Progress in Superconductivity Vol.2 No.1 pp 51-55 1 October 2000

A Superconducting $Y_1Ba_2Cu_3O_{7-\delta}$ Square Spiral Microstrip Antenna

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Received 12 October 2000

Abstract

A $Y_1Ba_2Cu_3O_{7-\delta}$ square spiral microstrip antenna (YBCO antenna) was epitaxially grown on a $LaAlO_3$ substrate by laser ablation. Also fabricated was a gold square spiral microstrip antenna (gold antenna) having the same structure as that of the YBCO antenna in order to compare the properties of both antennas. Both the YBCO antenna and the gold antenna were operated in Ku (12–18 GHz) band, and their properties such as the return loss, SWR, power gain, and radiation patterns were investigated at 77 K. The return loss below -10 dB was obtained in two frequency ranges, i.e., 14.05–14.90 GHz, and 16–18 GHz for the YBCO antenna at 77 K (YBCO superconducting antenna), and in the frequency range of 15.05–17.60 GHz for the gold antenna at 77 K. The SWR bandwidths are 0.85 GHz and 2 GHz for the YBCO superconducting antenna, and 2.55 GHz for the gold antenna at 77 K. The gain improvement of the superconducting YBCO antenna over the gold antenna at 77 K was about 10 dB in the frequency range of 16 GHz to 18 GHz. The radiation patterns show the YBCO superconducting antenna has the omni-directional property of a spiral antenna.

Keywords : YBCO Microstrip antenna, Gain, Bandwidth, Radiation pattern

I. Introduction

Since the discovery of high T_c superconductors (HTSs), such as YBCO, a great deal of effort has gone into understanding the superconducting mechanism and developing practical applications of HTS materials[1,2,3]. Microwave properties of HTS materials have been investigated intensively for two major reasons. First, they can contribute to understanding the superconducting mechanism of HTSs[4,5]. Second, the performance of HTS microwave devices can be superior to their copper or gold counterparts due to the fact that the microwave surface resistance (Rs) of HTS materials is one to two orders of magnitude less than that of those metals at 77 K[6,7,8]. Therefore, there have been many endeavors to fabricate several varieties of microwave devices, such as filters[9], resonators[10], and antennas[11], using HTS materials, and to investigate their properties.

The HTS microstrip antenna is one application that has been given particular attention. A microstrip patch antenna offers the advantages of light weight, low volume, low profile, and compatibility with integrated circuit technology, so that it can be widely used, not only in military applications, but also in commercial areas such as wireless communication systems[12,13]. However, microstrip patch antennas have some disadvantages, such as narrow bandwidth (1%–5%) and lower gain, compared to conventional microwave antennas.

An alternative to the problems described above is a spiral stack antenna. Spiral stack antennas are wideband radiators and most commercially available spiral antennas cover a 10:1 frequency range[14]. Hence, a spiral microstrip antenna has properties such as low volume, light weight, and wide bandwidth. Hence microstrip antennas can be fabricated to conform to surfaces of aircraft, satellites and other

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vehicles[15].

In this experiment a YBCO thin film antenna in a square spiral shape was fabricated. A gold thin film antenna equivalent to the YBCO antenna was also prepared for comparison. These thin-film antennas were deposited on $LaAlO_3$ substrates. The properties of both antennas, such as the return loss, SWR, power gain, and radiation patterns, were investigated and compared with each other at 77 K. Both of the antennas were operated in the frequency range between 12 GHz and 18 GHz (Ku-band), which is frequently used for inter-satellite communication [16].

II. Experimental

YBCO thin films were epitaxially grown on the $LaAlO_3$ substrates by laser ablation. The $LaAlO_3$ substrates measured 10 mm x 10 mm and were 0.5 mm thick. The energy density and pulse repetition of the KrF excimer laser used in this experiment were 1.7 J/cm^2 and 5 Hz, respectively. The wavelength of the laser was 248 nm. While the YBCO thin films were being deposited onto the substrates, the substrate temperature was maintained at 780 °C. The thickness of the YBCO thin films was approximately 560 nm, and Tc was approximately 89 K.

