**PROJECT OVERVIEW**

**Project Title**: Thermal emission control using mid-infrared metasurface micro-sources

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**Aim:** This project aims to design and simulate mid-infrared metasurface thermal emission micro-sources for targeted spectroscopic gas sensing.

**Objectives:**

1. To explore the design degrees-of-freedom offered through high-index metasurfaces for controlling emissivity (i.e. thermal emission).
2. To investigate how metasurface thermal emission responses can be tailored across a wide waveband (2-20 um), from narrowband to multi-band output.
3. To develop inverse-designed metasurfaces which provide multi-band emission responses matched to multiple gas absorption signatures.

**Background:** Mid-Infrared (MIR) spectroscopy is a powerful tool for identifying biochemical substances by their unique vibrational absorption signatures (wavelengths ~2-20 µm), playing a crucial role in biomedical diagnostics, remote sensing, and environmental monitoring. The efficiency, miniaturization, and cost-effectiveness of MIR radiation sources are essential for advancing MIR technology [1]. Unfortunately, light emitting diodes (LEDs) and lasers are exorbitantly expensive, lack broad spectral coverage across the entire waveband, often require rare earth elements, and are bulky. *Metasurfaces*—the 2D counterparts of 3D metamaterials—are engineered to possess unique properties not found in nature by manipulation of electromagnetic waves at the nanoscale [2]. The thermal emission of a *hot object* is related to its temperature and emissivity; metasurfaces can be used to tailor the emissivity. At room temperature, or by heating metallo-dielectric metasurfaces (electrically, optically or otherwise), it's possible to *manipulate* the resultant thermal emission beyond that of classical isotropic, broadband and unpolarized Blackbody emission [3].

**Project:** Metasurface micro-sources offer a pathway to significantly enhance miniaturized MIR spectroscopy applications, yet no such single-chip emission source covering the entire MIR has been realized thus far. The project will use commercial electromagnetic simulation software to design tailorable emissivity metasurface micro-sources operating across the MIR. The student will implement inverse-design optimization to generate a family of metallo-dielectric metasurface designs in which their emission responses are optimally targeted to several absorption bands of the same gas. In comparison to traditional 'single band' sensing systems, our approach aims to increase detection sensitivity and selectivity. The outputs will highlight the feasibility of thermal emission metasurface micro-sources for miniaturized, cost-effective light generation in MIR sensing/spectroscopy systems.

**Student and skills development:** The metasurfaces will be designed using finite difference time domain (FDTD) electromagnetic simulation software (Ansys Lumerical FDTD) with inverse-design including adjoint optimization methods implemented via Python (Pytorch integration). The student will develop electromagnetic computational and simulation skills, programming, data analysis and interpretation, and effective scientific communication.

**References:** [1] *Marris-Morini, D. et al. Nanophotonics (2018). [2] Wei, J. et al. J Appl Phys (2020). [3] Chu, Q. et al. Nanophotonics (2024).*