Abstract

This thesis offers an in-depth exploration of the design, fabrication, and optical characterization of three-dimensional (3D) opal-based photonic crystals (PhCs) integrated with metal layers, focusing on the excitation of optical Tamm states (OTS) and hybrid Tamm-photonic bandedge modes. The study aims to enhance light-matter interactions by examining the impact of metal morphologies, spacer layers, and cavity integration on the optical properties of these systems.

Cost-effective fabrication methods were employed to create large-area polystyrene (PS) opals using self-assembly, followed by sol-gel infiltration to produce inverse opals (IOs). These PhCs, coated with metal films, were analyzed under different configurations. Two specific metal-PhC arrangements were studied: corrugated silver layers on PS opals and flat gold films beneath the PhCs. Experimental and simulation results indicate that hybrid Tamm-PhC bandedge states appear only in corrugated metal structures, with metal thickness playing a crucial role, while flat metal layers exhibit only edge modes without hybridization. Spacer layers between the metal and PhC further enhanced the optical properties, optimizing electric field intensity and improving reflection spectra.

The research also investigates the transition from hybrid Tamm bandedge states to super Tamm states upon the introduction of spacer layers, revealing tunable optical properties via parametric variations. The coupling between microcavities and Tamm modes in hybrid and super-Tamm structures was explored, identifying parameters for strong mode coupling, crucial for designing integrated nanophotonic devices.

A key contribution is the application of inverse opal PhCs on platinum substrates for sensing non-volatile solvents. These structures utilized OTS at the metal-PhC interface, validated through simulations and experiments. Non-reactive solvents like methanol and ethanol induced noticeable shifts in OTS, consistent with theoretical predictions. Temporal dynamics studies demonstrated the ability of these sensors to detect real-time adsorption and desorption processes, with experimentally obtained sensitivities aligning with computed values, establishing IO-based OTS as a promising tool for sensing applications.

This work enhances the understanding of Tamm states in opal-based PhCs, paving the way for scalable, cost-effective photonic sensors. The findings offer significant contributions to the development of hybrid plasmonic-photonic devices for advanced optical sensing and nanophotonic technologies.

Keywords: Three dimensional photonic crystals, Photonic bandgap, Optical Tamm state, Surface plasmon polariton, Super-Tamm state, Photonic crystal cavity.