Electrically tunable superconducting terahertz switch metamaterials

Chun Li[1] and Biaobing Jin[2, *]
[1] Research Institute of Superconducting Electronics, Nanjing, China
[2] Research Institute of Superconducting Electronics, Nanjing, China

* Email: bbjin@nju.edu.cn; Tel.: +86-15850576995

This paper reports a new design of electrically tunable superconducting niobium nitride metamaterials device. The maximum transmission coefficient at 0.507 THz is 0.98 and decreases to 0.19 when the applied voltage increases to 0.9 V. A relative transmittance change of 80.6% is observed, making this device an efficient narrowband THz switch. Additionally, the frequency of the peak is red shifted from 0.507 to 0.425 THz, which means that the device can be used to select the frequency. This study offers an alternative tuning method to existing optical, thermal, magnetic-field, and electric-field tuning [1-4], delivering a promising approach for designing active and miniaturized THz devices.

The geometry and dimensions of the unit cell are shown in Fig. 1(a). In the periodic array of CSRs, each row of adjacent FSRs is connected not only as resonators but also as continuous wires in the circuit. When a bias voltage is applied to the ends of the metamaterial as shown in Fig. 1(b), a current loop is naturally formed in this system.

At a fixed temperature of 4.5 K, we measured the THz response of the NbN switch device with different applied voltages (currents). Figure 2(a) shows the measured transmission spectra through the sample as the voltage is varied from 0 to 1.3 V. For this switch, when the applied current increased, the volume of the normal state in the SC resonator increased. This was because of an increase in the resistance, leading to a significant increase in Ohmic loss. At about 0.8 V, the currents got the peak value of about 180 mA, corresponding to a critical current density of 6×10^5 A/cm^2 for a wire cross section of 100 nm $\times$ 5 μm (this metamaterial has 60 shunt branches). When the applied current exceeded the critical value, the electromagnetic response of the NbN film approached the normal state and the transmission peak disappeared. A red shift of the peak in frequency from 0.507 to 0.425 THz was observed. And a relative transmittance change of 80.6% was obtained when the applied voltage was 0.9 V. We also measured this sample under different temperatures from 4.5 to 18 K, shown in Fig. 2(b). It was found that the two tuning methods resulted in similar transmission behavior.

At fixed temperatures of 4.5 K, 7 K, 9 K, 11 K, and 13 K (as shown in Fig. 3–4), both the transmission amplitude and peak frequency had a similar variation with the increase in applied voltage. However, the dynamic range of the tuning dramatically decreased with increasing temperature. This is because the Ohmic losses at higher temperature increase and lead to the lower transmission at zero voltage. The temperature-dependent relationship of this device is in accordance with the electrical tuning at a fixed temperature of 4.5 K. Combining the temperature dependent and electrical effects, we can control the dynamic range of the variation of the NbN switching device under different working conditions.

This study delivers a promising approach for designing active and miniaturized THz devices.

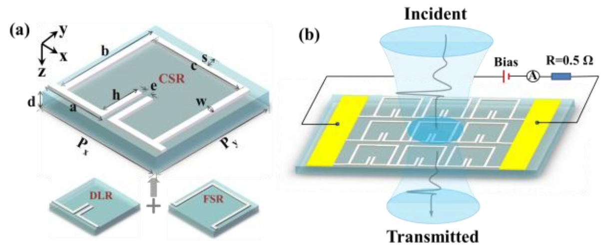

Fig.1 (a) Geometry and dimensions of the THz metamaterial switch: a=40 µm, b=68 µm, c=62 µm, w=5 µm, h=28 µm with a lattice periodicity P=84 µm. One unit cell of the CSR metamaterial is composed of a DLR and a FSR. (b) A schematic of the switching device. Each row of adjacent FSRs are connected to serve as conducting wires.

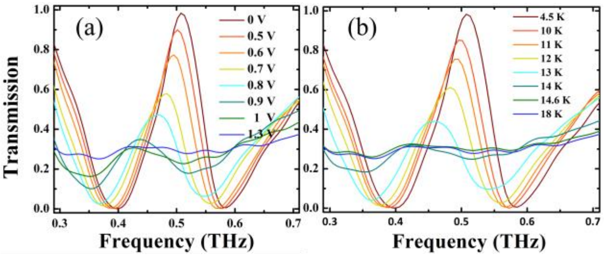

Fig.2 The *variation of the frequency-dependent transmission intensity with (a) a change in voltage at a fixed temperature of 4.5K and (b) a change in temperature.*

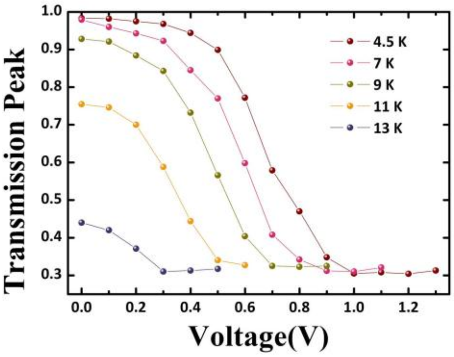

Fig. 3 Voltage-dependent transmission intensity of the THz radiation at 0.507 THz.

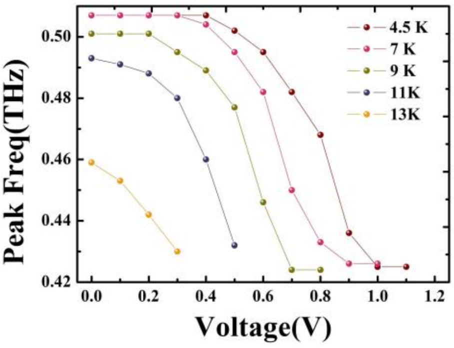

Fig. 4 Voltage-dependent peak frequency at various temperatures.

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