Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information

Exploiting the interaction between a semiconductor nanosphere and a thin metal film for nanoscale plasmonic devices

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1. Forward and backward scattering of a Si NS in the presence of a thin metal film

We have compared the forward and backward scattering of a Si NS in the presence of a thin metal film for two cases, as shown in Figure S1. In both cases, one can clearly see the modification of the scattering spectrum induced by the thin metal film. In the first case, the metal film is placed before the Si NS and the scattering intensity in the forward direction is more than 30 time larger than that in the backward direction. In the second case, the metal is put behind the Si NS and the scattering intensity in the backward direction is more than 50 time stronger than that in the forward direction. It is noticed that the spectral shape of the forward scattering in the first case is quite similar to that of the backward scattering in the second case. Both the sharp resonant mode and the near-zero scattering dip can be observed in the scattering spectra. In this work, we chose to study the first case because it can be realized in practical scattering measurements. For the second case, the scattering light cannot be accessed by using an objective with a large NA because of the thick SiO_2 substrate for the thin meal film.

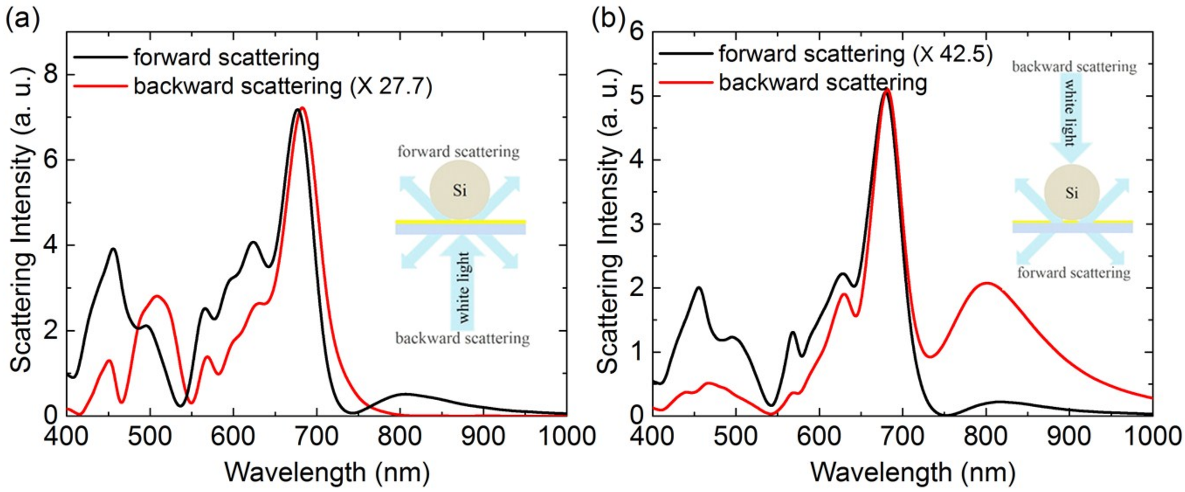

Figure S1. Comparison of the forward and backward scattering spectra of a Si NS with D = 204 nm in the presence of a thin Au film with d = 50 nm. (a) The Au film is placed just in front of the Si NS. (b) The Au film is placed just behind the Si NS.

2. Effects of the gold film thickness on the scattering properties of the Si NS.

We have examined the effects of the metal film thickness on the scattering properties of Si NSs, as shown in Figure S2. It was found that the forward scattering intensity decrease rapidly while the backward scattering increases rapidly with increasing the metal film thickness and vice visa. However, the shape of the forward scattering spectrum remains nearly unchanged. For metal films with thickness smaller than 10 nm, the resonant mode is broadened and the scattering dip is no longer equal to zero because the mirror image condition is not satisfied. The forward scattering spectrum will eventually approach to that of the Si NS in air for infinitely small thickness.

