Effect of absorber layer placement on absorption coefficient of uncooled microbolometer detectors

ASLI SUDE YORUK, M. YUSUF TANRIKULU*
Department of Electrical-Electronics Engineering, Adana Alparslan Türkeş Science and Technology University, Adana, Turkey

This paper investigates the effect of the placement of a thin-film absorber layer on the absorption coefficient of microbolometers. The absorption variation is analyzed by changing the absorber layer position through simulations using the cascaded transmission line model. Relocating the absorber layer increases the absorption coefficient from 69% in the classical design to 85%, which corresponds to a 23% relative increase in detector performance. The novelty of this study lies in the investigation of absorber layer placement, which has not been addressed in previous works. This improvement, achieved by a simple rearrangement of the layer sequence, offers a cost-effective method to enhance microbolometer performance.

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1. Introduction

Infrared sensors are temperature-sensitive detectors used in thermal imaging and sensing applications such as target recognition in unmanned aerial vehicles, cancer cell detection in the healthcare field, and night vision in automotive systems [1-3]. In microbolometers, which are the most popular uncooled infrared sensors, radiation is absorbed by the pixel structure, and this absorption increases the temperature of the pixel body. The increase in temperature causes the resistor structure to heat up and the resistance value to change. This change in resistance is converted into an electrical signal and detected with the help of the CMOS readout circuit, resulting in an infrared image [4].

Some important parameters that affect the microbolometer performance are thermal conductance, absorption coefficient, and the active area of the detector [5]. The absorption coefficient depends on the optical properties of the materials used in the active area of the detectors and the layer thicknesses. A thin-film absorber layer generally located on the top of microbolometer is used to increase the absorption coefficient of the microbolometer detector [4-6]. One way to cost-effectively improve the performance of microbolometers is to increase the absorption coefficient without significant modification in fabrication process, hence for this purpose, the change in the absorption coefficient with the change in the placement of the thin-film absorber layer is examined.

In this paper, three different absorber layer placement configurations are examined. The goal is to understand the effect of layer positioning on absorption. The first configuration is the classically used design in microbolometers, with the thin-film absorber layer on the top. In the second configuration, the thin-film absorber layer is located just above the sacrificial layer that is below the other structural and active layers. The third configuration has double thin-film absorber layers, one on the top of the microbolometer and the other just above the sacrificial layer. Absorption coefficients of these three configurations have been simulated using Cascaded Transmission Line (CTL) model [7], and the placement of the absorber layer for the maximum absorption coefficient is determined. To our knowledge, the effect of the placement of absorber layer on the absorption coefficient has not been addressed before in the literature, and it is investigated for the first time in this study.

2. Microbolometer design

A standard microbolometer structure which is the most known and used structure in the infrared imaging systems is chosen for simulations. The layers used in the microbolometers and the properties (physical and optical) of these layers are taken from previous studies with successful fabrication processes to obtain more realistic simulation results [7]. YBaCuO (YBCO) layer with a thickness of 0.28 µm is used as the active material, while Si_3N_4 layer with a thickness of 0.15 µm is used as the structural material. The thickness of the sacrificial layer is taken as 2.5 µm since it is quarter of the target wavelength, and the thin-film metallic absorber layer (TiN) with a sheet resistance of 377 Ω/sq is used in the simulations. The pixel size is chosen as 17 µm to be close to the state-of-the-art dimensions and the minimum feature size is chosen as 0.5 µm. Microbolometer structure is divided into two regions (instead of four as in the referred study) with different layer configurations in order to simplify the simulations. Fig. 1 shows the layout of the designed microbolometer structure and the regions with different layer configurations. From the layout it is calculated that the total area of the body of the microbolometer is 167 μm^2 where the area of Region 1 is 164.5 μm^2, while the area of Region 2 is 2.5 μm^2.

