A solid one-dimensional microstructured optical fiber with high nonlinearity and low dispersion at 1.55μm

X. Feng, A. Camerlingo, F. Poletti, P. Petropoulos, F. Parmigiani, P. Horak, W. H. Loh, and D. J. Richardson

Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK
E-mail: xif@orc.soton.ac.uk

Abstract: We report on the fabrication of a solid one-dimensional microstructured fiber with high nonlinearity and low dispersion at 1.55μm. A four-wave-mixing based tunable wavelength-conversion scheme was experimentally demonstrated in just 1.5m of this fiber.

Keywords: microstructured optical fiber, nonlinear optics.

1. INTRODUCTION

Microstructured optical fiber (MOF) technology provides the means to tailor the dispersion profile of an optical fiber over a very broad wavelength range due to the strongly wavelength-dependent nature of waveguide dispersion. Moreover, this technology can also give rise to extremely high values of effective nonlinearity per unit length. Both of these novel features arise from the combination of (i) the wavelength-scale features in the microstructured cladding and (ii) the high index-contrast between the background material and the material(s) used to define the microstructured features [1]. In Holey Fibres (HFs), the most common form of MOF, these microstructured features are air holes. High-index non-silica glasses, such as lead-silicate, tellurite and chalcogenide glasses, possess nonlinear indices of refraction n_2 that are 1-3 orders of magnitude higher than that of pure silica (2.5×10^{-20} m^2/W) [2]. This allows the feasibility of compact nonlinear devices based on meter-long highly nonlinear dispersion-tailored MOFs fabricated using non-silica glasses. However, it has been found that due to the steep viscosity curve of non-silica glasses, it is often challenging to fabricate a HF with a holey cladding conforming to a specific design and to the required tolerances. Consequently the optical properties of many fabricated non-silica HFs show relatively large deviations from the initial design target [3]. One of the most straightforward solutions to overcome this drawback is to use high index-contrast all-solid MOF rather than HF designs [4]. In this work, we report the fabrication of a solid one-dimensional (1D) MOF with low loss, high nonlinearity and low dispersion at 1.55μm. Broadband wavelength-conversion based on four-wave-mixing (FWM) has been demonstrated in the C-band from this solid MOF.

2. FIBER FABRICATION AND CHARACTERIZATION

Two commercial optical glasses, Schott SF6 and LLF1, were selected for making the solid MOF. The refractive indices of SF6 glass and LLF1 at 1.53μm are 1.7644 and 1.5288, respectively. A preform with 1D structure designed to provide a dispersion shifted highly nonlinear fiber was fabricated using the extrusion method [5]. The structured preform was first elongated to a cane with 1.09mm diameter and then inserted into an extruded SF6 glass jacket tube with 15.80mm outer diameter (OD) and 1.10mm inner diameter (ID). Fig. 1 shows the scanning electron microscopy (SEM) images of the MOF with 150μm OD drawn from this preform. The total yield of the fiber drawing was ~100m. The fiber has a circular high-index SF6 core with a diameter of 3.7μm. The high-index core is surrounded by alternating LLF1 and SF6 glass rings with a thickness ranging from 0.3-1.1μm. Fig. 2 compares the structural similarity in the structures on the 1.09mm OD cane before the fiber-drawing and the central microstructure around the core on the solid 1D MOF with 150μm OD. Three rectangular frames are drawn with their upper and lower horizontal sides inner-tangential with the core, the first high-index ring from the core and the third low-index ring respectively, for both the cane and the fiber. It is obvious that the structured claddings on the cane and the fiber are completely identical in terms of geometry, even though features that have been achieved in the final fiber are on the micron-scale. This directly illustrates the fabrication advantages of using all-solid MOF technology over HF technology - the former giving a controllable and predictable microstructured cladding in the final fiber.

Effective single-mode guidance was observed at 1.55μm from this 1D MOF. Using the cutback method, the propagation loss of the fabricated solid MOF was measured as 0.8±0.2dB/m at 1.55μm, with the total cutback length of 2.4m in the measurement. Note that the loss of 0.8dB/m is one of the lowest reported values amongst all the non-silica glass MOFs so far. The improvement in the fiber attenuation is believed to arise from the high surface quality of the polished discs used in the preform extrusion.

It was predicted numerically that the fabricated MOF has an effective mode area A_{eff} of 6.7μm^2 and an effective nonlinearity γ of $130W^{-1}km^{-1}$ at 1.55μm. Using the Boskovic method [6], the effective nonlinearity γ at 1.55μm was measured to be $120W^{-1}km^{-1}$, which is 120 times higher than that of standard single-mode silica optical fiber (SMF28).

