Detection Properties of Spiral-Antenna-Coupled Microbolometer Fabricated on Si_3N_4/SiO_2 Membrane at 200 GHz Band

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***Abstract*—Spiral-antenna-coupled Bi microbolometer was fabricated on a Si_3N_4/SiO_2 membrane. The DC sensitivity of the device was 335 W^{-1} and the responsivity was 110 V/W at 220 GHz for I_b = 1.0 mA. These values are about 10 times higher than those of the Bi bolometer fabricated on a dielectric substrate. The NEP was estimated to be 4×10^{-10} $W/Hz^{1/2}$ for a modulation frequency at 1 kHz.**

I. Introduction And Background

TERAHERTZ (THz) technology is attracting attention for practical applications in such as imaging, spectroscopy and communications. In these fields, antenna-coupled devices have been studied actively as one of the promising detectors[1]. Up to date, we have studied spiral-antenna-coupled VO_x bolometer detectors on fused quartz substrates by metal-organic decomposition (MOD)[2]. For further improvement of the responsivity of bolometer detectors, introduction of the membrane structure is an effective method because of its high thermal resistance[3]. Furthermore, the membrane is much thinner than a THz wavelength, so that the antenna located on the membrane effectively radiates THz-waves in free space. Therefore, we aim at realizing spiral-antenna-coupled VO_x bolometer detectors on the membrane by MOD as a next step.

In this study, to investigate the benefits applying the membrane structure to the antenna-coupled VO_x bolometer, we fabricated thin-film spiral-antenna-coupled Bi microbolometer on Si_3N_4/SiO_2 membrane and evaluated receiving and detection properties of the fabricated device at 200 GHz band.

II. Results

The antenna was selected to be the 2-arm Archimedean spiral antenna with a constant line width of the spiral arm, and designed so that it covers 140-220 GHz. The outer and inner diameters were 1.42 mm and 0.2 mm, respectively, and the angle at termination was selected to be 1300° (3-turns + 220°).

A Si_3N_4 (300 nm)/SiO_2 (300 nm) membrane was first fabricated using a $Si_3N_4/SiO_2/Si$ substrate. Si with a thickness of ~300 μm was etched by the KOH solution from the backside of the substrate until the transparent membrane was exposed. Next the spiral antenna was fabricated on the membrane using a photolithography and Ar ion milling. Then, Bi microbolometer was fabricated by a lift-off technique after the evaporation of the Bi thin film. Bi thin film can be fabricated easily, and it is conventionally utilized as a bolometer material. That is the reason why we selected Bi in this study. SEM photograph of the fabricated device is shown in Fig. 1. Whole structure of the device including the antenna is formed on the membrane. Bi microbolometer with the size of 20 × 50 μm^2 was located at the center of the antenna.

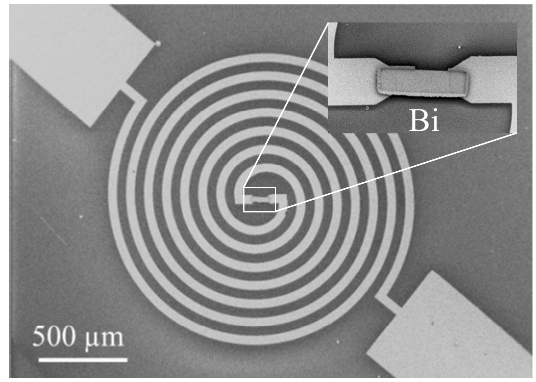

Fig. 1. SEM picture of the fabricated spiral-antenna-coupled Bi microbolometer on Si_3N_4/SiO_2 membrane.

Firstly, the DC sensitivity of the fabricated device was measured. The relationship between the normalized resistance of the Bi microbolometer and the input power to the bolometer at room temperature is shown in Fig. 2. The input power was varied by changing the applied DC bias. The DC sensitivity was calculated on the basis of the gradient in the figure, and the value was 335 W^{-1}.

Next, the device was mounted on a rotation stage. Mechanically modulated 140-220 GHz electromagnetic waves were irradiated to the antenna through a horn antenna. As a fundamental antenna property, antenna pattern was measured. Figure 3 shows the antenna patterns for E_ϕ and E_θ at 220 GHz. The solid and open circles denote the experimental values for E_ϕ and E_θ components, respectively. The antenna configuration and coordinate system are described in Ref. 4. The solid and dashed curves denote the theoretical values for E_ϕ and E_θ

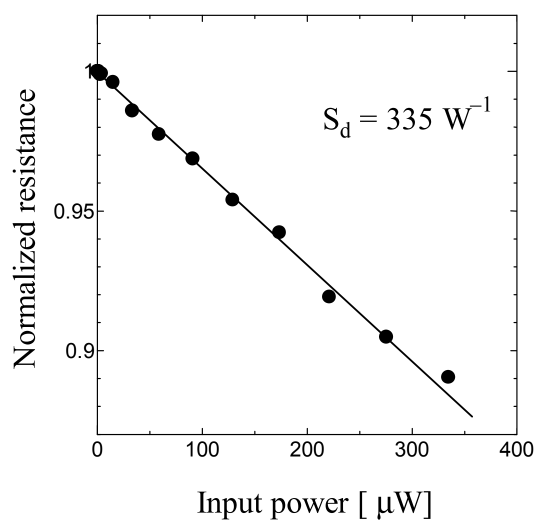

Fig. 2. Relationship between the resistance of the Bi microbolometer and the DC input power to the bolometer at room temperature.