A planar square spiral antenna was patterned by photolithography and Ar ion milling. The geometry of the square spiral antenna is shown in Fig. 1. In this experiment both the YBCO antenna and the gold antenna consist of two parts, one of which is a square

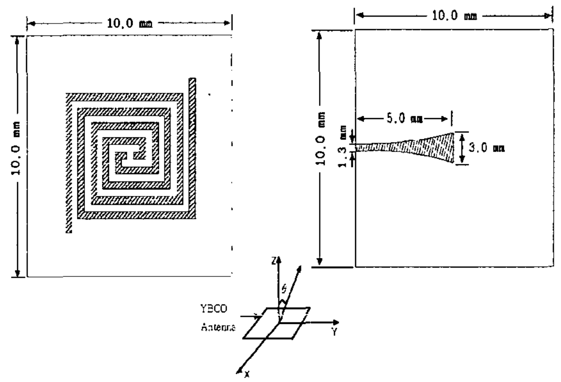

Fig. 1 Geometry of a square spiral antenna and tapered transmission line.

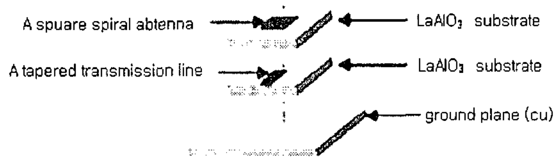

Fig. 2. Configuration of a square spiral antenna.

spiral radiator on an upper substrate, and the other is a transmission line used as a feed line on a lower substrate. This architecture is known as electromagnetic coupling and is shown in Fig. 2. As shown, the substrates are stacked on top of each other and the feed line is sandwiched between the two substrates.

The transmission line was connected to the microwave network analyzer (HP 8510B) by a 50-ohm flexible semi-rigid coaxial cable. The YBCO square spiral antenna (YBCO antenna) was mounted on the cold head of the cryogenic system, and was covered by a hemisphere. The hemisphere was made of high density polyethylene (HDPE) and had a radius of 8 cm. The properties of the YBCO antenna were measured at 77 K. The return loss, SWR, gain, and radiation pattern of the YBCO antenna were measured in the frequency range of 10 GHz to 18 GHz

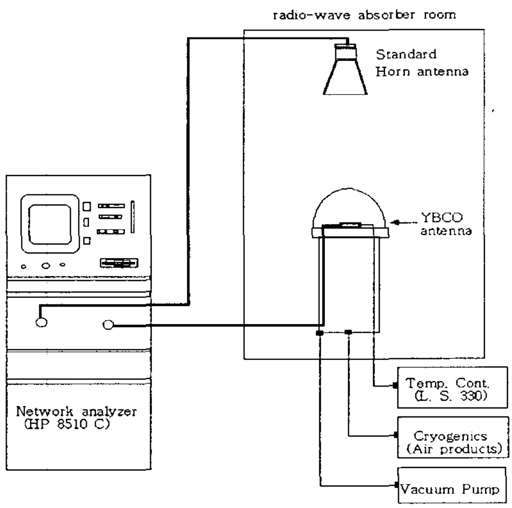

Fig. 3. Experimental arrangement for antenna gain, return loss, and radiation pattern measurement.

using a microwave network analyzer (HP 8510B) and a Ku-band horn antenna as the receiver antenna. The HDPE hemisphere separates the YBCO antenna from the horn antenna with a gap of 10 cm.

A microwave absorber surrounded the YBCO antenna and the horn antenna. The experimental arrangement for antenna gain, return loss, SWR, and radiation pattern measurement is shown in Fig. 3. The gold thin film antenna was fabricated and investigated using the same methods as for the YBCO antenna.

III. Results and Discussion

Fig. 4 shows the return loss of the YBCO superconducting antenna and the gold antenna at 77 K as a function of frequency. As shown, the return loss below -10 dB was observed over the frequency ranges of 14.05–14.90 GHz and 16–18 GHz for the YBCO superconducting antenna and over a frequency range of 15.05–17.60 GHz for the gold antenna at 77 K. This indicates more than 90% of the input power was transmitted into both antennas in the input power in the above-mentioned frequency ranges. In general, either SWR or return loss may be used to determine the bandwidth of an antenna, between which the SWR is preferred to the return loss measurement. Fig. 5 shows the SWR versus frequency data for the YBCO superconducting

