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A NEW METHOD FOR MEASUREMENT OF SURFACE PLASMON POLARITONS PROPAGATION LOSSES IN A LASER-CUT SINGLE SILVER NANOWIRE

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Abstract

In this work, we propose a new experimental approach to directly measure propagation losses of surface plasmon polaritons (SPPs) in a single silver nanowire (AgNW). Using a precise microinjector, a femtoliter droplet with up-converting nanocrystals (NCs) is deposited at one end of the nanowire. When illuminated with a laser, NCs provide a stable source of SPPs, which then propagate through the nanowire to its other end. The intensity of radiation measured at that end provides information about propagation losses. By gradually reducing the length of the nanowire through a precisely controlled laser-cutting technique, it is possible to measure the intensity of scattered polaritons versus the effective length of the nanowire. Interestingly, the experimental techniques presented in this work prove to be beneficial as an characterization tool due to their relatively low cost and ease implementation in an already built measurement setup.

1 Measurement setup

The experiment was carried out using a confocal microscope (Ti2, Nikon) equipped with two microscope objectives (Figure 1): a high numerical aperture (NA) oil immersion objective (Apo TIRF 60x, NA = 1.49, Nikon) operating in an inverted configuration, and a low numerical aperture air objective (LU Plan 50x, NA = 0.55, Nikon) mounted on a tripod-holder, placed directly above the sample and attached to sample stage.

The bottom objective was used to both collect photoluminescence (PL) signal from NC and cut the nanowire. The top objective was solely used to provide a stable excitation source for locally deposited nanocrystals. Raster scanning for luminescence image reconstruction is possible due to a piezoelectric sample holder (P-545, Physik Instrumente). As a light source, a single-mode fiber-coupled infrared laser diode operating at 980 nm (LP980-SA100, Thorlabs) was used. A photon counting module (COUNT-100C, Lasaer Components) was used to detect the signal acquired by the bottom objective.

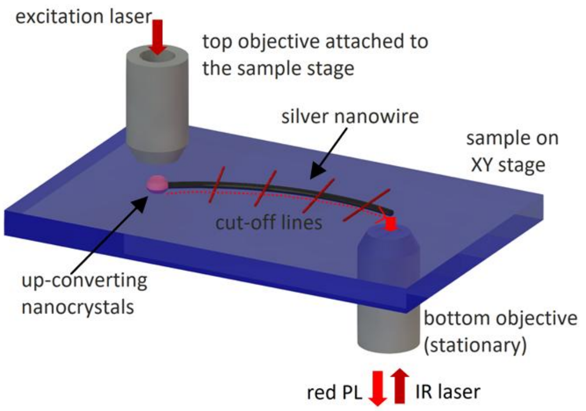

Figure 1 *Sketch of the experimental configuration.*

2 Sample preparation

As a sample base, regular coverslips (No 1, Roth) were chosen since glass does not introduce an additional attenuation of polaritons. Next, about 20 µL of colloidal silver nanowires in water were spin-coated on the coverslip for 30 s at 2500 rpm. One silver nanowire, isolated from other particles, was selected from the resulting random distribution of nanowires on the glass surface. By using a femtolitre capillary tip, a small NCs droplet of about 500 nm in diameter was deposited exactly at one end of the selected nanowire (Figure 2).

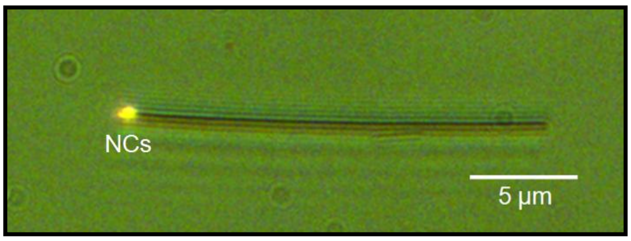

Figure 2 *Single, silver nanowire with nanocrystals deposited at one end, observed in transmitted light.*

3 Sample characterization

Initial dimensions of the nanowire were estimated using fully optical techniques. The length of the nanowire was about 23 µm and was measured using scattering imaging with an accuracy of about 0.5 µm (Figure 3).

