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Fabrication of Scalable and Reproducible Nanonocavity-Coupled Plasmonic SERS Platforms

Achieving reliable molecular detection via surface-enhanced Raman scattering (SERS) critically depends on the precise engineering of plasmonic nanoarchitectures capable of generating dense electromagnetic hotspots with high spatial reproducibility. Despite significant advances in nanostructure fabrication, achieving substrates that simultaneously offer large-area uniformity, scalable production, and consistent hotspot formation remains a central challenge in the field. Conventional approaches relying on colloidal aggregation or lithographic patterning are either limited by poor reproducibility or constrained by low throughput and high fabrication cost, underscoring the need for alternative substrate design strategies [1-3].

In this work, we present a hierarchical nanocavity-coupled plasmonic architecture in which metallic nanostructures are densely and controllably integrated within a highly ordered anodic nanocavity template. The substrate is fabricated through a scalable anodization-assisted process combined with selective chemical etching, yielding large-area structures with geometrically uniform nanocavity arrays over microscopic dimensions. Controlled physical vapor deposition within this templated environment enables tunable nucleation of metallic nanoparticles with well-defined size distributions and interparticle spacings. The resulting configuration promotes strong plasmonic coupling both among adjacent nanoparticles and between the nanoparticle ensemble and the surrounding nanocavity walls, thereby synergistically amplifying the local electromagnetic field and generating a high density of active hotspots across the substrate [4-6].

Using a thiol-based molecular probe under near-infrared laser excitation, the platform exhibits an order-of-magnitude enhancement in Raman intensity, reflecting strong plasmonic field amplification. These findings establish that the integration of self-organized nanostructure nucleation within ordered nanocavity templates represents a robust, scalable, and reproducible route to high-performance SERS substrates, thereby offering a versatile platform for sensitive detection applications in chemical and biological sensing [7-10].

References

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