CHARACTERIZATION OF PLANAR LOG-PERIODIC ANTENNAS AT LOW TEMPERATURES USING JOSEPHSON JUNCTIONS

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Abstract — Using the Josephson oscillations of high-temperature superconducting (HTS) grain boundary Josephson junctions (GBJJs), we have characterized HTS planar log-periodic antennas from 4.2K to the critical temperature of the GBJJs. The antennas were designed to operate from 25GHz to 3.2THz for a broadband receiver. As a result, several resonant steps were obtained in the dynamic resistance (*dV/dI*) - voltage (*V*) curves and the steps can be quite well explained by geometric resonances of the antenna.

I. INTRODUCTION

There are many groups using planar log-periodic antennas to improve the responses of the receivers [1]-[3] and the output power of the generators [4] at millimeter and submillimeter wave bands. General speaking, this kind of self-complementary antenna has a frequency-independent property over a broad band [5]. However, there are no extensive experimental studies, especially at low temperatures where superconducting devices, such as Superconductor-Insulator-Superconductor (SIS) junctions, Hot-Electron Bolometers (HEB) and so on, were used. Here, using Josephson oscillation effects and high-temperature superconducting (HTS) grain boundary Josephson junctions (GBJJs) integrated with the HTS planar log-periodic antennas, we have characterized the behavior of the planar log-periodic antennas at low temperatures.

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II. EXPERIMENTAL

$YBa_2Cu_3O_{7-x}$ (YBCO) thin films with a thickness of 200nm were deposited on MgO bicrystal substrates using a pulsed laser ablation method [1]. The GBJJs (with widths (*W*) of 3 to 10 μm) and the planar log-periodic antennas were fabricated using an ion milling method. The critical temperature of the GBJJs is about 70K. The antennas were designed to operate from 25GHz to 3.2THz for a broadband receiver [5]. An optical microscope photo of a YBCO GBJJ integrated with an antenna is shown in Fig. 1. A lock-in

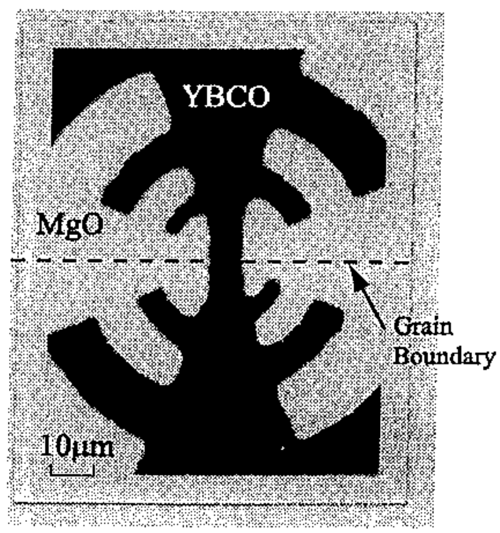

Fig. 1 Optical microscope photo of a YBCO GBJJ integrated with a YBCO planar log-periodic antenna.

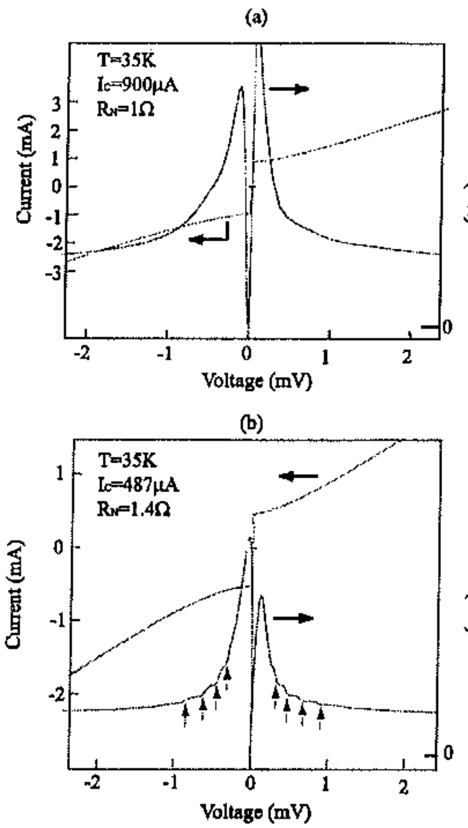

Fig. 2 I – V curves and dV/dI – V curves for the GBJJs integrated without (a) and with (b) the planar log-periodic antenna at T of 35K.