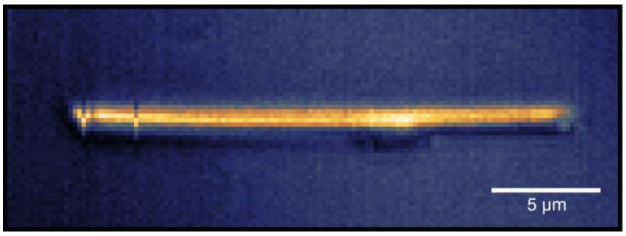

Figure 3 *Single, silver nanowire imagined using backscattered laser light.*

Due to the diffraction limit, nanowire diameter cannot be estimated using classical imaging techniques. One can, however, use an indirect method based on complex interactions between the silver nanowire and Gaussian beam [1]. A laser beam focused on the free end of the nanowire by an objective with a high numerical aperture launches $SPPs_{SL}$, which transports energy along x-direction to the nanocrystals deposited at the other end of the nanowire [2]. Excited nanocrystals launch $SPPs_{SPL}$ propagating back to the excitation/detection point (bottom objective). The shape and intensity of this emission strongly depends on the laser polarization and nanowire diameter which can be used to determine nanowire thickness [1]. It has been shown that in the case of thin nanowires (d<100 nm) and linearly polarized laser oriented perpendicular to nanowire long axis, only E_{0x} and E_{0z} laser field components are visible [1]. A four-lobe PL pattern observed for the investigated nanowire indicates that its diameter is below 100 nm (Figure 4).

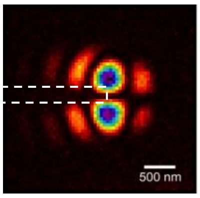

Figure 4 *PL distribution observed at the free end, excited by laser light polarized perpendicular to the nanowire.*

4 Experiment

The SPPs propagation losses measurement was realized using the configuration presented in Figure 1. The top objective is used to position the excitation laser spot on the NCs droplet, which then becomes a source of polaritons. Using low numerical aperture objective guarantees lower power densities, reducing the possibility of accidental damages of the nanowire. Eventually, $SPPs_{SPL}$ launched by NCs reach the opposite end of the nanowire and are collected by the bottom objective in the form of out-scattered radiation (PL). This radiation is then integrated and plotted versus nanowire length. After PL measurement, the laser was redirected to the bottom objective and polarized alongside the nanowire to ensure the most efficient absorption. Next, the laser power was increased to provide enough energy to melt the thin nanowire. After each melting step, the laser power was reduced and redirected back to the top objective to excite NCs again and collect PL image. This procedure was repeated for 11 different lengths of the nanowire. The first and last step of this process is presented in Figure 5. The distribution of integrated intensities plotted versus the temporary length of the nanowire (Figure 6) can be accurately described by the exponential function.

a) b)

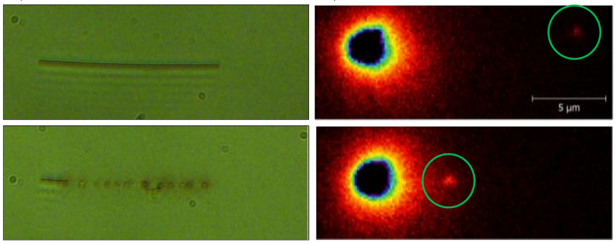

Figure 5 *First (upper images) and last (lower images) step of SPPs propagation losses measurements: (a) transmission and (b) PL images.*

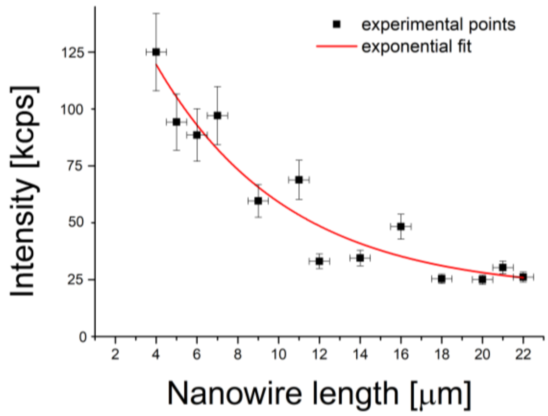

Figure 6 *The integrated intensities of PL signal, measured at the free end of the nanowire for different lengths of the nanowire.*

5 References

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