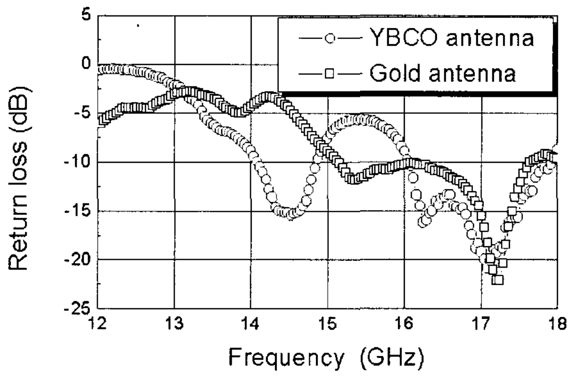

Fig. 4. Return loss of the YBCO superconducting antenna and the gold antenna at 77K as a function of frequency.

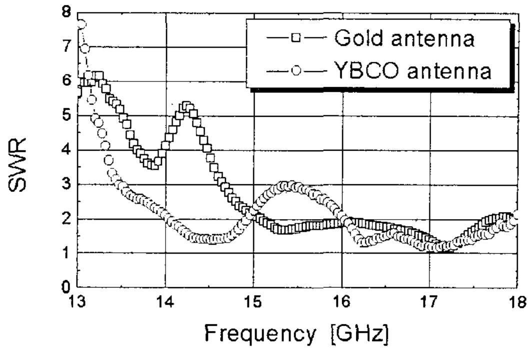

Fig. 5. SWR against frequency for the YBCO superconducting antenna and the gold antenna at 77K

antenna and the gold antenna at 77 K. As expected, the YBCO superconducting antenna has two frequency ranges in which the SWR is less than two, one of which has the lower and higher cutoff frequencies of 14.05 GHz and 14.90 GHz and the other has 16 GHz and 18 GHz as the lower and higher cutoff frequencies. For the gold antenna at 77 K, the lower and higher cutoff frequencies are 15.05 GHz and 17.60 GHz. Thus, even though having been designed for operating in Ku band, both the YBCO antenna and the gold antenna fabricted in this experiment could be effectively operated in some part of the frequency range between 14 GHz and 18 GHz.

The SWR bandwidths of the YBCO superconducting antenna were 850 MHz and 2 GHz, respectively, and percentage bandwidth (%BW) are 6% and 12%. For the gold antenna, the SWR bandwidth and %BW at 77 K are 2.55 GHz and 15.6%, respectively. The

Table I. The lower and higher cut off frequencies (f_L, f_H), mid band frequency(f_r), SWR bandwidth, and percentage bandwidth(%BW) of the YBCO supercnodcuting antenna and the gold antenna at 77K

	f_L (GHz)	f_H (GHz)	f_r (GHz)	BW (GHz)	%BW
YBCO antenna (77 K)	14.05	14.9	14.48	0.85	6
	16	18	17	2	12
Gold antenna (77 K)	15.05	17.60	16.33	2.55	15.6

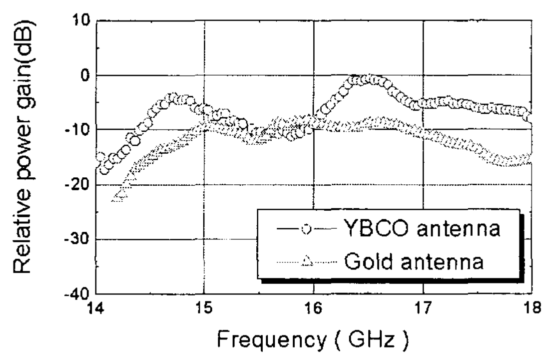

Fig. 6. Relative power gain of the YBCO superconducting antenna and the gold antenna at 77 K measured in the frequency range between 14 GHz and 18 GHz.

lower and higher cutoff frequencies (fL, fH), mid-band frequency (fr), SWR bandwidth, and percentage bandwidth (%BW) of the YBCO superconducting antenna and the gold antenna at 77 K are summarized in Table Ⅰ.

As shown in Table I, %BW of the YBCO superconducting antenna and the gold antenna at 77 K are less than 16%, which means neither antenna possesses a wide bandwidth, one of the characteristics of a spiral antenna.