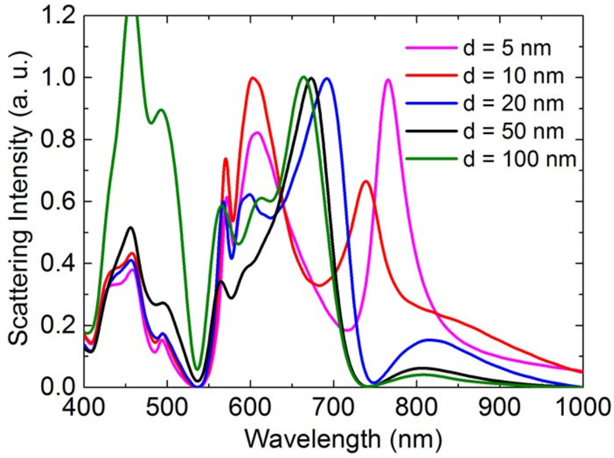

Figure S2. Scattering spectra of the Si NS with D = 202 nm placed on Au films with different thicknesses.

3. Influence of the incidence angle on the scattering spectrum of the Si NS

In the numerical simulations, the scattering spectra of Si NSs can be easily obtained in the normal incidence by using a white light source with a broad spectrum. In the case of oblique incidence, however, one has to calculate the scattering intensities at different wavelengths in order to obtain the entire scattering spectrum. This process is time consuming. In order to solve this problem, we have examined the influence of the incidence angle on the scattering intensity, as shown in Figure S3. It can be seen that the scattering intensity and shape of the resonant mode appear to be the same for the resonant mode and the scattering dip for incidence angles smaller than 30. For this reason, we have used the scattering spectra obtained in the normal incidence in many cases to illustrate the underlying physical mechanisms. It is noticed that the intensity of the electric dipole resonance on the left side of the resonant mode decreases when the incidence angle is increased. This is because that the induced ED in the Si NS, which is originally parallel to the metal surface, becomes inclined in the case of oblique incidence. As a result, the radiation of the ED entering into the detector parallel to the meal surface is reduced.

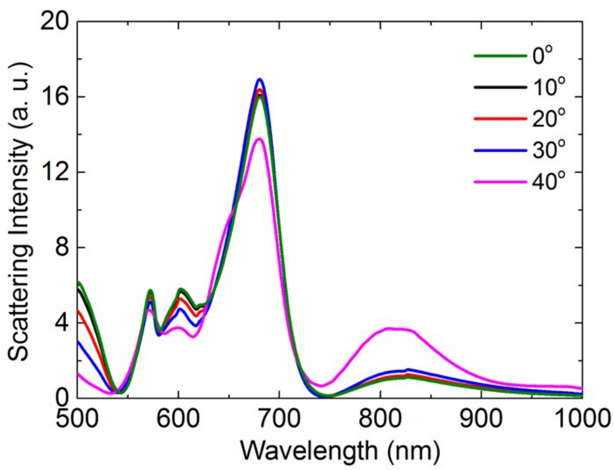

Figure S3. Dependence of the forward scattering spectrum of the Si NS with D = 202 nm on the incidence angle.

4. Scattering light from the Si NSs placed on a thin Au film

In Figure S4(a), we show the image of the scattering light of a large number of Si NSs distributed on a 50-nm-thick Au film. One can see that Si NSs exhibit more abundant color than those distributed on a glass slide. In Figure S4(b), we show the image of the scattering light of a large number of Si NSs distributed on a 50-nm-thick Ag film. Apparently, the Si NSs exhibit vivid scattering light with different colors more abundant than those observed for the Si NSs distributed on the thin Au film.

