Abstract

Nanophotonics has led to the miniaturization of photonic devices and finds applications in a variety of fields including sensors, light sources, detectors, and switches to name a few. Confining the light at the nanoscale vastly enhances the localized electric field, boosting the performance of photonic devices. The field of nanophotonics has been long held by metal-based plasmonics especially surface plasmon polaritons (SPPs). However, intrinsic ohmic loss of metals at mid-infrared (MIR) wavelengths restricts their use and calls for alternative materials which can mimic metallic response in MIR with lower losses. A potential candidate for MIR applications is a polar dielectric crystal that supports Phonon Polaritons (lattice vibrations coupled with photons). However, polaritons in conventional materials (metals and dielectrics) cannot offer control at sub-diffraction scales and also suffer from poor tunability. Two-dimensional (2D) materials and their heterostructures, commonly known as van der Waals (vdWs) materials also support various polaritons. Graphene, the most widely studied 2D material, exhibits a plasmonic response which can be actively tuned either by doping or electrostatic gating. Another genre of 2D materials is hyperbolic materials that support phonon polaritons in the MIR range, for example, Molybdenum Trioxide (MoO_3). Low-loss and large propagation lengths of phonon polaritons in MoO_3 make them a potential 2D material for various subwavelength MIR applications. However, their phononic response depends on crystal structure and atomic composition and cannot be altered. Therefore, merging various materials together to constitute vdWs heterostructures can usher properties benefitting from both of its constituent materials. In this thesis, the hybridization response of plasmon polaritons of graphene and phonon polaritons of MoO_3 has been studied numerically. Utilizing the tunable behavior of graphene plasmons, active control of hybridized plasmon-phonon modes via electrostatic gating of graphene has been achieved. The silver grating structure filled with MoO_3 demonstrates the extraordinary transmission response due to the formation of hybridized modes, possessing characteristics of both phonon polaritons and cavity modes. The graphene nanoribbons incorporated on the hybrid structure (Silver-grating with MoO_3) yield modulation in transmitted output. Such modulation behavior is used to obtain a switch with a bandwidth of 650 nm in the MIR wavelength range. Finally, a vdWs Heterostructure consisting of 2D silver grating with MoO_3/graphene is studied to detect molecular vibrations of multiple analytes. The coupling of molecular vibrations with the hybridized response of the proposed structure led to an overall enhancement in fingerprints, thereby leading to the detection of nanomole quantity (30 nm thick) of multiple analytes.

Keywords: 2D materials, Polaritons, Hybridization, Extraordinary Transmission (EOT), Surface Enhanced Infra-Red Absorption (SEIRA) based sensors.