Plasmonic Nanoantennas

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1. Introduction

Localized surface plasmon resonance endows noble metal nanostructures with attractive optical, photothermal, electronic, magnetic and catalytic properties. Taking advantage of the tunability of localized plasmon resonance and the recent advances in chemical synthesis and physical fabrication, numerous exciting research directions and applications have emerged in the field of plasmonics, such as surface-enhanced spectroscopies, biosensing and imaging, photothermal therapies, photocatalysis, and solar energy harvesting. However, so far, a majority of reported metal nanostructures possess only the electric dipole plasmon mode. Further development in this field necessitates advancements in diversifying the toolkit of plasmonic nanostructures, gaining more in-depth understanding of their plasmonic properties, and pushing these functional plasmonic nanostructures toward practical applications. We have developed a new type of high-quality and high-performance metal nanocrystals, i.e., high-aspect-ratio gold and silver nanorods. We have applied them for directional light scattering, color routing, and surface-enhanced infrared absorption (SEIRA) spectroscopy.

2. Results and Discussion

First, we have developed a wet-chemical approach for the growth of silver nanorods through gold nanobipyramid-directed silver overgrowth.[1–3] The aspect ratio of the silver nanorods are highly controllable over a wide range from ~3 to ~30. The high uniformity of these silver nanorods enables ensemble observation of multipolar plasmon resonances in the visible region, as well as the dipolar plasmon resonance in the near-infrared and mid-infrared regions. Moreover, we have recently developed a wet-chemistry method for the growth of high-aspect-ratio gold nanorods, because gold nanocrystals are more chemically stable than silver nanocrystals.

Next, we have applied the silver nanorods as optical nanoantennas for directional light scattering. We have demonstrated two types of directional light scattering. When the silver nanorods are placed on low-refractive-index substrates, the multipolar plasmon modes with odd and even symmetries exhibit different wavelengths and far-field scattering properties, enabling optical nanoantennas for color routing, that is, scattering light of different colors toward different directions.[4] When the silver nanorods are deposited on high-refractive-index substrates, such as silicon and germanium, a newly observed transverse-like plasmon mode leads to directional light scattering toward the two flanks of the nanorods.[5] We have performed systematic investigations on the factors affecting the far-field scattering behaviors of these nanoantennas. In addition, we have developed a theoretical model based on electric dipole arrays to describe the far-field scattering behaviors of the different plasmon modes supported by high-aspect-ratio silver nanorods.

Finally, we have employed the high-aspect-ratio silver and gold nanorods for ultra-sensitive molecular detection through SEIRA spectroscopy.[3] The longitudinal dipole plasmon wavelengths of the silver and gold nanorods can be varied from ~1 to ~10 μm, covering the "fingerprints" of most molecular vibrations. When the plasmon peak of the nanorods is in resonance with the molecular vibrations, enhanced infrared signals are obtained from even a minuscule amount of the probe molecules. To the best of our knowledge, this study is the first work on colloidally-synthesized metal nanostructures with tunable plasmon resonance wavelengths in the near- and mid-infrared regions and the first successful demonstration of their application for SEIRA.

3. Conclusions

Our facile method for the growth of high-aspect-ratio silver and gold nanorods, exploration of their near-field and far-field plasmonic properties, and demonstration of their applications in directional light scattering and SEIRA, are important for fostering this type of new nanomaterials from fundamental research toward various plasmon-based applications and devices.

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