Supporting Information

Plasmonic Coupling of Bowtie Antennas with Ag Nanowire

*Zheyu FANG[1], Linran FAN[1], Chenfang LIN[1], Dai ZHANG[3], Alfred J. MEIXNER[3], and Xing ZHU[1,2]**

[1]School of Physics, State Key Laboratory for Mesoscopic Physics, Peking University, Beijing 100871, China

[2]National Center for Nanoscience and Technology, Beijing 100190, China

[3]Institute of Physics & Theoretical Chemistry, University Tübingen, Tübingen D-72076, Germany.

*** E-mail: zhuxing@pku.edu.cn**

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1. Plasmon enhancement factor and emission efficiency.

1.1 Enhancement factor of plasmon coupling and emission.

The four configurations *No*.1 to *No*.4 in this paper are defined as the following:

***No*.1**: a single Ag nanowire with the length of 20 μm;

***No*.2**: a 20 μm Ag nanowire with one end placed in the feed-gap of coupling bowtie antennas with the arm-length of 250 nm.

***No*.3**: a single Ag nanowire with the length of 10 μm;

***No*.4**: a 10 μm Ag nanowire with both ends placed in feed-gaps of two bowtie-antenna pairs with the arm-length of 250 nm;

The schematic of these configurations is shown in Figure S1.

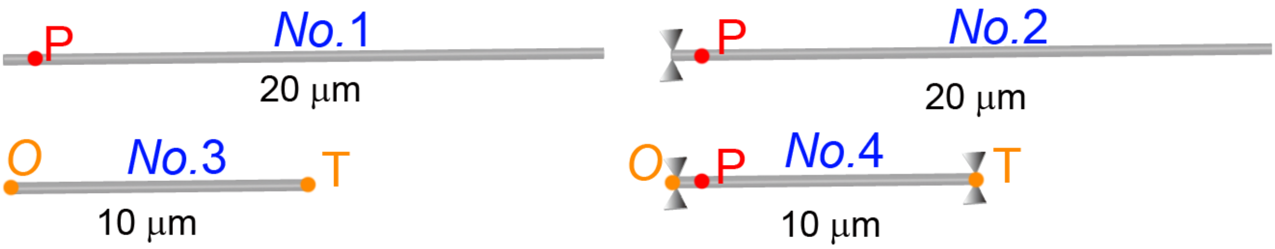

Figure S1. Schematic of four configurations *No*.1, *No*.2， *No*.3 and **No**.4. Point **O** denotes the incident end of the Ag nanowire; point **P** is an equivalent position with a distance of 1μm along the nanowire from the incident end; point **T** represents the emission end of the Ag nanowire.

For configurations ***No.1*** and ***No.2***, the 20 μm long Ag nanowire can be considered as an infinitely long plasmon waveguide, when take into account the guiding losses 0.43 dB/μm of the Ag nanowire (See Ref. 7, 16 in the main text). It is only 1.9% incident energy (17.2 dB for 40 μm) can go back to the incident end even if there is a perfect reflection at the terminal end facet of the nanowire. Thus, it's reasonable to consider that the amplitude of the reflected plasmon wave from the terminal facet of nanowire can be negligible.

To avoid the artifacts induced by the incident laser, the near-field optical intensity of an equivalent position (point **P**) at a distance of 1 μm along the nanowire from the incident end was recorded by using scanning near-field optical microscopy (SNOM) for both ***No*.1** and ***No*.2** configurations as $\boldsymbol{I_{1P}}$ and $\boldsymbol{I_{2P}}$, respectively. The enhancement factor for the plasmon coupling then was obtained as F_C=13.6 by calculating the ratio of $\boldsymbol{I_{2P}}$ and $\boldsymbol{I_{1P}}$.

It should be noted that the detected $\boldsymbol{I_{2P}}$ is also equal to the near-field intensity of point **P** in the configuration of ***No*.4**, i.e. $\boldsymbol{I_{2P} = I_{4P}}$. For the ***No*.4**, we cannot directly measure the $\boldsymbol{I_{4P}}$ by using

SNOM, because the Ag nanowire with the length of 10 μm cannot be considered as an infinitely long waveguide, and the reflected plasmon wave influences the measurement result.

With the same method, the near-field optical intensities at the terminal facet (point **T**) of the Ag nanowire in configurations of ***No*.3** and ***No*.4** can be recorded as $\boldsymbol{I_{3T}}$ and $\boldsymbol{I_{4T}}$, respectively. The enhancement factor for plasmon emission then can be obtained as $F_E = 45$ by calculating the ratio of $\boldsymbol{I_{4T}}$ and $\boldsymbol{I_{3T}}$.

1.2 Plasmon emission and total efficiencies

The distance between point **P** and emission end (point **T)** in ***No*.4** is 9.0 μm. The guiding losses for a 9.0 μm long Ag nanowire is 3.87 dB, thus the input plasmons at point **T** can be estimated as $\mathbf{0.407}\boldsymbol{I_{4P}}$. Because $\boldsymbol{I_{4P}} = \boldsymbol{I_{2P}}$, then the plasmon emission efficiency for the configuration ***No*.4** can be calculated as $\boldsymbol{\eta_E} = \boldsymbol{I_{4T}} / \mathbf{0.407}\, \boldsymbol{I_{2P}} = 80.8\%$. (The data of $\boldsymbol{I_{4T}}$ and $\boldsymbol{I_{2P}}$ were recorded by SNOM.)

