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Coupled Physics Analyses of VO_x-Based, Three-Level Microbolometer

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As an uncooled infrared (IR) detector, a vanadium-oxide(VO_x)-based microbolometer plays a very important role in the emerging IR imaging technology due to its low cost, small size, simple system-architecture, and etc. As the thermal conductance comes into conflict with the fill factor in the conventional two-level microbolometer structure, a three-level microbolometer structure is proposed using the same active material of VO_x. Coupled physics analyses of the proposed three-level device structure were carried out thermo-mechanically and electrostatically. The results of steady-state analyses show that the temperature increase and the resistance change amount to 29.3 mK/nW and 0.079 %/nW respectively, when the microbolometer is exposed to IR incidence. From the transient coupled physics analyses, the thermal conductance and time constant of the device were obtained as 3.4×10^{-8} W/K and 4.53 ms respectively. The obtained parameters are comparable to those of a two-level structure having 4 times larger area.

Keywords: microbolometer, VO_x, Coupled physics, FEM

1. INTRODUCTION

During the past few years, mirobolometers have attracted increasing attention for various applications such as military, automotive, security and surveillance, and so on.[1] Also micro-electromechanical system (MEMS) technology, which has been widely used in sensor applications,[2] makes a microbolometer smaller, cheaper, and more sensitive; The related market is expected to grow rapidly. The importance in military application, however, prevents free interchange between countries and thus it's required to localize the related technologies. The thermoelectric properties of VO_x material play a key role in the operation of the MEMS-based microbolometers. Though there is another type of microbolometers based on amorphous silicon, but they have little market share. The incidence of IR is partially absorbed by the microbolometer, where the absorbed IR increases the device temperature. Therefore the electric conductivity of VO_x increases and thus the device's resistance is reduced. In order to develop a microbolometer, a coupled physics analysis is unavoidable to consider the interaction between thermomechanics and electrostatics. In this paper, a coupled physics approach is presented and a three-level microbolometer for high fill-factor is proposed through the coupled physics analyses.

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2. THREE-LEVEL MICROBOLOMETER

A two-level microbolometer structure, which was developed by Honeywell and is generally used worldwide, consists of a metallic reflector on an underlying silicon (Si) substrate to increase the IR absorption and an upper silicon nitride plate containing a VO_x-based resistor.[3] The nitride plate is suspended over the Si substrate through two legs. The VO_x-based resistor shows resistance change as mentioned above when IR energy is incident. In order to maximize a temperature change due to IR absorption, the plate should be thermally isolated from the substrate. And the design must be balanced between a low thermal conductance for thermal isolation and a high fill-factor for IR absorption. The two-level microbolometer, however, has structural limitation. We overcome this conflict by proposing a three-level structure as shown in Fig. 1. The plate is made in the third

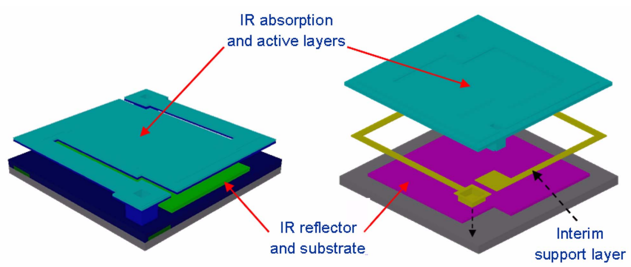

Fig. 1. Schematic view of VOx-based microbolometer: conventional two-level structure (left) and proposed three-level structure (right).

level while the legs are in the second level, which removes the conflict between the fill-factor and the low thermal conductance of the legs by decoupling the fill-factor and the thermal conductance. In the two-level structure, the second level is dominant layer related with both parameters. However, the fill-factor is controlled by the third layer while the thermal conductance by the second layer.

