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Width Dependence of Platinum and Titanium Thermistor Characteristics for Application in Room-Temperature Antenna-Coupled Terahertz Microbolometer

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Abstract

For the development of room-temperature THz antenna-coupled microbolometer, width effects on the temperature coefficient of resistance (TCR) and resistivity for platinum (Pt) and titanium (Ti) nanowire are studied. The TCR and resistivity have been described by empirical formulas for both Pt and Ti, with the average measured width instead of the design width for better accuracy. It is evident that there is a correlation between increased resistivity and reduced TCR as the wire width is decreased. It is also found that Pt has lower dependence of TCR on the variation of width than Ti, and therefore the noise equivalent power (NEP) of the bolometer could be improved by factor 2.3 by replacing Ti thermistor with Pt one with the same width of 100 nm.

1. Introduction

Detectors for far-infrared (FIR) and terahertz (THz) waves are broadly classified into photon detectors and thermal detectors and can be made of MEMS integration. MEMS technology is important for thermal devices, including radiation sensors like bolometer, thermal-conduction-type pressure sensor, thermoelectric generator, thermoelectric cooler, thermal actuator, etc. For THz microbolometer, the absorber becomes too large to be structurally supported and thermally isolated and then an antenna-coupled bolometer becomes more viable. Currently, the thermistor and heater are made separately to optimize the sensitivity [1]. One of the important parameters for such a microbolometer is the temperature coefficient of resistance (TCR) of the thermistor, as the responsivity is proportional to the TCR.
The merit of the use of metallic resistor is the expected low noise, which is dominated by the shot noise, and hence device performance can directly get benefit from the improved TCR. This is not always the case with widely used high-TCR materials like VOx and a-Si.

We have reported the fabrication of room-temperature antenna-coupled microbolometer for 1-THz region with a responsivity: 90 V/W, NEP: 4.5E-10 W/Hz$^{0.5}$, fc: 7 kHz [2,3]. As long as the resistance values and the bias current are kept the same and the noise is limited by shot noise produced by the bias current, it is expected that the noise equivalent power (NEP) is inversely proportional to the TCR. Considering the importance of TCR, the width effects on the TCR and resistivity for platinum (Pt) and titanium (Ti) are studied.

2. Experimental

The microbolometer consists of gold (Au) antenna, Ti or Pt heater, silicon dioxide (SiO_2) interlayer and Ti or Pt thermistor on thermally oxidized silicon (Si) substrate. The schematic diagram and scanning electron microscopic (SEM) pattern of a fabricated antenna-coupled Ti microbolometer is illustrated in Fig. 1(a) and 1(b) respectively [3]. The detailed process steps including fabrication of the microbolometer by Ti thin film, are discussed elsewhere [4]. Figs. 1(c) and (d) show the devices fabricated for measurement of the width effect on the thermistor, including wires with variable widths and fixed length and height. For the current design of microbolometer [3], the length for thermistor is ~19.72 μm, which could be availed by more complex layout pattern of the thermistor, such as a meander shape, with longer effective length, resulting in enhanced electrical responsivity.

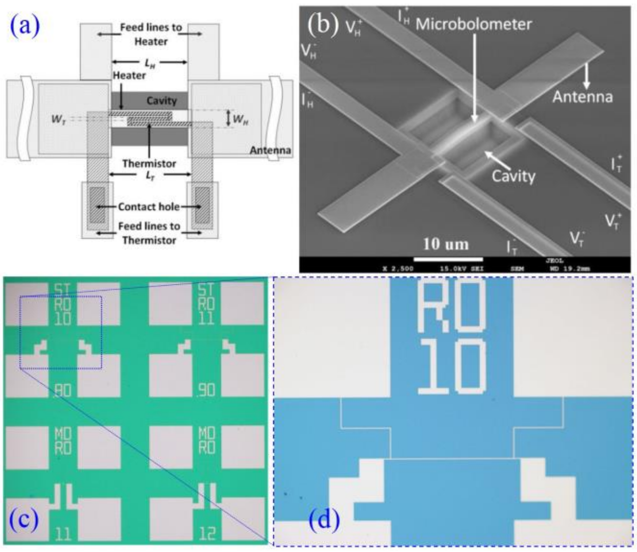

Fig. 1 (a) Schematic diagram of the Antenna-coupled Ti-microbolometer (b) SEM image of microbolometer fabricated by electron beam lithography (EBL) [3]. (c) & (d) shows the devices fabricated for measurement of the width effect on the thermistor.

3. Results and Discussion

Relationship of Design Width with Actual Width

For details analysis of width effect accurate measurement of the wire width is essential. Fig. 2(a) shows the top-view of a Pt thermistor (with L=100 μm, H=50 nm, and design width DW= 100 nm).

Due to the shadow effect in the vacuum evaporation, the width of the top and bottom of the thermistor is different. The top width is lower than bottom, seen as the demarcation lines in the SEM image. Fig. 2(b) shows variation of the average measured value of width for the inner and outer demarcation lines (corresponding to the top and bottom width of the thermistor), with DW. The differences between the DW and the average of the inner and outer width is noticeable, for the region of our interest (DW<1000 nm). Hence, for reliability, TCR and resistivity, have been analyzed with average measured width (AMW), instead of DW.

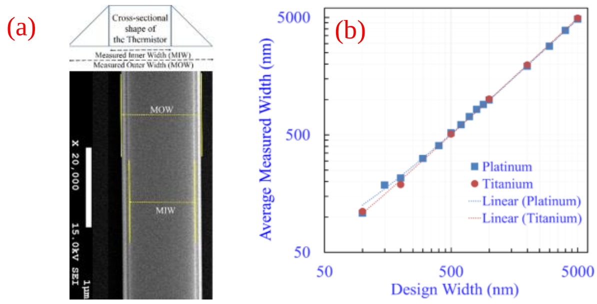

Fig. 2 (a) Pt-thermistor measured by FE-SEM (top-view). (b) The correlation of the average measured width with the design width.

