Abstract

Graphene is the thinnest material known till date, composed of a two dimensional (2D) arrangement of carbon atoms in a hexagonal lattice. It has interesting mechanical, electrical and optical properties, such as very high mechanical strength, large carrier mobility, short carrier life time, very high electrical and thermal conductivity and high optical transparency. Considering all these unique properties, graphene is predicted to revolutionize various fields of research pertaining to electronics, photonics, opto-electronics, photovoltaics, energy storage, biological and chemical sensing. Of particular interest is the suitability of graphene in opto-electronic applications arising from two important properties. Firstly, it shows ultrafast and broadband optical absorption with spectral range covering from ultra violet to far infra red. Secondly, it is possible to modulate its optical properties by doping or electrical gating which changes the Fermi level. Unfortunately, photonic applications of graphene suffer from two major disadvantages: (i) graphene absorbs only 2.3% of the incident light (ii) lack of band gap which does not allow spectral selectivity, thus making it unusable for operation as a switch or use in LEDs. One way to improve the light-matter interaction in graphene beyond its intrinsic 2.3% absorption efficiency, is to use plasmonic nanostructures in close proximity. The optical near field associated with nano particles of noble metals, particularly around their plasmon resonance frequency can increase the local electromagnetic field in the vicinity of graphene. Apart from enhancing the light matter interaction, spectral tunability can be achieved by integration of plasmonic nanostructures with graphene.

In the present study, graphene is integrated with plasmonic nanostructures and enhanced photodetection is achieved in the UV, visible and mid-IR regions of the electromagnetic spectrum. Novel schemes are developed for large area integration and patterning of graphene-plasmonic hybrid systems, using a combination of fabrication processes, materials and configuration strategies. This enables a high level of control over the spectral characteristics of the graphene-plasmonic hybrid photodetectors, ranging between deep UV and mid-IR.

Photodetection in the UV is achieved by integrating a single array of silver nanoparticles with a single layer graphene. Spectral photocharacteristics of the device show two enhanced peaks, one due to near field enhancement and the other due to enhanced absorption in graphene near the M point combined with disorder due to the presence of silver nanoparticles. The device responsivity achieved is orders of magnitude higher than commercial UV detectors.

Designs for maximising the field enhancement and photoresponse in the visible is analysed using numerical simulations. Different interparticle distances, orientations and materials are studied in detail for maximising the near field. The lowest possible interparticle distance for achieving maximum field enhancement is around 0.3 nm, below which quantum tunnelling is believed to quench the field enhancement.

A novel fabrication scheme leads to the the smallest possible plasmonic gap, equal to the thickness of a single layer graphene. The near field is highly enhanced at the junction of the nanoparticles and photovoltage achieved in the visible region is 300 times more than the existing graphene-plasmonic photodetectors. An alternate plasmonic material is also explored and the photodetection is extended to the IR region. Highly doped transparent conducting oxide film is optimized for a high carrier density and patterned with electron beam lithography for integration with graphene in order to sensitize graphene in the mid IR.

Our devices show sensitivity better than existing commercial detectors and the fabrication methods are also modular and scalable. We believe these technologies can be extended to many other applications, such as SERS, photocatalysis and optical sensing.