QUANTUM TECHNOLOGIES, METAMATERIALS, AND THE FUTURE OF CB SENSING

Photonic Crystal Fiber Optic Sensing Of Molecules With A Quantum Rectifying Infrared Metasurface

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Fiber optic-based detection of molecular threats is ideal for remote sensing. Optical fibers represent an extended standoff detector network covering a much greater area than point source detectors and are robust outdoors; e.g., tolerate wind in a ‘fence-line’ format. Building on years of experience with rectifying (nonlinear optical) metasurfaces [1-4] and colorimetric fiber-based DTRA-funded chemical sensing, we propose creating a new technology for sensing toxic molecules. A photonic crystal fiber (PCF) would sense molecules optically - in the visible and infrared regimes – with electrical readout. Previous fiber optical sensing has been constrained to the visible/near-infrared (vis/NIR) regime, partially due to silicon detectors. Additional molecular information in the short-wave and medium-wave infrared (SWIR/MWIR) could be harnessed to identify molecules, using inexpensive non-cryogenic (uncooled) infrared detectors. Our proposed technology would include highly efficient molecule-specific dyes embedded in a robust polymer matrix and a colorimetric detection system including our novel rectifying quantum metasurface for detection of gas and droplet (liquid) molecules via SWIR resonances. We plan experiments with simulant diethylchlorophosphate (DCP) gas or air-sprayed droplets. We would identify DCP by embedding a specific dye, chlorophenol red, into the PCF with a suitable polymer matrix. We found ethyl cellulose, an environmentally safe and robust biopolymer, was suitable for this dye. Carbon monoxide vapors could also be sensitively detected using a specific dye, potassium tetrachloropalladate(II), for which we have found that PVA is a good polymer matrix. We would introduce a polymer/dye solution into the PCF pores by capillary force, using a syringe pump, or coating the PCF. Capillary force would also pull droplets into the PCF pores to react with the specific dye, detecting them. Chemicals such as DEP, Cl_2, CEES, ammonia, etc. could be detected by the same method. We anticipate ppb level sensitivity based on our colorimetry experience and would test the dye’s specificity and effects of humidity and interferents.

We plan to extend fiber optic colorimetry from the previously explored vis/NIR regime into the SWIR, detecting additional resonances, using SWIR sources and our invented rectifying plasmonic metasurface [1-4]. Traditionally, nonlinear optical effects are from lack of symmetry at the atomic level: non-zero dipole susceptibility $\chi(2)$. We have discovered that Second Harmonic Generation and Optical Rectification (OR) can occur, manifesting itself as a measurable direct current flowing along the surface, in an asymmetric periodic array with intrinsic $\chi(2) = 0$. This OR current is a new mechanism for optical-to-electrical detection along the surface of a simple patterned plasmonic metal (Au) metasurface (with the great advantage of no semiconductors, no advanced processing/manufacturability, and metallic thermal management). In this quantum material, the transverse spin of the surface plasmon-polariton (SPP) is interestingly ‘locked’ to the photon momentum, creating a rectified persistent current of selectively excited SPPs, functioning as a unique uncooled and inexpensive SWIR quantum sensor for molecules incident on the PCF, enabling a much broader chemical detection range with our fiber-optic metasurface-coupled quantum rectifying detector.

[1] AIP Advances, 11, 115006 (2021).
[2] Phys. Rev. A 106 023521 (2022).
[3] Appl. Phys. Lett. 122, 261704 (2023).
[4] Phys. Rev. A 108, 033519 (2023).

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