The distance between points **P** and incident end (point **O**) in ***No*.4** is 1.0 μm, and the guiding losses for a 1.0 μm long Ag nanowire is 0.43 dB, thus the input plasmons at point **O** can be estimated as $\mathbf{1.1}\boldsymbol{I_{4P}}$. Then, the plasmon total efficiency for the configuration ***No*.4** can be calculated as $\boldsymbol{\eta_T} = \boldsymbol{I_{4T}} / \mathbf{1.1}\boldsymbol{I_{2P}} = 30.1\%$. (The data of $\boldsymbol{I_{4T}}$ and $\boldsymbol{I_{2P}}$ were recorded by SNOM.)

2. Reflection coefficient of plasmons with fundamental mode.

For the propagation modes on the Ag nanowire, because the intensity of higher-order modes is much smaller in comparison with the fundamental mode for the experimental detection, we only considered the propagation coefficient of the fundamental mode in our calculations.

The plasmon field A of the fundamental mode can be described as

$$A = A_0 e^{-\gamma x}\left(1 + |\Gamma_R| e^{i\varphi} e^{-2\gamma(10-x)}\right) \tag{S1}$$

where $\gamma = \alpha + i\beta$ is the propagation constant of the mode consisting of the decay constant α and the wave vector β, and $\Gamma_R = |\Gamma_R| e^{i\varphi}$ represents the complex reflection coefficient for plasmons at the nanowire terminus. These propagation coefficients can be determined with the plasmon standing-wave data obtained by FDTD simulations.

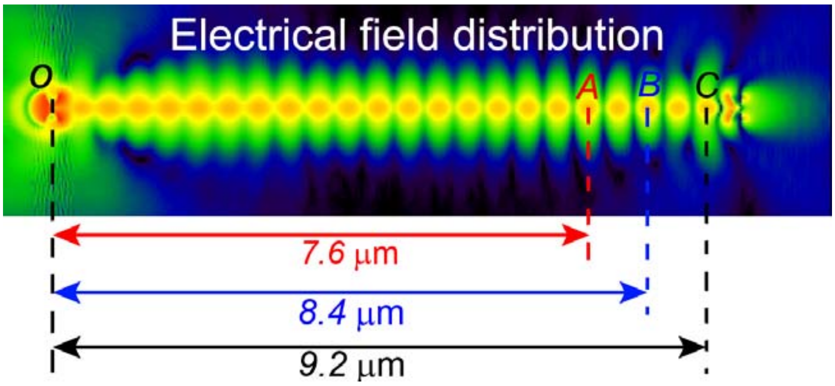

Figure S2. FDTD simulation of electric field distribution of the antenna-wire-antenna optical circuit. Three points A, B, and C closed to the nanowire terminus are chosen for the calculation of the reflection coefficient of the fundamental mode.

Figure S2 is the FDTD steady-state image of the plasmon standing-wave pattern under 28 degree incident angle. The length of the Ag nanowire is 10 μm, the arm-length for the coupling bowtie antennas is 250 nm, and the arm-length for the emission bowtie antennas is 200 nm.

To avoid the influence of higher order modes, the electric field data of three different points closed to the nanowire terminus are recorded to calculate the reflection coefficient Γ_R, as denoted in Figure S2. The distances for OA, OB, and OC are 7.6 μm, 8.4 μm and 9.2 μm. By substituting the simulated data into Eq. S1, we can calculated the $|\Gamma_R|$ for this configuration is around 50%. And with this method, the dependence of the $|\Gamma_R|$ on each arm-length for the bowtie antennas can be plotted, as shown in Figure 5a in the main text.

3. Characteristic impedance of Ag nanowire and corresponding SiO_2 substrate.

In our analytical model, the Ag nanowire and the SiO_2 substrate consist of an electric circuit for the current propagation. The current of the circuit is considered propagating into the Ag nanowire, and propagating out from the SiO_2 substrate, as shown in Figure 5d.

The characteristic impedance of Ag nanowire then can be defined as $Z_S=V/I$, where V is the voltage between the Ag nanowire and the SiO_2 substrate, obtained as a line integral of the complex electric field from the wire core to the bottom of SiO_2 using $V=\int E\cdot ds$; I is the current on the Ag nanowire at a given position evaluated according to the Ampere's law $I=\oint H\cdot ds$. Because H_x is zero at infinity, the conventional closed-loop integration path can be replaced with a sufficiently long path approximating a linear path from $-\infty \rightarrow +\infty$.

Figure S3 gives the distributions of the relevant components of the electric (**E**) and magnetic (**H**) field simulated by FDTD method, respectively. The nanowire impedance then is obtained as $Z_S=(138-3.2j)\Omega$.

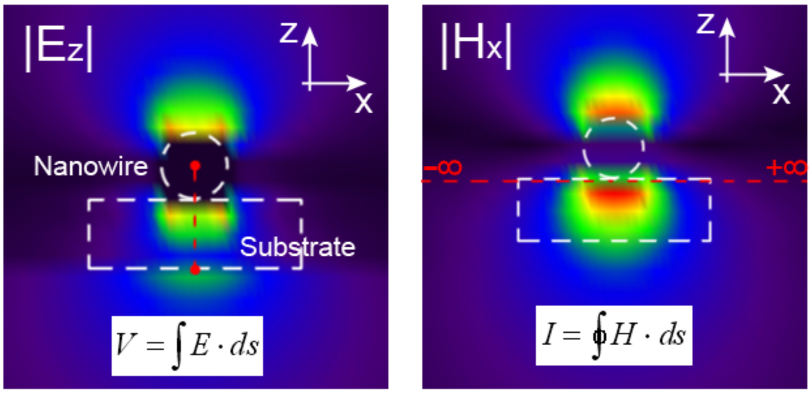

Figure S3. Distributions of the FDTD simulated electric (**E**) and magnetic (**H**) field components. The integration paths are indicated by the red-dashed lines. Since H_x is zero at infinity, we replace the close loop integration path with an equivalent linear path and integrate H_x from x=-∞ to x=+∞.