Tunneling measurements of $Nd_{1.85}Ce_{0.15}CuO_x$

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Tunneling spectroscopy measurements have been carried out on the electron-doped oxide superconductor $Nd_{1.85}Ce_{0.15}CuO_x$. Surfaces of a polycrystalline bulk sample of the compound were probed at low temperatures by a point-contact technique using Al as the counterelectrode. The differential conductance curve taken of the junctions exhibited a relatively well-pronounced gaplike structure near 5 mV at temperatures from 4.2 up to about 15 K. Taking the peak of the structure with the estimated T_c of the dominant phase of the sample, we obtain the reduced energy gap $2\Delta(0)/k_BT_c$ of 5.5 ± 1.2, which is consistent with values we have obtained previously from the hole-doped oxide superconductors.

The recent discovery of the electron-doped oxide superconductors[1] has once again opened a new page in the ongoing research in the high-temperature superconductors. The immediate and urgent question addressed here is whether (and how) this new system of superconductors exhibit different superconducting properties from the hole-doped high-T_c oxide superconductors. In this Brief Report, we present our result of tunneling measurements on a polycrystal bulk sample of the electron-doped oxide superconductor, $Nd_{1.85}Ce_{0.15}CuO_x$. The superconductive energy gap of the system is studied.

The polycrystalline bulk material was synthesized from metal oxides Nd_2O_3, CeO_2, and CuO. The pressed pellet of the mixture was first sintered in a stream of O_2 at 1050 °C for 10 h. Then the sample was further annealed in Ar atmosphere at 800 °C for 8 h during which period the compound underwent the reduction process. Afterward it was again annealed in O_2 at 400 °C for 4 h. Under these conditions, the grains grew on the average to the size of 1 μm. As can be seen in Fig. 1, the resistive transition of the sample has the $T_{c\,\mathrm{onset}}$ of 22.5 K and it shows a long tail which persists down to about 13.5 K, strongly reflecting the nonsingle phaselike nature of our sample. A simple inductance method was used to study the ac diamagnetism of the sample, where the onset of the diamagnetism of a sample placed inside a coil is monitored by the change in the self-inductance of the system. The result is shown in Fig. 1 as $\Delta L/L$. The total change in susceptibility here roughly corresponds to half the total volume of the sample. Assuming a symmetrical distribution of the T_c's of the material, the midpoint of this transition should reflect the most dominant phase of the sample at low temperatures. Taking the width of this transition as the uncertainty, we have the transition temperature $T_c = 20 \pm 4$ K.

The natural surface of the sample was brought to contact an Al counter-electrode in a cryogenic environment, which had the tip area on the order of 0.01 mm^2, and the junction impedance was varied manually and continuously from > 1 MΩ down to ~ 100 Ω, while differential conductance characteristics were monitored. This method appears to give successful and reliable data in that when Pb is used as the counter-electrode, its gap structure is consistently observed reflecting the adequacy of the formed tunneling barrier (and also the existence of some normal domains on the face of the sample).[2,3]

Figure 2 shows a typical set of differential conductance curves taken of a junction when the temperature was varied. The junctions were relatively stable mechanically, and rarely were we required to readjust the junction pressure even when the temperature was varied. Nonlinearities on the I-V characteristics were marginally observable even though there probably existed some linear leakage current. The curves in Fig. 2 are reasonably symmetrical, and they show a clear deflection with an accompanying gaplike rounding structure at voltage near 5 mV. The structure exhibits a broadening which steadily increases with increasing temperature, and at around 14 K, the smooth background is revealed. This broadened nature of the peak structures prevented us from closely monitoring the expected shift in the position of the structure at higher temperatures. The main broadening mechanism here probably lies in the fact that we are using a counter-electrode with a relatively large tip area to probe a poly-

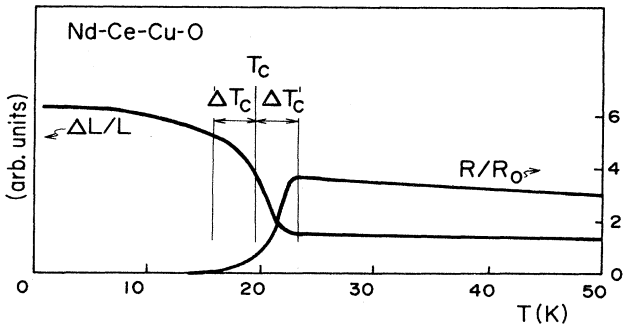

FIG. 1. Resistive and magnetic transition curves of our sample of $Nd_{1.85}Ce_{0.15}CuO_x$.

