ECSA-11 2024 Conference

The Influence of MIM Metamaterial Absorbers on the Thermal and Electro-Optical Characteristics of Uncooled CMOS-SOI-MEMS Infrared Sensors

Moshe Avraham, Mikhail Klinov and Yael Nemirovsky

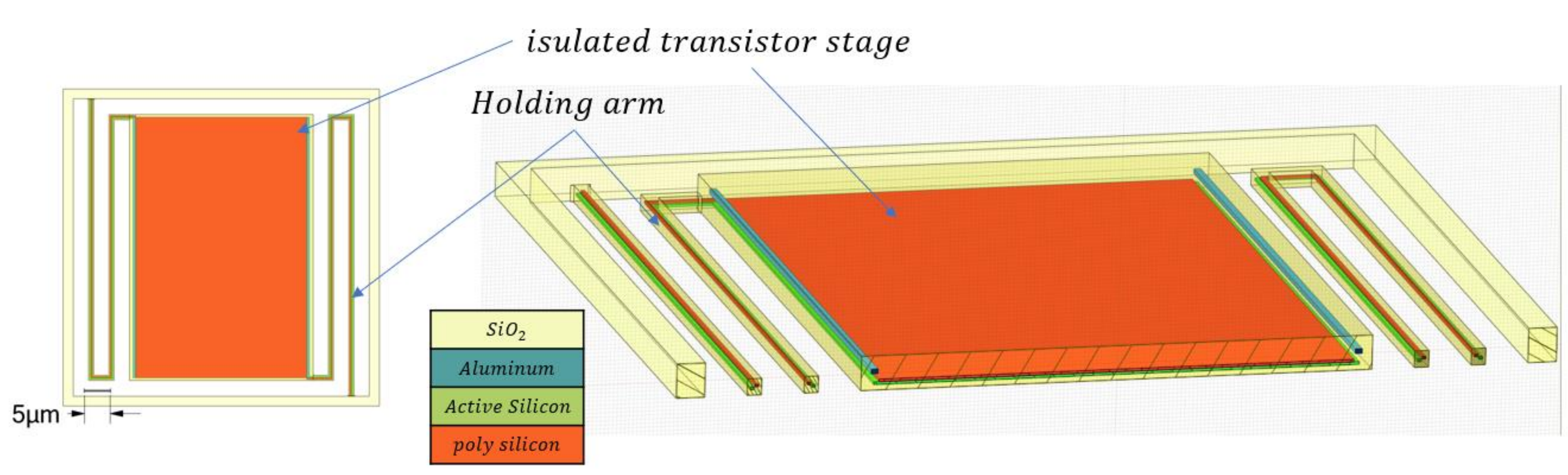
Electrical and Computer Engineering Department, Technion - Israel Institute of Technology

Abstract

Uncooled IR sensors, traditionally dominated by bolometers, thermopiles, and pyroelectrics, face size limitations for wearable and mobile applications. The emerging TMOS sensor, based on CMOS-SOI-MEMS, offers a promising solution. However, miniaturization challenges sensor sensitivity. Metamaterials, engineered materials with unique electromagnetic properties, can enhance sensitivity while enabling size reduction. This study investigates the impact of MIM metamaterial absorbers on the thermal properties (Gth, Cth, τ_{th}) and optical absorption efficiency of CMOS-SOI-MEMS sensors in the mid-IR region. We explore the effects of material selection, layer thickness, and metamaterial geometry on sensor performance using analytical and 3D thermal and electro-optical modelling and simulation.