The dispersion curve of the 1D MOF calculated numerically from an SEM image of the fiber, is shown in Fig. 3. Using the FWM method [7], the dispersion at 1.55μm for the 1D MOF was measured to be +12.5ps/nm/km (see the marked cross symbol in Fig. 3) and the dispersion slope estimated at $0.15ps/nm^2/km$, both in good agreement with the modeling predictions. It can be seen that this MOF is a dispersion-shifted fiber with a zero-dispersion-wavelength at 1475nm. For reference, the dispersion curve of the commercial silica fiber SMF28 is also illustrated in Fig. 3. At 1.55μm the dispersion values of the MOF and silica SMF28 are very similar, even though the effective nonlinearity of the MOF is 120 times higher than that of SMF28. A few meters of this 1D MOF can therefore exhibit a total nonlinearity equal to that of several hundreds of meters of SMF28 whilst exhibiting much less total dispersion - an important issue for many nonlinear applications such as FWM.

3. TUNABLE WAVELENGTH CONVERSION USING FOUR-WAVE-MIXING

In order to demonstrate the benefits of the low dispersion and high nonlinearity of this fiber, we performed an experiment on FWM-based wavelength conversion using 1.5m of the MOF. A 10 Gbit/s amplitude modulated pump beam comprising ~7ps pulses (full width at half maximum) and a central wavelength of 1545.5nm was launched into the MOF with a peak power of ~5W. A 2mW continuous wave (CW) probe signal was also launched into the fiber and tuned from 1542.5nm to 1530nm. Note that two different amplifiers were used to also independent control of the powers of the two signals. Fig. 4 shows the corresponding spectral traces at the output of the system as the wavelength of the CW beam was tuned. An idler (wavelength converted) signal is clearly visible for each CW probe wavelength chosen, confirming the tunabililty of the scheme due to the relatively low values of dispersion and dispersion slope.

4. CONCLUSIONS

In summary, we have presented a solid 1D MOF with low loss, high nonlinearity and low dispersion for the 1.55μm band. This has been experimentally confirmed by a tunable FWM-based wavelength-conversion scheme.

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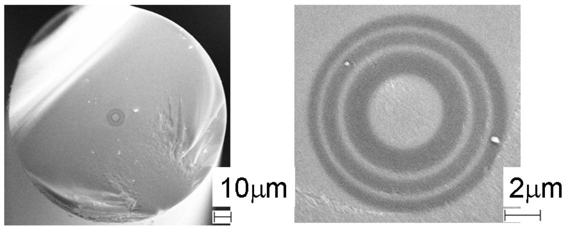

Fig. 1 Full view (left) and zoomed center view (right) of SEM images of the 1D MOF

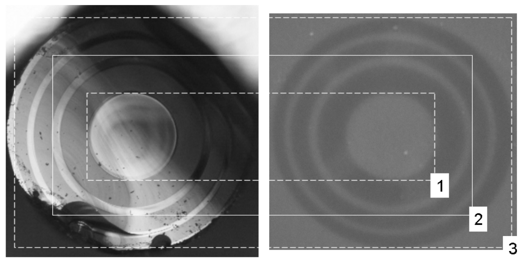

Fig. 2 Comparison between the structured cane (left) and the microstructured cladding in the final fiber (right)

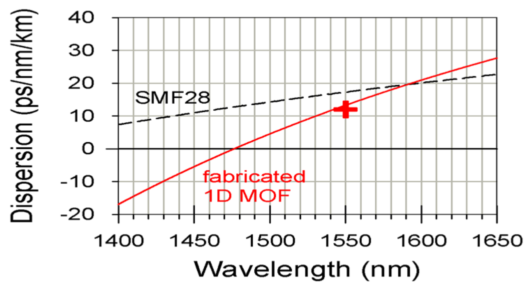

Fig. 3 Dispersion curves for the 1D MOF and SMF28

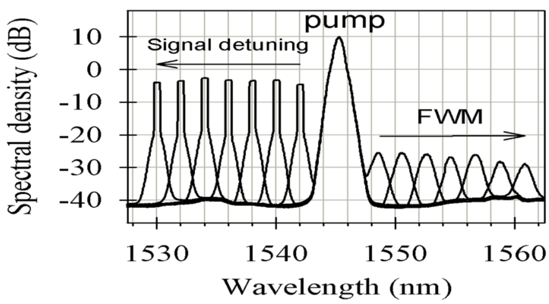

Fig. 4 Spectral traces obtained at the output of the 1D MOF