3. COUPLED PHYSICS ANALYSES

In order to analyze microbolometer performance, (a) the IR absorption, (b) the temperature change due to the absorbed IR energy, (c) the resistance variation induced by the temperature change, and (d) the self-heating effect caused by the bias condition should all be considered. As the IR absorption can be segregated from the other considerations, the conservation of electrical charge and the balance of thermal energy Eqs. 1 and 2, respectively, are coupled and solved using the finite-element method (FEM)

$$-\nabla \cdot \{\sigma(T)\nabla V\} = 0 \tag{1}$$

$$-\nabla \cdot \{k(T)\nabla T\} = \sigma(T)|\nabla V|^2 \tag{2}$$

where s is the electrical conductivity, T the temperature, V the potential (voltage), and k the thermal conductivity. The detailed analysis flow is shown in Fig. 2 and the related material properties[4] are summarized in Table 1, where TCR means the temperature coefficient of resistivity. The coupled physics analyses are comprised of a steady-state analysis, a transient analysis without self-heating effect, and a transient analysis including self-heating effect. Also a bias current of 20 µA amplitude is assumed to be applied for 65 µs.[5]

Through a steady-state analysis, a temperature change due to the IR absorption of 10 nW was obtained as shown in Fig. 3(a). The pixel size of a microbolometer is quite small, as small as 25 µm, and each material layer is very thin, less than 1 µm. Because of this, the max temperature change observed was 29.3 mK/nW and the resulting resistance variation was only 0.079%/nW as shown in Fig. 3(b). Thus microbolometers are built on the silicon readout integrated circuit (ROIC) substrate to minimize any noise.

From the transient response shown in Fig. 4, thermal conductivity and time constant were calculated as 3.4×10^{-8} W/K and 4.53 ms respectively. These are comparable to those of the published two-level device (3×10^{-8}~1×10^{-7}[W/K] and 10 ms to 40 ms) having 50 mm pixel size.[6] This means that it's possible to realize a much smaller microbolometer by using the proposed three-level structure. Furthermore, it is confirmed that the temperature change due to the IR absorption can be distinguished from that induced by Joule heating caused by the electric bias as shown in Fig. 5.

4. CONCLUSIONS

A coupled physics analysis method was presented for a

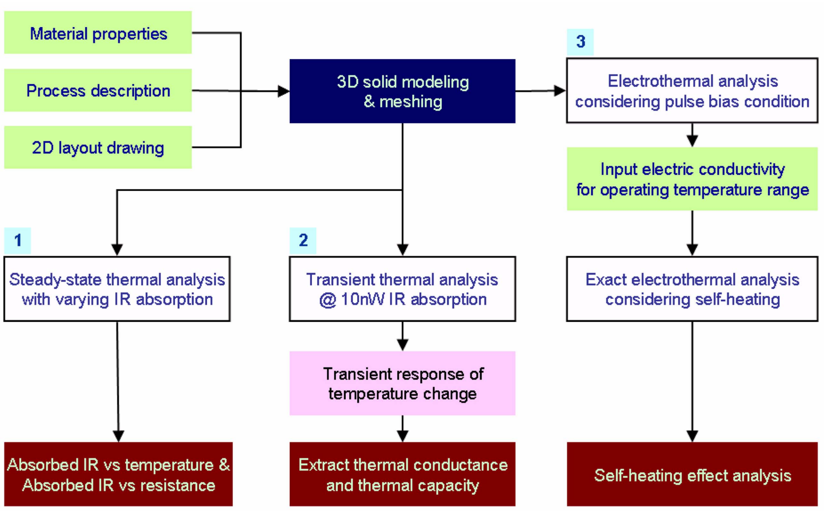

Fig. 2. Coupled physics analyses flow.

