Electronic Supplementary Material (ESI) for Nanoscale.

Supplementary Information

Excitation of surface plasmons from silver nanowires embedded in polymer nanofibers

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1. Absorbance of AgNWs in solution

Figure S1 shows the normalized absorbance spectrum of silver nanowires (AgNWs) dispersed in water which was measured using a Micro Spectrophotometer (CRAIC, 20/20 PV). It can be seen that AgNWs dispersed in water exhibit an absorption peak at 378 nm.

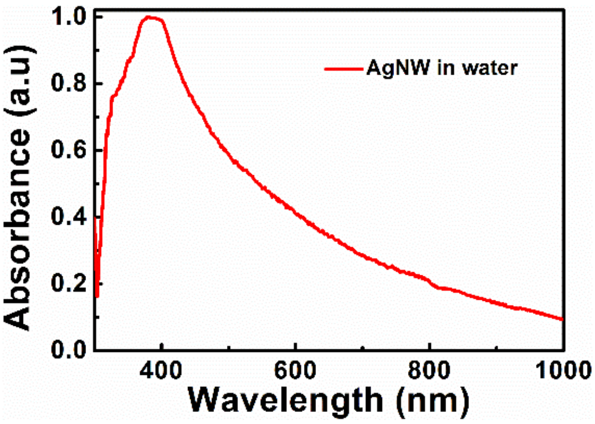

Figure S1. Absorbance of the AgNWs dispersed in water.

2. Fabrication of the tapered fibers

The tapered optical fiber was fabricated by drawing a commercial single/multiple-mode optical fiber through a flame-heating technique. The buffer and polymer jacket of the fiber were stripped off with a fiber stripper, forming a bare fiber of about 400-mm in length and 125-μm in diameter. The fiber was first heated for approximately 1 min until its melting point was reached. The drawing speed of 0.2 mm/s was firstly applied to the heated fiber, and the diameter of the fiber was decreased from 125 μm to approximately 15 μm over a 2-mm length. Then a high speed of 2 mm/s was applied until the fiber broke. Finally, the tapered fiber was fixed and manipulated in a micromanipulator. Figure S2 shows the optical image of the tapered fiber used in the experiment. The diameter of the tapered fiber used in the experiment is gradually decreased from 13 μm to 400 nm within 125 μm.

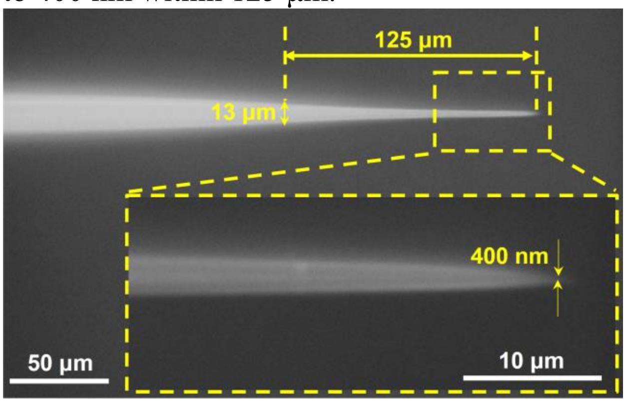

Figure S2. Optical microscope image of the tapered fiber.

3. Evanescent coupling

Figure S3 shows the optical microscope image of the experimental architecture. In the experiment, the tapered fibers 1 and 2 were carefully manipulated with the help of micromanipulators under a microscope. By placing the tapered fibers and the PMMA nanofiber in parallel and close contact, optical near-field in the tapered fiber and the nanofiber may strongly overlap, resulting in efficient coupling. The close contact between the PMMA nanofiber and the tapered fibers can be maintained by the van der Waals force and electrostatic force.

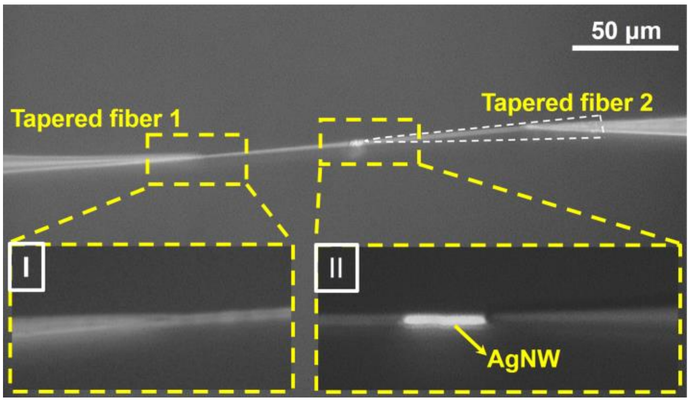

Figure S3. Optical microscope image of the experimental architecture. Inset I and II indicate close-up view of the coupling between PMMA nanofiber and the tapered fibers 1 and 2, respectively.