Fig. 6 shows the relative power gain of the YBCO superconducting antenna and the gold antenna at 77 K measured in the frequency range between 14 GHz and 18 GHz. The YBCO superconducting antenna shows a relatively high value of gain at two frequencies, 14.6 GHz and 16.5 GHz, due to the low return loss (Fig. 4). However, the frequencies at which the return loss has minimum values do not exactly match those at which the relative gain shows peaks. That may be caused by mutual coupling between the spiral radiator and its image reflected from the plane reflector (the ground plane)[12]. Compared to the gold antenna at 77 K in the frequency range of 16 GHz to 18 GHz in which the SWR behavior of both the antennas share similarities, the YBCO superconducting antenna gave about a 10-dB improvement in power gain. This is considered to be due to the microwave surface resistance of HTS materials being lower than that of gold at 77 K. As shown, the YBCO superconducting antenna exhibits the characteristics of a two-band antenna whose resonance frequencies are 14.6 GHz and 16.5 GHz.

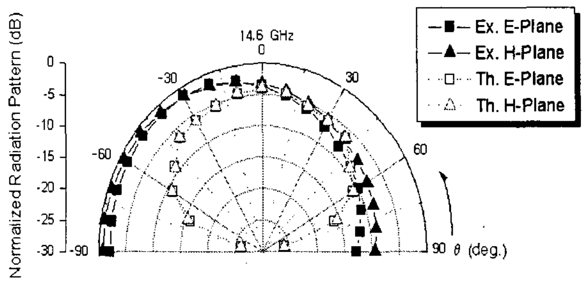

Fig. 7-a. Normalized radiation pattern of the YBCO superconducting antenna at 14.6 GHz.

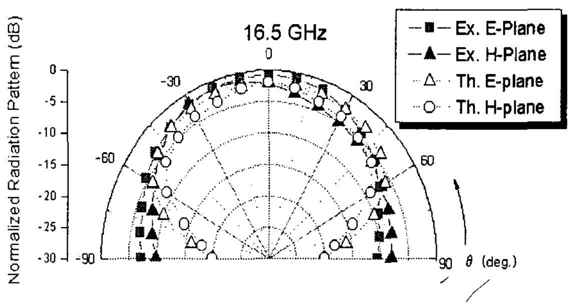

Fig. 7-b. Normalized radiation pattern of the YBCO superconducting antenna at 16.5 GHz.

Fig. 7-a and 7-b show the normalized radiation patterns of the YBCO superconducting antenna at 14.6 GHz and 16.5 GHz, respectively. Although the geometrical dimension of the YBCO antenna is symmetrical with respect to the z-axis, the patterns do not show symmetry, which may be caused by manufacturing tolerances in geometrical and physical parameters and imperfections in the measurement environment. The 3-dB beamwidths of the YBCO superconducting antenna at 14.6 GHz and 16.5 GHz are 90° and 100°, respectively. From these results, we obtained two values for the directivity[17], 1.516 and 1.399, at 14.6 GHz and 16.5 GHz, respectively.

Ⅳ. Conclusion

We fabricated, for the first time, a YBCO thin-film antenna and gold antenna in the shape of a square spiral. The properties of both antennas, such as the return loss, SWR, power gain, and radiation patterns, were observed at 77 K and in the frequency range of 12 GHz to 18 GHz. We also compared the properties of the superconducting YBCO antenna with those of the gold antenna at 77 K, and obtained the following results.

1. The return loss is less than -10 dB in the two frequency ranges of 14.05–14.90 GHz and 16–18 GHz for the YBCO superconducting antenna, and in the frequency range of 15.05–17.6 GHz for the gold antenna at 77 K.

2. The YBCO superconducting antenna behaves like a two-band antenna whose SWR bandwidths are 850 MHz and 2 GHz, while the gold antenna at 77 K shows a single band with an SWR bandwidth of 2.55 GHz. Both the antennas represent %BW below 16%. Thus, we do not have the advantage of a spiral antenna-a wide bandwidth- in both the squrare spiral antennas fabricated in this experiment.

3. The power gain improvement of the YBCO superconducting antenna over the gold antenna at 77 K is about 10 dB in the frequency range between 16 GHz and 18 GHz

4. The normalized radiation patterns of the YBCO superconducting antenna present 3-dB beamwidths of 90° and 100° , and directivity of 1.516 and 1.399 at 14.6 GHz and 16.5 GHz, respectively. Thus, the YBCO superconducting antenna shows an omni-directional property of a spiral antenna.

Acknowledgments

This work was financially supported by Hannam University.

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