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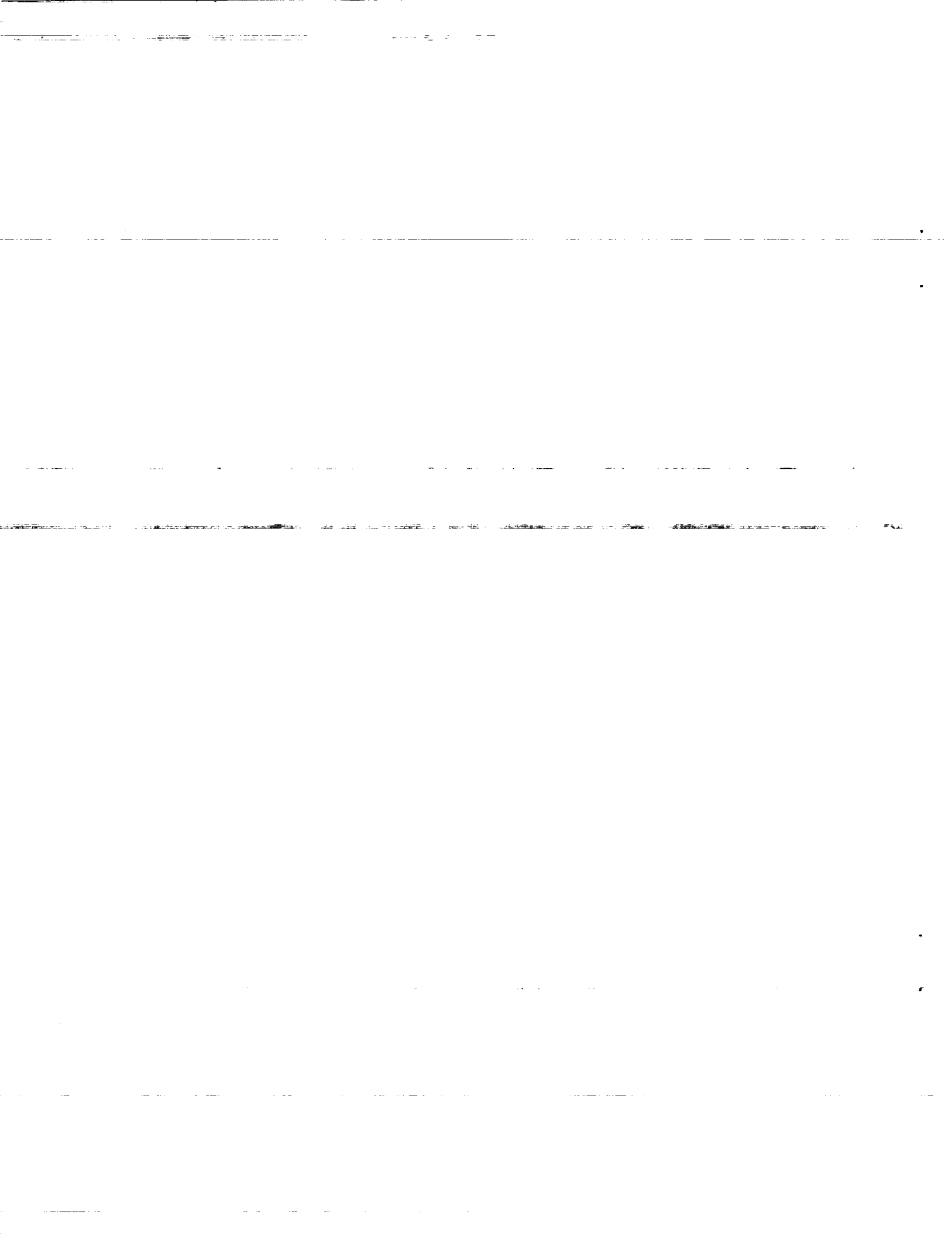


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CONDUCTOR-BACKED COPLANAR WAVEGUIDE RESONATORS OF Y-Ba-Cu-O AND Tl-Ba-Ca-Cu-O ON LaAlO_3

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Abstract--Conductor-backed coplanar waveguide (CBCPW) resonators operating at 10.8 GHz have been fabricated from Tl-Ba-Ca-Cu-O (TBCCO) and Y-Ba-Cu-O (YBCO) thin films on LaAlO_3 . The resonators consist of a coplanar waveguide (CPW) patterned on the superconducting film side of the LaAlO_3 substrate with a gold ground plane coated on the opposite side. These resonators were tested in the temperature range from 14 to 106 K. At 77 K, the best of our TBCCO and YBCO resonators have an unloaded quality factor (Q_u) 7 and 4 times, respectively, larger than that of a similar all-gold resonator. In this study, the Q_u 's of the TBCCO resonators were larger than those of their YBCO counterparts throughout the aforementioned temperature range.

