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Tunneling break-junction spectroscopy on the superconductor $NdFeAs(O_{0.9}F_{0.1})$

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ABSTRACT

Tunnel break-junction method has been adopted to study polycrystalline samples of iron-oxypnictide superconductor $NdFeAs(O_{0.9}F_{0.1})$ with $T_c = 48$ K. Measurements were carried out at 4.2 K. Break-junction (BJ) conductance *versus* voltage curves showed gap-edge peaks with the peak-to-peak distances $V_{p-p} = 4\Delta/e = 28–40$ mV at 4.2 K, where $2\Delta(T)$ is the superconducting energy gap, $e > 0$ is the elementary charge. This yields $2\Delta(0) = 14–20$ meV, so that the gap ratio $2\Delta(0)/k_BT_c$ is about 4.1 ± 0.7, k_B being the Boltzmann constant. This ratio implies strong-coupling superconductivity in the framework of Bardeen–Cooper–Schrieffer theory, being, however, much smaller than that for high-T_c copper oxides. This suggests a significant difference in the pairing mechanism between those classes of materials.

A discovery of iron-oxypnictide superconductors with their maximum critical temperature T_c of about 50 K [1,2] constitutes one of the great achievements in the superconductivity science after the finding of MgB_2 [3]. High-T_c superconductivity is induced in metallic FeAs layers due to extra itinerant electrons donated by fluorine ions form adjacent charge reservoir layers [4]. In the NdFeAsO compound, high T_c superconductivity also appears when oxygen is partially replaced by fluorine [2]. Since the layered crystal structure of those new compounds is in some sense similar to that of cuprates, and T_c is very high as compared to any material other than copper oxides, it is instructive to elucidate, whether the superconductivity mechanism in iron oxypnictides is the same as in cuprates. To gain insight into this problem, it is natural to measure superconducting energy gaps, the depth, width and form of which are intimately related to the peculiarities of the Cooper pairing.

In this paper, we present the results of electron-tunneling measurements directly probing the superconducting gap in $NdFeAs(O_{0.9}F_{0.1})$ with $T_c = 48$ K. A polycrystalline sample was synthesized by heating the mixture of starting material powders in a sealed SiO_2 tube filled with Ar gas at 1523 K during 40 h [1]. Tunneling was carried out using a break-junction, BJ, method, in which the platelet sample was *in situ* cracked at 4.2 K to form a tunnel junction [5].

Fig. 1 shows the temperature, T, dependences of the magnetic susceptibility, χ, and electrical resistance, R, for $NdFeAs(O_{0.9}F_{0.1})$. Superconductivity is resistively detected; the onset being observed at 52 K. χ starts to decrease below 48 K, when the resistance is already zero. The superconducting volume fraction at 5 K is 20% estimated from the observed diamagnetic signal during the field-cooled process with the applied magnetic field of 10 Oe.

In Fig. 2 the BJ tunnel conductance, dI/dV, curves are displayed against bias-voltage, V, for the same material as in Fig. 1 at $T = 4.2$ K. We have measured several different BJs made of samples from the same batch. Conductance curves shown here are the most representative ones. The background junction resistance is 60–150 Ohms at high bias-voltages ±(50 mV). Clear-cut dI/dV peaks are observed corresponding to the increase of electron density of states (DOS) at the gap edges. The gap structures are quite symmetric with respect to V except for the top curve exhibiting a weak asymmetry. In the BJ design, superconductor insulator superconductor (SIS) junctions are formed. In this case, very strong gap-edge peaks and well-depressed intra-gap floor should be observed because dI/dV is a convolution of two singular superconducting DOSes. However, in the present series of measurements, the slope changes of the current–voltage characteristics in the gap region monitored *in situ* by fast oscilloscope traces turned out to be very weak in almost all cases except for the top curve, which resulted in rather weak gap-edge peaks and shallow dips in the intra-gap conductances. For the three curves from the bottom in Fig. 2, the total variation of dI/dV constitutes 12–14% of the background value, and the depth of the gap being 6–7% of the high-voltage level. Such surprisingly faint gap features seem to be in contrast with a conspicuous bulk superconducting fraction. One of the plausible reasons for this controversy may be a contamination by SiO_2 used as

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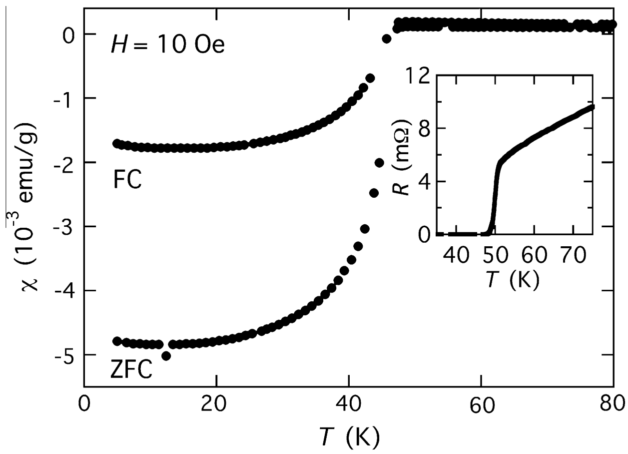

Fig. 1. Temperature, T, dependence of the magnetic susceptibility, χ, for NdFeAs($O_{0.9}F_{0.1}$) measured in field-cooled (FC) and zero-field cooled (ZFC) processes. Inset shows the T dependence of the electrical resistance R.