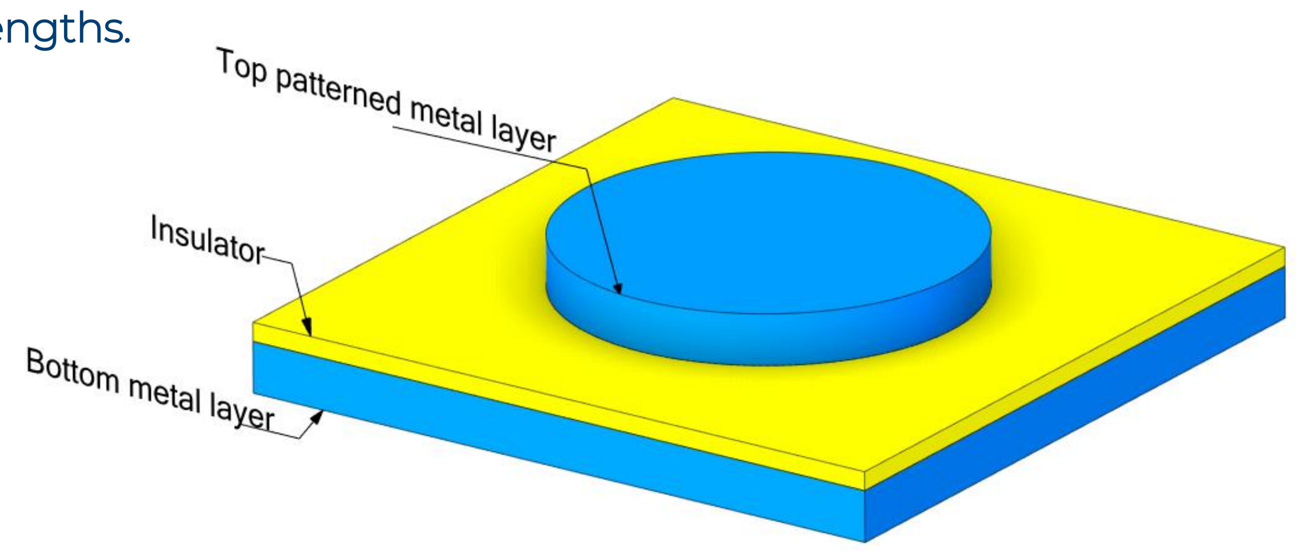
Introduction

- Uncooled infrared (IR) sensors are essential for various applications such as automotive, IoT, and wearable devices.
- Miniaturization is crucial, but smaller sensors often suffer from reduced sensitivity.
- This research explores the use of metamaterials to improve the performance of CMOS-SOI-MEMS IR sensors.



Metamaterials and Metal-Insulator-Metal Absorbers

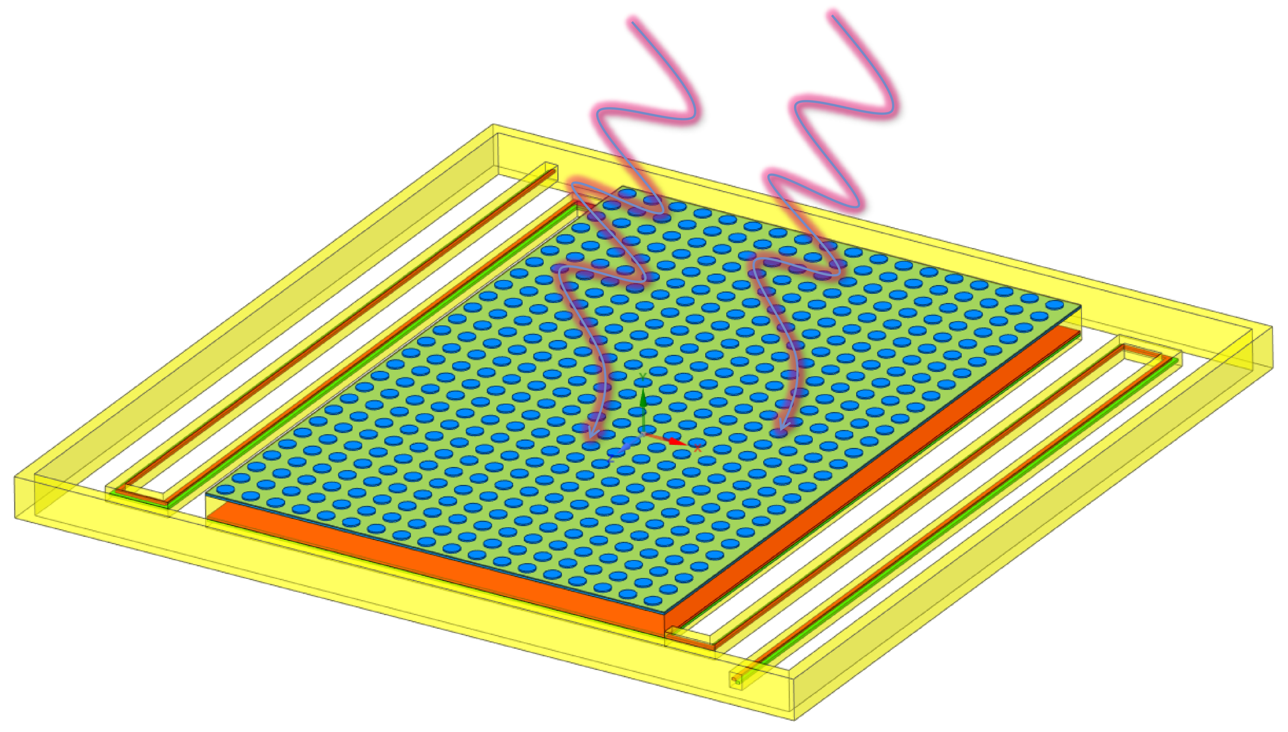
- Metamaterials are engineered materials with unique electromagnetic properties not found in nature.
- MIM (metal-insulator-metal) absorbers can be designed to perfectly absorb light at specific wavelengths.



