Extended Abstracts of the 2017 International Conference on Solid State Devices and Materials, Sendai, 2017, pp729-730

PS-2-02

Optimization of Narrow Width Effect on Titanium Thermistor in Uncooled Antenna-Coupled Terahertz Microbolometer

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Abstract

The narrow width effect on the temperature coefficient of resistance (TCR) and resistivity on two different substrates (SiO_2/Si and SiN_X/SiO_2/Si) for titanium (Ti) with varied design width DW=100~5000 nm are investigated. Increased resistivity and reduced TCR of the devices with the decreased line width, is observed and fitted with empirical formulae, which hold well for different substrates. It is evident from electron backscatter diffraction (EBSD) results showing reduced average grain size from Ti film to Ti nanowire (DW=100 nm), the reduced TCR not dependent on crystal orientation or phase variation of material but can be correlated with reduced grain size due to reduction of width, in addition to the conventional size effect by the increased surface scattering.

1. Introduction

Microbolometer is a radiation detector for infrared (IR) and terahertz (THz) waves. Other than ultrahigh-speed wireless communications, there are several exciting applications of THz spectroscopy and imaging e.g. non-contact inspection of concealed weapons, explosives, examination of defects in edibles, biomedical applications like diagnosis of tumors, analysis of DNA, gene, etc. [1]. However, the present ability of THz technology is still inadequate for actual use as overall performance in terms of sensitivity and speed of measurements is insufficient. The current study deals with fabrication of high performance THz detectors in terms of sensitivity and response speed, for which optimization of narrow width effect is essential in thermistor material.

The important parameters for microbolometer fabrication is the temperature coefficient of resistance (TCR) of the thermistor, as the responsivity of the detector is proportional to the TCR and the noise equivalent power (NEP) is inversely 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 thermal 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 VO_x and a-Si, which have large 1/f noise. 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$^{0.5}$, f_c: 7 kHz [2,3]. Considering the importance of TCR, the width effects on the TCR and resistivity for titanium (Ti) thermistors are studied.

2. Experimental

The microbolometer fabricated this time consists of gold (Au) antenna, Ti heater, silicon dioxide (SiO_2)/ nitride (SiN_x) interlayer and Ti thermistor on SiO_2/SiN_x substrate. The detailed process steps including fabrication of the microbolometer by Ti thin film, are discussed elsewhere [4, 5]. Fig. 1 shows the devices fabricated for measurement of the width effect on the thermistor, including 1(a) straight and 1(b) meander structures 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.

For precision, results have been analyzed with average measured width (AMW) of thermistors by scanning electron microscopy (SEM), instead of design with (DW).

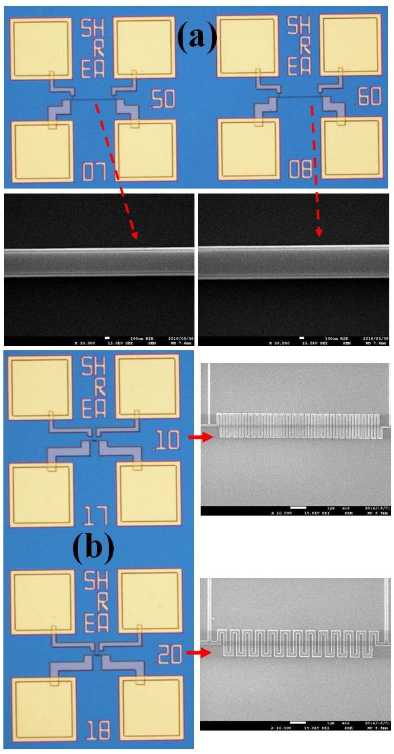

Fig. 1 OM image with enlarged FESEM image of (a) straight and (b) meander Ti devices with Au pads fabricated for measurement of the width effect on the thermistor.

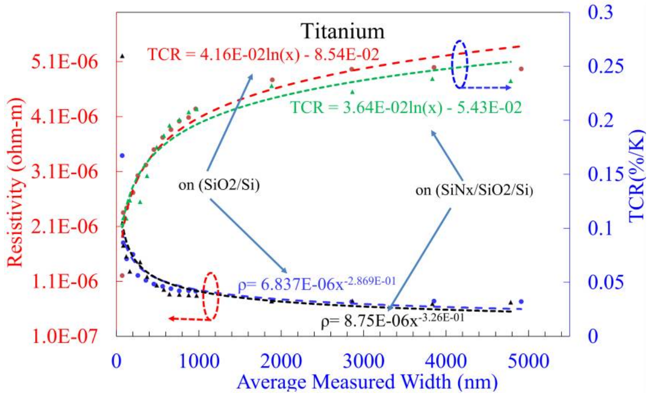

Fig. 2 Temperature coefficient of resistance (TCR) and resistivity (ρ) with the variation of average measured width for Ti thermistor with two different substrates.

