Electronic supplementary information

Gap controlled plasmon-dielectric coupling effects investigated with single nanoparticle-terminated atomic force microscope probes

Qian Huang,[a] Fernando Teran Arce,[b,c,d] Joon Lee,[b,c] Ilsun Yoon,[d] Josh Villanueva,[a] Ratnesh Lal,[b,c] and Donald J. Sirbuly*[a,c]

[a]*Department of NanoEngineering, University of California, San Diego, La Jolla, California 92093, United States. E-email: dsirbuly@ucsd.edu*

[b]*Department of Bioengineering, Department of Aerospace and Mechanical Engineering, University of California, San Diego, La Jolla, California 92093, United States*

[c]*Materials Science and Engineering Program, University of California, San Diego, La Jolla, California 92093, United States*

[d]*Currently: Division of Translational and Regenerative Medicine, Department of Medicine, Department of Biomedical Engineering, University of Arizona, Tucson, AZ 85721, United States*

[e]*Department of Chemistry, Chungnam National University, Daejeon 305-764, Republic of Korea*

Experimental Details

Materials. Gold colloidal NPs (diameter = 80 nm) were purchased from Sigma Aldrich. Silver colloidal NPs (diameter = 80 nm) were purchased from nanoComposix. The SnO_2 nanofiber WGs were synthesized via a thermal vaporization process in the presence of trace amounts of O_2 as described elsewhere.[1] The AFM tips used for NP linkage were triangular SiN MLCT tips purchased from Bruker with a nominal spring constant of k = 0.24 N m^{-1} (gold NP-terminated) and 0.6 N m^{-1} (silver NP-terminated).

Multimode AFM. The force mapping and attachment of individual gold or silver NPs onto AFM tips was carried out using a Multimode AFM with a "J" scanner in air (Veeco Nanoscope IV controller). The scanner has a scan range of a 150 x 150 μm^2 and was run by Nanoscope software 5.31R1 (Bruker).

Optical Microscopy. Optical characterization of the WGs were performed on a dark-field optical microscope equipped with a 50× (Nikon, NA 0.55) objective, CCD camera (Andor Technology), and a fiber coupled spectrometer (Princeton Instruments). WGs were excited with the 325 nm line of a horizontally polarized continuous-wave helium cadmium laser (Kimmon electric). The beam was focused onto the WGs at an angle of ~ 45˚ relative to the quartz substrate where the WGs were deposited. All the spectra are measured in water.

Integrated AFM/Optical Setup. Combined AFM/optical measurements were performed using a Dimension Hybrid XYZ scanner from Bruker integrated with a Zeiss Axiovert 135TV inverted light microscope. The AFM scanner has a scan range of a 90 x 90 μm^2 and was run by Nanoscope software 5.31R1 (Bruker). The helium cadmium laser was launched through a quartz slide from underneath at an angle of ~ 45˚ relative to the sample plane. The scattering intensities were collected through a 10 x objective with the 600 nm shortpass filter and captured by a CCD camera monitor. Sufficient noise isolation (~ 1 nm, as measured by the peak to peak oscillations on the horizontal region of the force curves at 0.01 Hz) was achieved by using a concrete slab placed on blocks of Styrofoam. Deflection sensitivity was calibrated after engagement, and the system was stabilized in the 1x PBS environment at least an hour before measurements were taken.

Approaching an AFM Tip onto the WG Surface. The scattering image of the reference gold NP was used to guide the approach of the NP-terminated AFM tip to the WG surface. The AFM tip was engaged very carefully on the sample surface using contact mode, and applied forces were minimized to prevent any damages to the NP. Single ramps were conducted by manually adjusting the X-Y offset position until the tip was located on top of the WG. AFM height images were acquired using force mapping mode.

Scattering Simulations. Guided p-polarized or s-polarized light from 400 nm to 600 nm, computed using the FDTD method (Lumerical software), was launched down the WG immersed in water. Using the FDTD method the powers from the gold NP scattering were calculated at different NP-WG separations. The NP was modeled as a sphere with a diameter of 80 nm.

