Structured light generation and sensing with metasurfaces for THz communications

Optica Foundation Challenge: Information

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Introduction: The global free space optical (FSO) communications market is projected to reach 7 billion USD by 20230 with CAGR of 30%. Terahertz (THz) radiation, located in the wavelength range from 3 mm to 30 µm, between the microwave and infrared, holds the promise of hosting a wide range of new communications protocols. It provides larger bandwidth than current microwave wireless standards such as IEEE 802.11b WiFi while imposing minimal effects on the human body (as it is non-ionizing in nature) making it ideal for indoor and short-haul communications. Besides FSO communications, THz waves have been widely utilized in non-invasive imaging, remote sensing, and material identification. However, the widespread use of THz waves has been hindered by the shortage of affordable cameras at room temperature with high sensitivity, fast speed, and broadband operation. Moreover, current THz camera sensors can primarily detect intensity information without retrieving phase and polarization — missing two rich information carriers of light. The goal of this project is to develop efficient schemes for sensing and generating THz beams in order to facilitate their use in free space communications and beyond.

Objective: We propose the use of metasurfaces to convert any 1D THz power detector array to a full 2D wavefront camera. Metasurfaces refer to flat optics made of subwavelength-spaced arrays of patterned structures which can control the phase, amplitude, and polarization of incident light, point-by-point. Our proposed system is composed of a static metasurface and a power detector array (for e.g., Schottky diodes or bolometers). The metasurface performs a discrete set of operations on incoming light and projects the result into diffraction orders which can be captured by the detector. From this discrete set of intensity measurements, the full wavefront of the incident THz beam can be fully retrieved including its 2D intensity, phase, and polarization profiles over a broadband. Besides their use at the receiver end, our metasurfaces can be deployed at the source as a wavefront shaping platform to generate light with complex spatial structures such as vortex and vector beams, unlocking a gamut of structured light modes in the THz regime.

Plan: The duration of this project is 12 months. It combines concepts from signal processing, holography, and nanophotonics. We will utilize the recently developed THz laser source by the group of Prof. Federico Capasso at Harvard University. The wide tunability of this source in the 0.25-0.955 THz range (and beyond) makes it ideal for free space communications. The experiment will be performed in collaboration with Dr. Paul Chevalier who built this laser. The metasurfaces will be fabricated at the Center for Nanoscale Systems (CNS) at Harvard University following standard lithography, deposition, and etching protocols. To build and characterize our setup, we will purchase Schottky diodes, lens kit, polarization optics, and a THz camera. The project will also involve a collaboration with the group of Prof. Nader Engheta from the University of Pennsylvania who will contribute expertise in electromagnetic wave modelling at THz.

Impact: Efficient and versatile detectors and generators of THz waves will facilitate their widespread use in a variety of applications such as free space communications (including 6G and IoT), remote sensing, and non-invasive imaging. Furthermore, owing to their lightweight, our metasurfaces can address many challenges in drone-based sensing and space domain awareness. Lastly, given their CMOS compatibility and compact footprint, our flat optics enable a direct route to integration and large scale. With the abundance of efficient and compact THz sensors and modulators, we will take a key step towards solving one of the open challenges in optics related to affordable, secure, and fast information processing.