Table 1. Material properties used in the coupled physics analyses.

	density [kg/m^3]	specific heat [J/kgK]	thermal conductivity [W/mK]	resistivity [Ωcm]	TCR [%]
SiN	2400	691	1	-	-
VO_x	4340	465	22	1.1×10^{-4}	-3
NiCr	8410	466	13	0.6	-

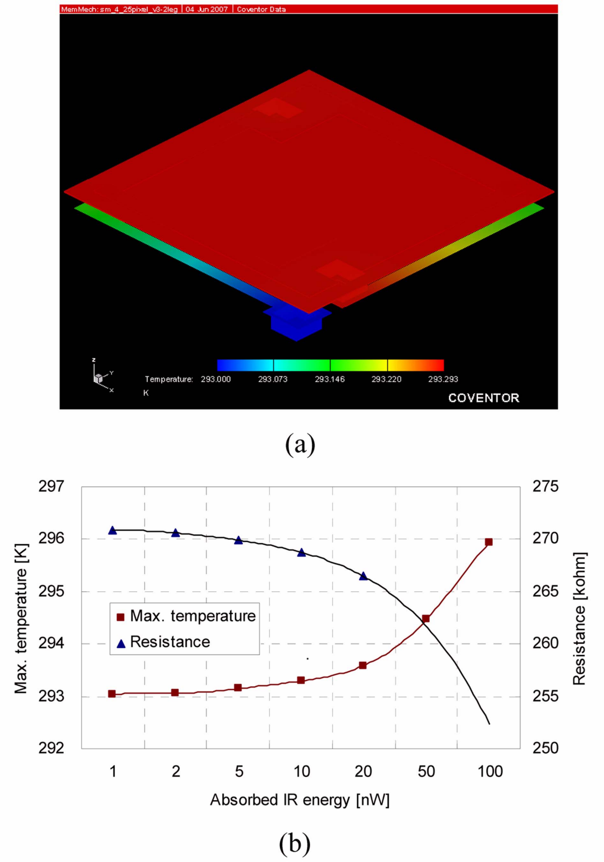

Fig. 3. Steady-state responses: (a) Temperature distribution over the microbolometer at 10nW IR absorption, (b) Max. temperature and resistance as a function of the IR absorption.

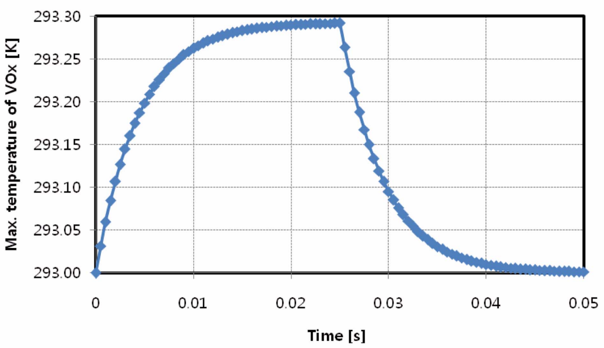

Fig. 4. Transient response assuming 10nW IR absorption but no self-heating.

VOx-based microbolometer, where the conservation of electrical charge and the balance of thermal energy equations were considered. Through the coupled physics analyses, a three-level microbolometer structure was designed and analyzed to overcome the conflict between the fill-factor and the thermal isolation. The coupled physics analyses showed a temperature change of 29.3 mK/nW, a resistance variation of 0.079 %/nW, a thermal conductivity of 3.4×10^{-8} W/K, and a

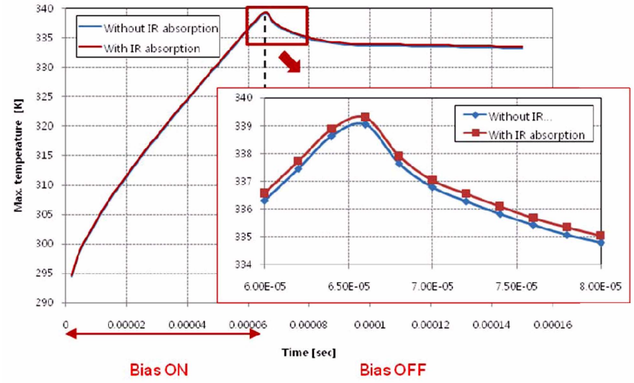

Fig. 5. Transient response assuming 10nW IR absorption and self-heating.

time constant of 4.53 ms. Comparing these performances to those of two-level devices, it's possible to reduce the device size to 1/4 the area while maintaining the device performance.

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