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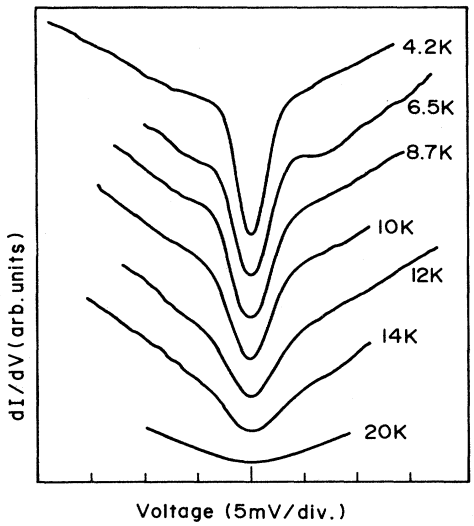

FIG. 2. Temperature dependence of a typical differential conductance curve of a Nd-Ce-Cu-O/Al junction.

crystal surface, which naturally consists of anisotropic grains of random orientations and local domains of T_c variations. The resulting characteristic is inevitably the overall average of the probed surface area under study. In such junctions, the broadening of the peak structures could be attributed to the plausible existence of the anisotropy in the gap energy[2,4] and the wide spread in the transition temperature observed in the sample. In fact, the polycrystal samples and epitaxial film samples showed distinctly different degrees of sharpness in the gap structures (Fig. 2 of Ref. 4).

From a typical peak value of the rounded gaplike structure (from the curve of 6 K in Fig. 2), the energy gap is estimated to be $\Delta(0) = 4.75 \pm 0.5$ meV. Assuming that the T_c of the dominant phase of the sample represents the surface layer material examined in tunneling, we combine this with the above T_c estimate and arrive at the ratio $2\Delta(0)/k_B T_c = 5.5 \pm 1.2$. The uncertainty is large, but the value agrees with our previous measurements on other copper oxide superconductors, which gave 6.0 ± 0.2 for thin films of Y-Ba-Cu-O and Bi-Sr-Ca-Cu-O in the direction of the c plane[2] and 6.1 ± 0.5 for polycrystalline Y-Ba-Cu-O and two compositions (2:2:1:2 and 2:2:2:3) of Tl-Ba-Ca-Cu-O compounds.[4] In order to account for the broadened gap structure such as the ones seen in Fig. 2, many models have been proposed to date. Based on models of anisotropic superconductors, several authors have shown that the diffusive tunneling conductance characteristics would peak at the maximum gap values.[5,6] Others have used different models and schemes to fit in interpreting their differential conductance data to deduce the energy-gap values.[7,8] The results of these seem to place the gap value at slightly smaller voltage points than the peak values of the structures. Ekino and Akimitsu have recently performed a tunneling measurement on a Nd-Ce-Cu-O sample, and deduced the reduced gap according to one such model from their conductance curves to be 5.2–5.5.[9] The uncertainty in the T_c was quite large in our experiment which obscured the difference in Δ deduced by various methods.

In conclusion, we have studied tunneling characteristics of a polycrystalline sample of the electron-doped oxide superconductor Nd-Ce-Cu-O. From the peak of a gaplike structure observed on the differential conductance curve and the T_c deduced from the magnetic transition of the sample, we calculate the estimated reduced energy gap $2\Delta(0)/k_B T_c = 5.5 \pm 1.2$, which is in agreement with our previous measurements on other copper oxide superconductors.

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