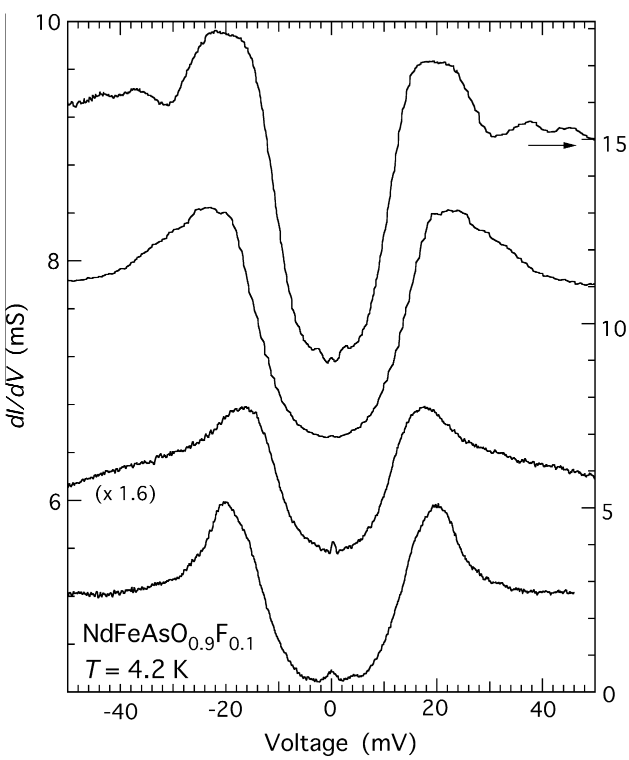

Fig. 2. Tunnel conductance, dI/dV, for NdFeAs($O_{0.9}F_{0.1}$) for several break junctions, BJ, at $T = 4.2$ K.

a sealing synthesis tube. Hence, small amounts of SiO_2 would be distributed along grain boundaries, covering the grain interfaces during the synthesis. A subsequent breaking of those grain boundaries may form contaminated junctions. Despite the problems concerned, the obtained curves dI/dV are quite smooth and involve superconducting features, which are worthy of consideration. For SIS junctions, including BJ ones, the conductance peak-to-peak distance V_{p-p} corresponds to $4\Delta/e$. To be specific, the coherent peaks occurring at ±14—20 mV in Fig. 2 should be identified as $\pm 2\Delta/e$, the gap value being $2\Delta = 14$—20 meV. Note, that the most characteristic top curve in Fig. 2, in which the total variation and the gap depth are 53—60% and 40% of the background, respectively, possesses extra subtle depressive structures at ±40—50 mV. Their nature will be a subject of future studies (cf. [6]).

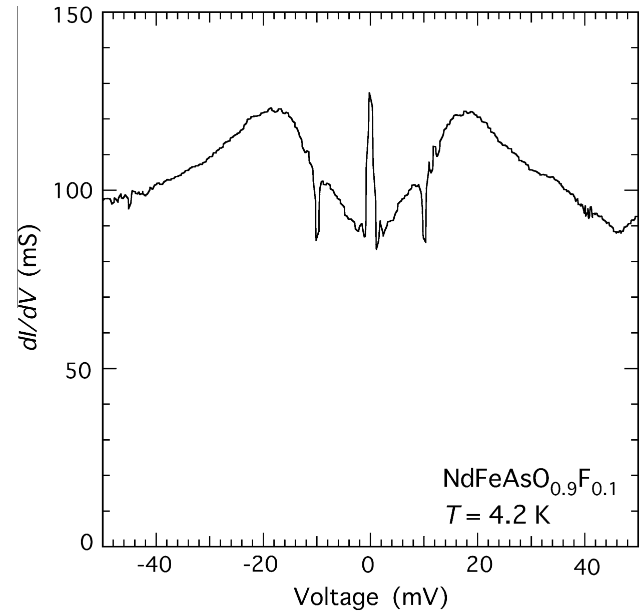

Fig. 3. The same as in Fig. 2 but after aging in He vapor atmosphere.

Fig. 3 demonstrates the aging effect of the BJ design. This dependence was obtained after exposing BJ, described as a second curve from the top of Fig. 2, to *in situ* He vapor atmosphere at 200 K for 12 h. New features include a zero-bias Josephson peak and a sharp dip at ±10 mV, leaving intact the original gap-edge peaks at ±20 mV (Fig. 2). Such peculiarities were not observed for freshly prepared junctions. At the same time, Fig. 3 conclusively confirms that the gap structures in Fig. 2 correspond to 4Δ for the SIS design.

To summarize, our tunnel measurements showed that the superconducting gap in NdFeAs($O_{0.9}F_{0.1}$) with $T_c = 48$ K is $2\Delta = 14$—20 meV. The obtained ratio $2\Delta(0)/k_BT_c = 4.1 \pm 0.7$ points to the existence of strong-coupling effects in superconductivity of this material. Nevertheless, this ratio is much smaller than that for a copper-oxide superconductor with a similar $T_c = 30$—40 K [7], which might reflect the difference in the pairing nature.

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