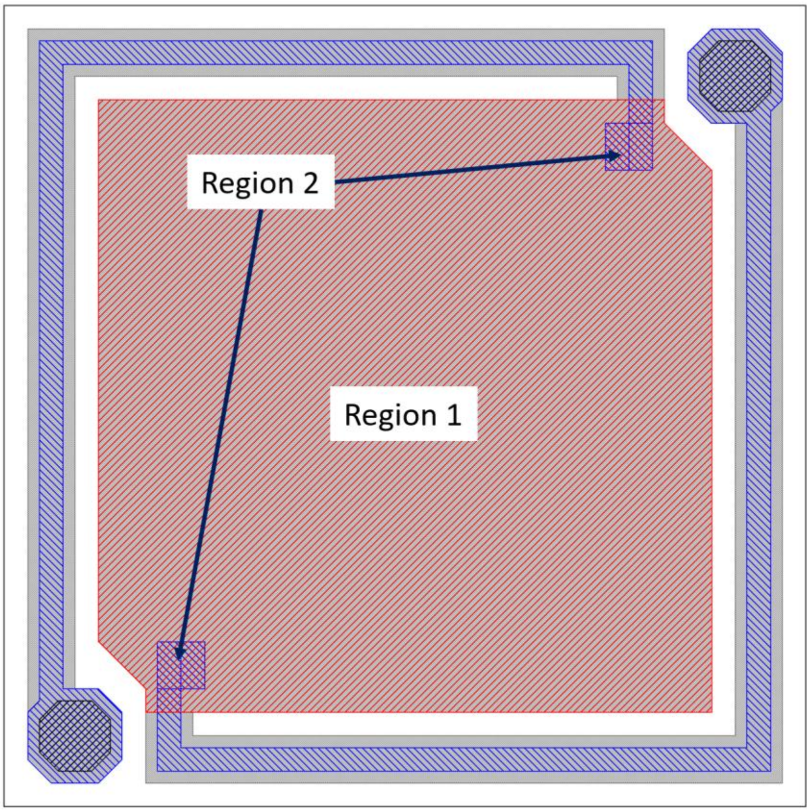


Fig. 1. Layout of the designed microbolometer detector and the different regions used in the simulations (colour online)

3. Structures formed by changing layer positions

In microbolometers, the thin-film absorber layer plays a crucial role in absorbing the incoming infrared radiation. In the classical microbolometer design, the absorber layer is located on the top surface. To investigate the impact of the absorber layer position, three-layer configurations are constructed with varying absorber layer locations. Fig. 2 gives the cross-sectional view of these layer configurations for Region 1 and Table 1 presents the layer sequence of different configurations for Region 2.

Configuration 1 is the classically used design where the thin metallic film absorber layer is on the top. Placing the absorber layer on the top surface ensures the impedance matching between the free space and the microbolometer structure. This minimizes the reflection losses and increases the optical absorption efficiency [8].

Configuration 2 is the design where the thin-film metallic absorber layer is just above the sacrificial layer, which is under the other layers of the microbolometer detector. In this design the impedance matching of free space with microbolometer structure is obtained for the infrared radiation reflected from the mirror under the detector [9].

Configuration 3 has double thin-film metallic absorber layers. The first absorber layer is located on top of the microbolometer surface, while the second layer is positioned just above the sacrificial layer, which serves to enhance overall energy absorption. The absorber layers are used by reducing their thickness by half (making the sheet resistance 754 Ω/sq which is twice the original value) in order not to cause reflection with too much metallic layer in the detector.

