Synthesis of sub-10 nm gold nanostars for applications in sensing, catalysis, and hyperthermia

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Gold nanostars (NSs) have emerged as highly promising nanostructures for advanced applications spanning biomedicine, catalysis, and chemical sensing [1]. Their distinctive anisotropic morphology—characterized by sharp protruding spikes radiating from a central core—provides exceptional optical performance and broad spectral tunability. Numerous wet-chemical synthetic strategies have been reported to produce NSs with diverse morphologies. In most cases, their size can be readily adjusted by modifying synthesis parameters, such as the seed-to-growth solution ratio in seed-mediated protocols. While the fabrication of large nanostars (>100 nm) is relatively straightforward, achieving significantly smaller NSs that still exhibit strong plasmonic responses at long wavelengths remains challenging. This limitation arises from the minimum structural dimensions required to induce crystal growth defects, promote anisotropic spike formation, and maintain sufficient spike volume.
In this work, we demonstrate that a poly(vinylpyrrolidone)-mediated reduction in dimethylformamide can be strategically modified through the introduction of copper ions, yielding nanostars with a greater number of sharper spikes that develop at earlier growth stages. This modification enables the synthesis of ultra-small nanostars (USNSs) with volumes as low as 420 nm^3 (corresponding to an equivalent spherical diameter of 9.2 nm), while preserving a plasmon resonance in the near-infrared region. To achieve this, we systematically investigate the influence of key synthesis parameters on NS size and optical behaviour. The LSPR can be further modified by the growth of Ag, generating ultrasmall Au@Ag NSs where Au tips protrude from Au@Ag core.
Finally, we evaluated the performance of the resulting USNSs in catalysis, surface-enhanced Raman spectroscopy (SERS) chemical sensing, and photothermal applications in the biomedical application of cancer treatments. In all cases, the USNSs exhibit excellent performance, benefiting from their reduced dimensions, which enhance properties associated with increased surface-to-volume ratio and improved colloidal diffusivity [2].

Keywords:
Gold nanostars, plasmonic, Au@ag coreshell, sensing, hyperthermia

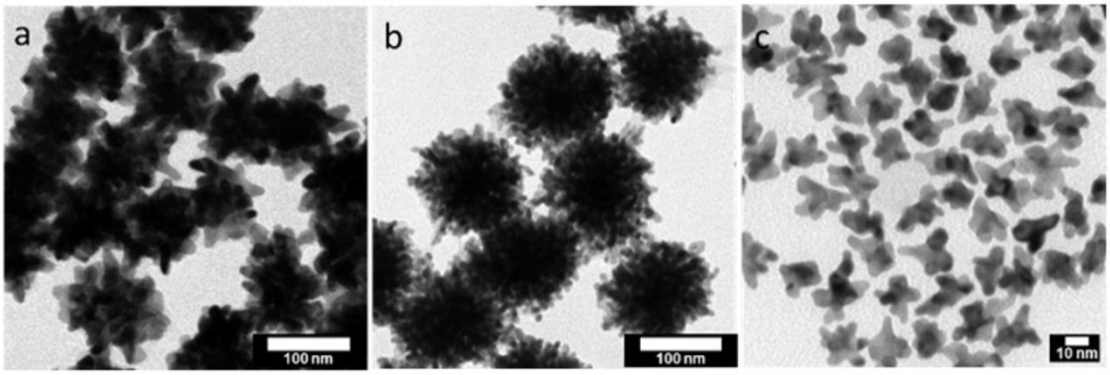

Figure: TEM images of gold NSs. a) Standard synthesis. B) Ultra-sharp NSs, c) ultra-small NSs.

References:

[1] Reguera J, Langer J, Jiménez de Aberasturi D, Liz-Marzán LM, *Chem. Soc. Rev.* (2017); 46, 3866.
[2] Abu Serea, E. S., Berganza, L. B., Lanceros-Méndez, S., & Reguera, J. *ACS Applied Nano Materials* , (2024) *7* (16), 19416–19426.

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