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High-Q $YBa_2Cu_3O_{7-\delta}$ microwave ring oscillators

H.K. Zeng, K.H. Wu, J.Y. Juang, T.M. Uen, Y.S. Gou*

Department of Electrophysics, National Chiao-Tung University, Hsinchu, Taiwan, Republic of China

Abstract

$YBa_2Cu_3O_{7-\delta}$(YBCO) superconducting ring resonators with YBCO ground plane were fabricated. The resonators exhibit a high quality ($Q > 10^4$) at 16 K, indicating high potential for applications. In addition, from the analyses of the surface resistance $R_s(T)$ and reactance $X_s(T)$, it was found that the derived London penetration depth $\lambda(T) - \lambda(5\ \text{K})$ displays a linear behavior over a wide range of temperatures. The results suggest that a distinct line node feature in the gap function of a d-wave pairing superconductor may extend to temperatures higher than previously reported.

Keywords: Microwave; Quality factor; Ring resonator; YBCO

One of the first realized practical applications of high temperature superconductor (HTS) are passive microwave devices [1]. However, the microstrips commonly used in HTS microwave circuits, though superior in performance over their normal metal counterparts, have suffered from nonuniform current distributions at the edges. The microwave ring oscillators are considered to have minimum edge effects. In this study, we demonstrate that ring oscillators with very low microwave insertion loss and very high quality factor (Q) are, indeed, attainable by using double-sided HTS films. The device also serves as an accurate tool in determining fundamental physical parameters such as the London penetration depth $\lambda(T)$.

The YBCO thin films were deposited epitaxially on both sides of a 0.5 mm thick $LaAlO_3$ substrate by pulsed laser deposition [2]. The substrate temperature was kept at 830°C with an oxygen partial pressure of 280 mTorr during the deposition. Both films were c-axis oriented, with thickness of 500 nm and $T_c = 90$ K. One of the thin films was patterned into a ring-shaped microstrip line, as shown in Fig. 1.

The temperature dependence of the resonance frequency $f_i(T)$, $\Delta f_i(T)$ and the unloaded quality factor $Q_i(T)$ were measured by a HP8510C microwave vector network analyzer operated at 3.6 GHz. $Q_i(T)$ is obtained as $Q_i(T) = f_i/[(1 - S_{21})\Delta f_i]$, and S_{21} is forward transmission coefficient.

The temperature dependence of the real and imaginary parts of the surface impedance, $Z_s = R_s + iX_s$, were then determined with the aid of the following equations: $R_s = \Gamma_s Q_i$ and $X_s = 2\Gamma_s \Delta f_i/f_i$, respectively. Here $\Gamma_s(\approx \pi\mu_0 d f_i)$ is a geometrical form factor and d is thickness of the dielectric spacer [3]. The fact that $X_s \gg R_s$, indicates the nonlocal characteristic of the system and allows one to determine the change in penetration depth $\lambda(T)$ as $\lambda(T) - \lambda(T_0) = [X_s(T) - X_s(T_0)]/\mu_0\omega$, where we take $T_0 = 5$ K.

Fig. 2 shows the temperature dependence of the quality factor of a ring oscillator. The result displays two distinct features. Namely, $Q_i(T)$ shows a linear temperature dependence for $T < 80$ K and a precipitous drop for $T > 80$ K. Furthermore, the quality factor reaches a value over 10^4 at the lowest temperatures, which is compatible with the best microstrip resonators [4]. In Fig. 3, the linear temperature dependence of the $\Delta\lambda(T) = \lambda(T) - \lambda(5\ \text{K})$ with a slope of 2.1 Å/K extends over almost the 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 $\Delta\lambda(T)$ is very close to that found in pure YBCO single crystals [5,6].

In summary, we have fabricated ring-shaped microstrip resonators of HTS YBCO films with very high quality factors. These devices are expected to have great

* Corresponding author.
E-mail address: ysgou@cc.nctu.edu.tw (Y.S. Gou)

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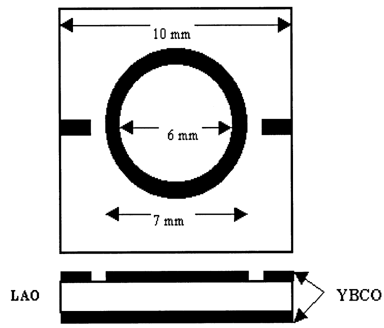

Fig. 1. The ring-shaped microstrip resonator adopted for surface impedance measurements on YBCO thin film.

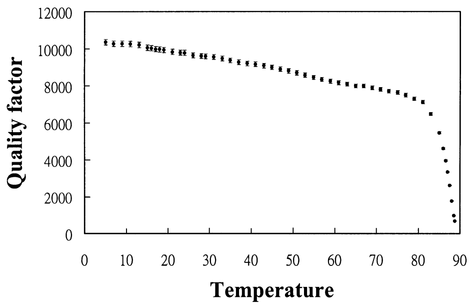

Fig. 2. Temperature dependence of the quality factor for a ring-shaped YBCO thin-film resonator.

potential for microwave applications. From the surface resistance analyses the linear temperature-dependence of London penetration depth was observed almost over the whole investigated temperature range. The result indi-

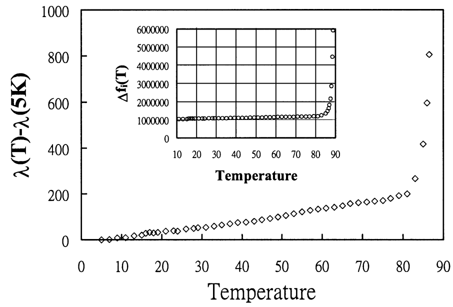

Fig. 3. Temperature dependence of $\lambda(T) - \lambda(5\ \mathrm{K})$ for YBCO thin film. The inset shows the temperature dependence of the $\Delta f_i(T)$.

cates that d-wave pairing symmetry in HTS may persist up to temperatures near T_c.

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