4. Measurement of the optical power

Figure S4 shows schematic of optical power measurement. An output light from the laser source was evanescently coupled into the PMMA nanofiber by a tapered fiber 1. P_{ex} is the optical power output from the tapered fiber 1, which was kept at 80 μW for 650, 532, and 473 nm lights in the experiment. Since the tapered fiber and the nanofiber contacted tightly each other by the Van der Waals and electrostatic forces, the coupling efficiency η between the tapered fiber and the nanofiber is estimated to be 90% [Ref. 28].

When the light coupled into the PMMA nanofiber is transmitted to the end face of the AgNW, some of the light will be converted into the surface plasmon modes in the AgNW, while the rest is scattered to free space or continuously transmitted in the polymer nanofiber outside the AgNW.

The light directly scattered to free space at the nanowire ends cannot be collected by a tapered fiber in the experiment. However, the intensity of light scattered to free space can be obtained by integrating the gray values of the bright spots on ends of the AgNW in the CCD picture. The relation between the scattering light intensity and the corresponding optical power can be estimated by measuring a scattering spot from a similar size endpoint of a nanofiber. Firstly, a laser of 650-nm wavelength was launched into a tapered fiber with an endpoint size of 400 nm (see Fig. S2), which is the same with the diameter of AgNW used in the experiment. The optical power scattered from the end of the tapered fiber can be measured by an optical power meter. By altering the scattering light power, the corresponding scattering spots were imaged by using the same CCD camera as that described in the manuscript without saturation. An 80×80 pixel area centering on the bright scattering spots is selected and the brightness is transformed into gray level by using Adobe Photoshop, and thus the scattered light intensity is obtained by summing up the gray values. The red line in Fig. S5 shows the calculated scattering intensity as a function of the optical power of the 650 nm light. It can be seen that the scattering light intensity is linearly increased with the optical power. Similar results can be obtained for 532 nm (green line) and 473 nm (blue line) lights as shown in Fig.

S5. Figure S6 shows the dark-field microscope images corresponding to Fig. 2b–d, respectively. By integrating the gray values of the bright spots in Fig. S6, the light intensities scattered to the free space at the AgNW ends for 650, 532, and 473 nm lights can be calculated to be 6.19×10^4, 9.65×10^4, and 11.77×10^4 (a.u.), respectively. Then, the powers of light scattered to free space at the nanowire end are estimated to be 0.37, 0.52, and 0.60 μW for the three wavelengths according to the results of Fig. S5. Compared to the powers of excitation light (P_{ex}, 80 μW), the optical power of light scattered to free space is small and can be ignored.

The optical power of light transmitted in the polymer nanofiber outside the AgNW can be measured by moving a tapered fiber 2 to a position M close to the input end A of the AgNW. For convenient manipulation in the experiment, the distance between A and M is chosen to be 800 nm. Here, the tapered fiber 2 is connected with an optical power meter. Taking into account that surface plasmons generated at the surface of the AgNW decay exponentially with distance from the surface, the optical power P_M picked up by the tapered fiber 2 at the position M is mainly the power of light transmitted in the PMMA nanofiber outside the AgNW. Thus, the optical power coupled into the AgNW can be calculated as $P_{in\text{-}Ag} = P_{ex} \times \eta - P_M/\eta$. Similarly, the optical power $P_{out\text{-}Ag}$ output from the AgNW can be also calculated as $P_{out\text{-}Ag} = (P_O - P_N)/\eta$, where P_O and P_N are the optical powers measured at positions O and N.

