Spinning metasurface stack for spectro-polarimetric thermal imaging

Ziyi Yang, Xueji Wang, and Zubin Jacob
Elmore Family School of Electrical and Computer Engineering,
Birck Nanotechnology Center,
Purdue University, West Lafayette, Indiana 47907, USA
zjacob@purdue.edu

Spectro-polarimetric imaging in the long-wave infrared (LWIR) region plays a crucial role in applications from night vision and machine perception to trace gas sensing and thermography (Fig. 1a). However, the current generation of spectro-polarimetric LWIR imagers suffers from limitations in size, spectral resolution, and field of view (FOV) (Fig. 1b-1d). While meta-optics-based strategies for spectro-polarimetric imaging have been explored in the visible spectrum, their potential for thermal imaging remains largely unexplored. In this work, we introduce an approach for spectro-polarimetric decomposition by combining large-area stacked meta-optical devices with advanced computational imaging algorithms [1].

The architecture of our spinning-metasurface based spectro-polarimetric imaging system is depicted in Fig. 1e. It comprises a broadband linear polarizer, three anisotropic and dispersive metasurfaces, and an LWIR imaging sensor. The polarizer is utilized to polarize the incoming thermal radiation signals, and the metasurfaces are utilized to realize spectral filtering. We design the metasurfaces with high anisotropy to produce distinct spectral responses for orthogonal polarizations. Additionally, the metasurfaces' dispersion rotates different wavelengths of radiation to varying polarization orientations. By using the metasurfaces in tandem and axially spinning the polarizer and metasurfaces to different angles, we obtain tunable transmission spectra that sample the incident thermal radiation in its spectral and polarimetric channels. We then reconstruct unknown spectra of imaging targets using compressive sensing and dictionary learning algorithms. Combining these two algorithms enables accurate and stable spectral reconstruction in the presence of noise and measurement errors.

Our spinning-metasurface-based spectro-polarimetric stack is compact (<10×10×10cm) and robust, and it offers a wide field of view (20.5°). Our approach represents a significant advance in the field of thermal imaging for a wide range of applications including heat-assisted detection and ranging (HADAR).

[1] Wang, X. et al. (2024) 'Spinning metasurface stack for Spectro-polarimetric thermal imaging', Optica, 11(1), p. 73.

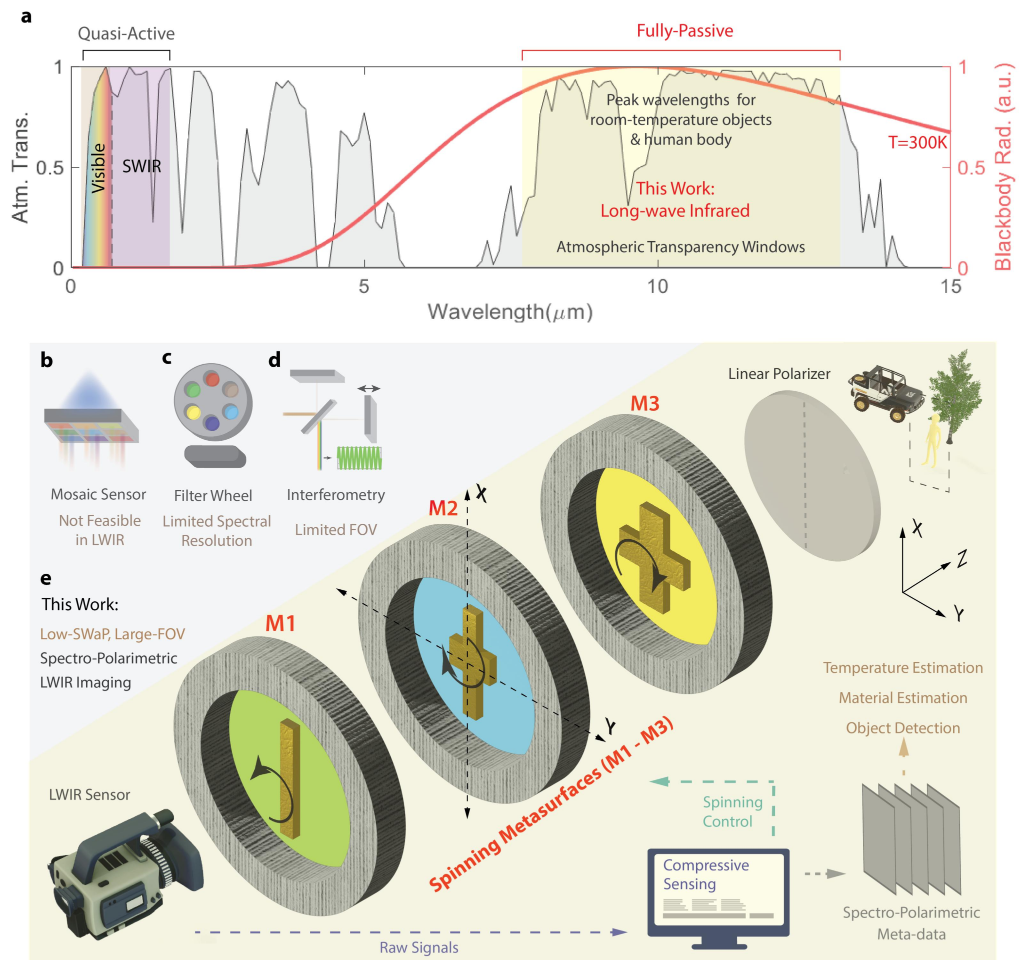

Fig. 1. Long-wave infrared (LWIR) spectro-polarimetric thermal imaging. (a) Room-temperature blackbody radiation (shown in red) and atmospheric transmission spectrum (shown as a shaded area). The LWIR spectral region is crucial for thermal imaging due to its peaked room-temperature thermal radiation spectrum and the atmospheric transparency window. (b)–(d) Conventional methods for spectral imaging, such as using (b) a mosaic sensor, (c) a filter wheel, or (d) interferometry, either pose limitations or are infeasible for LWIR thermal imaging. (e) In this study, we propose a new approach for spectro-polarimetric thermal imaging, achieved by combining large-area spinning metasurfaces and compressive sensing reconstruction algorithms.