Width Dependence of Platinum Thermistors

Fig.3 shows the TCR and resistivity with the variation of the average measured width of the Pt thermistors, with length L= 100 µm, height H=50 nm. The results are fitted to the following empirical equations with AMW in nm, ρ in ohm-m and TCR in %/K.

$$TCR= 6.34E\text{-}02(AMW)^{1.49E\text{-}01} \quad (1)$$
$$\text{Resistivity } (\rho) =8.17E\text{-}07(AMW)^{-1.49E\text{-}01} \quad (2)$$

Based on the empirical equations (1 & 2),
Pt(AMW=5000nm): TCR=.226 %/K, ρ =2.28E-7 ohm-m; Pt(AMW=100nm): TCR=.126 %/K, ρ =4.10E-7 ohm-m. Hence Pt(narrow width effect)= TCR reduction to 56%, ρ~ increase by a factor of 1.8.

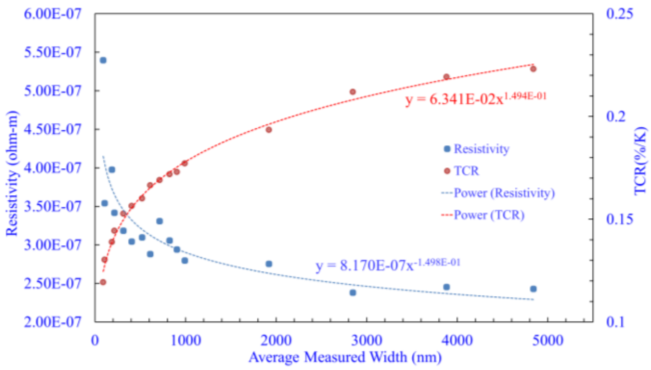

Fig. 3 TCR ρ with the variation of AMW for Pt thermistor.

Width Dependence of Titanium Thermistors

Fig.4 shows the TCR and resistivity with the variation of the AMW of the Ti thermistors, with length L= 100 µm, height H=50 nm. The results are fitted to the following empirical equations with AMW in nm, ρ in ohm-m and TCR in %/K:

$$TCR= 1.04E\text{-}02\ (AMW)^{3.62E\text{-}01} \quad (3)$$
$$\text{Resistivity } (\rho) =1.72E\text{-}05(AMW)^{-3.51E\text{-}01} \quad (4)$$

Based on the empirical equations (3 & 4),
Ti(AMW=5000nm):TCR=.229 %/K, ρ=8.62E-7 ohm-m; Ti(AMW=100nm):TCR=.055 %/K, ρ =3.41E-06 ohm-m. Hence Ti(narrow width effect)= TCR reduction to 24%, ρ~ increase by a factor of 4.0.

It is evident, from TCR point of view, Pt has lower dependence of TCR on the variation of width and realizes a factor of 2.3 improvement relative (with AMW=100 nm) to Ti.

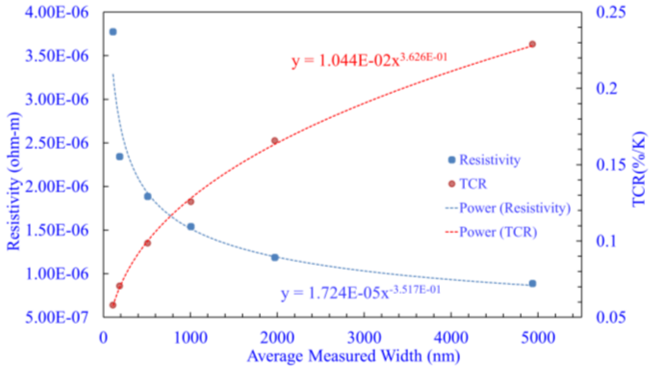

Fig. 4 TCR and ρ with the variation of AMW for Ti thermistor.

3. Conclusions

Assuming the application to microbolometers, width effects on TCR and resistivity for Ti and Pt are evaluated. The important findings are: a) correlation between increased resistivity and reduced TCR, with the line width decreased, is commonly observed in Ti and Pt. b) Pt shows smaller width dependence and hence it is expected that the NEP of the antenna-coupled microbolometer can be improved by factor 2.3 by replacing thermistor material (with AMW=100 nm) from Ti to Pt, while keeping its resistance constant by increasing its length by factor 8.3. This can be attained by making use of the meander structure as long as the target frequency is 1 THz.

In order to understand the mechanism of the resistivity-TCR correlation, detailed material studies are necessary, which may lead to the improved performance of the metal-resistor-based bolometers.

Acknowledgements

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References

[1] M. Aoki, M. Takeda and N. Hiromoto, Inter-Academia 2012, 2A-3 (Budapest, 27 August 2012).

[2] N. Hiromoto, A. Tiwari, M. Aoki, H. Satoh, M. Takeda, and Hiroshi Inokawa, 39th Int. Conf. on Infrared, Millimeter, and THz Waves (IRMMW-THz 2014) R3/A-27.6 (Univ. Arizona, Tucson, AZ, USA, Sep. 14-19, 2014).

[3] A. Tiwari, H. Satoh, M. Aoki, M. Takeda, N. Hiromoto and H. Inokawa, Int.J. ChemTech Res. **7** (2014-2015) 1019.

[4] A. Tiwari, H. Satoh, M. Aoki, M. Takeda, N. Hiromoto and H. Inokawa, Aisan J. Chem. **25** (2013) S358.