Linear and nonlinear optical applications of plasmonics

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Plasmonics is able to confine the electric field of light to its proximity and provide great field enhancement, which promises possibilities to control light in nanoscale. The plasmon-enhanced molecular sensor allows direct detection of weakly emission from molecules which circumvents the need for labeling. Furthermore, in nonlinear applications, the enhanced localized field can enhance the light-matter interaction, which is promising to increase the efficiency and reduce the laser power consumption. We apply plasmonics in linear and nonlinear optics to study plasmonic structures and explore the advantages in them.

Nonlinear optics describe the light behaviour in nonlinear media where the dielectric polarization responds nonlinearly to the light field. Theoretically, we propose a fully vertical nonlinear coupled-wave equation model for lossy plasmonic waveguides and use the model to investigate third-harmonic generation (THG) in plasmonic waveguides. Two different kinds of plasmonic waveguides are studied, i.e., metallic plasmonic waveguide and graphene plasmonic coupler. For the proposed hybrid plasmonic structure, THG conversion efficiency up to 1.4732×10^{-5} is predicted. This effective conversion is mainly induced by the large field enhancement. THG efficiency in the graphene coupler is found to surpass up to 12 orders of magnitude compared with bare monolayer graphene where the high enhancement comes from the combined effects of the great plasmonic enhancement, phase-matching, and large graphene third-order nonlinear susceptibility. For both of these two structures, phase-matching condition (PMC) is needed to make sure the laser power can convert to the third harmonic power continually. For the THG measurements from the bowtie silicon hybrid plasmonic waveguide, no PMC is needed. THG conversion is enhanced by 23.3 times compared to that from a bare silicon substrate, despite the low surface coverage (~4.2%) of the bowtie arrays and the small volume where the electric field is localized.

Doped graphene hosts long-lived, electrically tunable plasmons that interact strongly with light. Due to the general poor interaction of infrared light with nanometric-scale molecules, unique electro-optical properties of the graphene-based device is exploited to demonstrate a tunable biosensor with high-sensitivity for chemically specific label-free detection of nanometer protein layer. By applying a voltage onto the coupler, graphene Fermi level can be tuned to dynamically tune the plasmonic resonance so as to selectively probe the molecular attached above the graphene surface. From the calculation, we show that the significant spatial light confinement of graphene plasmons produces a high light overlap with nanometer size biomolecules, enabling super-sensitivity in the detection of the molecular refractive index and chemical vibrations. On the other hand, surface enhanced Raman scattering (SERS) has become an attractive analytical technique to obtain the molecular specific chemical fingerprints. We develop a novel graphene-fragmented gold nanostructure system which is facile and reproducible to study the ultra-wideband graphene-SERS. The graphene-fragmented gold platform is beneficial for sensing the top assembled Rhodamine 6G and Rhodamine B dye molecules, enabling a wideband tracer of analytes species.

The transformation tool is powerful since the whole problem in the small-sized metallic geometry (much smaller than the wavelength) can be solved under quasi-static approximation. We use this method to study the instability in SERS under dynamical backaction effect. The radiation damping (beyond the quasi-static limit) is taken into account in our calculation to extend the range of validity of the transformation optics approach. Due to the dynamical backaction, the scattering phonon number is greatly enhanced and instability can be obtained with high laser intensity. According to our calculation, the laser blue detuning value has no need to be equal to the molecular vibration to achieve instability. We also study the molecular position effect to demonstrate the maximum electric field enhancement which the molecular can feel can be obtained when the molecule is put into the gap centre at small gap geometry and near the metal surface at large gap geometry.