A room temperature NbN bolometer for terahertz detection

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***Abstract*— Using RF magnetron sputtering and electronic beam lithography, a NbN microbolometer integrated with a planar logarithm periodic antenna is fabricated on a SiO_2/Si (100) substrate for detecting signals from 0.05 THz to 0.4 THz. The best attainable responsivity of the device is about 100 volts per watt at 300K.**

I. Introduction And Background

Bolometers based on superconducting NbN films are very sensitive detectors at terahertz frequencies, and can thus find many applications in remote sensing, medical diagnosis, radio astronomy, and national security. To make the applications easier and wider, we have tried to operate these bolometers at room temperatures in the hope that, although they are no longer superconducting, rather high sensitivity or, equivalently, high responsivity can still be maintained. In this paper a successful example in this regard is described and discussed. The best attainable responsivity of the device at 300K is about 100.5 volts per watt, good enough for many practical applications. This device offers tremendous opportunities in making Si-based hybrid integration circuits, which will be used in detection and imaging array at terahertz frequencies.

II. Results

Using radio frequency (RF) magnetron sputtering and electron beam lithography, a microbolometer made of NbN thin film integrated with a planar logarithm periodic antenna is fabricated on a SiO_2/Si substrate for detecting signals from 0.05 THz to 0.4 THz. To match the resistances between the antenna and the microbolometer, the latter is of the sizes of 0.5 μm×4 μm while the thickness is 60 nm. To ensure good performances of a bolometer, it is crucial to have high temperature coefficient of resistance (TCR), which is defined as

$$\mathbf{TCR} = -\frac{1}{\mathbf{R}} \bullet \frac{\mathbf{dR}}{\mathbf{dT}} \qquad (1)$$

To get a high TCR of NbN thin film, a thin layer of SiO_2 (~250nm) is deposited on the single crystal silicon substrate so that the poor thermal conductivity of SiO_2 is made use of to prevent the absorbed radiation from escaping quickly. During RF sputtering of NbN thin film, a high N_2 to Ar ratio (2:1) is used while the total pressure is 2 Pa. From the resistance (R) vs temperature (T) curve of the film measured experimentally using four-probe arrangement (see Fig. 1), the square resistance (R□) of NbN thin film is about 4K Ω and the TCR is about 0.9% at room temperature (T=300K) ,which is higher than that of Nb and Bi bolometer at the same temperature [1-3].

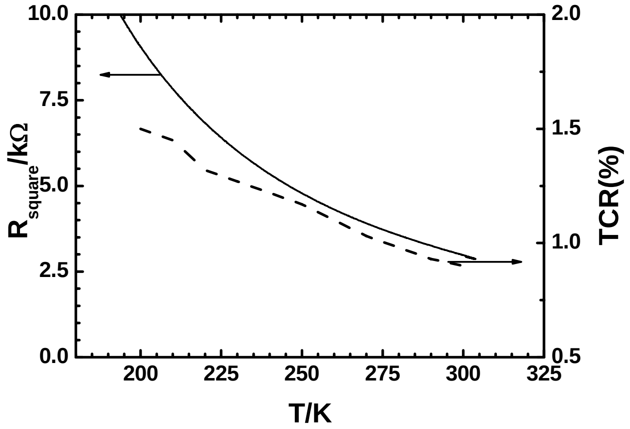

Fig.1 R-T and TCR curve of NbN film grown on SiO_2/Si substrate

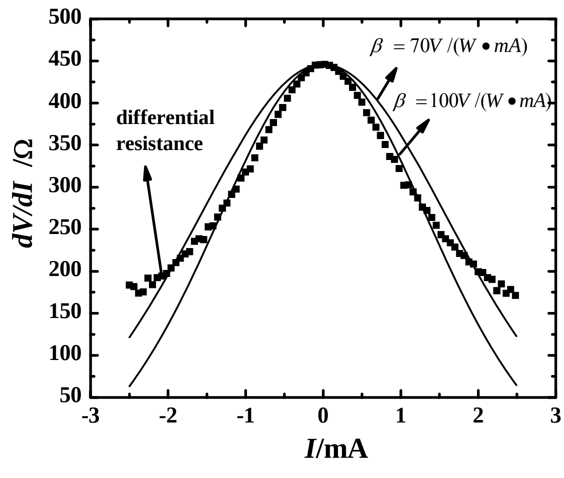

Fig.2 dV/dI -I curve of NbN microbolometer

When radiation is absorbed by the microbolometer, the voltage V across it is given by[4]

$$\mathbf{V} = \mathbf{IR} = \mathbf{I}(\mathbf{R}_0 - \beta \mathbf{IV}) \qquad (2)$$

where *I* is the bias current, R_0 is the resistance of the bolometer at zero-bias, and $\beta = G^{-1} dR / dT$ with G being the thermal conductance of the bolometer. Solving for *V* and differentiating with respect to *I* gives

$$\frac{\mathbf{dV}}{\mathbf{dI}} = \frac{\mathbf{R}_0(1-\beta\mathbf{I}^2)}{(1+\beta\mathbf{I}^2)^2} \qquad (3)$$

Fig.2 shows the differential resistance *(dV/dI,* dots*)* of a NbN microbolometer as a function of bias current I at room temperature, the lines are the *dV/dI-I* curves for β *=70 V/(W• mA)* and β *=100 V/(W• mA)* calculated from Eq.3.

To get efficient coupling between the antenna and the bolometer, we select R_0 = 450 Ω as the microbolometer resistance at zero-bias. The steeper the *dV/dI* curve, the larger the response to THz radiation signal is possible. The response of the bolometer is tested under irradiation at 100 GHz, and the DC current is set between 0.5 mA and 2.5 mA.

The responsivity $\Re$ can be written as

$$\Re = \beta \mathbf{I} \qquad (4)$$

and the noise equivalent power (NEP) of device was give as

$$\mathbf{P_{NE}} = \mathbf{S}_v / \Re \qquad (5)$$

where S_v is the voltage noise spectral density. In our experiment, the voltage noise spectral density of the device measured is about $40nV/\sqrt{Hz}$. The electrical NEP of the detector at various current bias are shown in table 1.

Table1 mesured $\Re$ and NEP at various currents of NbN microbolometer.

I/mA	$\Re$ [V/W]	NEP[$10^{-10}W/\sqrt{Hz}$]
0.5	50.2	7.97
1	85.4	4.68
1.5	95.5	4.19
2	100.5	3.98
2.5	90.4	4.42

From the table1, we get the best responsivity of the device is about 100.5V/W biased at 2 mA. And the NEP of the system is as low as 3.98×10^{-10} $\mathbf{W}/\sqrt{\mathbf{Hz}}$.

III. CONCLUTIONS

We have fabricated a kind of NbN bolometer operated at room temperature for terahertz detection, using radio frequency (RF) magnetron sputtering and electron beam lithography. And the best attainable NEP is about 3.98×10^{-10} $\mathbf{W}/\sqrt{\mathbf{Hz}}$.

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