Design

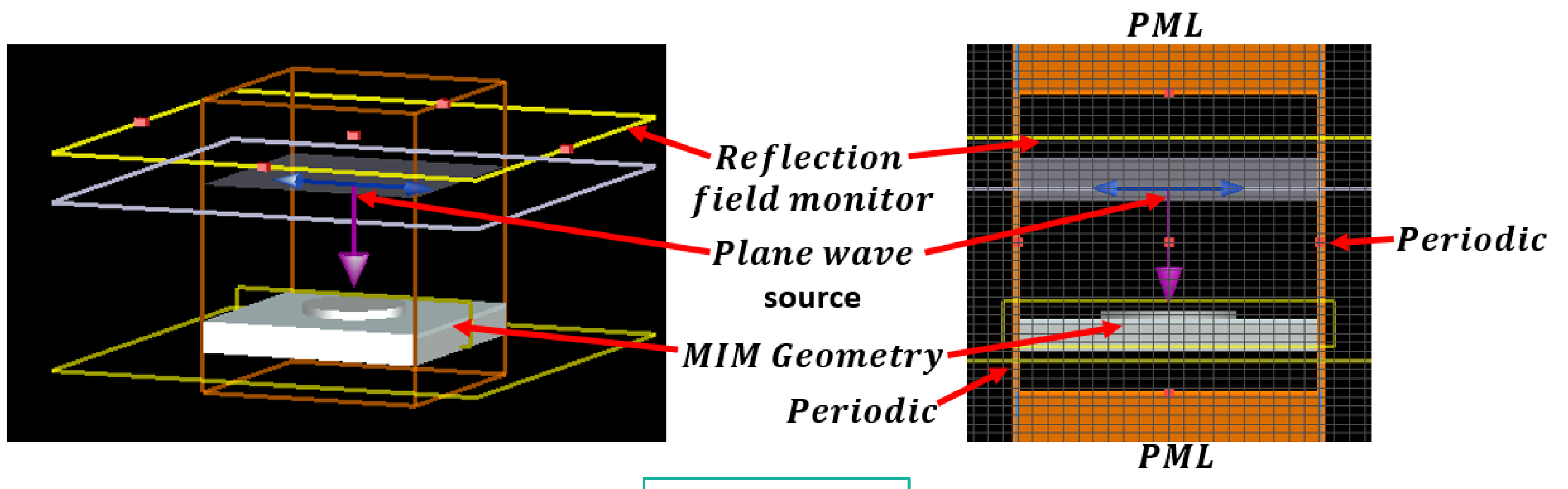
Integrating MIM Absorbers with CMOS-SOI-MEMS Sensors

- This study investigates the effects of integrating MIM absorbers on the thermal and electro-optical characteristics of TMOS sensors.
- FDTD simulations were used to optimize the MIM design for maximum absorption in the mid-infrared range.
- Thermal simulations were conducted to assess the impact of the MIM absorber on the sensor's thermal performance.



Methodology

Electromagnetic Simulation and Modelling Techniques



$$A = 1 - R$$

Thermal Simulation and Modelling:

- **Power balance equation:**

$$P_{absorbed} = C_{th}\frac{d\Delta T(t)}{dt} + G_{th}\Delta T(t)$$

- $P_{absorbed}$ = Absorbed optical power
- *Cth*: Thermal capacitance of the device
- *Gth*: Thermal conductance of the device
- ΔT: Time-dependent temperature change

- **Thermal time constant:**

$$\tau_{th} = C_{th}/G_{th}$$

- **Thermal Conductance:**

$$G_{th,arm} = \frac{k_{arm}A_{arm}}{L_{arm}} = \frac{1}{L_{arm}}\sum_{i=1}^{N} k_i A_i$$

- Primarily determined by holding arms due to deep vacuum packaging and device dimensions
- *k*: Thermal conductivity of material i
- *A*: area that heat flows through of material i
- Larm: holding arm length

