Abstract

Two-dimensional (2D) materials are an emerging class of nanostructured low-dimensional materials and have been extensively studied due to their unique electronic, optoelectronic, optical and mechanical properties. Due to the increasing technological revolution, the requirement for more economical and sustainable 2D materials has increased to meet the future generation's needs. These 2D materials can be easily exfoliated to monolayers from their bulk counterparts, imparting them properties useful for a wide range of optical applications such as biosensing, switching, energy storage, photodetector and many more. Among various 2D materials, graphene and hexagonal boron nitride (hBN) have attracted researchers' attention because of their high potential capability. In this dissertation, we have focused on two potential applications- biosensing and switching using these low-dimensional materials to meet the needs of the future generation. Firstly, we have designed a biosensor consisting of hBN-graphene van der Waals (vdW) heterostructure. Stacking of layered 2D materials forms vdWs heterostructure with unique properties. The biosensor consists of hBN-graphene vdW heterostructure placed on top of the silver grating. The biosensor is capable of detecting the vibrational fingerprints of multiple organic molecules- CBP and nitrobenzene in mid-infrared (IR) using tunable phonon polaritons in hBN-graphene vdW heterostructure. Near-perfect absorption is achieved for the enhanced detection of fingerprints using surface-enhanced infrared absorption spectroscopy (SEIRA). Further, quantitative analysis is done to calculate the minimum number of molecules that can be detected using the proposed biosensor.

Secondly, we have proposed a dual-band biosensor based on hBN-graphene vdW heterostructure. The proposed biosensor consists of CaF_2 gratings to produce guided-mode resonance (GMR) in visible and silver grating with hBN-graphene vdW on top to produce a tunable phonon polariton peak. GMR is responsible for detecting refractive index shift and tunable phonon polariton is responsible for

detecting multiple vibrational fingerprints of organic molecules in mid-IR using SEIRA spectroscopy. We showed the detection of nitroethane and nitrobenzene with a sensitivity of 360.6 nm/RIU and 313.4 nm/RIU, respectively, with their fingerprint detection at 6.43 μm and 6.56 μm, respectively.

In the third part, we have designed a dual-channel selective optical switch at telecommunication wavelength. The device consists of two layers of asymmetric silicon nano bars that produce discrete Fano resonance at telecommunication wavelengths of 1.53 μm and 1.57 μm. We have explored two types of asymmetricity in silicon nano-bars: asymmetry in width and length. Further, these resonances could be tuned independently between 'ON' and 'OFF' states by changing the graphene sheet's Fermi potential (E_f) placed beneath each optical resonator. We have shown four possible combinations of the switch – "ON-ON, ON-OFF, OFF-ON, OFF-OFF".

Keywords: Two-dimensional materials, Graphene, Hexagonal Boron Nitride, Biosensor, Optical Switch.