

**The 11th Asian-Australasian Conference on Precision Agriculture (ACPA 11)
October 14-16, 2025, Chiayi, Taiwan**

Thermoelectric Infrared Sensor Integrated with SHA Absorber

Yu-Nuo Liu¹, Zhi-Xuan Dai^{1*}

¹Department of Bio-Industrial Mechatronics Engineering, National Chung Hsing University,
Taiwan.

*Corresponding Author: enochliuc666@gmail.com

ABSTRACT

This paper details the design of a high-performance thermoelectric infrared (IR) sensor using the UMC 0.18 μm CMOS-MEMS process, targeting the 8–14 μm wavelength for applications like IoT. To enhance performance, the sensor integrates two key innovations: a Sub-Wavelength Hole Array (SHA) absorber and a novel double-layer thermopile structure with 64 pairs of thermocouples. Finite-Difference Time-Domain (FDTD) simulations show the SHA structure achieves an average IR absorptivity of 72.2%. Based on thermal analysis, the proposed double-layer design is expected to achieve a high responsivity of 54.7 V/W and a detectivity of $2.12 \times 10^8 \text{ cm}\cdot\text{Hz}/\text{W}$.

Keywords: CMOS-MEMS, Infrared Sensor, Thermopile.

INTRODUCTION

The growing demand for low-power, uncooled infrared (IR) sensors for applications like the Internet of Things (IoT) has highlighted the need for mass-producible solutions. Recent studies have focused on enhancing sensor performance through methods such as creating periodic surface cavities to improve IR absorption or integrating novel materials like reduced graphene oxide (Chen et al., 2020; Li et al., 2023). Building on this foundation, this study presents a thermoelectric IR sensor designed using the UMC 0.18 μm CMOS-MEMS process, leveraging the platform's advantages in cost-effective fabrication and System-on-Chip (SoC) potential.

The objective of this research is to enhance sensor performance by introducing two key design features. We integrate a sub-wavelength hole array (SHA) to improve IR absorption in the 8–14 μm range and implement a novel double-layer thermopile to significantly boost thermoelectric conversion efficiency, aiming to substantially improve the sensor's responsivity and detectivity.

MATERIALS AND METHODS

The infrared sensor was designed for the UMC 0.18 μm 1P6M CMOS-MEMS standard process, as shown in Fig.1(a). This suspended membrane provides thermal isolation and is created via a post-CMOS process, which involves anisotropic etching of the SiO_2 layers followed by isotropic etching of the silicon substrate. To enhance performance, the design incorporates a Sub-Wavelength Hole Array (SHA) within the SiO_2 absorption layer to maximize IR absorption efficiency. Two thermopile configurations using Poly1 and Metal1 were compared: comparing a 32-pair single-layer design with a 64-pair double-layer one, the thermopile types are shown in Figures 1(b) and 1(c). Device performance was modeled using Ansys software. The optical properties of the SHA were simulated with Ansys Lumerical FDTD, calculating absorptivity (A) from reflectance (R) and

transmittance (T) using $A = 1 - R - T$ for an 8-14 μm incident plane wave. Steady-state thermal analysis was performed in Ansys Workbench to determine the temperature gradient (ΔT) across the thermocouples. This simulation applied a radiant heat flux of $189.97 \text{ pW}/\mu\text{m}^2$ to the absorber, with the substrate maintained at 25°C and an air convection coefficient of $50 \text{ pW}/\mu\text{m}^2\text{K}$.

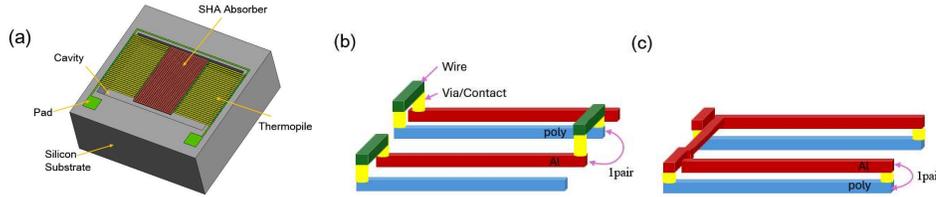
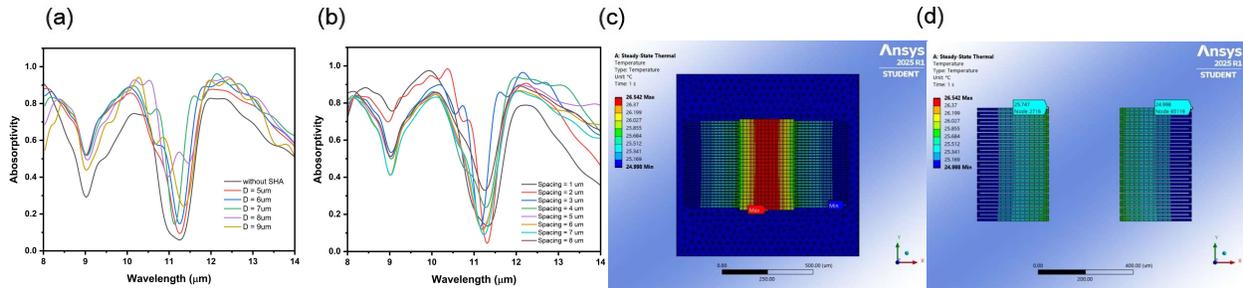


Fig.1 (a) Design Model, (b) Single Layer Thermopile, (c) Double Layer Thermopile.

RESULTS & DISCUSSION

The simulation results validate the proposed design. Optical analysis showed the Sub-Wavelength Hole Array (SHA) enhances the average IR absorptivity from 57.8% (plain structure) to 72.2% in the 8–14 μm range. This improved absorption is critical for maximizing the initial thermal signal. Steady-state thermal simulations predicted an effective temperature difference (ΔT) of 0.75°C across the thermocouples, as shown in Fig.2(d). Consequently, the proposed double-layer thermopile is calculated to achieve a high responsivity (R_v) of 54.7 V/W and a specific detectivity (D^*) of $2.12 \times 10^8 \text{ cm}\cdot\text{Hz/W}$. This performance is approximately double that of a conventional single-layer design and surpasses values reported in several recent works, confirming the effectiveness of our integrated design approach.



REFERENCES

- Chen, S.-J., and B. Chen. 2020. Research on a CMOS-MEMS infrared sensor with reduced graphene oxide. *Sensors* 20(14): 4007.
- Li, Y.-C., et al. 2023. Periodic cavities on the IR-absorber for responsivity enhancement of CMOS-MEMS thermoelectric IR sensor. In *Proc. 2023 IEEE 36th International Conference on Micro Electro Mechanical Systems (MEMS)*, 1143-1146. Munich, Germany: IEEE.