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Scaling Study of Antenna-Coupled Microbolometer

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Abstract

Proper scaling of the microbolometer dimensions is important in tuning and enhancing its performance. In order to understand the scaling behavior, we have evaluated the responsivity and cutoff frequency of the integrated heater and thermistor with respect to their length, considering the possible use in an antenna-coupled microbolometer.

1. Introduction

An antenna-coupled microbolometer is anticipated as a high-sensitivity room-temperature-operating detector at around 1 THz, where the absorber for conventional bolometer becomes too large to be structurally supported and thermally isolated [1]. In order to understand the scaling behavior of such a detector, integrated heater and thermistor with various lengths are fabricated, and their responsivity and frequency response are analyzed. Based on the results, method of the proper scaling of the microbolometer will be discussed.

2. Device Fabrication

The microbolometer fabricated by electron beam lithography (EBL) consists of heater, SiO_2 interlayer and a thermistor on thermally oxidized Si substrate. Both heater and thermistor are made of titanium (Ti), but they are separated by SiO_2 interlayer. The process steps in the fabrication of Ti microbolometer are discussed elsewhere [2]. The detailed device parameters are shown in the Table 1. Here we have varied the microbolometer length from 25 to 100 µm to understand the scaling behavior. The schematic diagram and SEM image of microbolometer are shown in Fig. 1. It can be seen that four-terminal configuration is used for both heater and thermistor to assure accurate measurements.

Table 1. Device dimensions, and material properties at 300 K.

Parameters	Thermistor	Heater
Thickness (nm)	46	96
Width (µm)	0.1	1.24
Length (µm)	25~100	25~100
Resistivity (Ωm)	3.08×10^{-6}	1.80×10^{-6}
TCR (K^{-1})	4.10×10^{-4}	1.25×10^{-3}

3. Material Characterization

Electrical resistivity, its temperature coefficient (TCR), and thermal conductivity are important material parameters for bolometer. They are evaluated from R versus I^2 characteristics, where linear relationship can be found reflecting the

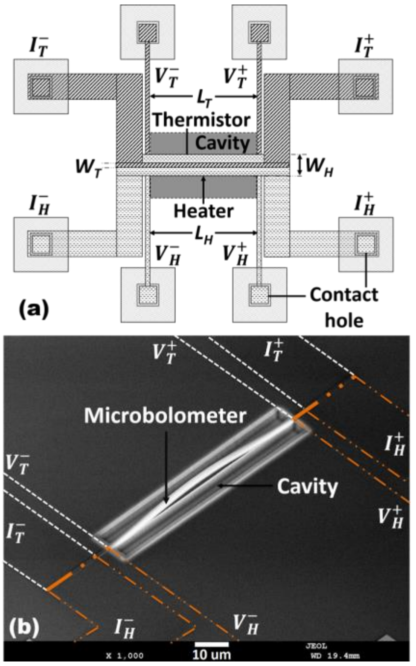

Fig. 1. (a) Schematic diagram and (b) SEM image of the Ti microbolometer. Here W_T , W_H are the width of the thermistor and heater, respectively. I_T^+, I_T^- and V_T^+, V_T^-, and I_H^+, I_H^- and V_H^+, V_H^- are the current and voltage terminals of thermistor and heater, respectively.

temperature rise proportional to the input power. By extrapolation, R_o for I=0 can be obtained, and its temperature dependence gives TCR. The higher value of resistivity and smaller TCR values are observed in thermistor due to the size (narrow-width) effect. They are summarized in Table 1.

Thermal conductance of the heater/thermistor line can be extracted from the slope of the R/R_o-I^2 line (Fig. 2), based on the method proposed by Zhang *et al.* [3]. Thermal conductivities of the constituent Ti and SiO_2 can be decomposed by comparing the cases of the independent thermistor and the integrated thermistor/heater, assuming the common conductivities for thermistor/heater Ti, and thermally oxidized/deposited (interlayer) SiO_2. Measured Ti thermal conductivity of 5.78 W/(Km) is smaller than the reported 21.9 W/(Km), which can be correlated to the measured and reported resistivities of 1.8×10^{-6} and 4.2×10^{-7} Ωm, respectively, by Wiedemann-Franz's law. Measured SiO_2 thermal conductivity of 1.20 W/(Km) is close to the reported 1.32 W/(Km), showing the quality of electron cyclotron resonance (ECR) sputtered interlayer film.

