Design of Planar Antennas for the Superconducting Terahertz Detector

M. Yu, W. W. Xu [a)], D. Y. An, M. Y. Zhang, Y. C. Xu, J. Chen, and P. H. Wu
Nanjing University, Nanjing 210093, China
Email: [a)]wwxu@nju.edu.cn

***Abstract*—The heart of the integrated antenna and detector is the matching network between them. In this paper, four type antennas for matching the small impedances of high temperature superconducting terahertz detectors at 650GHz are proposed. And the coupling efficiency has improved for high temperature superconducting YBa_2Cu_2Ox (YBCO) Josephson junction detector with these antennas. Meanwhile, the array structures are designed to harvest more terahertz energy from the space. The resonant property and the coupling efficiency are measured by the terahertz time-domain spectroscopy (THz - TDS) system.**

I. INTRODUCTION

BROADBAND antenna of complementary structure is often applied on superconducting Josephson junction in THz frequency for the enhancement of coupling, such as log periodic antenna[1], spiral antenna, *etc*. However, the coupling efficiency is always low because of the impedance mismatch between the antenna and the junction. The input impedance of the antenna with complementary structure is 188.5 ohm, while the normal resistance of the junction, like the high temperature superconducting YBCO Josephson junction[2], is only several ohm. On the other hand, narrowband antennas are hardly used in THz systems due to the measurement of these terahertz antennas are very difficult.

Conventional measurement method for antennas is restricted by the small size of THz antennas. THz-TDS system has the advantages of broadband from 0.1 to 5THz, high signal-noise ratio (SNR) and availability at room temperature. Therefore, THz-TDS is suitable to measure the resonant properties of the artificial structures.

In order to match with the low impedance of the superconducting junction, the log periodic antenna (Fig. 1(a)) and log periodic sinuous antenna (Fig. 1(b))[3] of which the impedance is both 50 ohm at 650 GHz are designed. Meanwhile, the bow-tie antenna with a quarter wavelength matcher (Fig. 1(c)) and double-U antenna (Fig. 1(d))[4], of which the impedance is both 7 ohm are also designed. In the simulation structure, the high temperature superconducting YBCO Josephson junction is deposited on a 500 μ m-thick MgO wafer. The simulated reflection spectra of these antennas were shown in Fig. 2. The return losses are all below -20dB.

Furthermore, the impedance mismatch also exists while the terahertz signal transmits from air to the junction. Considering the difficulty to measure one antenna and the low coupling efficiency from space to the sample, the arrays of these antennas are designed to harvest more energy from the space. The resonant structure of the array is concerned initially. Actually, the resonant property and the coupling efficiency of the arrays in normal incident direction have been measured by THz-TDS system[5]. As our THz-TDS system, Advantest TAS7500SP, could eliminate the effect of thick substrate which would affect the resonant property, the silicon substrate is used to reduce production costs.

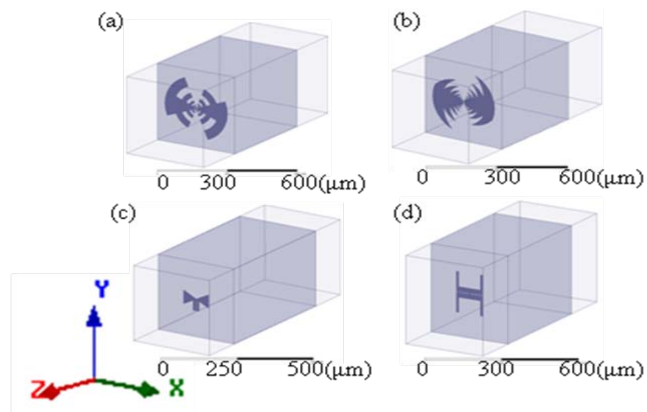

Fig. 1. Simulated model of the antenna by HFSS. (a) Log periodic antenna. (b) Log periodic sinuous antenna. (c) Bow-tie antenna with a quarter wavelength matcher. (d) Double-U antenna.

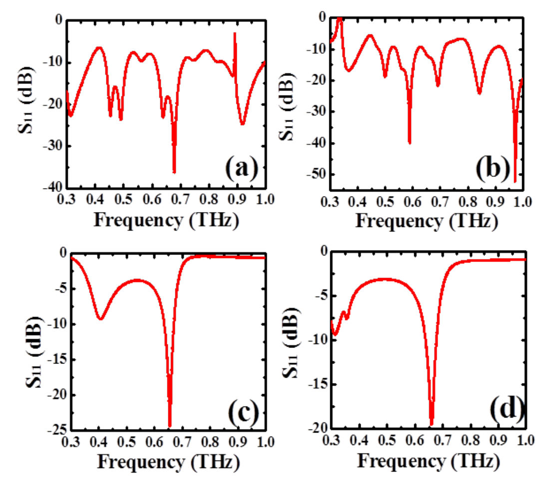

Fig. 2. Simulated reflection spectrum of the antenna by HFSS. (a) Log periodic antenna. (b) Log periodic sinuous antenna. (c) Bow-tie antenna with a quarter wavelength matcher. (d) Double-U antenna.

