Plasmonic Nano-Resonators in Metal-Coated Fibre Tapers

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Abstract Summary: Plasmonic slot nanoresonator (PSNR) embedded in a gold-coated optical fibre tapers are studied, can show strong three dimensional localization when optimised.

Introduction:

In recent years, research in plasmonics and surface plasmon polaritons has attracted considerable interest because of their extraordinary potentials in energy confinement and nanoantennas. Nanoscale apertures in thin noble-metal films, with dimensions comparable to the light wavelength, can form plasmonic nano-resonators and show astonishing optical properties leading to enhanced and selective light transmission and confinement. A number of different nano-structures have been considered and studied in detail for their ability to concentrate light [1]. At resonance, such structures can concentrate an incident light field into a small volume with orders-of-magnitude intensity enhancement. So far, the transmission properties of slot nano-resonators have been studied under plane-wave excitation directed perpendicularly to the plane of the resonator [2,3]. In this paper, we study theoretically a strongly-coupled 3D PSNR by embedding a slot nano-cavity in a plasmonic cylindrical waveguide formed by a thin-metal-film coated microfibre. Also, for the first time, both theoretically and experimentally, the transverse excitation of a strongly-coupled 3D PSNR is investigated by embedding a rectangular slot nano-cavity in a plasmonic structure formed by a thin-metal-film coated optical fibre tip.

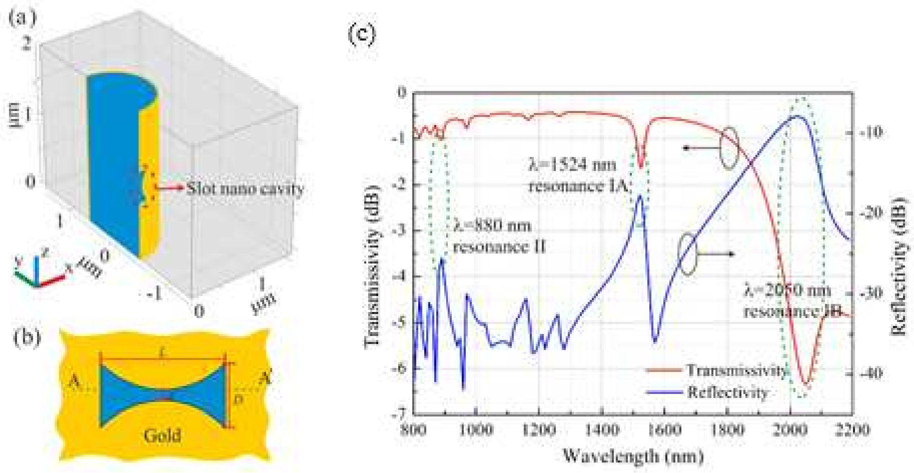

Fig. 1 (a) Geometry of the PSNR embedded in the plasmonic microfibre; (b) top-view of the bow-tie; (c) transmissivity (red) and reflectivity (blue) of the bow-tie PSNR embedded in the microfibre.

Simulations: Theoretical analysis on a strongly-coupled 3D PSNR by embedding a slot nano-cavity in a metal-coated fibre taper was carried out using a 3D finite element method. Light is launched from one of the fibre pigtails into the 1 μm diameter taper coated with a 30 nm gold layer (see Fig. 1 (a)) and the various resonances can be identified simply monitoring the transmitted and reflected spectral features. Fig. 1 (b) gives the top-view of the bow-tie PSNR. Fig. 1 (c) shows the transmissivity and the reflectivity of the composite structure when the bow-tie PSNR has L=400 nm, D=200 nm, and d=34.4 nm. Three main resonances were identified that at λ=880 nm corresponds to a second-order resonance, with two intensity maxima along the length of the bow-tie PSNR. The resonances at λ= 1524 nm and 2050 nm correspond to first-order PSNR resonances, with only one intensity maximum along the bow-tie length. From the electric field at several wavelengths corresponding to the major (λ=880 nm, 1524 nm and 2050 nm) resonances, the electric field is highly localized and centered at the bow-tie waist. A single resonator shows enhancement factor in excess of 9×10^5, which we believe is the biggest enhancement factor calculated in all types of nano-resonators so far.