I. INTRODUCTION

Since their discovery in 1986, high transition temperature superconducting (HTS) compounds have been employed in the development of passive microwave transmission structures such as resonators, filters, and delay lines [1-3]. Ease of fabrication and performance reliability are two requirements that these HTS compounds should meet in order to be used in microwave circuits. Because of its geometrical attribute of having the ground planes on the same surface as the signal transmission line, coplanar waveguide (CPW) structures are advantageous for HTS-based microwave integrated circuits. When a good conducting layer is deposited on the opposite side of the CPW supporting substrate the structure is known as a conductor-backed coplanar waveguide (CBCPW).

Recently, reports on YBCO-based CPW and CBCPW resonators have been published [4-7]. Until now, a comparative study to determine which type of HTS compound is more appropriate for the optimization of these structures for micro-

wave applications has not been done. In this paper we present our results on the performance of CBCPW resonators fabricated from TBCCO and YBCO thin films on LaAlO_3 .

II. EXPERIMENTAL

Figure 1 shows a schematic representation of the CBCPW resonators analyzed in this study. The TBCCO resonators were custom made by Superconductor Technologies Inc. from laser ablated films (~800 nm thick) deposited onto $1.0 \times 1.0 \times 0.05$ cm (100) LaAlO_3 substrates. The YBCO resonators were patterned by us on laser ablated (NASA-Lewis) and magnetron sputtered (Conductus Inc.) thin films (~350 nm) on LaAlO_3 substrates of the aforementioned dimensions and crystallographic orientation. The pattern shown in Fig. 1 was transferred to the HTS films using standard photolithography techniques followed by a "back-etching" process using a 1% phosphoric acid (H_3PO_4) solution. The ground plane on the opposite side of the substrate was formed by successive evaporations of a 150 Å thick chromium layer and a ~2.5 μm thick gold layer. A similar all-gold CBCPW resonator, with its CPW layer ~1.2 μm thick, was also fabricated for comparison purposes. The testing of the resonators was done by mounting them on a brass test fixture bolted to the cold finger of a closed-cycle-helium-gas refrigerator and enclosed inside a vacuum can with feedthroughs to allow coupling between the resonator and a coaxial waveguide. The coupling between the coaxial line and the resonators was achieved through an SMA launcher. The center pin of the connector was placed in direct contact with the feed line that tapered from 0.559 mm to the width of the center conductor over a length (L1) of 1.000 mm. Coupling to the resonator was achieved across a gap (G1) 0.050 mm wide. The reflection coefficient of the resonators was measured using an HP-8510C network analyzer, and was used

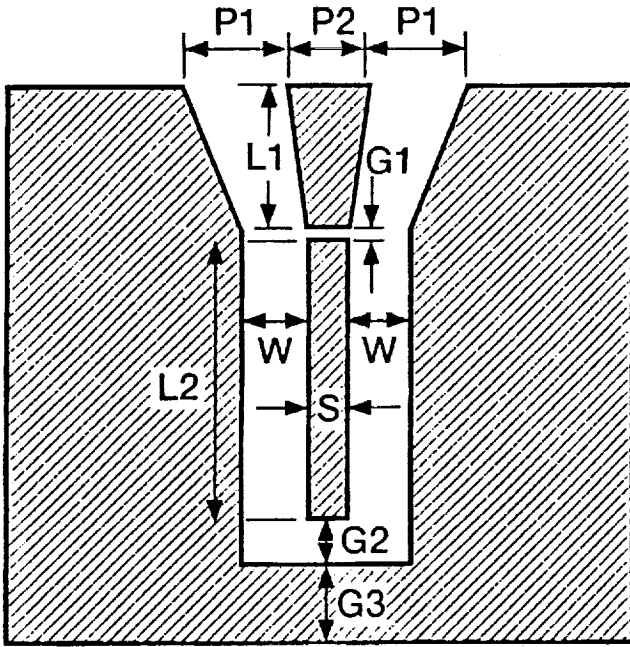


Fig. 1 Top view of the conductor-backed coplanar waveguide resonator (9.230x9.230 mm). $P1=0.533$ mm, $P2=0.559$ mm, $L1=1.000$ mm, $L2=7.020$ mm. $W=0.530$ mm, $S=0.200$ mm, $G1=0.050$ mm, $G2=0.530$ mm, and $G3=0.630$ mm. The relative dielectric constant (ϵ_r) of the substrate is 22. The crosshatched sections represent the HTS material.

to determine the unloaded quality factor (Q_u) of the resonator according to the procedure described in [8]. Before the beginning of each measurement cycle the network analyzer was calibrated with short, open, and load standards.

