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고온초전도 박막을 이용한 두 고리형 공진소자의 고주파 특성

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Microwave Performance of High Tc Superconducting Double Ring Resonator

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Abstract We investigated a double ring resonator (DRR) device to improve the resonating Q value of a superconductor resonator. To make a DRR device, we made a large area YBCO film on a MgO substrate by pulsed laser deposition (PLD). The transition temperature was 88 K and the film was uniformly deposited. We also deposited 500 Å $SrTiO_3$ on the YBCO thin film to protect the superconducting properties from degradation. The loaded Q value was measured as 50000 from simulation and as 2000 from experiment near 10GHz at 77K.

1. INTRODUCTION

Low noise microwave devices are essential elements in military or communication systems and many areas of high temperature superconducting (HTS) passive device have been successfully developed[1,2]. Ring resonators, for example, are used in HTS microwave oscillators[3] as well as in characterizing HTS thin films. The Q value of HTS ring resonators is generally larger than that of the dielectric resonators. The electrical tuning range of the ring resonator is also wider than the dielectric resonator[4]. The microwave loss of the superconducting films is measured by a technique that patterns the film into a ring shaped of planar transmission line resonator[5]. Since a microwave system requires many components, simple and fast deposition techniques for large area superconducting thin films are also needed for the realization of HTS devices in microwave applications.

In this paper, three recent works are presented. A DRR design to improve loaded Q factor and free spectral range(FSR), and their measurements by means of simulation and experiment; up scaling the established HTS (YBCO) deposition techniques with PLD using a MgO substrate of 40mm x 20mm size; stabilization of the superconducting properties by means of thin layer $SrTiO_3$ deposition on a YBCO/MgO film.

2. THE DRR

The structure of the DRR under investigation is shown in Fig. 1. The DRR consists of two ring resonators with different radii located between the input and the output ports. When the two resonant conditions of the DRR are fitted, a transmitted resonant wave is generally observed from the other side port. The strip and ground plane in this system are defined as perfect conductors. The transmitted characteristics of each single ring resonator have the resonant peaks similar to ones reported by K. Odda et al[6].

For each ring resonator, the resonating peaks (or free spectral ranges : FSR) are inversely proportional to the radius r_i as given by the following equation : $FSR = \frac{c}{\pi n r_i}$ where c is the speed of light in vacuum and n is the refractive index of the wave. These two ring resonators give rise to two independent resonant frequencies. Thus, the final FSR is defined by the wider frequency spacing due to fitted ratios between two rings such as interference and the resonating peak becomes higher.

3. EXPERIMENTAL APPROACH

The superconducting YBCO film used in the DRR study was prepared on one side of the polished 40 mm x 20 mm MgO(001) substrate by laser ablation. The deposition of approximately 5000 Å thick YBCO film was achieved in a chamber with 10^{-6} torr base pressure maintained. For ablation, Lumonics EX-700 KrF Eximer laser with 248 nm wavelength, 14 ns pulsewidth, and 400 mJ per pulse(ps) was used. The details of film preparation is described elsewhere[7].

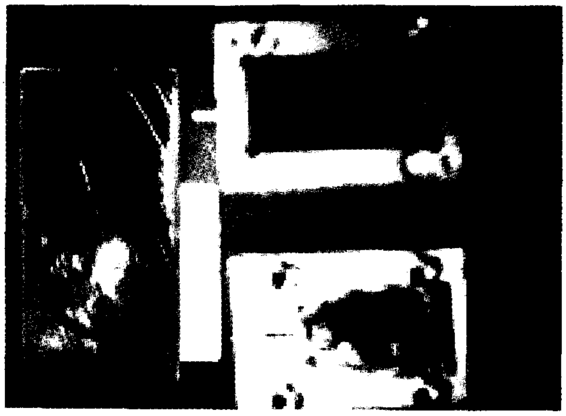

Fig. 1. Schematic diagram of a DRR and the microwave housing.

In order to make the large area YBCO film, a target was made with 45° cone shape. The substrate and the laser beam in the chamber was controlled with a stepping motor, within ±15 theta ps(1.8 degree per ps) rotating angle and sweeping height of about ±180 ps. 500 Å $SrTiO_3$ deposition on YBCO/MgO was introduced to prevent degradation during patterning process.

YBCO film was patterned into a double ring resonator with a positive e-beam mask which was designed by the microwave design system(MDS) simulator, as shown in Fig. 1. The backside ground plane was uniformly deposited with high quality gold over 5000 Å thickness by the sputtering.

The designed strip width was 1 mm and the mean diameters of the double rings are 6.65 and 3.15 mm, respectively. The ring was coupled to a microstrip line with 1.125 mm gap and the two rings were coupled with 1.3 mm gap. The strip line was designed with 50 ohm impedance matching by MDS. A view of the microwave housing is shown in Fig. 1 and is similar to one reported by B. McAvoy et al.[8] The housing for DRR is composed of the brass assembly. Microwave power was coupled into the DRR using Wiltron K-connector which was tested in the range of 5–20 GHz. It had 4 holes for the screw on the walls. 4 screws were up and balanced with surrounded spring to make a good contact between coupling pins and the conducting port of the film. It was essential to keep gold ground plane electrically neutral during the experiment.

The resonance characteristics for the DRR in the nitrogen dewar was determined by measuring the transmitted power. The circuits were measured by using a HP 8510B network analyzer with an X-band sweeper.