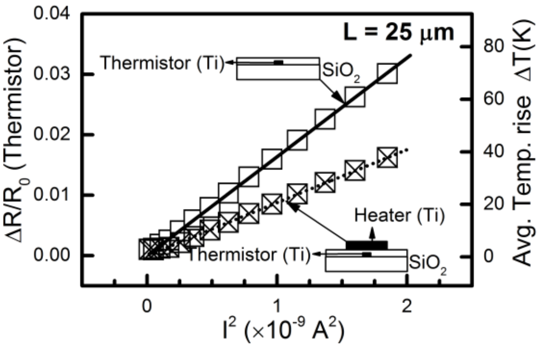

Fig. 2. Dependence of $\Delta R/R_0$ on I^2 for independent thermistor and integrated thermistor/heater with 25 μm length.

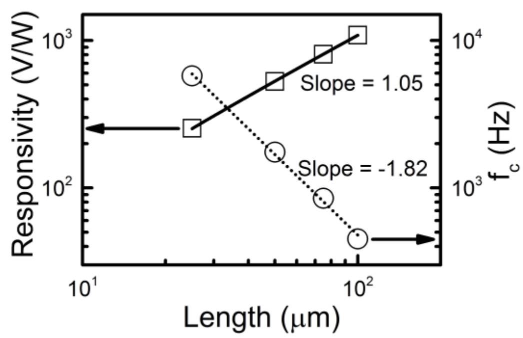

Fig. 4. Length dependence of microbolometer`s responsivity, and cutoff frequency.

4. Bolometer Performance and Scaling Possibility

Performance of the microbolometer is evaluated by the electrical responsivity defined as the thermistor output voltage relative to the heater input power, and the cutoff frequency where the output voltage decreases by 3 dB.

Fig. 3(a) shows the output voltage with respect to the input power for various heater/thermistor lengths under the constant-voltage condition, where thermistor bias current is inversely proportional to the length, and the bias voltage and the temperature rise are kept constant in order not to damage the device. The responsivity (slope of the line) increases from 255 to 1085 V/W when the length increases from 25 to 100 μm. Fig. 3(b) shows the frequency responses for various lengths. The cutoff frequency decreases from 5750 to 450 Hz with increasing length.

Fig. 4 summarizes the results in Figs. 3(a) and (b) as a double logarithmic plot. It can be seen that the responsivity and the cutoff frequency follow the power law with exponents of 1.05 and -1.82, respectively. According to P. W. Kruse [4], the responsivity $\Re_v$ can be formulated as

$$\Re_v = \alpha_{th} I_{th} R_{th} \Big/ G\sqrt{1+(f/f_c)^2}\,, \qquad (1)$$

where α_{th}, I_{th} and R_{th} respectively are TCR, bias current and resistance of thermistor. G is the thermal conductance in the microbolometer, and f_c is the cutoff frequency expressed as

$$f_c = G/(2\pi C), \qquad (2)$$

where C is the thermal capacitance in the bolometer. Eq. (1) suggests that the responsivity is inversely proportional to G, and consequently proportional to the length under the constant-voltage (constant-$I_{th}R_{th}$) condition, supporting the experimental power-law relationship with exponent of nearly unity. Since the C is proportional and G is inversely proportional to the length, eq. (2) implies that f_c decreases as the inverse square of the length, supporting again the experimental result.

One possible method to simultaneously improve the responsivity and cutoff frequency is to proportionally scale all the dimensions down. In such a case, in constant-voltage operation, the responsivity and the cutoff frequency are inversely proportional to the size and square of the size, respectively.

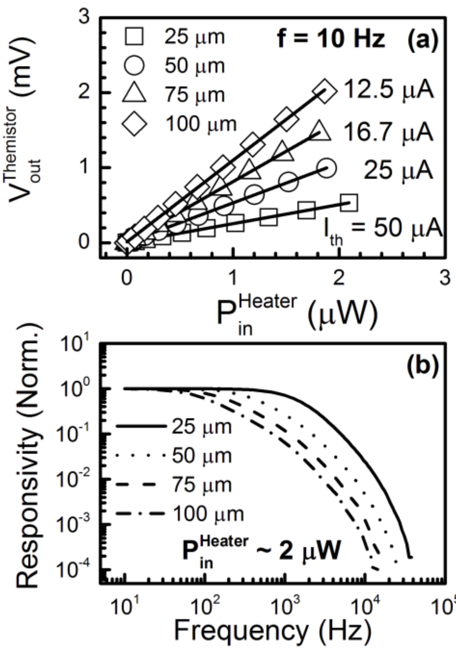

Fig. 3. Microbolometer`s (a) responsivity, and (b) frequency response for each length.

5. Conclusions

Responsivity and cutoff frequency of the integrated heater and thermistor with various lengths were evaluated experimentally. It was found that the responsivity was proportional to the length, and the cutoff frequency was inversely proportional the square of the length for the constant-voltage operation. These results could be explained theoretically, and extended to the prediction that both performance parameters could be improved simultaneously, if length, width and thickness were proportionally scaled down.

References

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