In order to improve the contact between the launcher and the feed line, silver contacts (~250-300 nm thick) were evaporated onto the end of the feed line and the coplanar ground planes. Immediately after the evaporation the resonators were annealed in flowing oxygen (~1 SLM). The YBCO resonators were annealed at 450°C for 1 hr, and cooled afterwards at a rate of 2°C/min to room temperature. The TBCCO resonators were annealed at 450°C for 10 min, followed by a rapid cooling on a fire brick. The contact resistivity was measured by a three-point probe method, and was found to be $\sim 2.7 \times 10^{-6}$, 9.0×10^{-8} , and 4.5×10^{-9} Ωcm^2 for the laser ablated YBCO, the magnetron sputtered YBCO, and the TBCCO films, respectively. The transition temperature ($T_c(R=0)$) of the resonators was measured before and after silver contacts deposition and annealing using a standard four-point probe technique.

III. RESULTS

Table I shows a summary of the results of the characterization of the CBCPW resonators. The T_c values and film thicknesses correspond to measurements performed after patterning and annealing of the films. The Q_u 's versus temperature of the resonators analyzed in this work are shown in Fig.2.

Table I. Properties of Conductor-Backed Coplanar Waveguide Resonators at 77·K.

Sample	Film Thickness (nm)	T_c (K) ^a	Q_u ^b	R_s (m Ω) ^c	f_{01} (GHz) ^d
Au	1200		110	24.0	10.803
1 (YBCO)	310	84.0	159	16.6	10.662
2 (YBCO)	350	91.1	412	6.4	10.805
3 (YBCO)	350	89.9	470	5.6	10.755
4 (TBCCO)	800	103.5	471	5.6	10.742
5 (TBCCO)	800	103.0	577	4.6	10.750
6 (TBCCO)	800	104.2	823	3.2	10.680

^a dc transition temperature after patterning and annealing.

^b Unloaded quality factor.

^c Effective surface resistance.

^d Resonance frequency.

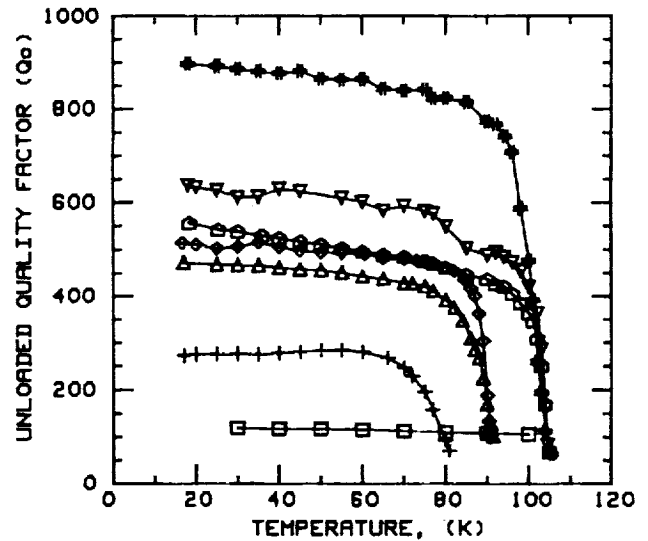


Fig. 2 Unloaded quality factor (Q_u) versus temperature for CBCPW resonators on LaAlO_3 . Sample 1 (LA YBCO, +), sample 2 (LA YBCO, Δ), sample 3 (MS YBCO, \diamond), sample 4 (LA TBCCO, \triangle), sample 5 (LA TBCCO, ∇), and sample 6 (LA TBCCO, $\frac{1}{2}$). A Au resonator (\square) is also shown for comparison.

These data were found to be independent of applied power within the range of -5.0 to -26.0 dBm. The lowest Q_u observed in this study for any of the HTS resonator corresponded to a laser ablated (LA) YBCO film (sample 1, Tab. I). This film exhibited a $T_c=84$ K after annealing, and although Scanning Electron Microscopy (SEM) micrographs showed a smooth surface, some porosity was noticeable on one of the coplanar ground planes which gave it a hazy appearance. A very smooth surface was also observed for YBCO sample 2, also laser ablated, but not for YBCO sample 3 (magnetron sputtered, MS) which exhibits outgrowths on its surface ranging in size from 1-3 μm . Note that in spite of their different surface morphologies, the Q_u 's of these

two resonators were comparable which shows that surface roughness does not necessarily equate to a poorer microwave performance, at least for YBCO thin films deposited by the two techniques considered here. This is consistent with microwave results obtained by power transmission measurements in the same type of YBCO thin films [9]. The highest Q_0 's amongst the YBCO resonators were exhibited by sample 3. Its Q_0 at 77 K was 470 which is ~ 4.3 times better than that of the gold resonator at the same frequency and temperature. This value is lower than reported Q_0 's for YBCO-based CPW resonator at the same temperature and at frequencies close to 10 GHz [6]. The lower Q_0 may be due to the effect of adding a back conductor to the CPW structure. However, direct comparison between different resonant structures should be done cautiously due to the differences in their geometrical configuration. X-ray diffraction (XRD) analysis showed that the YBCO films considered here have a crystallographic orientation where the c-axis is predominantly oriented perpendicular to the substrate plane. No evidence of change in the XRD patterns was observed for these films after the annealing process.