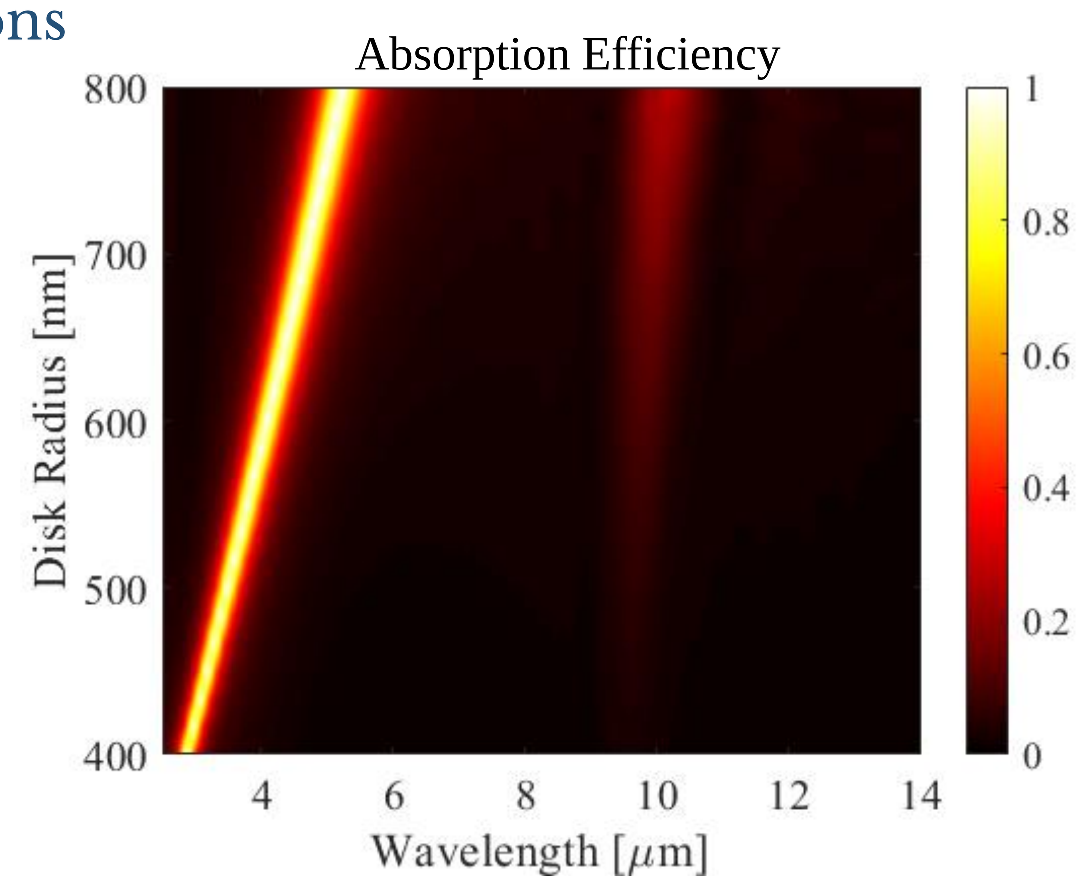
- **Thermal Capacitance:**

$$C_{th} = \rho c V = \sum_{i=1}^{N} \rho_i c_i V_i$$

- Primarily determined by the isolated transistor stage
- ρ_i : mass density of material i
- c_i : specific heat capacity of material i
- V_i : Volume of material i

Results and Conclusions

- The results show near-perfect absorption (greater than 98%) in the mid-infrared region
- The radius of the MIM disk affected the absorption spectrum. Larger radii caused redshift and decreased quality factor.



- The MIM structure has a minimal impact on thermal conductance, but it influences thermal capacitance and time constant.
- The MIM insulator thickness significantly affects thermal performance, with thicker structures increasing thermal time constants.
- Metal choice has a minimal impact on thermal performance.

	Units	Without MIM	With MIM
η - Optical absorption efficiency	$N.A$	0.77	0.9871
G_{th} – Thermal conductance	$\frac{W}{K}$	1.0069×10⁻⁷	1.0089×10⁻⁷
τ_{th} - Thermal time constant	ms	86	96.25
$R_T(\omega = 0) = \frac{\Delta T}{P_{opt}} = \frac{\eta}{G_{th}}$ DC temperature responsivity	$\frac{K}{W}$	7.65×10⁶	9.78×10⁶

Acknowledgements

The authors thank Prof. Nemirovsky's group for their support and advice, and the VLSI lab for providing the necessary infrastructure..