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The Optical and Near Field Properties of Janus Plasmonic Nanoparticles: An FDTD Study

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INTRODUCTION & AIM

Surface-Enhanced Raman Spectroscopy (SERS) enables trace-level detection with molecular specificity, but conventional isotropic substrates lack the directional control and tunability required for localized sensing or for discriminating signals in mixtures with overlapping Raman signals. Janus nanoparticles can combine a noble metal (e.g., gold) and a dielectric (e.g., silica) to address these challenges through asymmetric, polarization-sensitive localized surface plasmon resonance (LSPR) that creates spatially confined hotspots for signal amplification.

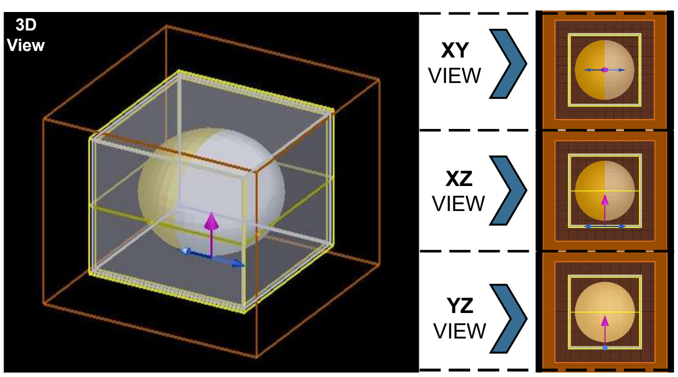
OBJECTIVE

- Calculate scattering and absorption spectra
- Quantify spatial electric field intensity ($|E|^2$) distributions around the Janus interface
- Explore variations in incident wave polarization and particle size to determine conditions that maximize near-field enhancement at the metal-dielectric boundary.

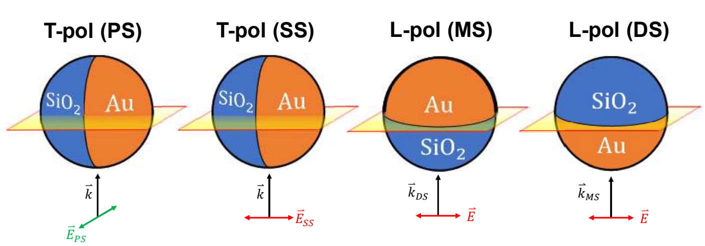
METHOD

Finite-difference time-domain (FDTD) simulations were performed to investigate the optical response of SiO_2–Au Janus particles.

- The simulation region (brown box) consisted of a SiO_2–Au (silver–gold) Janus particle embedded in a cubic domain with an incident plane wave (purple arrow) linear polarized (blue arrow). Optical monitors (yellow boxes) were placed around the particle to record scattering, absorption, and $|E|^2$ distributions.

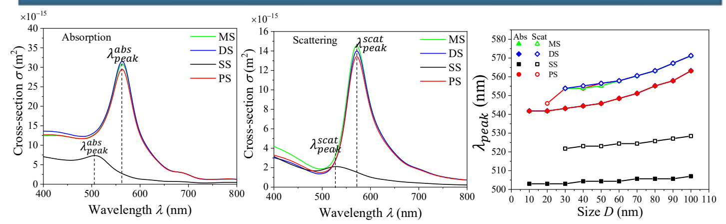


- Four distinct polarization configurations were examined:
  - Two transverse modes (**T-pol(PS)** and **T-pol(SS)**) incident to the split
  - Two longitudinal modes (**L-pol(MS)** and **L-pol(DS)**) incident on each face of the Janus particle.

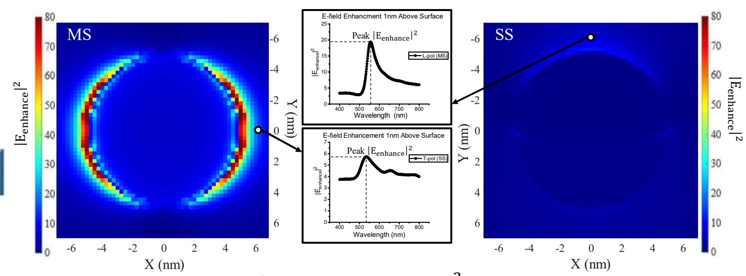


- Particle diameter was adjusted from 10nm to 100nm in order to observe size effect for each polarization.
  - The particle sizes were iteratively adjusted until the absorption and scattering cross-section values intersected and the near field enhancement dropped.

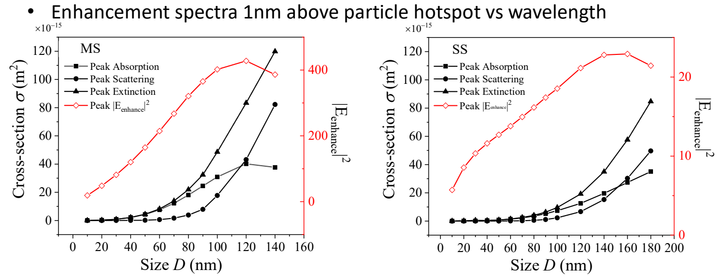
RESULTS & DISCUSSION



- Calculated scattering and absorption spectra for a 100nm Janus particle.
- Peak wavelengths plotted with increasing particle diameter.



- Calculated $|E_{enhance}|^2 = |E_{local}/E_{incident}|^2$ field distributions for a 10nm Janus particle at peak wavelength
- Enhancement spectra 1nm above particle hotspot vs wavelength



- Peak $|E_{enhance}|^2$ plotted with increasing particle diameter. Dotted line shows maximum peak enhancement occurs when abs and scat cross sections are equal.

DISCUSSION

- **Parallel polarization** (L-pol(MS), L-pol(DS), T-pol(PS)) **led to strong redshifts in absorption** (541.8 → 563.2 nm) **and scattering** (553.8 → 571.2 nm) **with size** (10 → 100 nm).
- **Perpendicular polarization** (T-pol(SS)) **showed weaker shifts in both absorption** (503.0 → 507.0 nm) **and scattering** (521.7 → 528.4 nm) **with size** (10 → 100 nm).
- **Maximum field enhancement** occurs near the intersection of absorption and scattering cross sections:
  - Around 120 nm for parallel and 160 nm for perpendicular polarization.
  - At these sizes, **the parallel configuration yields an electric field enhancement ~18.7x greater than the perpendicular case.**

CONCLUSION

FDTD simulations show that both polarization direction and particle size strongly influence the plasmonic response of SiO_2–Au Janus particles. Polarization parallel to the metal–dielectric interface significantly enhances electric field intensity—**almost 20x stronger than perpendicular configurations.** Together, polarization and size optimization can enable stronger near-fields and tunable optical responses for advanced sensing applications.

AKNOWLEDGEMENTS

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