Towards a sub-10nm optical fibre light source

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1. INTRODUCTION

Light sources with sub-10nm spot sizes have a wealth of applications, including optical memories, optical tweezers, SNOM microscopy and photolithography, just to cite a few. Overall, light confinement is limited by diffraction, which can be seen as a direct consequence of Heisenberg's uncertainty principle [1]. Recent results show that "sub-wavelength" light sources can be manufactured using many techniques, including metamaterials and negative refractive index materials [2,3]. Very often these techniques have been proven inefficient, bulky and do not work at short wavelengths. In this paper, light confinement is attained in nanostructured optical fiber tips exploiting surface plasmon polaritons (SPP).

2. EXPERIMENTS

An optical fiber single-moded at 800nm (Nufern 780HP) was tapered to a diameter d~1μm, cleaved at an angle α suitable to excite surface plasmon polaritons (SPP) and then coated with gold. A small aperture was finally made with a focused Ion Beam (FIB) system. The angle α was chosen to excite SPPs at the gold-air interface, thus the projection of the light propagation constant along the surface k_α matches the SPP propagation constant β. A SEM micrograph of the nanostructured tip is shown in Fig. 1. The sub-wavelength aperture ~150nm wide is used to demonstrate the improved light confinement by SPP. In order to characterize the sample, a supercontinuum source delivering 400 fs, 50 nJ pulses in the wavelength range 700-1000 nm was connected to the sample and the transmitted light was collected with an OSA. Coupling optimization was achieved using a xyz stage. Measurement results are presented in Fig. 2. Figure 2 shows the sample spectrum in dry and humid air: a big resonance peak is clearly visible at ~770nm, which is attenuated in the humid environment where SPP resonance conditions change. The maximum normalized transmission in Fig. 2 is ~8% at λ=770 nm, nearly one order of magnitude higher than transmitted because of pure geometrical reasons at the peak tails (at 700nm and 1000nm): in other terms, approximately 10% of the intensity propagating in the fiber is confined to sub-wavelength spot-sizes using the conversion light→SPP→light.

This preliminary demonstration can be extended to even smaller apertures. Fig.3 shows a schematic of the manufacture scheme for a sub-10nm source. A fibre taper with tip diameter d~1μm (a) is cleaved (b) on four sides at an angle α and then coated with gold (c). A small aperture is cut with FIB at a distance h from the tip top. Since the SPP attenuation length is larger than 20μm in the near IR in gold, the biggest limitation to minimum confinement is the SPP dispersion, which in practice limits the confinement to few nanometres.

3. SUMMARY

The nanostructuring of optical fibre tips and the use of surface plasmon polaritons can be used to efficiently confine light into sub-wavelength spot-sizes. ~7% conversion efficiency has been shown in a gold coated nanostructured tip. Surface plasmon polaritons dispersion seems to be the most important factor to limit confinement at a nm scale and in practice limits the efficient confinement to few nanometres.

REFERENCES

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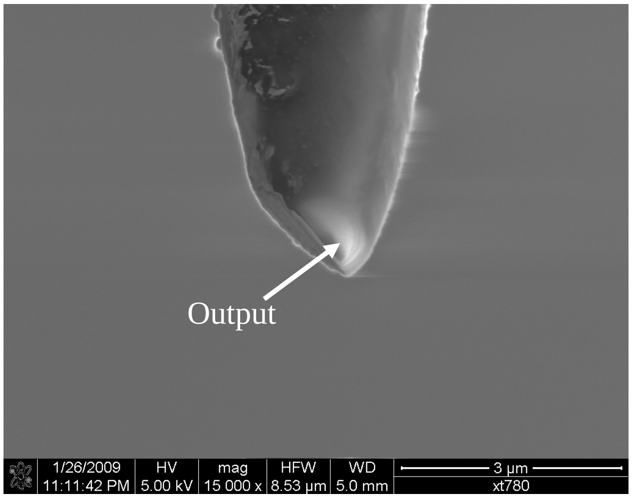

Fig.1 SEM micrograph of the optical fibre sub-wavelength source. The bright spot at the bottom of the fibre tip is bare silica, while the dark areas are gold coated. The source output size is approximately ~150nm.

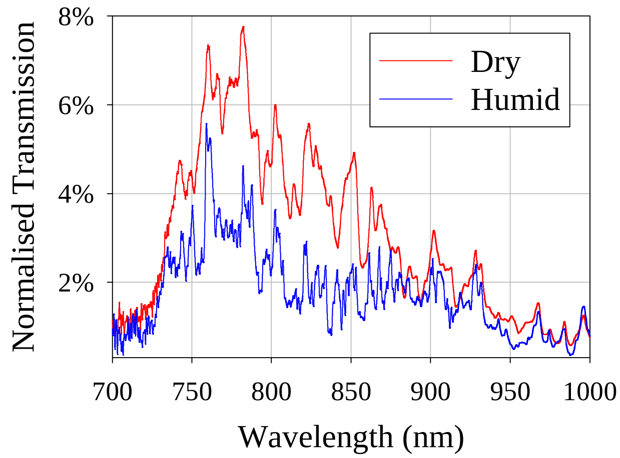

Fig.2 Normalised transmission spectra of the sample in dry and humid atmosphere. The broad peak at 770nm is given by the surface plasmon polaritons (SPP). Without SPP the transmission efficiency of the device would be ~1% over the whole spectrum.

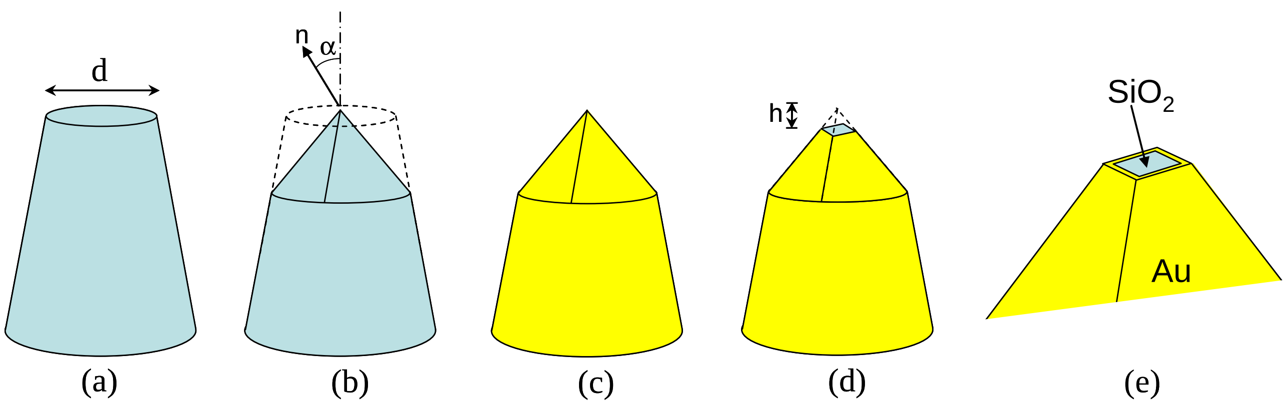

Fig. 3 Schematic of the process for the fabrication of the nanostructured sub-wavelength source. (a) A single mode fibre is tapered until its tip has a diameter d. (b) Focused ion beam (FIB) milling cuts surfaces at an angle α, at which the light propagation constant along the newly formed surface matches the surface plasmon polariton (SPP) propagation constant. (c) Metal coating (gold). (d) FIB milling generates a sub-wavelength window: h represents the amount of material removed from the coated fibre tip. (e) Detail of the tip.