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Resonant Dielectric Nanoparticles as Efficient Nanoantennas in Optical Regime

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1. Introduction

Low-loss optical nanoantennas composed of high index dielectrics have attracted much attention as an alternative to plasmonic antennas that often suffer from losses of noble metals. Among several high-index dielectrics, Si has some advantages such as earth abundance, CMOS- compatibility and most importantly, the small imaginary part of the permittivity in the optical regime. However, the previously developed fabrication methods have problems in the control of the size, shape and crystallinity and in the scalability for mass production.

In this work, we develop crystalline 50-250 nm Si nanospheres (NSs) dispersible in alcohol.[1] Thanks to the perfect dispersion of Si nanospheres, they can be placed on an arbitrary substrate, enabling the formation of functional nanoantennas. We study in detail the light scattering properties and Purcell effect in Si NSs on metal mirror antennas.[2]

2. Results and Discussion

Figure 1(a) shows electron microscope image and extinction spectrum of Si NSs dispersed in methanol. Si NSs with average diameter of 130 nm exhibit the extinction peak around 530 nm arising from electric and magnetic Mie resonances. To study in detail, we show in Fig. 1(b) the scattering spectra of single Si NSs with different diameters placed on silica substrates. Si NSs show the scattering color depending on the size, which are well-reproduced by the Mie theory (dashed curves). These suggest the high-quality (shape and crystallinity) of our colloidal Si NSs. In the presentation, we will also discuss the scattering directionality from the forward and backward scattering spectra obtained from single Si NSs.

We also fabricated a hybrid nanoantenna structure composed of a Si NSs placed on a Au film separated by a very thin dielectric spacer (Fig. 2(a)). This structure can confine electric fields in the gap very effectively at the resonance wavelengths of the gap modes, and thus can further enhance the optical responses of a material in the gap. We demonstrate fluorescence enhancement in the hybrid nanoantenna by placing a monolayer of luminescent quantum dots (QDs) in the gap. As shown in Fig. 2(b), we observe strong fluorescence enhancement of QD monolayer compared to that without Si NSs (i.e., an Au film). By combining with numerical simulations, we will demonstrate that the observed fluorescence enhancement is mainly due to the large Purcell enhancement in a Si NS antenna.

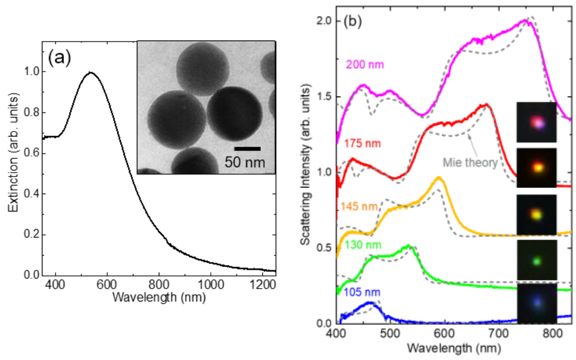

Figure 1.(a) Extinction spectrum and electron microscope image. (b) Measured (solid curves) and calculated (dashed curves) scattering spectra of single Si NSs with different diameters on silica substrates.

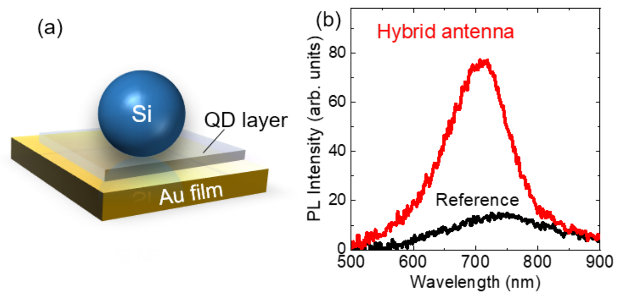

Figure 2.(a) Schematic of Si NS on Au mirror antenna with QD monolayer. (b) PL spectra of QD layer (~3 nm in thickness) on Au film with (red) and without (black) Si NP (130 nm in diameter).

3. Summary

We fabricate the colloidal Si nanoantenna exhibiting efficient Mie resonances in optical regime. The hybrid nanogap antenna structures prepared by a bottom-up approach showed the Purcell enhanced emission of QD layer integrated in the gap.

References

[1] H. Sugimoto and M. Fujii " *Advanced Optical Materials*, 5, 1700332 (2017)
[2] H. Sugimoto and M. Fujii " *ACS Photonics*, 5, 1986 (2018)