The TBCCO resonators shown in Table 1. are representative of two different deposition batches, with samples 4 and 5 originating from the same batch and sample 6 from a separate batch. From Fig. 2 it can be seen that the Q_0 's for the TBCCO resonators were larger than those obtained for their YBCO counterparts. For the best TBCCO resonator (sample 6, Fig. 2) a Q_0 of 823 was obtained at 77 K. This value is ~ 7.4 times that of the gold resonator and is ~ 1.75 times larger than the Q_0 of our best YBCO resonator. It was observed that after the annealing the Q_0 's of the resonators increased (almost by a factor of 2 for sample 6) with respect to those obtained before the annealing. The enhanced Q_0 's can be correlated with an increase in oxygen content in the films as reflected by the rise in T_c with respect to that measured before the annealing process. For the YBCO films this increase was ~ 1.0 - 1.3 K while for the TBCCO films it was ~ 2.0 - 3.0 K. Observe that for the YBCO resonators (especially for the two laser ablated ones) the discrepancies in Q_0 's are well correlated with their T_c values. However, for the TBCCO resonators, although the difference between their T_c values after the annealing was less than 1.3 K, and the temperature at which a measurable resonance was first observed was almost the same (~ 105 K), still there was a large discrepancy between their respective Q_0 's. This difference can be associated with the morphology of the films. The XRD patterns contain only the (00 l) reflections for both the 2212 and the 2223 phases. Based upon the relative peak intensities it appears that the films are similar in composition and composed primarily of the 2212 phase. However, SEM analysis revealed that samples 4 and 5 are characterized by a "terrace-like" surface morphology which is absent in sample 6. As such, we believe that the effective thickness of sample 4 and 5 is less than that of sample 6 and thus is responsible for their lower Q_0 's.

The effective surface resistance (R_s) for the YBCO and TBCCO HTS films was determined from the unloaded quality factor [10]. The surface resistance of the all-gold resonator was determined from measurements of the dc resistivity (ρ) and using the expression $R_{s,Au} = (\mu_0 \omega \rho / 2)^{1/2}$, where μ_0 is the permeability of free space and $\omega = 2\pi f$, where f is the frequency. Values of R_s at 77 K for the HTS-based and all-Au based CBCPW resonators are shown in Tab. 1. Note that the lowest R_s for YBCO is ~ 0.25 of that for Au, and compares well with those reported by others [6,10] if we assume that the R_s of the superconductor is proportional to the square of the frequency. For TBCCO, our lowest R_s is ~ 0.13 of that for Au. However, the R_s values obtained in this study for our best TBCCO resonator is ~ 6 times larger than the value obtained by others from ring resonators fabricated on films from the same source as ours ($R_s \sim 6$ m Ω at 35 GHz and 77 K; $R_s \sim 0.5$ m Ω at 10 GHz and 77 K, assuming a $R_s \propto f^2$) [1]. This may be explained in terms of the current distribution in the conductors of the resonator. In the CPW section of the CBCPW resonator the currents are concentrated near the edges of both the center conductor and the ground planes. Therefore this structure is more sensitive to defects at the edges of the conductors that may arise during the patterning process, resulting in an increase in R_s [11].

IV. CONCLUSIONS

Conductor-backed coplanar waveguide resonators have been patterned on YBCO and TBCCO HTS thin films on LaAlO_3 . These resonators were tested in the temperature range from 14 to 106 K. Unloaded quality factors Q_0 as high as 823 and 470 were obtained at 77 K and 10.8 GHz for TBCCO and YBCO resonators, respectively. The highest Q_0 's at 77 K for the TBCCO and YBCO resonators were nearly a factor of 7 and 4, respectively, better than that of an all-gold resonator of the same geometry at the same temperature and frequency. In this study, the Q_0 's of the TBCCO resonators were larger than those of their YBCO counterparts throughout the aforementioned temperature range. Our results support the observation that a high T_c does not always correlate with a good microwave performance. In addition, they suggest that the TBCCO films may be the material of choice for cryogenic microwave applications given the fact that there is still room for improvement of aspects such as the porosity of the films. However, more work is necessary to correlate Q_0 with porosity for films having similar T_c 's.

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