Two-Dimensional Ordered Nanostructures for Sensing and Lasing Applications

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Plasmonic nanoparticles like Cu, Ag, and Au, during the last decade attract attention of many researchers because of the localized surface plasmon resonance (LSPR) effect. This effect is important for many of the applications that employ localized surface plasmons and is described as collective charge oscillations confined to metallic nanoparticles. Such metallic nanoparticles can serve as the basis for nanoscale devices and sensors with high selectivity and sensitivity. The resonances strongly depend on the local environment, allowing them to be used as ultrasensitive chemical and biological sensors. In addition, the strong electromagnetic field generated in the vicinity of the scatterer can greatly enhance the magnitude of the Raman scattering signal. This enhanced scattering process is known as surface-enhanced Raman scattering (SERS) - a term that emphasizes the key role of the noble metal substrate in this phenomenon.

In the current work, the recent research results on the optical studies of colloidal solutions of silver nanoparticles, production of regular two-dimensional nanostructures employing capillarity-assisted particle assembly (CAPA), as well as studies of surface lattice resonance (mixed mode of LSPR and light diffraction in a regular structure) will be presented and discussed [1-5]. The steady state light absorption measurements performed together with ultrafast transient pump-probe spectroscopy enabled the definition of spectral response as well as kinetics of the processes on the picosecond time scale. These issues are important in the mentioned fields of applications, including the development of smart sensors exhibiting high sensitivity. As an example, we present a comprehensive theoretical and experimental study of wavelength-tailored SERS substrates with improved sensitivity, exploiting the surface lattice resonance (SLR) in a plasmonic lattice comprised of CAPA assembled Ag nanoparticles. We found that SLR-based substrates had 10 times overall higher sensitivity and 100 times higher sensitivity at the target wavelength compared to non-tuned counterparts. Furthermore, we compared monomer and tetramer unit cell cases and found that the combined effect of tuned SLR and hot spots further improves the enhancement factor more than 400 times over a substrate with a random layer of nanoparticles.

Silver nanocubes featuring excellent plasmonic properties due to their single-crystal nature and low-facet roughness were used in CAPA to produce substrates comprising single nanocubes in a lattice exhibiting surface lattice resonance (SLR). Combined with the laser dye pyrromethene-597, the nanocube array photoluminesces at 574 nm with a low linewidth (<1 nm) and low lasing threshold (<100 μJ/cm^2), along with beam characteristics of a resonator with low divergence (<1 mrad) were registered.

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