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Microwave Properties of High Tc Superconducting Microstrip Antenna with Temperature Dependence

고온초전도 마이크로스트립 안테나의 온도 종속 초고주파 특성

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We report microwave properties of high-T_c superconducting (HTS) microstrip antennas without impedance matching circuits, where the impedance mismatching is obvious under the critical temperature (T_c). The superconducting thin films used in this report were $YBa_2Cu_3O_{7-x}$ (YBCO) films deposited on MgO substrates produced by pulse laser deposition (PLD) technique. At around T_c, 86 K the reflection coefficient rapidly drops, and the standing wave ratio (SWR) becomes almost unity, and the characteristic impedance based on the Smith chart is nearly 50 Ω. The reflection coefficient and the SWR of the HTS microstrip antenna were - 62.52 dB and 1.0015, respectively, at the resonant frequency of 11.812 GHz at 86 K.

1. Introduction

The advantages of microwave systems are commonly known today, as they have been employed in various applications, such as, Cellular\PCS\LAN\DBS, and so on. Therefore there is a rapidly growing market for diverse microwave devices, which combine wireless communication systems. The recent remarkable growth in fabrication technique of the high-T_c superconducting thin film gives the possibility to develop these devices applying HTS.

However, in spite of great efforts to improve the performance of the HTS microwave devices [1-3], the microwave properties particularly at around T_c has not been investigated precisely. We report here the anomalous microwave properties of the HTS microstrip antenna of which impedance mismatching between the HTS radiation patch and 50 Ω feed line is clear in common sense. These anomalous properties of the reflection coefficient, the SWR, and the characteristic impedance, were observed at around critical temperature only but below around T_c, no anomalous behaviors were observed. These phenomena have not been reported until now, since researches have been mainly focused on the microwave properties for the HTS microwave passive devices at liquid nitrogen temperature, 77 K. Moreover, the existing electromagnetic theories mainly based on the normal conductors [3,4] are unable to describe microwave properties at around T_c. Here we report that at around T_c, the reflection coefficient drops off below about - 60 dB and the SWR and characteristic impedance approach ideal values using YBCO superconducting microstrip antenna without matching circuits.

2. Preparation of HTS thin film

The HTS thin films used in this report were YBCO superconducting thin films deposited on MgO substrate using the PLD technique. The laser pulses had an energy density of 2 J/cm^2 on the target surface and were delivered to the target at a repetition rate of 5 Hz in an ambient of pure oxygen. The MgO substrate with a size of 10 mm × 10 mm × 0.5 mm was mounted on the substrate holder at a distance of 4 cm from the target surface. The YBCO thin films were deposited at 750 ℃ at a chamber pressure of 200 mTorr of oxygen and then the substrate temperature was lowered to 500 ℃ at 400 mTorr of oxygen. A detailed deposition procedure and deposition condition of the PLD techniques have been previously published (5). Characterizations of the YBCO thin films have been performed by the X-ray diffraction and temperature-dependent resistivity by four probe method. The T_c was 88 K. The X-ray diffraction patterns show that c-axis of the YBCO thin films used in this report is aligned normal to the MgO substrate. These data agree well with other reference [5]

3. Design, Fabrication and Experimental Setup of The HTS Antenna

We designed a simple HTS microstrip antenna with resonant length, L of 5,430 μm

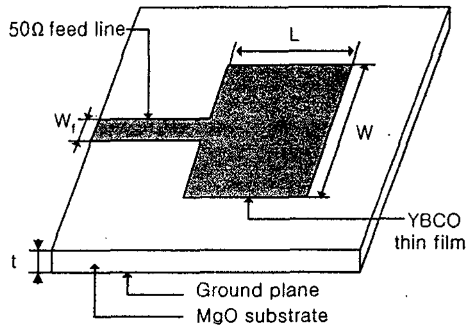
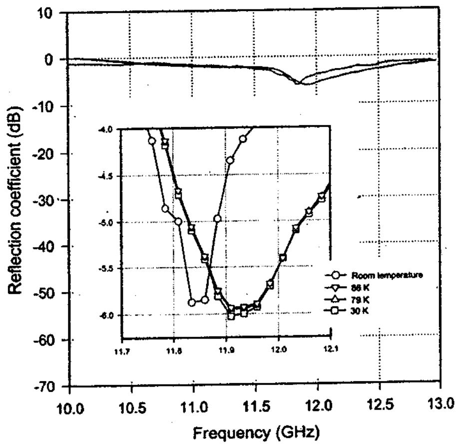