amplifier was used to measure the dynamic resistance (dV/dI) of the GBJJs. The sample holder had a two layer μ-metal cylinder shielding and was kept at different heights in a liquid helium Dewar to control the operation temperature (T) of the samples above 4.2K.

III. Results and Discussion

Fig. 2 shows the typical current (I) - voltage (V) curves and dynamic resistance (dV/dI) - V curves for the GBJJs integrated without (a) and with (b) the planar log-periodic antenna at T of 35K. The GBJJs show the resistively shunted-junction (RSJ) behaviors from 4.2K to 70K. Several resonant structures, related with the steps in the I-V curves and shown by arrows in Fig. 2(b), were observed in the dV/dI – V curve only for the GBJJ integrated with the antenna. This implies that this phenomenon should be due to the antenna together with the GBJJ. Also, the voltage positions of the steps do not change when a GBJJ with a different W is used, or when T of the GBJJs is changed from 4.2K to the critical temperature (about 70K).

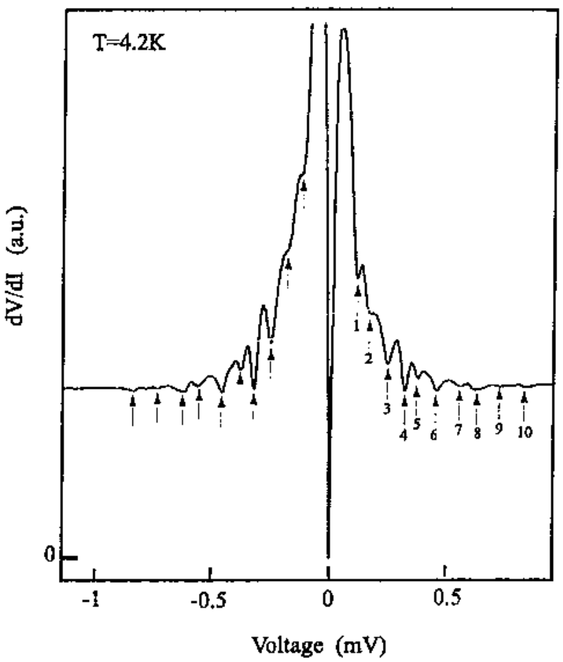

Fig. 3 dV/dI - V curve for a GBJJ integrated with a log-periodic antenna at T of 4.2K.

For Fiske steps in I-V curves of the Josephson junctions, the constant voltage steps V_n can be expressed by [6]

$$V_n = n\,(h/2e)(\upsilon/2W) \qquad (n=0, \pm1, \pm2, \pm3 \cdots), \qquad (1)$$

where h, e and υ are the Planck's constant, the electron charge, and the propagation velocity of the electromagnetic waves in the junctions. The intervals for the Fiske steps, which are due to the junctions only, should be at even intervals and dependent on the width of the GBJJs. In our case, the intervals between the steps, as shown by the arrows in Fig. 2(b), are not at even intervals and independent on the W. Thus the observed steps can not be Fiske steps.

Fig. 3 shows a dV/dI- V curve for a GBJJ integrated with a planar log-periodic antenna at T=4.2K. To study the steps in detail, we picked up the voltages (V_n) of the steps as shown by the arrows in Fig. 3 and calculated the respective frequencies (f_n) using the Josephson relationship [6]:

$$V_n = hf_n/2e\,. \qquad (2)$$

The results are listed in Table 1. Also, the geometric oscillation frequencies in the antenna were calculated assuming $\lambda/2$ resonator at the edges of the teeth in the

TABLE 1

Voltages and frequencies for the resonant steps as shown by arrows in Fig. 3.