II. RESULTS

The arrays of resonant structures were fabricated by conventional photolithography and metallization processing. A 200nm-thick Au film was deposited on a 500 μ m-thick silicon wafer adhered by a 10nm-thick NbN layer. Fig. 3 shows the microscopic images of fabricated four types of resonant structure unit cells. Each sample was fabricated with the dimension of 1cm$\times$1cm. The periodicities of the log periodic structure array in the *x* and *y* direction are both 350 μ m. The periodicities of the log periodic sinuous structure array in the *x* and *y* direction are both 590 μ m. The periodicities of the bow-tie structure array with a quarter wavelength matcher in the *x* and *y* direction are 210 μ m and 190 μ m, respectively. The periodicities of the double-U structure array in the x and y direction are 200 μm and 290 μm, respectively.

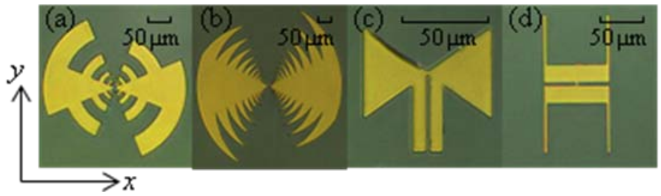

Fig. 3. Microscopic images of lithographically fabricated unit cells. (a) Log periodic structure. (b) Log periodic sinuous structure. (c) Bow-tie structure with a quarter wavelength matcher. (d) Double-U structure.

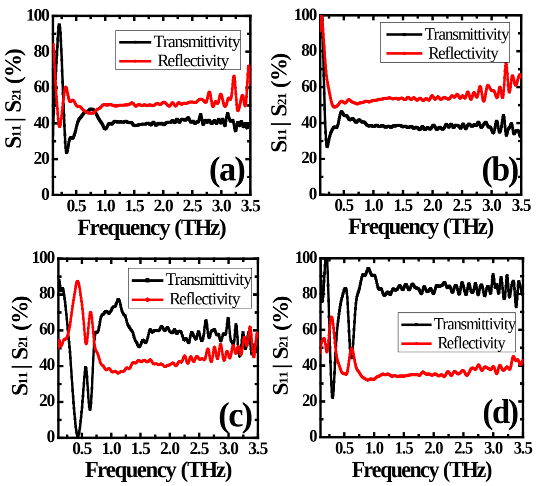

Fig. 4. Measured transmission spectrum and reflection spectrum of the array by THz-TDS system. (a) Log periodic units array. (b) Log periodic sinuous units array. (c) Bow-tie antenna with quarter wave matcher. (d) Double-dipole units array.

Fig. 4 shows the transmission spectrum and reflection spectrum of array structures measured by THz-TDS system. Log periodic structure array (Fig. 4(a)) and log periodic sinuous structure array (Fig. 4(b)) display the broadband character, while bowtie structure array (Fig. 4(c)) and double-U structure array (Fig. 4(d)) show the narrow band character with the resonant frequency at 650GHz. As the angle of reflection is 11°, the coupling efficiency of the array structures in normal incidence at 650GHz can be calculated approximately according to the formula of $\eta = 1 - |S_{11}|^2 - |S_{21}|^2$. The calculated coupling efficiencies are all more than 50%, which indicate that more than 50% energy from the space is harvested by these array structures.

III. Summary

In summary, the log periodic antenna, log periodic sinuous antenna, bow-tie antenna with a quarter wavelength matcher and double-U antenna on high temperature superconducting YBCO Josephson junction detection are designed at 650GHz. The return losses of these antennas on MgO substrates are all below -20dB. On the other hand, the THz energy can be absorbed more than 50% from space in normal incidence by designed array structure.

The work was supported by the National Basic Research Program of China (Grant Nos. 2011CBA00202 and 2014CB339804), the National Natural Science Foundation of China (Grant Nos. 61371036,11234006 and 11227904), the Natural Science Foundation of Jiangsu (BK2012013), and the Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions.

IV. Final Abstract

The designed antenna matched with the junction was fabricated in the array structure, whose resonant property can be measured by THz-TDS. The structure can get more THz energy from the space which can improve the THz absorption.

These antennas have be applied on superconducting YBCO terahertz detector. The harmonic order of the mixer can be more than 200 at 650GHz. The antenna array will be used to improve the signal coupling for superconducting YBCO terahertz detector in next work.

References

[1]. C. Brendel, J. M. Scholtyssek, and F. Ludwig, "HTS Josephson junction cantilever with integrated near field THz antenna," *IEEE transactions on applied superconductivity*, vol. 21, no. 3, pp. 319-322, June, 2011.

[2]. D.Y. An, J. Yuan, and N. Kinev, "Terahertz emission and detection both based on high-Tc superconductors: Towards an integrated receiver," *Applied physics letters*, vol. 102, p. 092601, 2013.

[3]. Y. Divin, M. Lyatti, and U. Poppe, "Josephson spectroscopy for identification of liquids," *IEEE transactions on applied superconductivity*, vol. 21, no. 3, pp. 311-314, June, 2011.

[4]. Z. Wen, J. R. Gao, and M. Hajenius, "Twin-slot antenna coupled NbN hot electron bolometer mixer at 2.5 THz," *IEEE transactions on terahertz science and technology*, vol. 21, no. 3, pp. 378-382, June, 2011.

[5]. J.B. Wu, B.B. Jin and J. Wan, "Superconducting terahertz metamaterials mimicking electromagnetically induced transparency," *Applied physics letters*, vol. 99, p. 161113, 2011.