Fig. 1 Layout of the HTS microstrip patch antenna

and width, W of 3,925 μm. 50 Ω feed line with width, W_f of 490 μm, directly coupled with the mid point of radiating edge. Therefore, the impedance mismatching between the feed line and the radiating edge should exist in this design. The layout of our HTS microstrip antenna was shown in Fig. 1. To investigate the correlation between the film thickness of the HTS microstrip antennas, four samples of the HTS microstrip antennas with the same dimensions and various thicknesses (120 nm, 150 nm, 200 nm, 400 nm) of the HTS film were fabricated. In order to compare the HTS antenna with its gold counterpart, the gold microstrip antenna with the same dimension was also fabricated. Both the HTS antenna and the gold antenna have ground planes of gold with 400 nm in thickness using thermal evaporator. To measure the properties of the HTS antennas and its gold counterpart, the HP 8510C vector network analyzer and the similar measurement systems to the reference (3) were used. A careful preliminary OSL (Open, Short, Load) calibration was performed for various frequencies in order to eliminate the effect of differential coaxial connectors. It is customary that matching circuits are necessary between the radiating patch of the microstrip antenna and 50 Ω feed line [6-7], irrespective of the HTS antenna. As shown in Fig. 1,

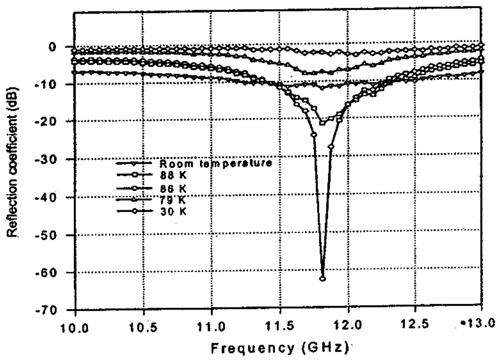
Fig. 2 Reflection coefficients of gold microstrip antenna; The inset is an enlargement of the

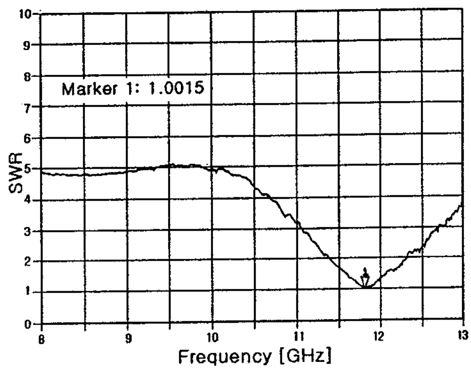


band from 11.7 to 12.1 GHz with the reflection coefficient from - 6 to - 4 dB

(a)

(b)





(c)

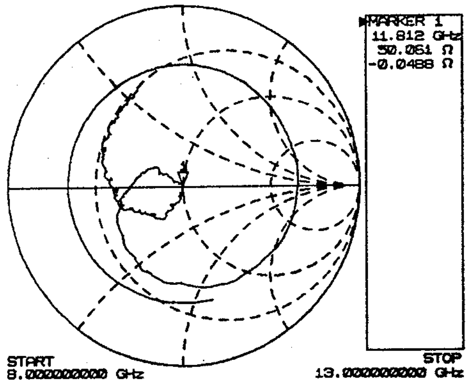


Fig. 3 Microwave properties of the HTS antenna with 400 nm in thickness : (a) Variations of reflection coefficients of the HTS microstrip antenna with temperature (b) The SWR at 86 K and (c) Characteristic impedance based on the Smith chart at 86 K.

since there is no matching circuit between 50 Ω feed line and radiating patch of HTS microstrip antenna.

