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Temperature Dependence of the Penetration Depth in $YBa_2Cu_3O_{7-\delta}$ Measured by Microwave Ring Resonators

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$YBa_2Cu_3O_{7-\delta}$(YBCO) superconducting ring resonators with a YBCO ground plane were fabricated using double-side YBCO films deposited on $LaAlO_3$ (LAO) substrates. The temperature dependent London penetration depth, $\Delta\lambda = \lambda(T)-\lambda(5K)$, was systematically studied by varying the oxygen content of the same resonator structure. For fully oxygenated condition ($\delta = 0.05$), the resonator exhibits a quality factor $Q > 10^4$ at 16K, and $\Delta\lambda(T)$ displays a linear behavior over a wide range of temperatures. With increasing δ (e.g. $\delta = 0.2$), although $\Delta\lambda$ is still linear in temperature, the slope changes by more than a factor of 2. As δ is further increased, $\Delta\lambda(T)$ changes from T- to T^2-dependence. The results suggest that in the underdoped regime, the incoherent scattering of charged carriers may become increasingly prominent.

1. INTRODUCTION

Microstrip circuits made of high-T_c superconductors (HTS) have become important realistic applications of these materials. In addition to their superior performance as microwave devices, these structures are also playing important roles for investigating some of the fundamental properties of HTS materials at high frequencies.

In this study, the penetration depth of YBCO films is measured by using high-Q ring oscillators made of double-sided YBCO films. The ring structure has the advantage of minimizing the edge effects commonly suffered in stripline structures. By controlling the oxygen content in a reversible manner over the same oscillator, the effect of the pseudogap opening on the temperature dependent behavior of penetration depth, $\Delta\lambda = \lambda(T)-\lambda(5K)$ is revealed.

2. EXPERIMENTAL

The YBCO thin films were deposited epitaxially on both sides of a 0.5 mm thick $LaAlO_3$ substrate by pulsed laser deposition. The substrate temperature was kept at 830 ^{0}C, with an oxygen partial pressure of 280 mTorr during the deposition. The as-deposited films were all c-axis oriented, with a typical thickness of 500 nm and T_c of 90 K. One side of the YBCO film was then patterned into a ring oscillator. The line width and the outer radius of the ring are 0.5 mm and 3.625 mm, respectively. The coupling level between the microstrip feeding line and resonator [1] is about 0.4 mm.

The desired oxygen content of the YBCO film [2] was obtained by varying the oxygen pressure and the corresponding temperature according to the pressure-temperature phase diagram [3].

The temperature dependence of the resonance frequency f(T), frequency shifts Δf(T) and the forward transmission coefficient S_{21} were measured by a HP8510C microwave vector network analyzer at about 3.6 GHz.

3. RESULTS AND DISCUSSION

Figure 1 shows the temperature dependence of resonance frequency f(T) of the same ring oscillator for $\delta = 0.05$, 0.2 and 0.4, respectively. By analyzing the frequency shift as a function of temperature, the temperature dependence of the London penetration depth was extracted by expressing the surface impedance in the local limit, $Z_s = R_s + iX_s$. Here R_s is the residual surface resistance originated from various surface defects and X_s is the reactance reflecting the nondissipative energy stored in the superconductor. In the local limit, where $X_s >> R_s$, the change in penetration depth $\Delta\lambda(T)$ defined as

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$\Delta\lambda(T) \equiv \lambda(T)-\lambda(T_0)$, can be expressed as $\Delta\lambda(T) = [X_s(T)-X_s(T_0)]/\omega\mu_0$. We took T_0 = 5 K for simplicity.

Figure 2 shows $\Delta\lambda(T)$ as a function of oxygen content. As can be seen for $\delta = 0.05$, $\Delta\lambda(T)$ extends over almost entire temperature range measured. It is suggestive that, within the scenario of d-wave pairing, a line node feature can persist to temperatures near T_c. We also note that the slope of $\Delta\lambda(T)$ (see the inset of Figure 2) is very close to that found in pure YBCO single crystals [4, 5]. By reducing the oxygen stoichiometry to $\delta = 0.2$, although the transition temperature T_c ($T_c \approx 83$ K in this case), and the quality factor are degraded by some extent, $\Delta\lambda(T)$ is still linear in temperature, except that the slope changes by a factor of 2 or so. It is suggestive that the characteristic of d-wave symmetry pairing did not change significantly with moderate changes in reducing hole concentration. However, at $\delta = 0.4$, the behavior of $\Delta\lambda(T)$ has changed from T- to T^2-dependence. Within the same d-wave pairing scenario, a large suppression of T_c due to tremendous increase in defect level will be required to produce a T^2-dependence in $\Delta\lambda(T)$ [5]. We argue that this is unlikely in the present case, since the oxygen controlling process is completely reversible [3], indicating no microstructure changes other than oxygen content was occurring during the process. On the other hand, the results may be due to the opening of pseudogap in the underdoped regime, which is known to enhance the inelastic scattering of carriers, in addition to reducing its density, significantly [6].

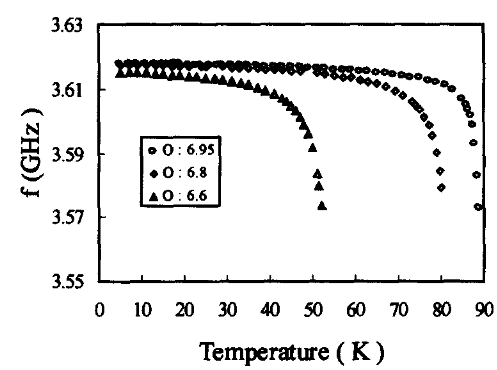

Figure 1. The temperature dependence of resonate frequency f(T) of the same ring oscillator for δ = 0.05, 0.2 and 0.4, respectively.

The temperature dependence of the London penetration depth in YBCO as a function of oxygen content was studied by using superconducting ring resonators. The result indicates that d-wave pairing symmetry alone maybe inadequate to account for the apparent changes in the temperature dependence of $\Delta\lambda(T)$.

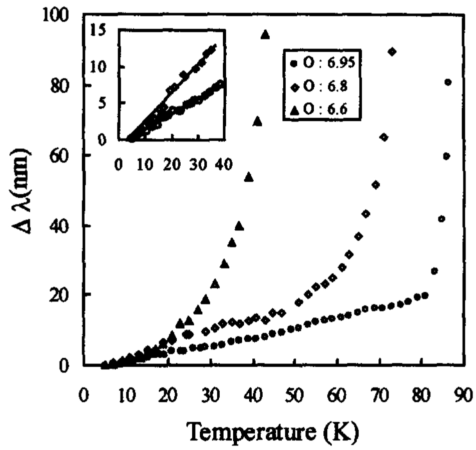

Figure 2. The temperature dependence of the $\Delta\lambda(T)$ as a functon of oxygen content. The inset shows the linear temperature dependence of the $\Delta\lambda(T)$ with a slope of 2.1 Å/K and 4.5 Å/K at δ = 0.05 and 0.2, respectively.

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