Invited talk

Microstructured Optical Fibre Semiconductor Metamaterials

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We have synthesised arrays of semiconductor wires and tubes inside microstructured optical fibres. These extreme aspect ratio structures have highly functional optoelectronic properties and initial characterisation studies of their waveguiding properties are presented here.

1. Introduction

Silica based microstructured optical fibres (MOFs) incorporate periodic arrangements of air-holes running throughout their length which defines their transverse refractive index profile. The structural parameter space explored by such air-silica optical fibre metamaterials has already given rise to a wealth of scientific and technological applications due to unique photonic properties including broad band single mode guidance, widely engineerable dispersion, nonlinearity, mode area tailoring over three orders of magnitude, and photonic band gap effects guidance [1]. To further augment their properties, we have we have begun to add compositional complexity to these structures by depositing crystalline semiconductors within the micro/nanostructure of MOFs. This presents radically novel electronic, photonic and plasmonic degrees of freedom for the design of complex optical fibre devices with exceptional tuneable optical and electrical properties. The inclusion of functional materials in nanostructured MOFs also brings together optical fibre waveguides with the growing field of semiconductor nanowire technology [2].

2. Results

Our initial device structures were fabricated by filling a 2 μm silica capillary with silicon using a high pressure chemical deposition technique. As can be seen in the SEM picture of the resulting silicon optical fibre (*Figure 1)*, silicon was deposited within the capillary void forming a uniform ring with wall thickness of 600 nm.

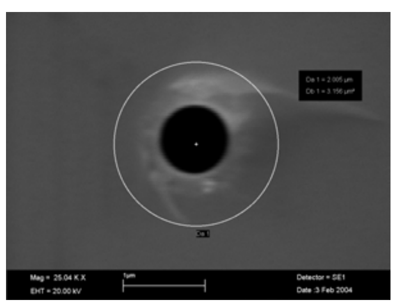

Fig. 1. SEM micrograph of a silica capillary fibre that has been filled with silicon. The circle indicates the original hole size (2 microns). The hole diameter after deposition was 800nm.

To determine its optical properties, ASE radiation (1530 – 1570 nm) was launched into the silicon optical fibre which was immersed in index matching fluid to remove any cladding light, and the resulting near field output was then imaged onto an infrared camera. As it can be seen in *Figure 2*, the experiments reveal strong evidence that a significant fraction of ASE has been guided by the silicon waveguide.

Fig. 2. Near field output of the ASE radiation guided by the silicon filled optical fibre

With the aim of better understanding the guiding properties of semiconductor optical fibres, beam propagation method software was used to determine the mode profile and the number of optical modes allowed to propagate within the silicon core at 1.55 µm. As expected from the high contrast between silicon and silica refractive indices, the simulations reveal the multimode behaviour of the silicon optical fibre at 1.55 µm and the strong energy confinement in the semiconductor core. *Figure 3* presents the mode profile of the fundamental propagating mode calculated by means of the BPM. As can be seen in *figures 2* and *3*, the experimentally near field output closely matched the fundamental mode obtained by BPM simulation.

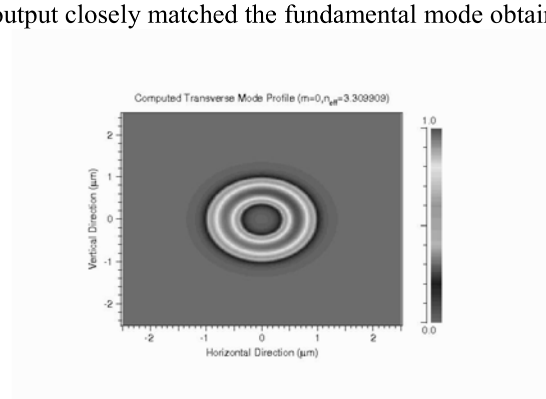

Fig. 3. Computed fundamental mode distribution. The scale bar indicates the power density.

3. Future directions

The deposition of semiconductors within microstructures optical fibres will open new possibilities for innovative fibre based device structures with potential impact on novel sensing applications and systems design. Recent progress in the fabrication of all-silicon based optoelectronics [3] for example, has demonstrated optical gain via stimulated Raman scattering. With the wide transparency window of Group IV semiconductors in the near and mid-infrared, it may prove possible to design cascaded amplification stages for mid-IR sources operating in the 2 – 5 micron range for Lidar applications.

4. References

[1] P. Russell, "Photonic crystal fibers", *Science* **299**, 358-362 (2003).

[2] A. M. Morales and C. M. Lieber, "A laser ablation method for the synthesis of crystalline semiconductor nanowires", *Science* **279**, 208-211 (1998).

[3] H. Rong, R. Jones, A. Liu, O. Cohen, D. Hak, A. Fang and M. Paniccia, *Nature* **433** 725-728 (2005).