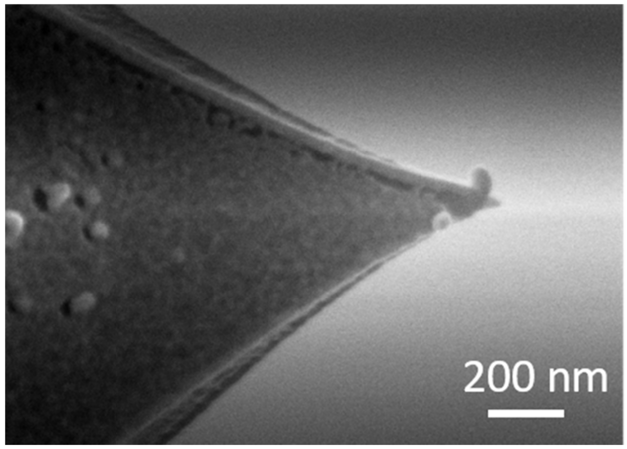

Fig. S1†. SEM image of a commercially available gold-sputtered AFM tip that shows damage after indentation experiments.

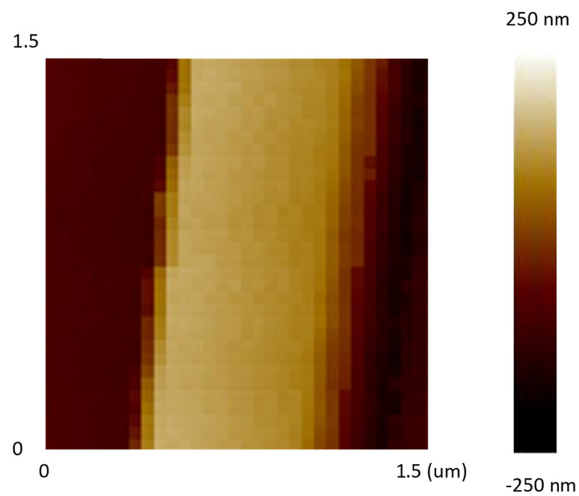

Fig. S2†. Force-mapping image of a nanofiber used in our experiments.

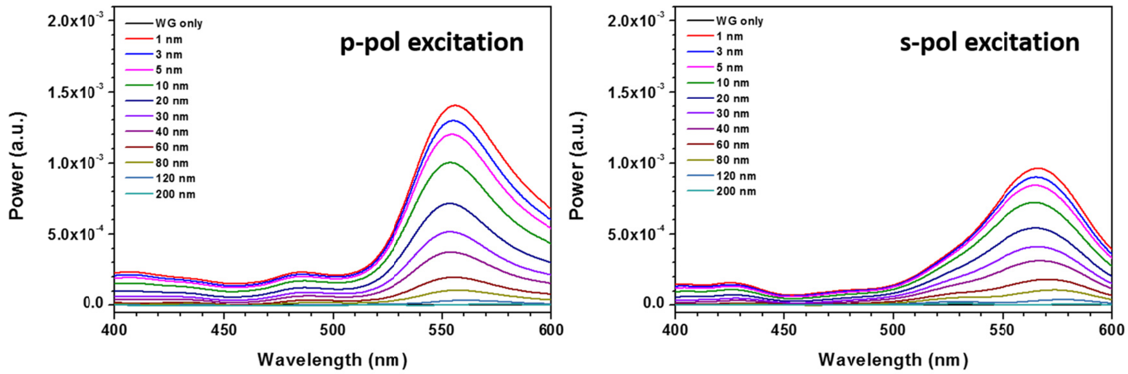

Fig. S3†. Simulated scattering spectra of a gold NP at different distances from the WG surface while being excited with p-polarized (left) and s-polarized (right) light.

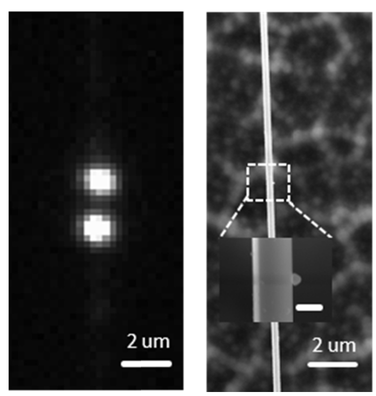

Fig. S4†. Two 80 nm gold NPs are detected in the optical scattering image (left) but only 1 is observed in the SEM image (right). The top NP in the optical scattering image is on the side of the WG and visible with the SEM, but the bottom NP is on the back side of the WG (not visible to SEM) but still produces a similar scattering intensity. In the inset the scale bar is 200 nm.

References

1 M. Law, D. J. Sirbuly, J. C. Johnson, J. Goldberger, R. J. Saykally and P. D. Yang, *Science*, 2004, **305**, 1269-1273.