HIGH-T_c SUPERCONDUCTING HIGH-Q COPLANAR RESONATOR MADE ON MgO

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ABSTRACT

Coplanar 2-port transmission line resonators were made using high-T_c superconducting $EuBa_2Cu_3O_x$ film on MgO. The $EuBa_2Cu_3O_x$ films were prepared by magnetron sputtering and patterned by photolithography and Ar ion milling. We measured the resonator characteristics as a function of temperature and power. The highest unloaded Q value obtained was 12500 at 28 K and at 3.9 GHz and the surface resistance of the film was estimated at about 40 $\mu\Omega$. No change in Q values was not observed at input power levels less than -20 dBm.

INTRODUCTION

The resonator is very important not only as a component for passive microwave devices, but also as a device for evaluating the microwave surface resistance of high-T_c superconducting film. Therefore, the high-Tc superconducting film resonators have been widely studied. High-Q resonators made from laser-ablated high-T_c films on $LaAlO_3$ substrates have been reported (1-3). However, a problem with $LaAlO_3$ substrates is the striation structure, which is caused by twinning, and with laser ablation large area deposition is difficult. To overcome these problems, we selected an MgO substrate and sputtering method. A homogeneous MgO substrate is commercially available, though it has large lattice mismatch of 8 % to high-T_c superconductors. A sputtering method is suitable for homogeneous and large area deposition. We have succeeded in making low surface resistance $EuBa_2Cu_3O_x$ films sputtered on MgO (4-6) and fabricated coplanar transmission line resonator using these films. The coplanar transmission line has the advantages of single film construction, compactness, and low radiation, as compared with microstrip line. In this paper, we describe the characteristics of coplanar 2-port transmission line resonators made from $EuBa_2C_3O_x$ film sputtered on MgO.

FABRICATION AND MEASUREMENT

C-axis-oriented $EuBa_2C_3O_x$ films A and B were prepared on 1-inch square and 0.5 mm thick (100) MgO substrates by dc magnetron sputtering (4-6). T_c and J_c of the films are shown in Table 1. Film A is a high quality film and film B is commonly thought to be a good film. Resonators (A1, A2) and B were made from films A and B, respectively. The patterning was carried out by photolithography and Ar ion milling suitable for high-resolution patterning.

Figure 1 shows the structure of the coplanar 2-port transmission line resonator. Two types of coplanar resonator with transmission line widths of 100 μm (A1, B) and 50 μm (A2) were fabricated. The gaps between the line and ground are 40 μm and 20 μm, and the resonators are coupled to the

Table 1 Properties of $EuBa_2Cu_3O_x$ films sputtered on MgO. Surface resistance R_s was estimated using the Q values of resonators A1 and B.

	t	T_c	J_c(A/cm^2)		R_s($\mu\Omega$) at 28K
	μm	K	at 90K	at 77K	and 3.9GHz
Film A	0.5	93	1.4×10^6	4.0×10^6	40
Film B	0.4	90	-	1.0×10^6	110

lead conductor with 10-μm and 5-μm gaps, respectively. The transmission line length of the resonators is 16.4 mm, the λ/2 resonant frequency is 3.9 GHz and the characteristic impedance is designed as 50 Ω (7). The resonators were housed in a metal microwave housing with K-connectors as shown in Fig. 2. The loaded quality factor Q_l was measured using an HP 8703A network analyzer. The unloaded quality factor Q_0 was calculated by the Q_l and insertion loss α relationship of $Q_0=Q_l/[1-10-(\alpha/20)]$.

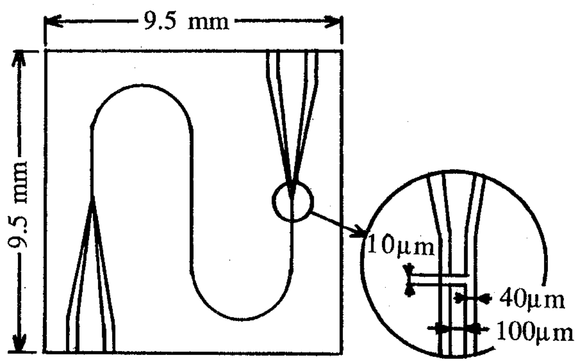

Fig. 1 Structure of coplanar 2-port transmission line resonator of high-T_c $EuBa_2Cu_3O_x$ film sputtered on MgO.

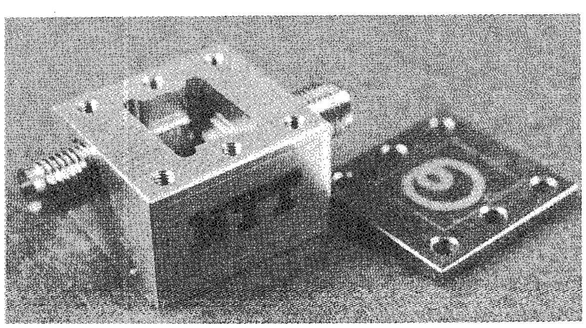

Fig. 2 Photograph of coplanar resonator.