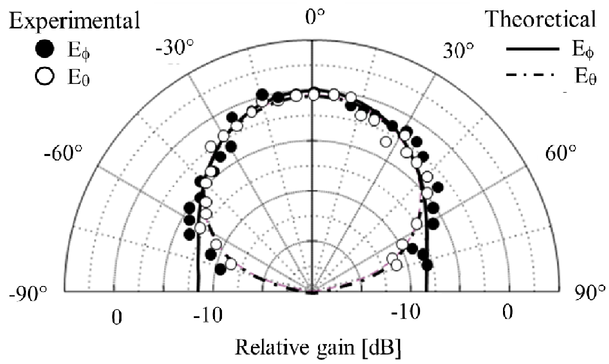

Fig. 3. Antenna patterns for 220 GHz electromagnetic wave at $\phi = 90°$.

components derived from the theory of the wire antenna in the air[5], respectively. As can be seen from the figure, the experimental patterns almost agree with the theoretical patterns. Furthermore, the frontal detected voltages ($\theta = 0°$) for E_ϕ and E_θ components have almost the same values. This indicated that the antenna has the circularly polarized property at 220 GHz. From these experimental results, it was confirmed that the spiral antenna fabricated on the membrane operated as an antenna in the air. The frequency band characteristic was also evaluated by measuring the relationship between the frequency and frontal ($\theta = 0°$) detected voltage. The frontal detected voltages for E_ϕ and E_θ components were almost constant within the change of ~3 dB at 140 - 220 GHz. The wide band characteristic of the antenna ranging from 140 to 220 GHz was obtained.

Finally, we evaluated the responsivity and noise equivalent power (NEP) of the device. Figure 4 shows the relationship between the incident power to the bolometer and the detected voltage at 220 GHz with a bias current (I_b) of 1.0 mA. The detected voltage is almost in proportion to the incident power. On the basis of the gradient in the figure, the responsivity of the Bi microbolometer is estimated to be about 110 V/W. These values of the DC sensitivity and responsivity are about 10 times higher than that of the Bi microbolometer on the fused quartz

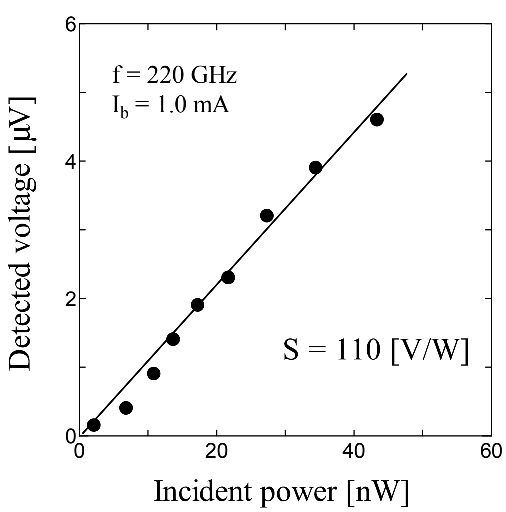

Fig. 4. Incident power dependence of the detected voltage at 220 GHz.

substrate[2]. This improvement of the responsivity is due to the introduction of the membrane structure.

Noise voltage of the device was dominated by the 1/f noise for I_b = 1.0 mA at room temperature. The 1/f noise can be expressed as

$$\frac{S_v}{V^2} = \frac{k}{f} \qquad (1)$$

where S_v, V represent the noise power spectral density as a function of frequency (f) and the measurement voltage, respectively, and k is a 1/f noise factor[6]. The value of k, 8.0×10^{-12}, was obtained by fitting the spectrum which was measured by the other device having almost the same device structure. Then, the NEP was theoretically estimated to be 4×10^{-10} W/Hz$^{1/2}$ for a modulation frequency at 1 kHz using the values of the k and responsivity of 110 V/W.

III. Conclusion

Thin-film spiral-antenna-coupled Bi microbolometer was fabricated on the Si_3N_4/SiO_2 membrane. The DC sensitivity of the microbolometer was 335 W^{-1}. The spiral antenna fabricated on the membrane operated as an antenna in the air. The receiving property of the antenna, which does not depend on the frequency, can be expected. The responsivity of the bolometer was 110 V/W and the NEP was theoretically estimated to be 4×10^{-10} W/Hz$^{1/2}$. From these experimental results, a high performance of the Bi microbolometer integrated with the spiral antenna was obtained by introducing the Si_3N_4/SiO_2 membrane structure. We could find some benefits applying the membrane structure to the antenna-coupled microbolometer detector. A high performance of the spiral-antenna-coupled VO_x microbolometer fabricated on Si_3N_4/SiO_2 membrane can be expected in the THz frequency region.

Acknowledgement

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