Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp791-792

Effect of Joule Heating on Titanium Microbolometer with Integrated Heater and Thermistor

Durgadevi Elamaran[1], Ko Akiba[2], Hiroaki Satoh[3], Norihisa Hiromoto[2] and Hiroshi Inokawa[3]

[1] Graduate School of Science and Technology, Shizuoka Univ. Japan
[2] Graduate School of Integrated Science and Technology, Shizuoka Univ. Japan
[3] Research Institute of Electronics, Shizuoka Univ. Japan

Abstract

Titanium (Ti) microbolometer with the width of 2.7 μm and the length of 50 μm was fabricated to study the effect of Joule heating treatment. Noticeable change in thermistor resistance (R_0) 14 times larger from the initial resistance was observed after employing Joule heating. Negatively large TCR of -0.32 %/K was also observed after the treatment. As a result, responsivity (R_v) was improved 4.5 times from the pristine one. However, improvement could not be seen in noise equivalent power (NEP) due to the increased flicker noise.

1. Introduction

For resistive bolometers, the important parameters are the temperature coefficient resistance (TCR) and the resistance of thermistor material, since the responsivity (R_v) is proportional to them. Especially, the device performances of metallic bolometer directly get benefit from the improved TCR as the noise is generally small and is not correlated to the TCR. However, the TCR of thin and narrow metallic wires is reduced by the presence of defects or grain boundaries [1] and could be improved by annealing them out. Among various methods of annealing, such as furnace annealing, laser annealing and Joule heating by direct current through the resistor, we selected the last one considering the possibility of many trials in a single chip and *in-situ* monitoring of the annealing process. For this purpose, titanium (Ti) straight wire integrated thermistor and heater were fabricated with the width of 2.7 μm, length of 50 μm and the thickness of 77 nm. The device structure and its cross-sectional view are shown in Figs. 1 (a) and (b), respectively. Fig. 1 (c) represents the FE-SEM image of the Ti bolometer after Joule heating.

2. Experimental Methods

Fabrication Process

Oxidized silicon substrate with oxide thickness of 400 nm was taken for the fabrication of Ti microbolometers. Ti wire was formed by patterning of electron-beam (EB) evaporated Ti thin film using laser lithography and liftoff. After that the deep cavity for thermal isolation was formed by CHF_3 RIE and SF_6 plasma etching.

Measurement Procedure

An initial devices resistance, TCR, R_v and V_n was measured for the fabricated device. Then, Joule heating was employed on thermistor by applying large constant voltage instead of current so that thermal runaway does not takes place. To avoid the breakage of device, step by step constant voltage up to 6.6 V was applied for 30 s at every step. Same parameters were measured again to see the effect of Joule heating.

3. Results and Discussion

Figs. 2 (a) and (b) represent the measured electrical resistance before and after Joule heating. (c) and (d) represent the resistance and resistivity. Resistance becomes non-linear and large increment in resistance (from 252.6 to 3596 Ω) was observed after Joule heating. Resistance decreases with respect to temperature which implies negative TCR. Negatively large TCR (-0.32 %/K) as in semiconductor was observed, which may be caused by the impurity-induced phase change during the annealing. Further investigation on material characteristics is in process to understand the result. Change of current and resistance during the annealing for various constant step voltages is given in Fig. 3. Initially the resistance decreases as in ideal case and then increases with the applied voltage. The process was continued until the large change in resistance (R/R_0) during the annealing was observed.

The performance metrics such as R_v and NEP was also verified before and after Joule heating. R_v increased by 4.5 times from the initial measurement due to large thermistor resistance and TCR. However, significant improvement could not be seen in NEP, which degraded slightly due to the increased flicker noise at the low frequency even with reduced bias current to realize the constant power consumption. The calculated value of NEP from the V_n and R_v are 1.07 $\mu W/\sqrt{Hz}$ and 5.01 $\mu W/\sqrt{Hz}$ at 10 Hz, respectively.