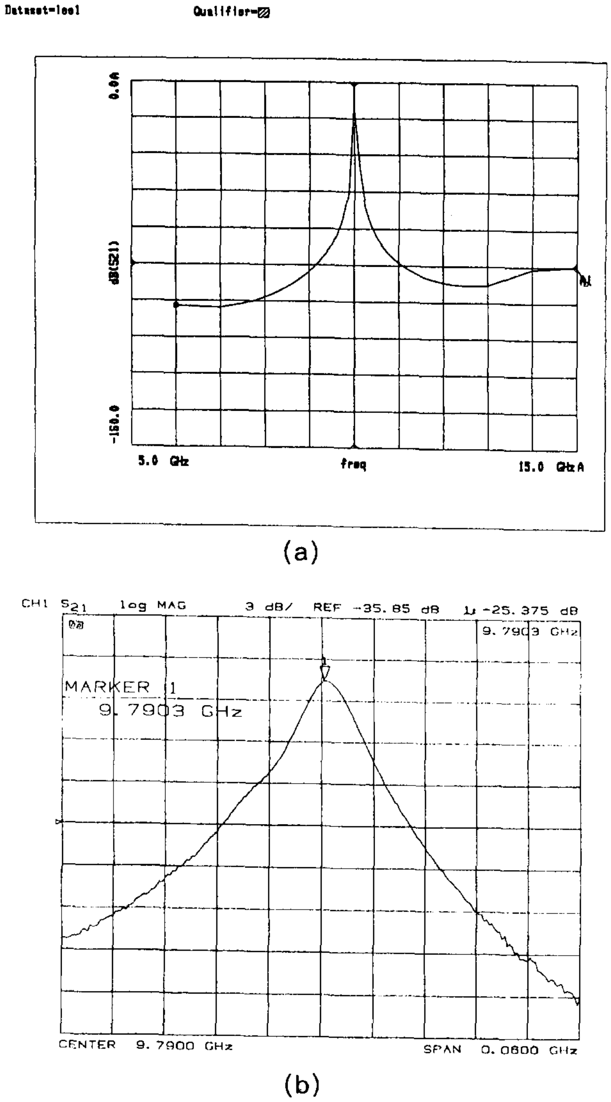

Fig. 2. The transmitted power for a DRR(YBCO/MgO) from (a) simulation (b) experiment.

4. RESULTS AND DISCUSSION

Fig. 1. gives the double ring resonator structure of YBCO/MgO with backside gold ground plane. The transition temperature (T_c) of 40 mm x 20 mm YBCO film was measured on the patterned film by the usual four-probe method. Although a simple large area thin film was made by the laser ablation method, this YBCO thin film had a transition temperature above 88 K. The deposition was uniform and featureless in all area as observed in the Scanning Electron Microscope(SEM). The conventional X-ray diffraction pattern of the film confirmed that the material was c-axis aligned with no secondary phases. Critical current (J_c) was $1.0 \times 10^6 A/cm^2$ at 77K.

After the surface of the substrate was cleaned in chemical etcher and Ar sputtering, 5000 Å gold for the ground plane was deposited by Ar ion sputtering. This was done to protect the resonance characteristics from degradation due to the thickness dependence[9].

For simulation of DRR, $\tan\delta = 4 \times 10^{-4}$, almost infinite conductivity[10], and surface roughness of 0.01 micron were used to meet the criteria for a superconducting thin film device in MDS. For conduction electron thickness of the patterned film, 5000 Å was used which was bigger than the penetration depth λ. For the simulation of device that operates at 77 K, it was assumed that the patterned device is made of a very good conductor(almost infinity). The simulated result shown in Fig. 2(a) demonstrates that the loaded quality factor is 50,000 and insertion loss is less than 10 dB for an input power. Since the pass band cutoff is sharpened, the sharpness value of the DRR configuration is increased more than those of a single ring resonator. This means that the 3 dB pass bandwidth becomes narrow and the resonating frequency is widened by the DRR configuration.

Fig. 2(b) shows a plot of the measured insertion loss near 10 GHz at 77 K with an input power of -10 dBm. The loaded Q factor near 9.8 GHz was about 2000, and the measured insertion loss was 25.5 dB. The difference in the resonant frequency between simulation and experimental results can be explained by following. When temperature went down to 77 K, the dielectric constant of MgO substrate is changed, and the pattern fabrications on the film also make a little differences from the ideal pattern design.

The measured Q value was not as good as the simulated one, because the $\tan\delta$ may not be the same as the simulated value and the network analyzer has a limited resolution. The measured Q at 4 K can be much better than the Q value at 77 K which was obtained in this experiment. For the simulation, the radiation loss was not considered. It is believed that only the fringing field of quasi-TEM modes for our structure in experiment is coupled, and the rest are returned. Hence, the insertion loss was higher than simulation result. If the width of an input and output ports are changed, and a high quality YBCO/MgO thin film is obtained, the insertion loss would be reduced.

5. CONCLUSION

A large area YBCO/MgO thin film has been prepared by a PLD method. This film showed a transition temperature of 88 K and is known to uniformly deposited to a thickness of 5000 Å, as indicated by SEM. In order to obtain a good quality resonator, 500 Å thick $SrTiO_3$ was deposited on YBCO film. This process provides a protection layer that prevents degradation of YBCO superconducting properties due to the fabrication. The simulation and the experimental results were also compared. These results indicate that the double ring resonator can be incorporated as a filter or stabilizing elements in microwave circuits.

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