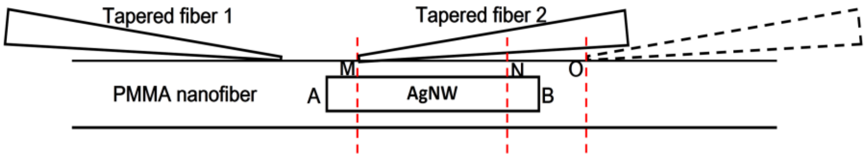

Figure S4. Schematic of the optical power measurement

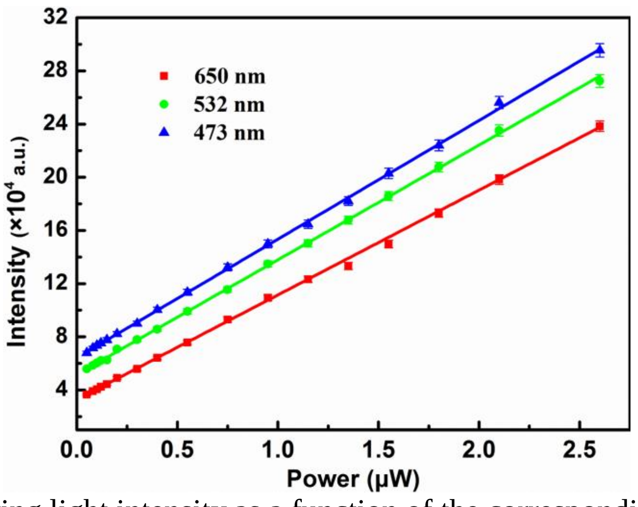

Figure S5. The scattering light intensity as a function of the corresponding optical power.

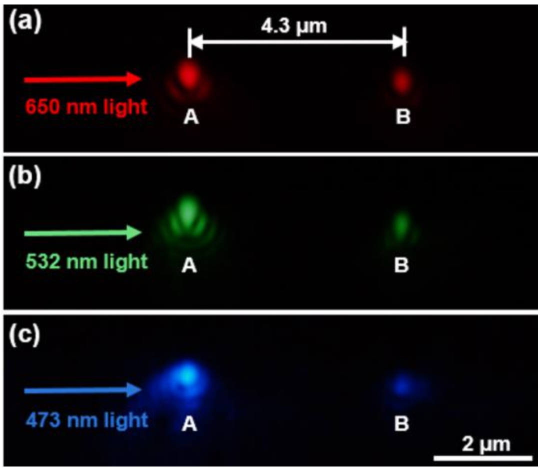

Figure S6. Dark-field microscope images corresponding to Fig. 2b–d, respectively. The AgNW with a length of 4.3 μm was excited by (a) 650 nm, (b) 532 nm, and (c) 473 nm lights.

5. Simulation of surface plasmons in AgNW

The simulated electric field intensity distributions for the AgNW embedded in the PMMA nanofiber are shown in Figure S7. In the simulation, the AgNW was assumed to be a cylinder (diameter of 400 nm and length of 4.3 μm) embedded in the PMMA nanofiber which was also modeled as a cylinder (diameter of 760 nm and refractive index of 1.49). It can be seen that the electric field distributions for excited lights of 650, 532, and 473 nm are concentrated at the AgNW surface of and decay quickly with distance from the surface. Besides, it is worthwhile to notice that the electric field distributions for the three wavelengths show distinct nodes and the number of nodes changes with the excited wavelength, which is due to that different excited wavelengths induce different surface plasmon modes in the AgNW. It is also obvious that along the direction of the AgNW, decay of the electric field intensity for 473 nm lights is more quickly than that for 650 nm lights, which is in agreement with the result of experiment.

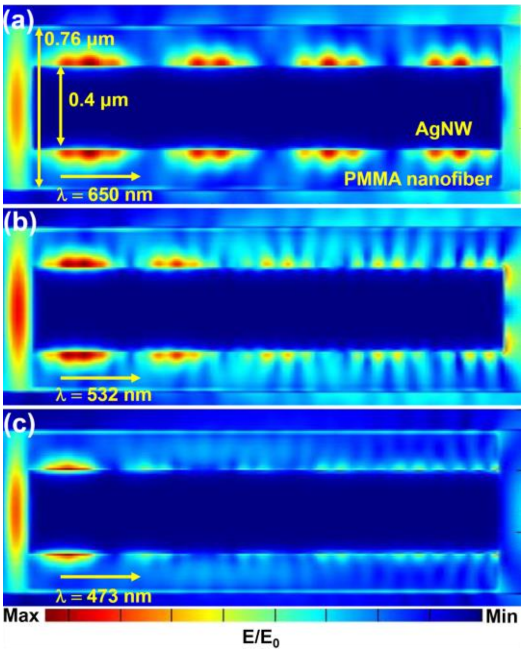

Figure S7. Simulation results of electric field intensity distributions around single AgNW embedded in PMMA nanofiber for (a) 650, (b) 532, and (c) 473 nm lights.