Superconductivity in iron-based F-doped layered quaternary compound Nd\([O_{1-x}F_x]FeAs\)

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The recently discovered quaternary arsenide oxide superconductor La\([O_{1-x}F_x]FeAs\) with the superconducting critical transition temperature \((T_c)\) of 26 K [1], has been quickly expanded to another high-\(T_c\) superconducting system beyond copper oxides by the replacement of La with other rare earth elements, such as Sm, Ce, and Pr etc. [2-4], and the Pr\([O_{1-x}F_x]FeAs\) has become to be the first non-cuprate superconductor that holding a \(T_c\) above 50 K. All these arsenide (including phosphide) superconductors formed in a same tetragonal layered structure with the space group \(P4/nmm\) which has an alternant stacked Fe-As layer and RO \((R = \text{rare earth metals})\) layer. Here we report the discovery of another superconductor in this system, the neodymium-arsenide Nd\([O_{1-x}F_x]FeAs\) with an resistivity onset \(T_c\) of 51.9 K, which is the second non-cuprate compound that superconducts above 50 K.

The superconducting Nd\([O_{1-x}F_x]FeAs\) samples were prepared by a high pressure synthesis method directly. Nd pieces, As, Fe, Fe\(_2\)O\(_3\), FeF\(_3\) powders (the purities of all starting chemicals are better than 99.99%) were mixed together according to the stoichiometric ratio of Nd\([O_{0.89}F_{0.11}]FeAs\), then ground thoroughly and pressed into small pellets. The pellets were sealed in boron nitride crucibles and sintered in a high pressure synthesis apparatus under a pressure of 6 GPa and temperature of 1300\(^\circ\)C for 2 hours. The structure of the samples was characterized by powder X-ray diffraction (XRD) analysis on an MXP18A-HF type diffractometer with Cu-\(K_{\alpha}\) radiation from 20° to 80° with a step of 0.01°.

The XRD patterns indicate that all samples include mixed multi-phases, while the main phase adopts the same PrOFeAs structure as shown in Fig. 1. The impurity phases have been determined to be known oxides, arsenides, and fluorides that formed by starting chemicals, which do not superconduct at the measuring temperature. The existence of impurity phases is due to the insufficient synthesis time that can be tolerated by our high-pressure apparatus. Compared with
the Pr[O$_{0.89}$F$_{0.11}$]FeAs superconductor, the right-shifted XRD peaks indicate a shrinkage of lattice parameters for this Nd[O$_{0.89}$F$_{0.11}$]FeAs superconductor.

The resistivity was measured by the standard four-probe method. The results are shown in Fig. 2. A clear resistivity drop can be observed as the temperature down to 51.9 K, and the resistivity becomes unmeasurable at 48.8 K. The middle of the superconducting transition is at 50.1 K. Compared with Pr[O$_{0.89}$F$_{0.11}$]FeAs superconductor, the $T_c$ (zero) increases about 5 K while the $T_c$ (onset) has no obvious change. Currently we believe that the chemical pressure caused by the shrinkage of crystal lattice promotes the increase of $T_c$ [5], which is indeed observed by our series of superconducting samples with different rare earth metal substitutions.

The magnetization measurements were performed on a Quantum Design MPMS XL-1 system during warming cycle under fixed magnetic field after zero field cooling (ZFC) or field cooling (FC) process. The AC-susceptibility data (with the measuring frequency of 997.3 Hz and the amplitude of 0.5 Oe) and DC-susceptibility data (measured under a magnetic field of 1 Oe) are shown in Fig. 3 (we note that the background is caused by magnetic impurities). The sharp magnetic transitions on both of AC and DC curves indicate the good quality of this superconducting component. The onset diamagnetic transition determined from the differential ZFC curve is 51 K, which is a little higher than that of Pr[O$_{0.89}$F$_{0.11}$]FeAs superconductor.

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References:

[1]. Kamihara Y., Watanabe T., Hirano M. and Hosono H. Iron-Based Layered Superconductor La[O$_{1-x}$F$_x$]FeAs$_x$ (x = 0.05-0.12) with $T_c$ = 26 K. J. Am. Chem. Soc. 130, 3296 (2008).


Figure captions:

Figure 1: X-ray powder diffraction pattern of the Nd[O$_{0.89}$F$_{0.11}$]FeAs superconductor compared with that of Pr[O$_{0.89}$F$_{0.11}$]FeAs superconductor; the arrows indicate the main phase diffraction peaks and the vertical bars correspond to the calculated diffraction intensities.

Figure 2: The temperature dependence of resistivity for the Nd[O$_{0.89}$F$_{0.11}$]FeAs superconductor.

Figure 3: The temperature dependence of AC-susceptibility, DC-susceptibility, and differential ZFC curve for the Nd[O$_{0.89}$F$_{0.11}$]FeAs superconductor.
Figure 1:
Figure 2: 

![Graph showing the resistivity ($\rho$) of Nd[O$_{0.89}$F$_{0.11}$]FeAs as a function of temperature (K). The inset shows a magnified view of the resistivity drop with the transition temperatures of 48.8K and 51.9K.]
Figure 3: