NONLINEAR SPECTRAL BROADENING OF FEMTOSECOND PULSES IN A BRAGG FIBER: EXPERIMENTAL DEMONSTRATION

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Abstract: Propagation of femtosecond pulses in a photonic band-gap silica core Bragg fiber is experimentally studied. Nonlinear spectral broadening is demonstrated in conformity with predictions made in a recent theoretical paper.

1. INTRODUCTION

Yeh et al. [1] were first to propose the concept of Bragg fiber. Such a fiber consists of a core surrounded by alternating layers of high and low refractive index materials. The mode is confined by a photonic bandgap relating to the Bragg refection of light from this concentric structure. Bragg fiber affords tailoring of the zero dispersion wavelength (ZDW) around or below 1 µm whilst maintaining a large mode size [2]. Tailored dispersion at this wavelength would allow the design of all fiber pulse compression systems for Yb^{3+} doped fiber lasers and the development of short pulse fiber delivered femtosecond lasers. Indeed, solid core Bragg fibers have been fabricated that exhibit ZDW at 1060 nm [3]. Photonic crystal fibers (PCF) could also be used to shift the ZDW to such wavelengths but at the expense of a reduced core size. This makes coupling often difficult and limits the power handling property of the fiber. We demonstrate nonlinear spectral broadening of femtosecond pulses in a silica core Bragg fiber at a pump wavelength of 1067 nm. This is, to the best of our knowledge, the first observation of nonlinear spectral broadening in a photonic bandgap (PBG) Bragg fiber. Previously, theoretical studies were reported on nonlinear pulse propagation though Bragg fiber predicting generation of supercontinuum light in these fibers including designs of dispersion decreasing Bragg fibers for optimisation of the nonlinear spectral broadening. In this paper we study a Bragg fiber with properties very similar to that modelled in [4,5] albeit with no taper in the fiber.

2. FABRICATION

The solid-core Bragg fiber used in our experiments was designed as per the recipe/model reported in [4] for achieving ZDW at 1044 nm and a dispersion slope of ~ 0.4 $ps/nm^2.km$. It was fabricated through the mature technology of MCVD method. This allows very accurate control of the preform fabrication. The resulting fiber was cleaved and examined with an optical microscope. An optical micrograph of the end face of the drawn fiber is shown in Fig. 1 together with the characteristic dimensions of the fiber. The fiber geometry will allow simple integration with standard fibers. The drawn fiber had 12 periodic bi-layers surrounding the lower index primarily silica core. Refractive indices of the cladding rings were 1.458 and 1.470, respectively. The average thickness of the high and low index cladding rings was measured to be 1.4 µm and 1.6 µm, respectively. The drawn fiber was found to be robust and could be easily cleaved using a commercial fiber cleaving tool.

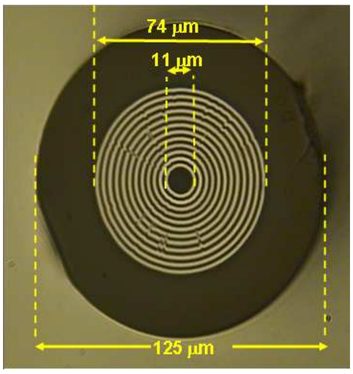

Figure 1. End face image of the photonic bandgap Bragg fiber.

3. OPTICAL CHARACTERISATION

A 48 cm section of the fiber was used to record the mode profile of the fiber. Figure 2 (a) and (b) show inverted near field output mode images of the fiber output when a CW laser source at 1064 nm was launched into it using an x10 0.2NA microscope objective. When alignment is optimal (Fig. 2 (a)), most of the light is confined within the core and first few cladding rings. The mode field diameter at 1064 nm was measured to be 7.9 µm. Figure 2 (b) shows a higher order mode structure with the increased cladding light that is associated with a high loss mode – this was observed for a small misalignment of the fibre position. Figure 2 (c) shows the output for the case where the fiber is misaligned and shows cladding modes in the Bragg structure.