Table 1 represents the summary of the annealed devices. Annealing was done on two more devices with identical structure and dimension, to confirm the reproducibility. The results are analogous in that the large change in resistance and negatively large TCR are obtained after the Joule heating. The factor $dR/dI^2/R_0^2$ represents the increased TCR and reduced thermal conductivity (k) of the Ti material for better R_v.

3. Conclusion

Effect of Joule heating was studied on 2.7 μm wide and 50 μm long Ti bolometers. Interestingly, drastic increase in thermistor resistance and negatively large TCR were observed after Joule heating, and resultantly R_v became 4.5 times larger although the NEP was degraded slightly. The Joule heating treatment is useful in increasing the bolometer output and relaxing the required input-referred noise of the readout circuit.

Reference

[1] A. Banerjee, et al., Sens. Actuator A-Phys., 273 (2018) 49-57.

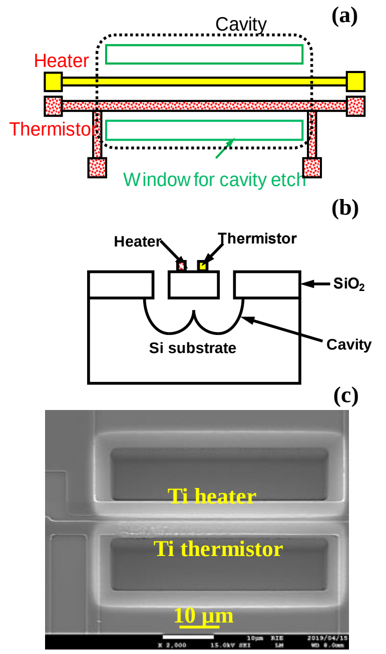

Fig. 1 (a) Fabricated device structure with integrated Ti heater and thermistor (b) cross-sectional view (c) FE-SEM image of Ti microbolometer after Joule heating

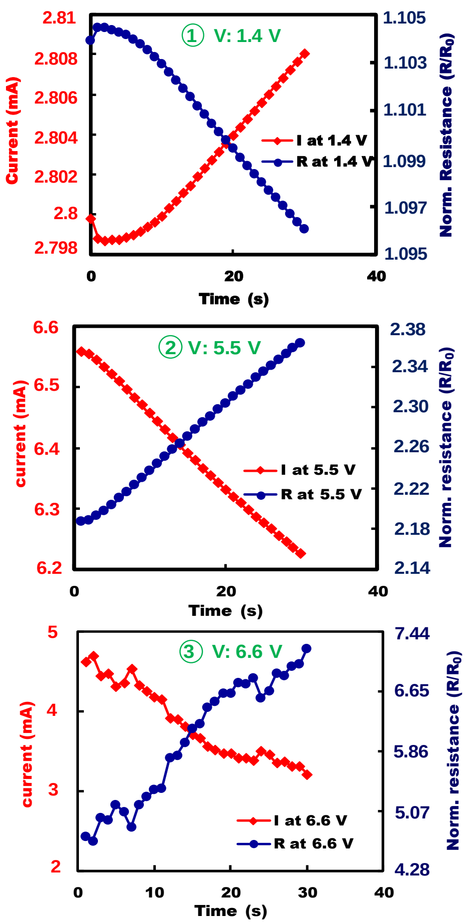

Fig. 3 Change of current and resistance during Joule heating, representing 3 different step voltages.