3. Results and Discussion

Narrow Width Effect in Titanium Thermistors

Fig. 2 shows the TCR and resistivity with the variation of the AMW of the Ti thermistors, with length L=100 µm, height H=50 nm. Increased resistivity and reduced TCR of the devices with the decreased line width, is observed and could be fitted with empirical formulae, which hold well for different substrates.

Based on these formulae, the narrow width effect in Ti is the TCR reduction to 44% and the ρ increase by a factor of 3.6 at AMW=100 nm.

Width Dependence of Titanium Thermistor Material

Fig. 3 shows electron backscatter diffraction (EBSD) results showing phase map, local diffraction patterns, grain distribution and average grain size for (a) Ti film (150 x 150 µm area) and (b) Ti nanowire with design width DW=100 nm. In EBSD result it is observed that average grain size reduces form Ti film to Ti nanowire (DW=100 nm), however there is no substantial variation in crystal orientation or phase of material.

4. Conclusions

Increased resistivity and reduced TCR of the devices with the decreased line width, is observed, independent of different substrates. The narrow width effect found in Ti is the TCR reduction to 44% and the resistivity increase by a factor of 3.6. It is evident from electron backscatter diffraction (EBSD) results showing reduced average grain size form Ti film to Ti nanowire (DW=100 nm), the reduced TCR not dependent on crystal orientation or phase variation of material but can be correlated with reduced grain size due to reduction of width, in addition to the conventional size effect by the increased surface scattering. 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.

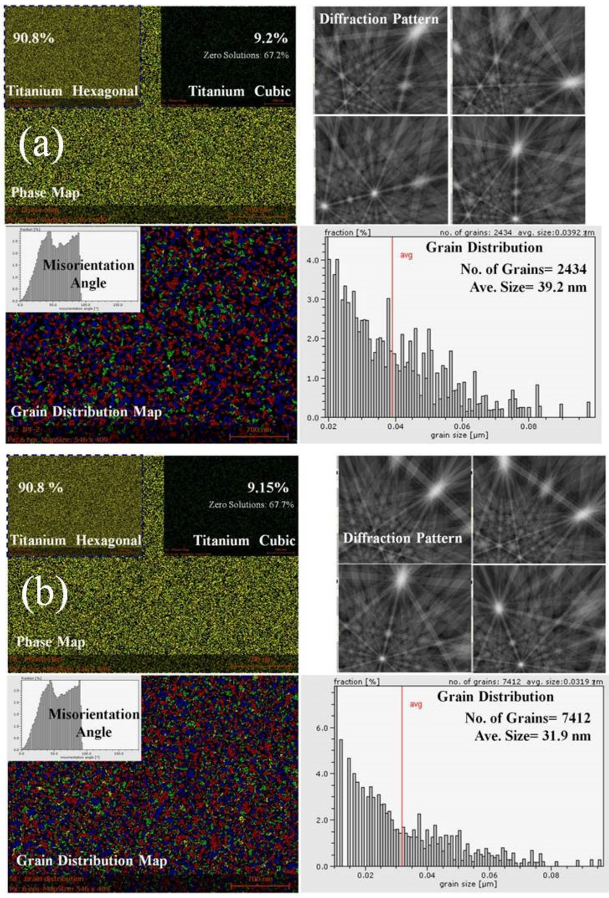

Fig. 3 Electron backscatter diffraction (EBSD) showing phase map, local diffraction patterns, grain distribution and average grain size for Ti (a) film (150 x 150 µm area) and (b) nanowire with width 100 nm.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number 15H03990, and the Cooperative Research Project of Research Institute of Electronics, Shizuoka University.

References

[1] N. Kukutsu, Y. Kado, Overview of Millimeter and Terahertz Wave Application Research, NTT Microsystem Integration Laboratories, Japan, https://www.ntt-review.jp/archive/ ntttechnical.php?contents=ntr200903sf1.html

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

[5] A. Banerjee, H. Satoh, A. Tiwari, C. Apriono, E. T. Rahardjo, N. Hiromoto and H. Inokawa, Jpn. J. Appl. Phys. **56** (2017) 04CC07.