Abstract

Metasurfaces are the two-dimensional analogue of metamaterials. Due to its precise wavefront control, this new class of artificially engineered surfaces have found its prospects in the various nanophotonics domain. Along with the planar, low-cost fabrication, metasurfaces have the added advantage of device integration. However, the major prospects of the research are on the passive structures. The advent of 2D materials like graphene has given birth to the field of active metasurfaces. On the same lithographic platform, it is possible to tune or modulate the frequency region of operation dynamically. However, the proposed devices are mostly bulky, hybrid-dielectric metal-based, which significantly throws the dust of disadvantage factor to the active applications. In this dissertation, we explored the various domains of metasurfaces to demonstrate active applications of graphene by proposing simplistic designs, ranging from the mid-infrared (MID-IR) to the terahertz (THz) frequency range.

Firstly, in the domain of chirality, we propose an all-graphene-based chiral metasurface structure at the MID-IR range. This is the first demonstration of its kind, which was previously on mostly graphene-metal hybrids. We modulate the chirality factor with the chemical potential, achieving a proper dynamic control on the circular dichroism at a MID-IR wavelength. To the potential application of the design, we propose a refractive index (RI) sensing by tuning the CD value. Next, we explore the non-radiating states in photonics through active metasurface designs. First, we venture into the design of the 'anapole' metasurface. We have proposed for the first time a magnetic anapole state on an all-graphene structure that can be tuned from the long wavelength infrared region to the far infrared by the chemical potential of the graphene. We also investigate bound states in the continuum (BICs) in metasurfaces, another type of non-radiating state in nanostructures. We have proposed a design of an all-graphene-based symmetry-protected structure where the quasi-BIC transmission can be tuned by varying the chemical potential of the graphene in the far infrared THz region. To the potential application of the Q-BIC metasurface, we propose RI sensing by tuning the Q-BIC transmission spectra. Lastly, in the domain of electromechanically tunable metasurface, we proposed a tunable THz absorber & modulator. Our demonstration is the first proposal of a graphene-based electromechanical structure in the THz region, which were previously on bulky metal structures. Our study has shown a wide range of tunability in the THz range using low external voltages. Additionally, our proposed THz modulator demonstrated a high value of extinction ratio. With these emerging topics in the broader range, we filled the gap of tunable aspects of graphene plasmonics in active metasurfaces. All the proposed device architectures are in the subwavelength dimension of the region of operation. In the broader aspects, we envision that these works will carry forward the field of active metasurfaces a step ahead, particularly the applications of novel 2D materials like graphene.

Keywords: Active metasurface, Graphene, Chiral metasurface, Magnetic Anapole, Bound states in the continuum, Electromechanical.