

Abstract

Photonic crystal (PhC)-based optical sensors have emerged as versatile platforms for detecting volatile organic compounds (VOCs) due to their high sensitivity, label-free detection, and potential for low-cost, real-time monitoring. This thesis investigates four classes of PhC-based sensing approaches: opal-based photonic crystals, polymer-based random lasing sensors, polydimethylsiloxane (PDMS)-coated one-dimensional photonic crystals (1DPhCs), and Bloch surface wave (BSW) sensors, focusing on their response to solvent-induced perturbations and their applicability for environmental and chemical monitoring.

Opal-based PhC sensors, composed of three-dimensional self-assembled silica structures, exhibit a photonic stop band (PSB) that dynamically shifts with changes in the refractive index of infiltrated analytes. This work establishes a detailed correlation between solvent properties, such as vapor pressure, and the dynamic PSB response, enabling the detection of methanol adulteration in ethanol with fast, reproducible performance.

Random lasing (RL) sensors were developed using flexible, freestanding polymeric disordered inverse opals doped with dye molecules. The RL modes demonstrated high sensitivity to VOC concentration changes, such as cyclohexane in n-hexane mixtures, enabling rapid, label-free detection.

PDMS-coated 1DPhC sensors were investigated for the detection of volatile aromatic compounds, specifically benzene, toluene, xylene, and chloroform, by monitoring shifts in the photonic stop band induced by analyte infiltration, providing reliable, real-time detection. In addition, BSW based sensors were fabricated using 1DPhC structures coated with polyvinyl alcohol (PVA) for the detection of 1-propanol and 2-propanol vapors. A cost-effective white-light Kretschmann–Raether coupling scheme was implemented for BSW excitation, enabling tunable, reproducible, and well-defined vapor detection.

Collectively, this thesis addresses critical gaps in understanding PhC-based sensor performance, establishing the relationship between solvent properties and sensor dynamics while proposing flexible, scalable, and low-cost platforms for real-time VOC detection. The outcomes provide a foundation for environmental monitoring, industrial safety, and chemical diagnostics using optical photonic crystal sensors.

Keywords: Photonic crystal, Random laser, Bloch surface wave, Opal sensor, Refractive index sensing, Volatile organic compounds, Real-time optical sensing.