4. Results And Discussions

Figure 2 shows the reflection coefficients of gold microstrip antenna (400 nm in thickness) with temperature. The reflection coefficient of the gold microstrip antenna was -5.85 dB at 11.86 GHz at room temperature, as shown in Fig. 2. With decreasing temperature under 88 K, the reflection coefficient of the gold microstrip antenna was stable at - 6.03 dB at 11.93 GHz. As might be expected of impedance mismatching, the reflection coefficient of gold microstrip antenna was very poor at all temperature, since there is no matching circuits between 50 Ω feed line and radiation patch of gold microstrip antenna. The resonant frequency between room temperature and low

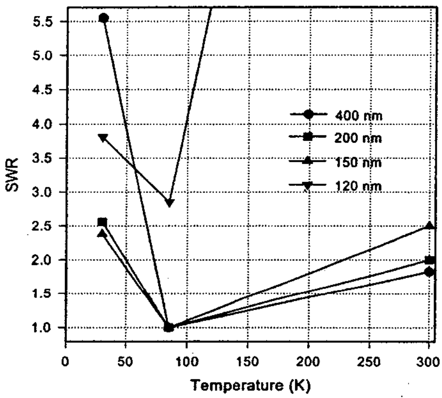


Fig. 4 The SWR of the HTS microstrip antenna for film thickness of 120, 150, 200, and 400 nm as a function of temperature ; The SWR at 120 nm (inverse triangle) approach 23 at room temperature, which is not shown in the figure.

temperature is shifted due to the slight reduction in permittivity of MgO substrate with temperature, in good agreement with the previous reports [3,8].

Figure 3 shows the microwave properties of the HTS microstrip antenna (400 nm in thickness) with temperature. The HTS microstrip antenna that resonance had not been observed at room temperature, started resonance at 88 K and exhibited the maximum resonance at 86 K as shown in Fig. 3 (a). The resonant frequency was 11.812 GHz and the reflection coefficient was dramatically reduced to - 62.52 dB. However, this phenomenon was observed at exactly 86 K only. With decreasing temperature below 86 K, the anomalous drop in the reflection coefficient disappeared. The SWR was 1.0015 at the same resonant frequency and the same temperature, as shown in Fig. 3(b). Figure 3 (c) shows the characteristic impedance of the HTS microstrip antenna based on the Smith chart at the same condition above. The real and imaginary parts of the impedance were 50.06 Ω and - 0.049 Ω,

Table 1 Microwave characteristics of the HTS and gold microstrip antenna for 120, 150, 200 and 400 nm in thickness ; The resonant frequencies vary slightly, with the film thickness within the error range of etching tolerance. respectively. These results are surprising, since no matching circuits between feed line and radiating patch were used. These results were fully reproducible with different experimental environments.

Sample	thickness (nm)	SWR	S_{11} (dB)	Re(Z_c) (Ω)	Im(Z_c) (Ω)	fr (GHz)
HTS	120	2.8529	- 6.359	31.35	- 39.22	broad band
HTS	150	1.0032	- 55.81	49.92	- 0.143	11.36
HTS	200	1.0043	- 53.42	50.09	- 0.195	11.41
HTS	400	1.0015	- 62.52	50.06	- 0.049	11.81
Gold	400	2.4607	-5.939	101.2	- 42.08	11.93

Figure 4 shows the SWR of the HTS microstrip antennas with different thicknesses (120, 150, 200, 400 nm) as a function of temperature. A zero-temperature penetration depth is assumed to be 150 nm, typical for the HTS film on MgO substrate [9]. The HTS microstrip antenna with the penetration depth of 120 nm in thickness, which is below zero-temperature penetration depth, had the SWR of 2.853, no resonance was observed and the reflection coefficients was - 6.359 dB over the entire frequency band (10 ~ 13 GHz). However, the HTS microstrip antennas above a zero-temperature penetration depth (150, 200, 400 nm) showed almost unity at around critical temperature, 86 K.

The diverse experimental results were summarized in Table 1. Compared to the data obtained with matching circuits [3,10], we emphasize here that the HTS microstrip antenna shows unusual reflection coefficient, the SWR, and the characteristic impedance at 86 K even without the matching circuits. Below around T_c, 86 K matching circuits are required to obtain impedance matching of the HTS microstrip antenna. Despite clear and reproducible experimental evidence for anomalous behavior of microwave properties of the HTS microstrip antenna, the microscopic origin of such phenomena is not clear at this moment. More systematic searches are required. This phenomenon should be observable in the microwave devices made of the HTS such as filters, resonators, and phase shifters.

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