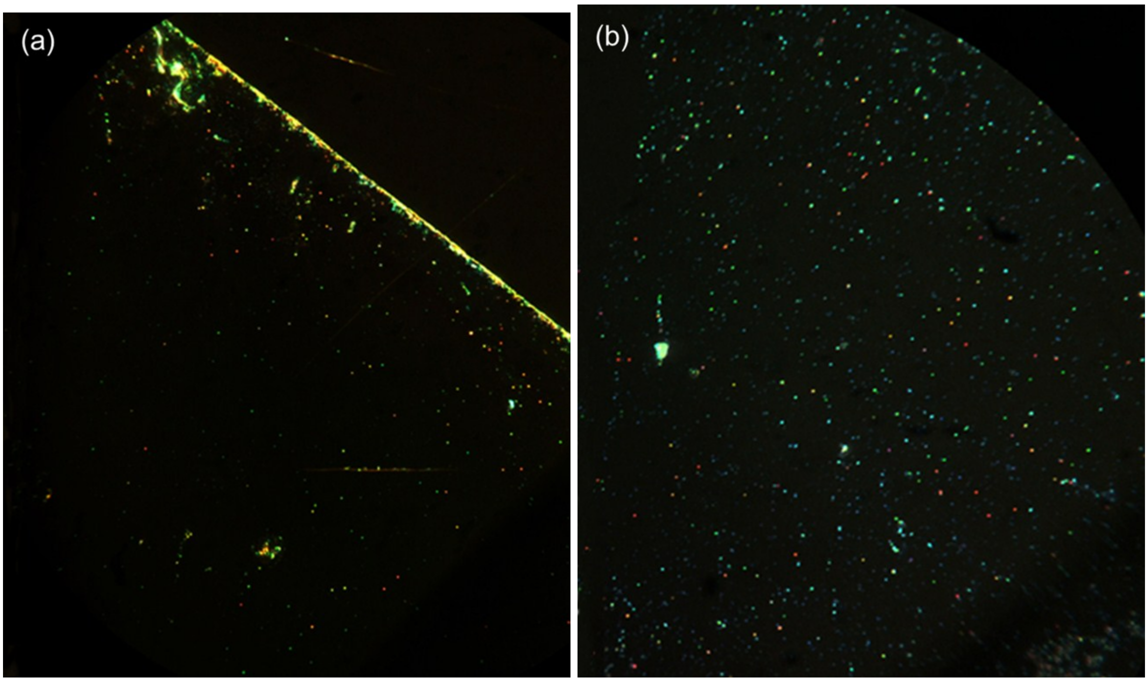

Figure S4. Dark-field microscope image of Si NSs on a thin (a) Au and (b) Ag film.

5. Complex refractive indices for Au and Ag used in the numerical simulations

The effects of the thin metal film on the scattering properties of Si NSs are determined mainly by the complex refractive index of the thin metal film. In Figure S5, we show the complex refractive indices of Au and Ag which are used in the numerical simulations. It can be seen that the real parts of the complex refractive index are much different for the two materials, especially in the wavelength region of 400-550 nm. In addition, the imaginary part of the complex refractive index Ag is larger than that of Au over the entire wavelength region of 400-1000 nm. These differences are responsible for the vivid scattering light from Si NSs placed on the thin Ag film.

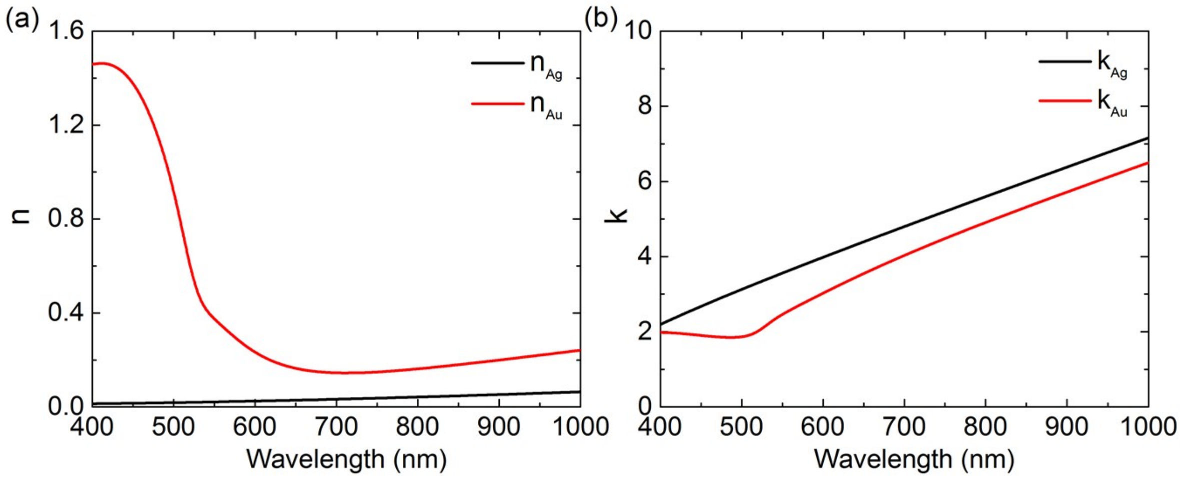

Figure S5. Comparison of the (a) real and (b) imaginary parts of the complex indices of Au and Ag in the visible to near infrared spectral region.

