Collective plasmon modes in two-dimensional diffractive arrays of metal nanoparticles: effect of asymmetric environment

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Abstract: We examine excitation of plasmon resonances in ordered diffractive arrays of gold nanoparticles in asymmetric refractive index environment. We report experimentally, that efficient coupling take place under appropriate parameters of periodic arrays.

It has been shown in theoretical modeling [1,2] and optical experiments [3-5] that diffractive coupling between surface plasmons of metal nanoparticles in periodic arrays may lead to significant narrowing of plasmon resonance spectral line shape. These studies have been reported on such coupling interactions in symmetric refractive index environment. However many potential applications of these type of plasmon structures addressing sensing, chemical identification spectroscopy or bio molecule detection require low refractive index superstrate compared to the substrate. It has been suggested that efficient long range coupling is incompatible with the asymmetry of environment [3] having particle sizes 50-120 nm in experiment. From the other side, it has been reported from another experimental research [4] and theoretical modeling [6], that diffractive coupling may take place in asymmetric configuration for relatively large particles. However experimental studies that show how efficient diffraction coupling can be in asymmetric environment and how it depends on particle size are missing. Another crucial factor that has not been investigated experimentally is to what extend the asymmetry can be increased without suppression of collective plasmon modes.

In this contribution, we study the conditions of excitation of collective plasmon modes with narrow spectral profile in two-dimensional periodic arrays of gold nanoparticles in asymmetric environment. We show that by optimizing particle size and interparticle distance efficient particle-particle interaction in the far field can be reached.

Gold nanoparticle arrays with varying periodicities were fabricated by e-Beam lithography on 20 nm thick indium tin oxide layer on borosilicate substrates. Fig. 1(a), (b) shows the evolution of transmission spectra of ensemble of 150 nm particles arranged in square lattice with varying period in water (Fig. 1(a)) and air (Fig. 1(b)). One can observe that the dip in the spectra red shifts and becomes narrow under increase of the lattice period. Theoretical modeling show that sharp transmission dip appears due to efficient particle-particle interaction in the far field. At this condition, the in plane light momentum of evanescent diffraction order matches the one of the collective plasmon mode that is sustained by the nanoparticle array. Fig. 1(c) shows one of the FDTD simulated transmission spectra together with measured spectra corresponding to nanoparticle array of 650 nm that produce sharp resonance in water. The calculated spectra are found to be in good agreement with experiment.

In conclusion, we perform optical studies of ordered ensembles of gold nanoparticles that sustain collective plasmon modes with narrow spectral profile when superstrate medium has low refractive index compared to substrate. We found the range of particle sizes and interparticle separations for which efficient long range coupling can be achieved.

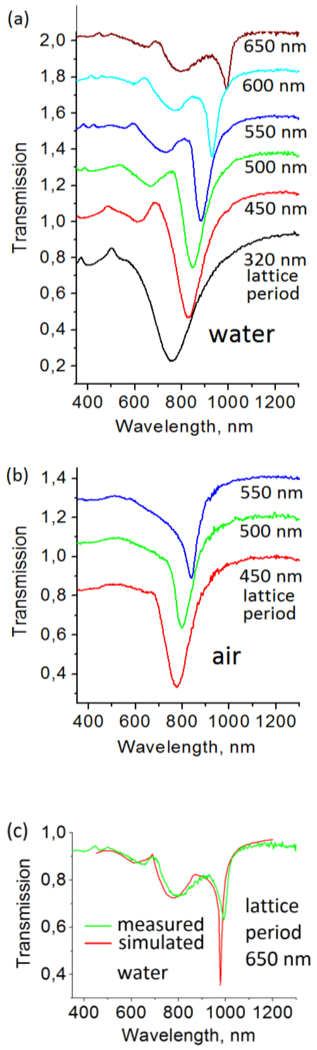

Fig.1. Measured transmission spectra of gold nanoparticle arrays with different periods of square lattice in (a) water and (b) air; (c) FDTD simulated and measured transmission spectra of 650 nm array in water.

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