Rainbow Radiating Single-Crystal Ag Nanowire Nanoantenna

Taejoon Kang,† Wonjun Choi,‡ Ilsun Yoon,† Hyoban Lee,† Min-Kyo Seo,*§& Q-Han Park,*‡ and Bongsoo Kim*†&

†Department of Chemistry, KAIST, Daejeon 305-701, Korea
‡Department of Physics, Korea University, Seoul 136-701, Korea
§Department of Physics, KAIST, Daejeon 305-701, Korea
&KAIST Institute for the NanoCentury, KAIST, Daejeon 305-701, Korea

*E-mail: (B.K.) bongsoo@kaist.ac.kr; (Q.-H.P) qpark@korea.ac.kr; (M.-K.S.) minkyo_seo@kaist.ac.kr
Experimental Details

**Synthesis of single-crystalline Ag NWs.** We placed a Ag slug in an alumina boat at the middle of a 1 in. diameter horizontal quartz tube furnace (Figure S1a).

The Ag slug was heated to 800 °C and then carrier gas transports Ag vapor to the lower temperature region, where Ag NWs were grown on a sapphire substrate. The distance from the center of a heating zone to the substrate was 5 cm and Ar gas flowed at a rate of 100 sccm, maintaining the chamber pressure of 5 ~ 15 torr. The reaction time was 30 min.

**Figure S1.** (a) Schematic of the horizontal quartz tube furnace system for the synthesis of Ag NWs. (b,c) TEM images of Ag NWs. (d) High resolution TEM image and SAED pattern of a Ag NW.

**Measurement of radiating near-field patterns of SPP antenna from the longer Ag NW.** In order to investigate the operation wavelength range of longer single-crystalline Ag NW, we employed three different color laser sources with wavelengths of 440 (blue), 532 (green), and 632.8 (red) nm. Three figures at the top of Figure S2 are radiating near-field patterns excited by these three lasers when the polarizer was set to detect only the light polarized parallel to the NW and three figures at the bottom
detect only the light polarized perpendicular to the NW. At all three wavelengths, we clearly observed unique antenna radiation patterns of multi-lobes in the Fresnel region.

![Figure S2](image)

**Figure S2.** SPP antenna radiations excited by 633 (red), 532 (green), and 440 (blue) nm lasers, respectively. The Ag NW placed on a glass substrate has a length of 7.1 µm and a diameter of 150 nm. Three figures at the top are radiating near-field patterns when we detect only the light polarized parallel to the NW and three figures at the bottom perpendicular. The antenna radiations are strongly polarized along the NW axis.

**FDTD simulations.** In the three dimensional FDTD simulation, the Drude metal was employed with the dielectric function as $\varepsilon(\omega) = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2 + i\gamma \omega}$. The plasma frequency and collision frequency, ($\varepsilon_\infty$, $\omega_p$), were set to be $(8.4 \times 10^{15}, 4.2 \times 10^{14})$, $(8.8 \times 10^{15}, 2.4 \times 10^{14})$, and $(8.9 \times 10^{15} \text{ Hz}, 1.8 \times 10^{14} \text{ Hz})$ for each incident light wavelengths of 440, 530, and 630 nm. We used a background dielectric constant of 2.0. In the calculation of the Ag NW antenna, the domain size and grid size were $7.0 \times 3.0 \times 9.0 \ \mu m^3$ and 10.0 nm, respectively. The convolutional perfectly matched layer (CPML) was used as the absorbing boundary condition. In the calculation of the SPP current dispersion, we examined SPP
currents excited in an infinite length of Ag NW and performed spatial Fourier transform of the near-field electric fields of the SPP currents. The position of the peak of the Fourier transform result in the momentum space ($k$-space) represents the propagation wavevector, $2\pi/\lambda_{\text{SPP}}$, of the SPP currents. Due to the finite size of the grid and the time interval, we guarantee the first two significant figures in the results of the simulations.

![Graphs showing line scans of the vertical component profiles of the Poynting vectors obtained by FDTD simulation of Figure 4a.](image)

**Figure S3.** Line scans of the vertical component profiles of the Poynting vectors obtained by FDTD simulation of Figure 4a. The line scans were taken along the length of the Ag NW.

**Antenna theory analysis.** In the antenna theory analysis, the electric and magnetic fields at an observation position, $(x,z)$, are obtained from the magnetic vector potential, $A_i(x,z)$, as $-i\omega \mu \varepsilon E_i(x,z) = \partial_x^2 A_i(x,z) + k^2 A_i(x,z)$, $-i\omega \mu \varepsilon E_z(x,z) = \partial_z \partial_x A_i(x,z)$, and $\mu H_y(x,z) = -\partial_x A_i(x,z)$. 
In order to calculate the vector potential via SPP currents, we employed the SPP current wavelengths obtained in the FDTD simulation of SPP dispersion along the infinite Ag NW with a diameter of 150 nm. The employed values of the SPP current wavelengths along the NW were 300, 420 and 520 nm for the free-space wavelengths of 440, 530 and 630 nm, respectively. In Figure 5, we calculated the vertical component of the Poynting vector, $S_z(x,z)$, at a height of 150 nm from the NW axis where the radiating near-field patterns were obtained in the FDTD simulations.

REFERENCES