6. Electric and magnetic distributions calculated at the scattering dip and the original MD

In order to gain a deep insight into the physical origin for the resonant mode and the scattering dip, we have calculated the magnetic distributions at the resonant mode [see Figures. 5(b) and (c)] and the electric and magnetic field distributions at the scattering dip (see Figure S6).

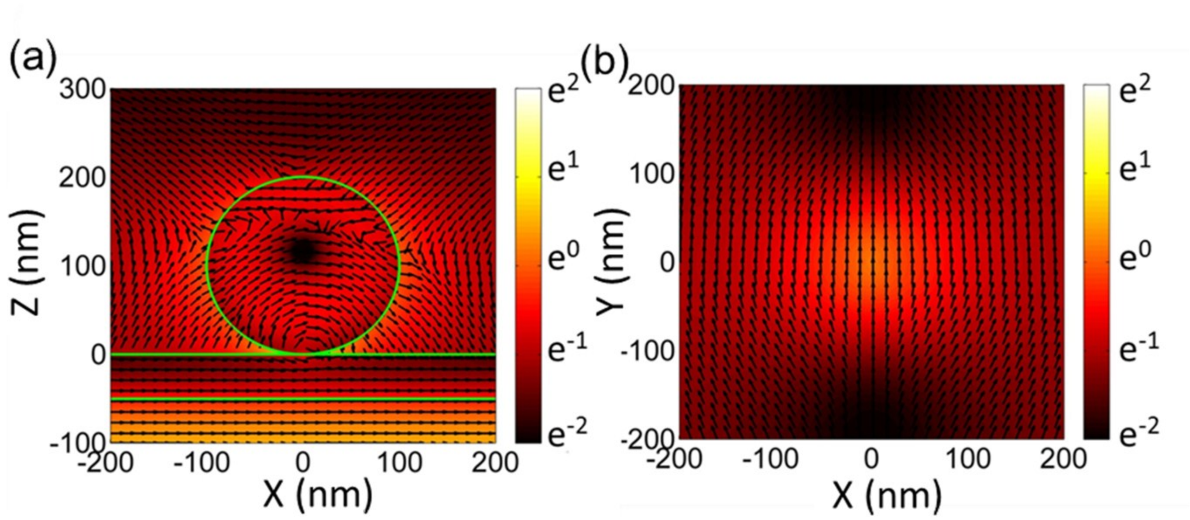

Figure S6. (a) Electric and (b) magnetic distributions calculated at the scattering dip.

7. Influence of the shape of a Si NS on the scattering spectrum

Since the measured linewidth of the resonant mode is narrower than the calculated one, we have examined the influence of the shape of a Si NS on the scattering spectrum by considering Si nanoellipsoids (NEs) with their long axis parallel or perpendicular to the metal surface. An increase of intensity as well as a narrowing of linewidth is observed for the resonant when the long axis of the Si NE is increased [see Figure S7(a)]. In sharp contrast, one can see a broadening and a weakening of the resonant mode when the short axis of the Si NE is reduced [see Figure S7(b)]. This behavior interprets why the measured linewidth can be narrower than the calculated one. In general, the fabricated Si NSs with elliptical shapes tend to sit on the metal film with their long axis parallel to the metal surface.