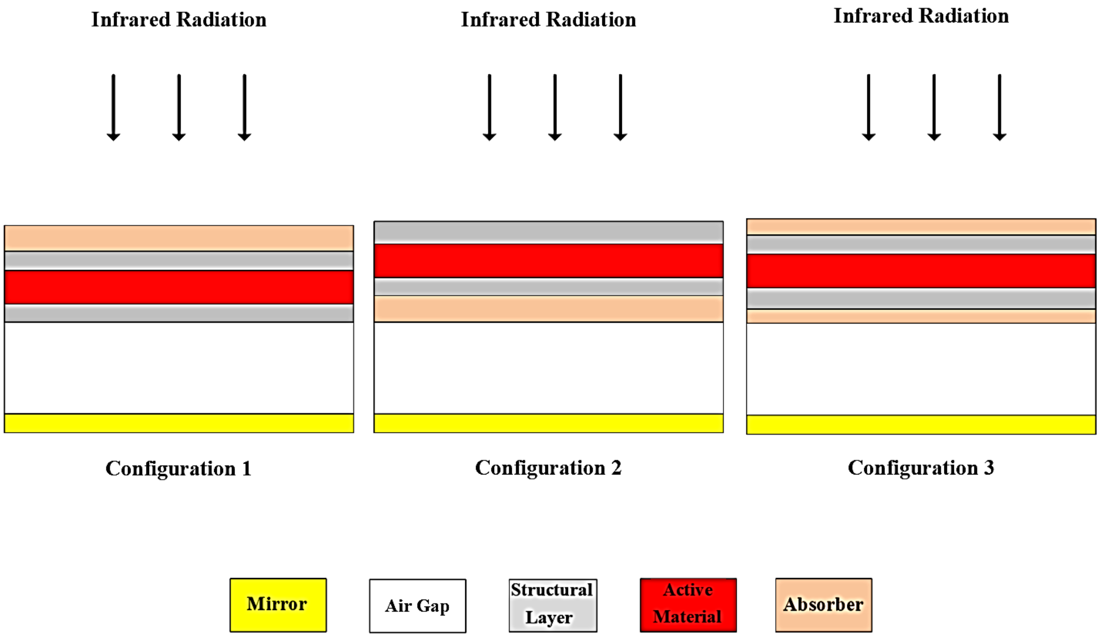


Fig. 2. Cross sectional view of the different layer configurations for Region 1 given in the layout (colour online)

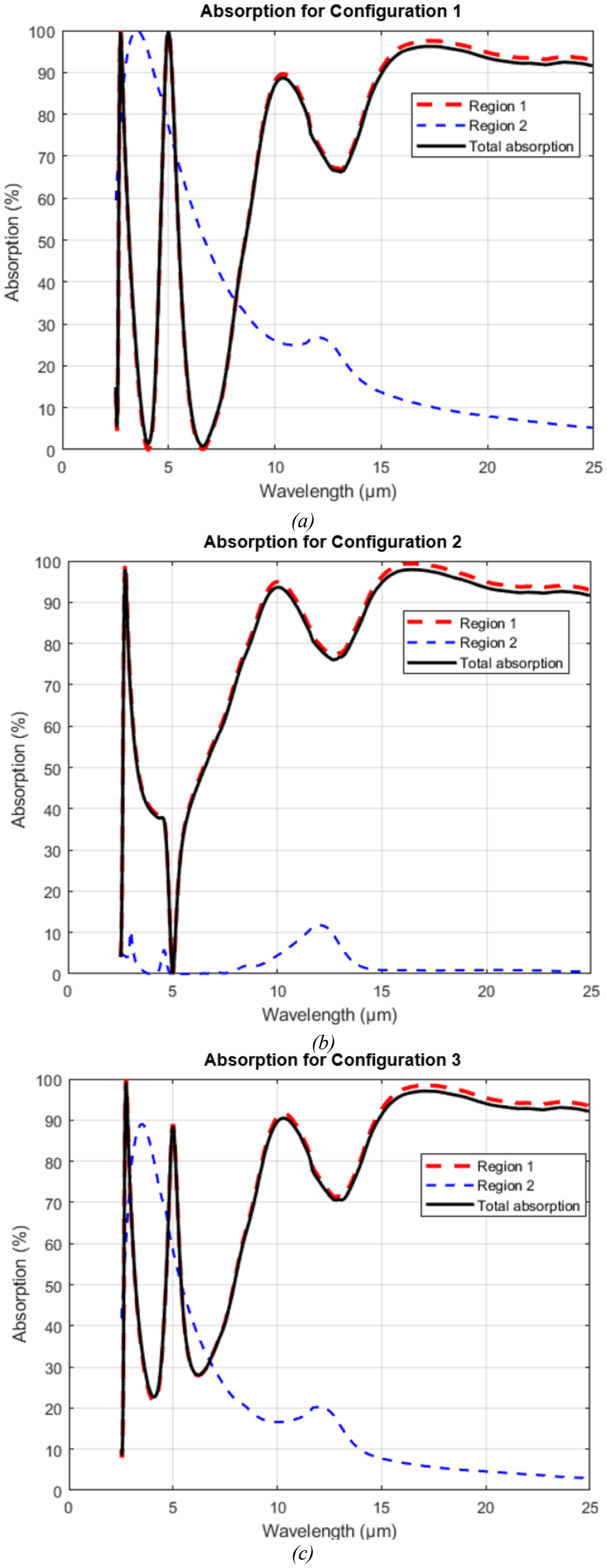
Table 1. Layer sequence of Region 2 for different configurations

Configuration	Layers
1	Absorber Layer – Structural Layer – Active Layer – Electrode Metal – Structural Layer – Air Gap – Mirror
2	Structural Layer – Active Layer – Electrode Metal – Structural Layer – Absorber Layer – Air Gap – Mirror
3	Absorber Layer – Structural Layer – Active Layer – Electrode Metal – Structural Layer – Absorber Layer – Air Gap – Mirror