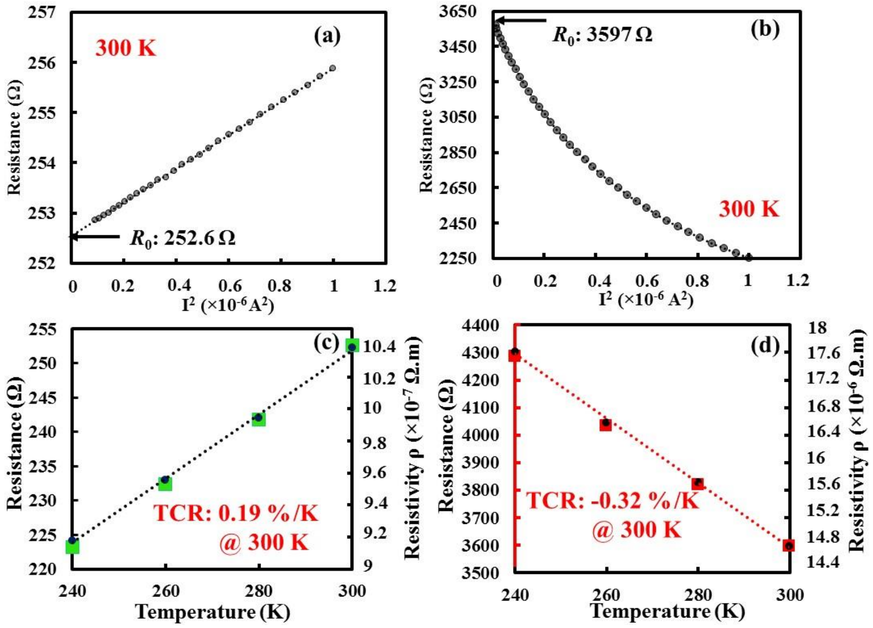

Fig. 2 (a) & (b) Electrical resistance of Ti thermistor before & after Joule heating (c) & (d) sheet resistance and resistivity of Ti thermistor before & after Joule heating.

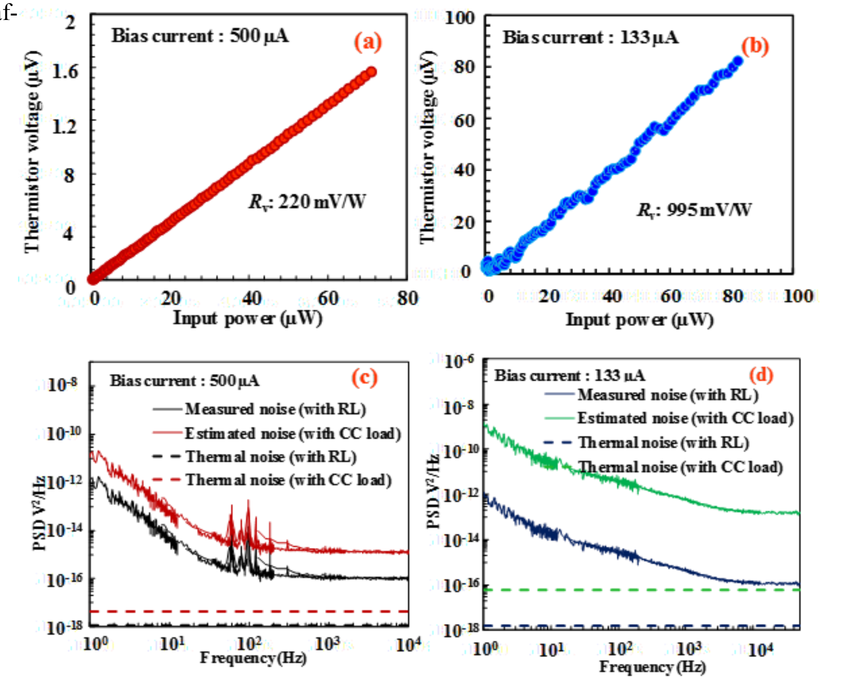

Fig. 4 (a) & (b) Electrical responsivity of Ti thermistor before and after Joule heating (c) & (d) Voltage noise of Ti thermistor before and after Joule heating with load resistance (RL =100 Ω) and constant current load (CC).

Table 1 Summary of annealed devices with identical device structure

Device position	Resistance (Ω)		TCR (%/K)		$dR/dI^2/R_0^2$ (1/W)	
	Before annealing	After annealing	Before annealing	After annealing	Before annealing	After annealing
UR	253	3597	0.19	-0.31	52.2	-249
UL	254	3140	0.19	-0.33	52.9	-178
LR	250	4224	0.19	-0.5	47.8	-864