sample Sr$_4$Cr$_{0.8}$Ti$_{1.2}$O$_6$Fe$_2$As$_2$. One can see that all the main peaks can be indexed to the structure of FeAs-42622 with the space group of $P4/nmm$. The peaks from the impurities, as marked by the asterisks etc., are indexed to the phases FeAs, SrO and Sr$_2$TiO$_4$. The lattice constants of our samples are $a = b = 0.3900(3)$ nm, $c = 1.5837(6)$ nm.
were determined to be $a = b = 3.9003 \, \text{Å}$ and $c = 15.8376 \, \text{Å}$ from the diffraction data. We can see that both the $a$-axis and $b$-axis lattice constants of this material are slightly smaller than those of (Sr$_3$Sc$_2$O$_5$)Fe$_2$As$_2$ (FeAs-32522) compound, and the distance between neighboring conducting layers (FeAs-layers) ($c = 15.8376 \, \text{Å}$) is larger than that of the FeAs-32522 phase ($c/2 = 13.4 \, \text{Å}$). This has become a common feature of this system and we have argued that this feature may be intimately related to the high-$T_c$ superconductivity in this system.

In Fig. 2 we present the temperature dependent resistivity data under 0 T and 9 T. A metallic behavior can be seen in the temperature region above 30 K in both fields. With the decrease of temperature, resistivity displays a superconducting-like transition with the onset temperature as high as 29.2 K (see inset of Fig. 2). Then after a rather wide transition, resistivity becomes zero below about 6 K. We think that it is possible that the superconductivity may occur at 29.2 K for the Cr-FeAs-42622 phase. But due to the nonuniform distribution of the doped Ti content in the sample, the superconducting transition is broad. However, we could not exclude another possibility that the superconductivity at 29.2 K is derived from other minority phase. A magnetic field of 9 T didn’t move the onset transition point significantly but seemed to broaden the transition. This suggests a rather high upper critical field for the superconducting transition at 29.2 K. The inset of Fig. 2 shows the enlarged view of the resistivity curve in low temperature region under zero field.

To further confirm the presence of bulk superconductivity in our sample, we also measured the magnetization of this sample using the ac susceptibility method. Temperature dependence of ac susceptibility measured with $H_{ac} = 0.1 \, \text{Oe}$ and $f = 333 \, \text{Hz}$ for the sample Sr$_4$Cr$_{0.8}$Ti$_{1.2}$O$_6$Fe$_2$As$_2$. The magnitude of the diamagnetic signal confirms the bulk superconductivity in this sample. The onset transition temperature was determined to be about 6 K from this figure, giving quite good agreement with the zero-resistance temperature obtained in Fig. 2.

![Graph showing temperature dependence of resistivity](image1)

**FIG. 2:** (Color online) Temperature dependence of resistivity for our sample Sr$_4$Cr$_{0.8}$Ti$_{1.2}$O$_6$Fe$_2$As$_2$ under two different fields 0 T and 9 T is shown in the main frame. The inset presents the enlarged view in the low temperature region under zero field. One can see a superconducting-like transition with the onset temperature of 29.2 K. Zero-resistance was observed below about 6 K.

![Graph showing ac susceptibility](image2)

**FIG. 3:** (Color online) Temperature dependence of the ac susceptibility measured with $H_{ac} = 0.1 \, \text{Oe}$ and $f = 333 \, \text{Hz}$ for the sample Sr$_4$Cr$_{0.8}$Ti$_{1.2}$O$_6$Fe$_2$As$_2$. The magnitude of the diamagnetic signal confirms the bulk superconductivity in this sample. The onset transition temperature was determined to be about 6 K from this figure, giving quite good agreement with the zero-resistance temperature obtained in Fig. 2.
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* Electronic address: hhwen@aphy.iphy.ac.cn

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