3. Results and discussion

Three different configurations are simulated using the physical parameters given in Section 2. Fig. 3 gives the absorption coefficients for different layer configurations and different regions of the microbolometer detectors. In all configurations, the absorption characteristic is mostly determined by Region 1, which covers the largest surface area of the detector. This is because the area of Region 2 is designed to be very small since it includes a metal reflection layer before the air gap, and the effect of anti-resonant structure due to quarter wavelength is not observed. Fig. 4 gives the total absorption amount of three different layer configurations with the changing wavelength. In Configuration 1, the average absorption between 8-12 µm wavelength range is 69%, while it reaches around 87% at 10 µm wavelength. In Configuration 2, the average absorption between 8-12 µm wavelength range is around 85% while it is 94% at 10 µm wavelength. Configuration 3 gives an average absorption of 77% in the same wavelength range while the absorption coefficient is around 90% at 10 µm wavelength. By changing just the position of the absorber layer, a 16% increase in the absorption coefficient is observed in Configuration 2 when compared to the Configuration 1 which is the classical design. By using the double absorber layer with half thickness, the increase in 8-12 µm wavelength range is simulated to be approximately 8%. These results show that it is possible to obtain more than 23% performance increase in microbolometer structures by just changing the placement of the thin-film metallic absorber layer.

Besides the absorption performance, the layer configurations also differ in terms of practicality and implementation. The classical configuration is widely used due to its simplicity and compatibility with standard microbolometer fabrication processes. The second configuration does not introduce any additional processing steps, since only the placement of the existing layers is rearranged. Therefore, Configuration 2 maintains the same fabrication cost and complexity as the classical design while providing a significant improvement in absorption, which represents a major practical advantage and one of the key novelties of this study. Configuration 3 includes two absorber layers, and although the thickness of each absorber is reduced to minimize added thermal mass and metallic content, this configuration still requires an additional deposition and alignment step, which slightly increases fabrication complexity and may affect process yield. Consequently, Configuration 2 offers the best trade-off between performance improvement and manufacturability.



(c)

Fig. 3. Absorption simulation result of the microbolometer detectors with different layer configurations (colour online)

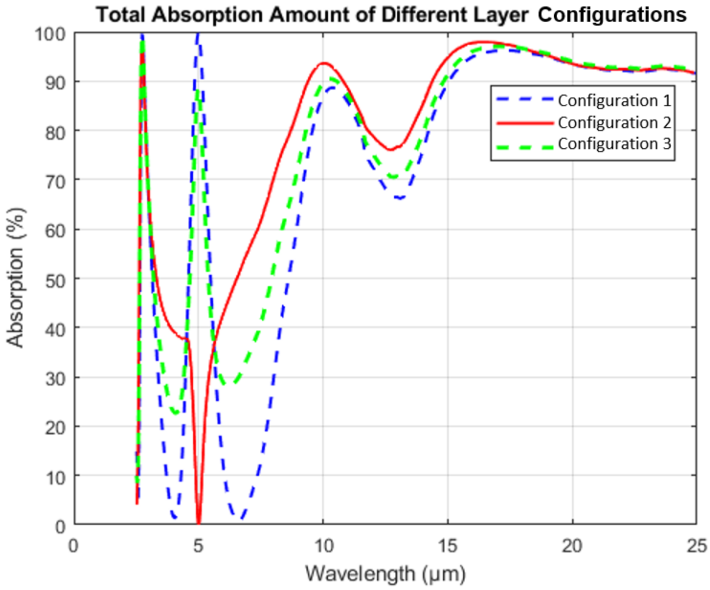


Fig. 4. Total absorption amount of different layer configurations (colour online)

4. Conclusion

This paper presents a new approach for microbolometer fabrication that demonstrates the effect of the placement of the thin-film absorber layer on the absorption coefficient of detectors. The absorption coefficients of different combinations of layer placements are simulated using the characteristic impedance values of each layer based on the CTL model. In comparison to the generally used Configuration 1, an increase of 16 percentage points in absorption coefficient is observed, resulting in a 23% improvement in microbolometer performance for Configuration 2, where the absorber layer is located just above the air gap. This enhancement, achieved by a simple change in the position of the thin-film metallic absorber layer, can be considered a cost-effective method to increase the performance of microbolometer detectors. Therefore, Configuration 2 offers the most practical and efficient solution, as it achieves a remarkable performance improvement without introducing any additional fabrication steps, providing the best trade-off between manufacturability and detector performance.

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[*] Corresponding author: mytanrikulu@atu.edu.tr