TEMPERATURE DEPENDENCE

Figure 3 shows the temperature dependences of the loaded quality factor, unloaded quality factor and surface resistance of the resonators A1 and

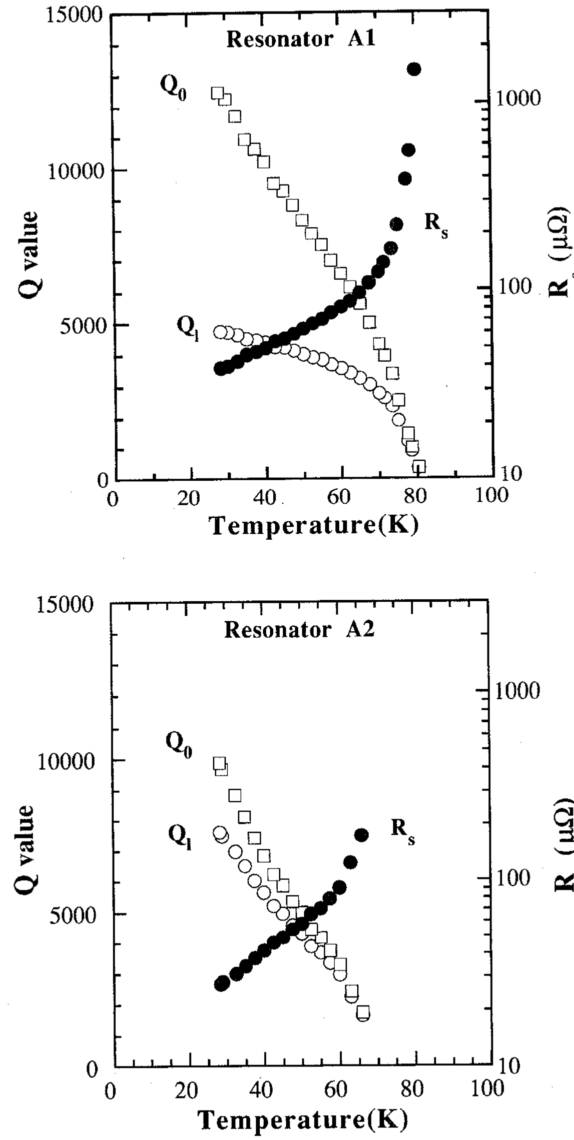

Fig. 3 Temperature dependences of the loaded quality factor Q_l (○), unloaded quality factor Q_0 (□) and surface resistance R_s (●) of the resonators A1 and A2. Input power is -30 dBm.

A2.With resonator A1, the resonant peak could be detected below 80 K. The Q values and the surface resistance change sharply with temperature from 80 K to 70 K, and the changes become moderate and linear below 70 K. The Q_0 value is much larger than the Q_l value at low temperature, because the resonator coupling becomes strong. To our knowledge, the Q_0 value of 12500 at 28 K is currently the highest among coplanar transmission line resonators. With resonator A2, the coupling is weaker than that of resonator A1. Therefore, the temperature, where the resonant peak could be detected, is lower, and the difference between the Q_l and Q_0 values becomes smaller. The Q_l of 7600 at 28 K is about 1.5 times higher than that of resonator A1. The Q_0 value of resonator B is much lower than those of resonators A1 and A2 as shown in Fig. 5.

The Q_0 of a coplanar resonator is given as $1/Q_0=1/Q_c+1/Q_r+1/Q_d$. The Q_c, Q_r and Q_d are the quality factors due to conductor loss, radiation loss and dielectric loss in the substrate, respectively. Ghione et al. have evaluated these losses for a $\lambda/2$ coplanar resonator(7). The calculated Q_r values are 3.4×10^5 and 1.4×10^6 at 3.9 GHz for 100 μm (A1, B) and 50 μm (A1) wide resonators, respectively. Assuming the relation of $f/\tan\delta$ = constant, $\tan\delta$ of MgO at 3.9 GHz is calculated as 2.5×10^{-6} from $\tan\delta$ of 6×10^{-6} at 9.6 GHz, which we measured at 20 to 80 K using the dielectric resonator method(8). The Q_d is calculated as 4.5×10^5. The obtained Q_0 value is much smaller than Q_r and Q_d. Therefore, conductor loss is the major loss in our coplanar resonators.