Different bow-tie PSNRs with different waist and different edge width, multiple cascaded bow-tie PSNR, and rectangular PSNR were numerically investigated [4]. Wavelength shift rates were found to be strongly dependent on the nature of the associated resonance and the plasmonic waveguide characteristics.

Experiment: A rectangular PSNR was inscribed on the surface of a gold-coated fibre tip. The fabrication process involved three main steps: manufacture of optical fibre tip, deposition of a thin gold layer and focused ion beam (FIB) nanopatterning [5]. The SEM image of the rectangular PSNR on a plasmonic fibre tip is shown in Fig. 2(a). The optical properties of the PSNR embedded in plasmonic fibre tips were characterized with the set-up shown in Fig. 2 (b). Many resonance features were observed in the reflectivity of the samples recorded at the polarization perpendicular to the PSNR (Fig. 2 (c) red solid curve). The simulations (blue dashed curve in Fig. 2 (c)) were modelled with the dimensions obtained from the SEM image. The biggest enhancement factor 7.24×10^3 is observed numerically at resonance λ=1450 nm, which is few times larger than that at the other resonance wavelengths. The two curves in Fig. 2 (c) show a number of differences, like different resonance peak positions, slightly different reflection amplitudes and number of peaks. A possible explanation might be related to imperfect taper and gold layer surfaces and to particles attached to the gold layer surface. Particles induce plasmonic effects even when their size is small. Moreover, part of the gold layer was removed due to the re-deposition of material in the FIB processing and formed additional extremely small nano-cavities. This not only causes plasmonic cavities but also changes the interference condition in the plasmonic fibre tip.

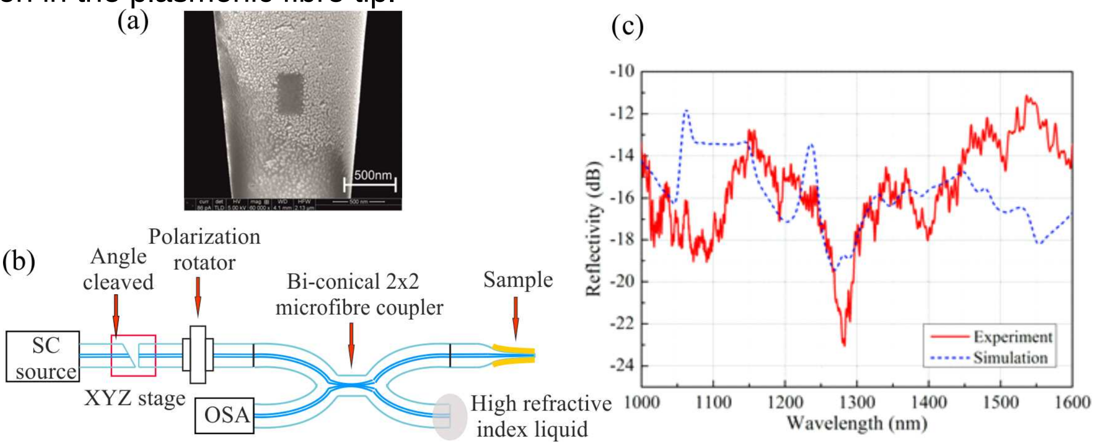

Fig. 2 (a) SEM image of the plasmonic fibre tip with a rectangular PSNR;(b) Schematic of experimental set-up to characterize the PSNR spectral properties; (c) reflectivity spectrum of the sample in the experiment (the red solid curve) and in the simulation (the blue dashed curve).

This device can find a wide range of applications such as SERS, optical filtering, spectroscopy and bio-sensing. This will be discussed further in the conference

References

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