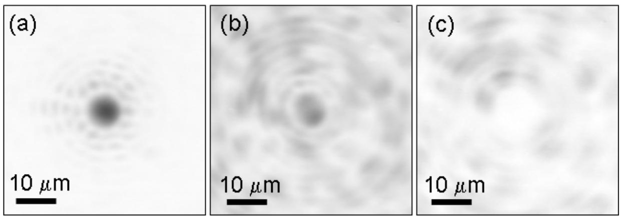

Figure 2. Inverted near field output mode images taken with 1064 nm light launched into the Bragg fiber for cases where (a) aligned to the core, (b) showing a higher order mode and (c) misaligned.

Transmission loss measurements were performed at 1064 nm using the cutback method. The propagation loss was measured to be 11 dBm^{-1} at this wavelength with a coupling loss of 5.5 dB. This high transmission loss is in good agreement with the simulation results in [5] however imperfections in the bilayer structure that can be seen in the micrograph in Fig. 1 are thought to also contribute to this propagation loss. This fiber is also known to exhibit high bend losses and this aspect will be the subject of further study.

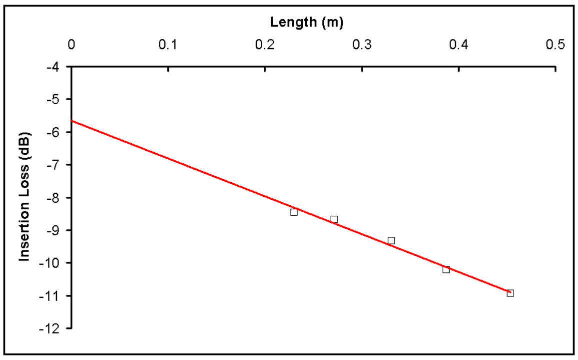

Figure 3. Cutback measurement for a 48 cm section of photonic bandgap Bragg fiber at 1064 nm. Fit to the slope gives a propagation loss of 11 dBm^{-1}, intercept with the *y*-axis indicates a coupling efficiency of 5.5 dB.

4. NONLINEAR SPECTRAL BROADENING

The nonlinear properties were studied by using a frequency doubled idler output from a 1 kHz femtosecond OPA system tuned to 1067 nm, with a peak power of 208 kW. The OPA provided pulses of 120 fs pulse width, which were launched into a 4 m section of the Bragg fiber using an x10 0.2NA microscope objective. The output was collected with a 600 µm core diameter silica fiber and the spectrum was recorded using a near infrared (Ocean Optics NIR512) spectrometer. Spectral broadening is evident in the transmitted spectra shown in Fig. 1(d). The spectral shape suggests that broadening is dominated by self phase modulation (SPM). The spectral broadening predicted in a PBG fiber [5 with physical parameters closely matching this fiber, showed a similar trend. Besides the SPM-dominated peak centered around 1067 nm, the peak at ~ 950 nm corresponds to the influence of dispersive waves. The proximity of the resonant wavelength of the dispersive waves to the center of the input pulse could be attributed to the relatively large value of the dispersion slope [7]. Down tapering the fiber (during drawing), which would induce a decrease in dispersion with length, could broaden the spectral bandwidth further [5] and hence our study opens up new possibilities in the realm of nonlinear optics and pulse shaping.

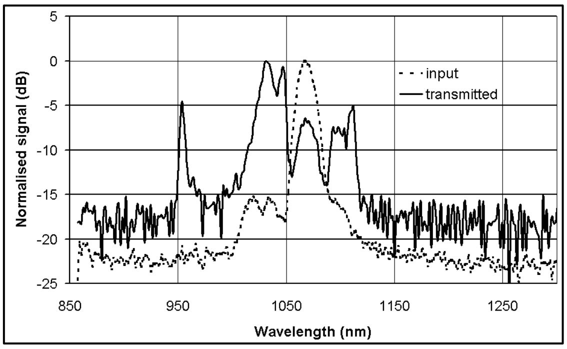

Figure 4. Nonlinear spectral broadening in 4 m of Bragg fiber pumped with 25 nJ pulse energy. Both the input (broken line) and output (solid line) spectra are shown.

5. SUMMARY

We have demonstrated nonlinear spectral broadening in a silica-based Bragg fiber that appears to be consistent with recently predicted theoretical results. The fiber dimensions and mode size make it compatible with standard commercial fiber and so offers ease of integration with existing devices (such as fiber lasers). The high losses of the design may be reduced through a more rigorous control of the preform deposition to remove bilayer imperfections. A detailed study of the bend losses in this fiber is planned as this is a known artefact of Bragg fibers [6].

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