Surface resistance can be estimated using the Qc value(7). The lowest surface resistance is 40 μΩ and 28 μΩ at 28 K in resonators A1 and A2, respectively. These values are comparable to that of a patterned high quality film on $LaAlO_3$(2) assuming the f^2 dependence of surface resistance.

POWER DEPENDENCE

Figure 4 shows the input power dependences of the Q_l values for resonators A1, A2 and B at 28 K. The Q_l value is constant at low input power and decreases over a certain limiting input power. The limiting input powers are -20 dBm, -40 dBm and -50 dBm for resonators A1, A2 and B, respectively. The quality of the resonator does not drastically decrease above the limiting input power. The resonators A1 and A2 maintain a higher performance than that of an ideal copper resonator up to at least an input power level of 5 dBm. We estimated the effective power and average current density in the resonators, using the same calculating procedure reported in ref. (9). For example, the input power of 5 dBm is corresponding to 35 dBm / 7×10^5 A/cm^2 in resonator A1 and 33 dBm / 1.8×10^6 A/cm^2 in resonator A2.

The Q value of resonator B is low and begins to decrease at a lower input power than that for resonators A1 and A2. The T_c and J_c of film B are relatively lower than those of film A as shown in Table 1, though the T_c and J_c of film B are commonly thought to be good. Thus, the microwave properties are very sensitive to the high-T_c superconducting film quality.

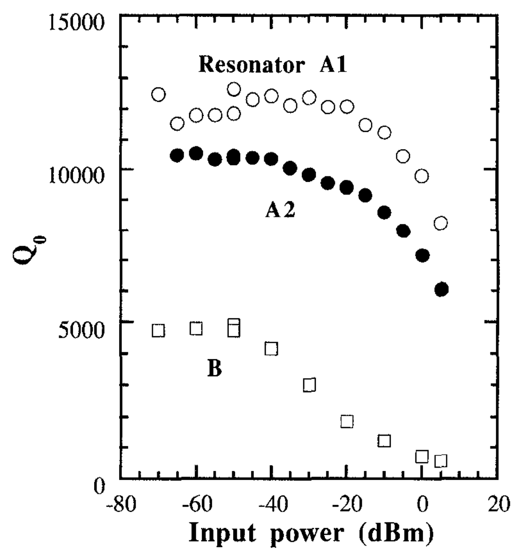

Fig. 4 Input power dependence of the unloaded quality factor Q_0 for resonators A1 (○), A2 (●) and B (□) at 28 K. Cable loss between the network analyzer and coplanar resonator is 1 dBm.

OXYGEN ANNEALING

With coplanar transmission lines, the current concentrates at the line edges. Therefore, there is a possibility that damage to the edges caused by patterning processes lowers resonator properties. In general oxygen annealing at about 500 ^{o}C is thought to be effective in restoring the superconducting properties. So, we annealed resonators A1 and B in oxygen. The Q_0 value of resonator B is increased more than two times by oxygen annealing at 500 ^{o}C for 30 minutes as shown in Fig. 5. The limiting input power was also improved from -50 dBm to -30 dBm. The Q_0 value of resonator A1 was not changed by the annealing. Thus, the effectiveness of oxygen annealing is confirmed, though it is different for films of different qualities.

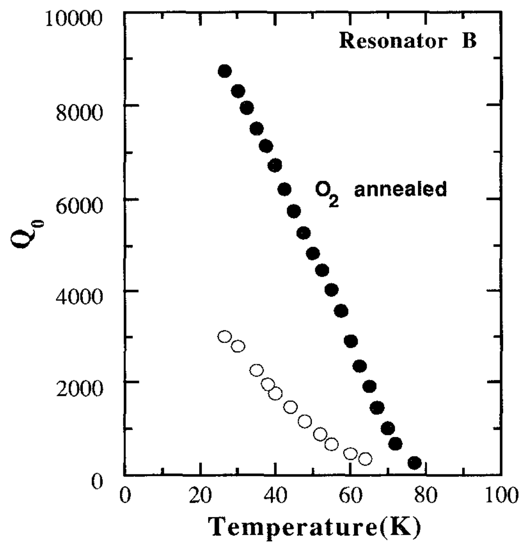

Fig. 5 Improvement in the unloaded quality factor Q_0 of resonator B by 500 ^{o}C oxygen annealing for 30 minutes. (○) : unannealed and (●) annealed. Input power is -30 dBm.

CONCLUSION

In conclusion, we have demonstrated coplanar 2-port end-coupled transmission line resonator with an unloaded quality factor of 12500 at 3.9 GHz and 28 K.The resonator qualities are very sensitive to film quality. The resonator quality is not limited by radiation loss and tan δ of MgO, so that the quality will be enhanced by improving techniques for fabricating and patterning high-T_c superconducting films.

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