Seminar

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Institute for Plasma Research

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Title: Sequential Growth of Ag Nanoparticle on Ion-Induced Rippled Surfaces for Enhanced SERS Applications

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Abstract

Surface-Enhanced Raman scattering (SERS) is a phenomenon in which the vibrational signal of a molecule is greatly amplified when it is located in the close vicinity of noble-metal nanoparticle (NP). The enhancement in Raman signal arises primarily from enhanced near-field of light due to the resonant interaction of surface plasmon available on noble metal NP surfaces [1, 2]. Metal NPs exhibit unique optical properties compared to bulk materials due to localized surface plasmon resonance (LSPR), whose frequency depends on factors such as size, shape, and the refractive index of the surrounding medium. The strongest field enhancement occurs at high-curvature regions (tips/edges) and in nanoscale gaps between NPs, known as hot-spots [3,4]. Nanostructured surfaces fabricated by lithography or ion-beam irradiation are under research for producing ordered NP arrays as these can make several hot-spots for SERS detection. The latter offers a self-organized approach to tune interparticle gaps down to ~5 nm. However, such structures often exhibit LSPR anisotropy, leading to direction-dependent SERS responses due to different near-field interactions along and across nanoripple patterns. In this work, we demonstrate the reduction of LSPR anisotropy through a sequential growth mechanism and present an approach to create multiple SERS hot-spots via forming dense dimer arrays. Furthermore, integrating graphene with Ag NPs by aligning graphene along nanoripples modulation prior to NP growth significantly enhances SERS intensity through reduced interparticle gap and charge transfer effects. The detailed results and mechanisms of the same will be discussed.

In the current work, a novel sequential deposition approach discussed earlier is introduced and validated using finite-difference time-domain (FDTD) simulations, which show that interparticle gap, aspect ratio, and NP shape strongly affect the LSPR shift and field enhancement. Experimentally, the sequential method yields nearly spherical, closely packed Ag NPs due to restricted uniaxial growth of adatoms. Reflection spectra reveal reduced LSPR shifts and uniform SERS responses across the substrate when tested with crystal violet dye [5]. Ripple asymmetry, analyzed by Grazing Incidence Small Angle X Ray Scattering (GISAXS), is found to influence nanoparticle growth under different deposition configurations, while Grazing Incidence Wide Angle X Ray Scattering (GIWAXS) confirms their crystalline nature. Molecular dynamics (MD) simulations further indicate a reduced growth rate along the x-axis during sequential deposition, explaining the decreased anisotropy [6]. For low-amplitude silicon ripples (~2nm), NP coalescence leads to low aspect ratio spherical particles; therefore, higher ripple amplitudes (~ 40nm) are required to develop dimer arrays to increase hot-spot density. This is achieved on soda–lime glass substrates by tuning ion beam energy.

Bidirectional deposition promotes the formation of NP dimers across ripples, enhancing plasmonic coupling and local electric fields, enabling detection of low-concentration (0.1 nM) dyes such as sunset yellow and quinoline yellow which are hard to detect due to very low Raman scattering cross-section [7]. Overall, this integrated approach provides a scalable strategy to minimize anisotropy, enhance plasmonic coupling, and significantly improve SERS performance for practical sensing applications [8].

References:

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