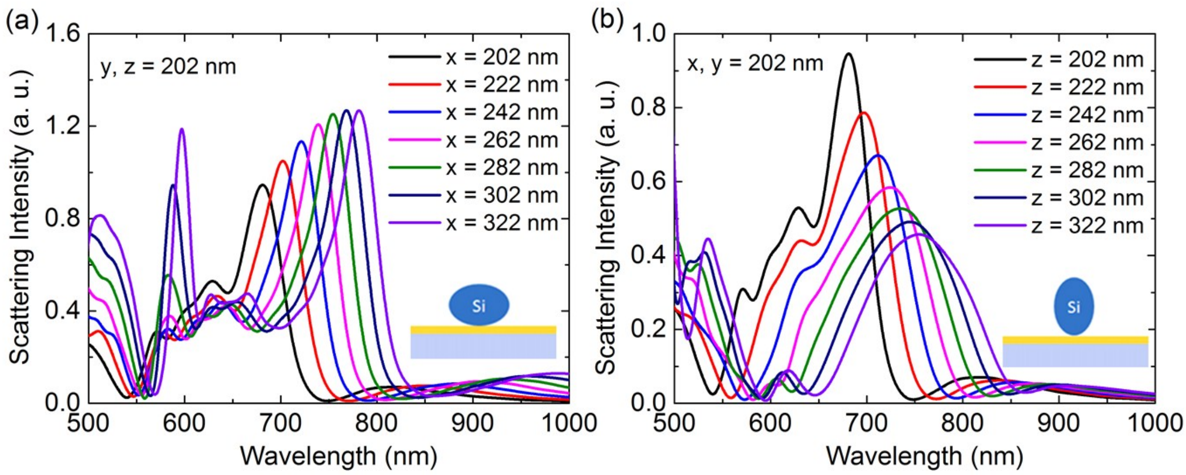

Figure S7. (a) Scattering spectra calculated for Si NEs with fixed short axis of 202 nm and varying long axis parallel to the metal surface. (b) Scattering spectra calculated for Si NEs with fixed long axis of 202 nm and varying short axis parallel to the metal surface.

8. Effects of the surround environment on the scattering spectrum of the Si NS

We have investigated the change of surrounding environment on the scattering spectrum of the Si NS. Here, we show the evolution of the scattering spectrum when the refractive index of the surrounding environment is varied [see Figure S8(a)]. It can be seen that the increase of the refractive index of the surrounding environment leads to the broadening, weakening and redshift of the resonant mode In addition, the near-zero scattering dip disappears for n > 1.1. In addition, we present the evolution of the scattering spectrum of the Si NS when the thickness coated Pt film is increased [see Figure S8(b)]. In this case, one can see the broadening, weakening, and blueshift of the resonant mode. The near-zero scattering dip also disappears for t > 1.0 nm.

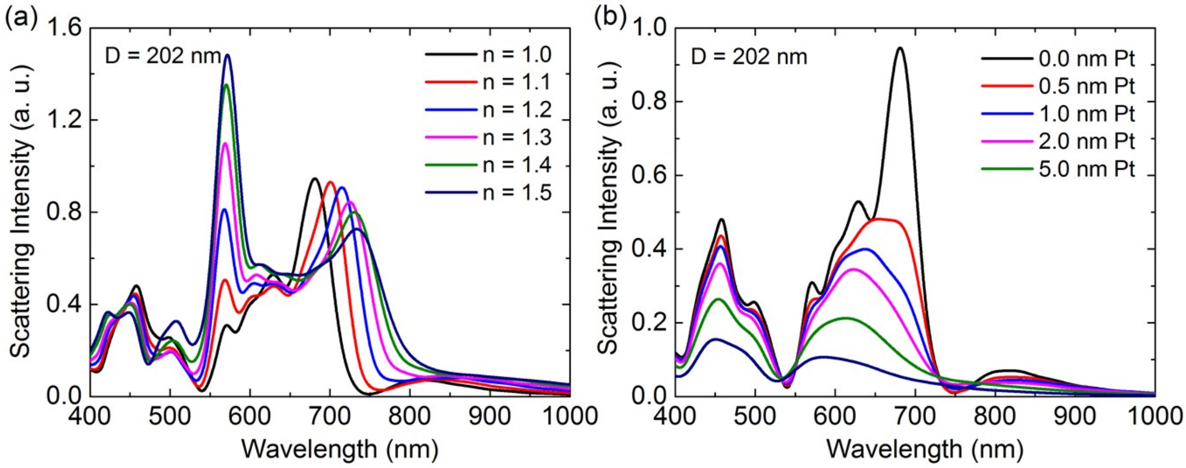

Figure S8. (a) Evolution of the scattering spectrum of the Si NS with D = 202 nm when the refractive index of the surrounding environment is increased. (b) Scattering spectra calculated for the Si NS with D = 202 nm coated with Pt films with different thicknesses.