Nanostructured optical fibre tapers

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Since 2003 [1], optical fiber microwires (OFM) have increasingly attracted a considerable interest [2], because of their extraordinary properties, which include:
1) Strong confinement: the beam propagating in the OFM can be confined to the diffraction limit for a length thousands times longer than the Raleigh length, allowing for strong nonlinear interactions like nonlinear switching or high harmonic and supercontinuum generation;
2) Large evanescent fields: the power propagating outside the OFM physical boundary can be considerable if the OFM diameter (d) is significantly smaller than the wavelength, allowing for easy inter-OFM coupling and for the realization of high-Q resonators;
3) Configurability: OFM are mostly manufactured by stretching optical fibres, thus their input and output pigtails preserve the original optical fibres size and they allow for low-loss and easy connection to other fiberized components;
4) Flexibility: since moments of inertias are proportional to the power of d and OFMs have an extremely small size, extremely small bending radii (typically few microns) can be achieved;
5) Robustness: OFMs exhibit ultimate strengths in excess of 10GPa and can be easy handled with conventional optical lab equipment.
Most of the applications [1] have exploited the large evanescent field for the realization of a variety of optical devices which include sensors and lasers. Here OFM are nanostructured to introduce new functionalities, like frequency selection and extreme light confinement.

OFM nanostructuring was carried out with focused ion beam (FIB) milling, which allows for great flexibility as it is a direct writing technique. Two types of structures have been investigated: 1) a microfiber Bragg grating (FBG), which allows for 3D confinement to the diffraction limit, and 2) an apertured tip, which allows for 2D confinement to sub-100nm spot-sizes. Examples of nanostructured OFMs are shown in figure 1.

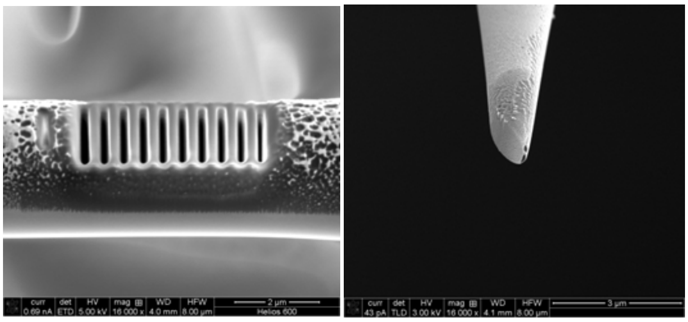

Fig. 1 a Bragg grating machined into an OFM (left) and a nanostructured apertured tip with ~60nm aperture (right).

Since the refractive index difference Δn between silica and air can be as high as ~0.45 at $\lambda = 1\mu m$, Bragg gratings can be extremely compact, typically in the order of 10μm [3] or three orders of magnitude smaller than conventional fibre Bragg gratings (fig.1,left). If a phase shift is inserted in the grating periodicity, a miniaturised cavity can be realised. Light confinement over a volume of the order of a μm^3 has been demonstrated [4].
Nanostructured apertured tips allow to confine light to even smaller areas. The device in fig. 1 (right) has an aperture of~60nm, allowing for efficient confinement to spot sizes smaller than $\lambda/10$. The OFM tip was coated with a 30nm layer of gold and then slant cut at an angle of ~46^o; after recoating the machined sample with gold for the second time, a small aperture is created. For small diameters, there is no mode propagation along the metal-coated tip and only a longitudinal evanescent field exists [5]. Yet, by optimizing the tip profile and exploiting plasmonic effects, transmission efficiencies well in excess of 1% can be achieved. This could find a range of applications in optical memories and nano-biosensing.

Reference

1. L. Tong, R. R. Gattass, J. B. Ashcom, S. He, J. Lou, M. Shen, I. Maxwell & E. Mazur, *Nature* **426**, 816 (2003).
2. G. Brambilla, *J. Opt. A* **12**, 043001 (2010).
3. M. Ding, M. N. Zervas & G. Brambilla, *Opt. Express* **19**, 15621 (2011).
4. M. Ding, P. Wang, T. Lee & G. Brambilla, *Appl. Phys. Lett.* **99**, 051105 (2011).
5. B. Hecht, B. Sick, U.P. Wild, V. Deckert, R. Zenobi, O.J.F. Martin & D.W. Pohl, *J. Chem. Phys.* **112**, 7761 (2000)