No. (n)	Voltage V_n (mV)	Frequency f_n (GHz)
1	0.11	53.1
2	0.17	82.1
3	0.24	118.0
4	0.31	150.0
5	0.37	177.6
6	0.45	219.8
7	0.54	260.0
8	0.62	299.5
9	0.73	352.6
10	0.84	405.7

antenna and compared them with the frequencies listed in Table 1. It was found that each resonant steps shown in Fig. 3 and Table 1 can be associated with geometric oscillations at the edges of the teeth in the antenna, as shown in Fig. 4. As a Josephson junction is a broad continuous frequency oscillator and/or detector, HTS GBJJs can irradiate and detect the electromagnetic wave from very low frequencies to several THz at least [1]. This association suggests that the structures we are observing in the (dV/dI) - V curves arise from the frequency dependence at the terminal impedance at the antenna. Also, similar results were reported at room temperature and low frequencies by photoconductive sampling [7]. This effect should be considered in applications.

IV. Conclusion

Using Josephson oscillation effects and YBCO GBJJs integrated with the YBCO planar log-periodic antennas, the antennas were characterized above 4.2K. As a result, several resonant steps were obtained in the dV/dI - V curves and the steps can be quite well explained by geometric resonances of the antenna. This means in fact the antennas have frequency-dependent properties and this effect should be more carefully characterized. Also, It was found that the Josephson effects of the HTS junctions could be simply used to characterize the planar antennas at low temperatures.

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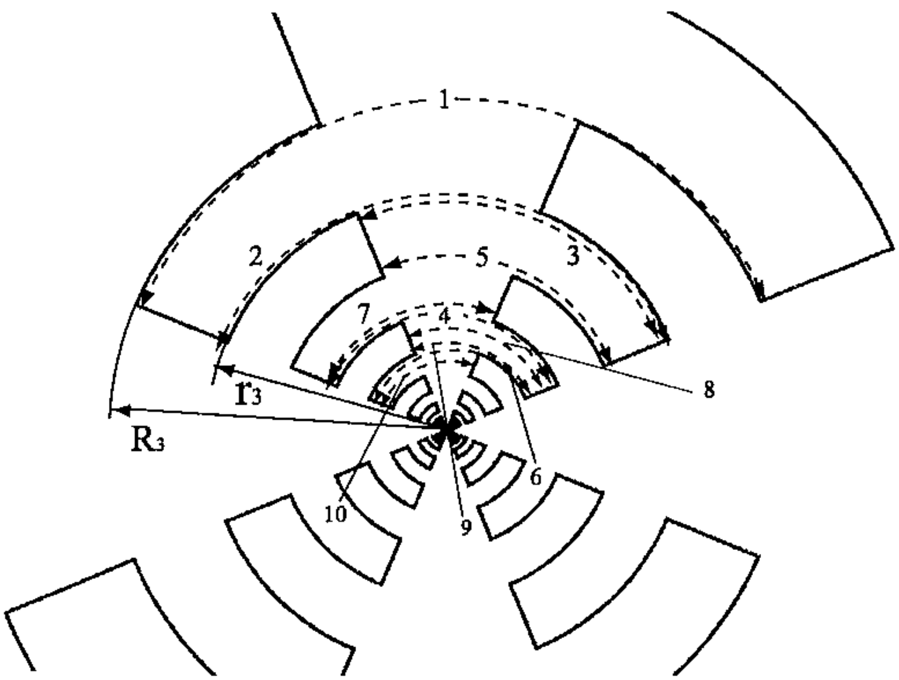

Fig. 4 The $\lambda/2$ geometric resonant lengths, shown by the dotted lines with arrows, at the edges of the teeth in the antenna. The number shown in here is corresponding to that in Fig. 3 and Table 1.

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