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Widely Tunable Mid-Infrared All-Fibre Lasers Based on Mechanically Robust Fibre Bragg Gratings

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Abstract: We report on the inscription of a mechanically robust fibre Bragg grating and its integration into a tunable all-fibre mid-infrared laser. Experimental results show a 37 nm wavelength tuning range of a fluoride fibre laser.

OCIS codes: 060.3510 Lasers, fiber, 060.3735 Fiber Bragg gratings, 060.2390 FIber optics, infrared.

1. Introduction

Fibre lasers are efficient and versatile waveguide devices that utilise an actively doped optical fibre as the gain medium. Fibre lasers with emission wavelengths in the 2-5 μm range correspond to photon energies that overlap with the strong vibrational molecular resonances of most common constituents of atmospheric gasses, as well with those of liquid water contained in biological tissues. Tunable laser sources operating in this mid-infrared (mid-IR) spectral region have several applications ranging from remote gas analysis (spectroscopy) [1] and optical coherence tomography to laser-induced ablation of skin [2]. However, a major obstacle for mid-IR fibre lasers is the lack of fibre coupled optical components to form a laser cavity. This significantly impairs the commercialisation and use of tunable mid-IR fibre lasers for spectroscopic and medical applications.

Spectral tunability and narrow linewidth are common requirements for fibre lasers for many applications. An efficient wavelength selection component like fibre Bragg grating (FBG) is essential for the development of narrow band tunable laser systems. Several demonstrations [3, 4] show that FBGs can be inscribed using femtosecond laser pulses and a phase mask, to create all-fibre mid-IR laser systems emitting around 2.9 μm. In this paper, we describe the fabrication of mechanically robust FBGs, inscribed through the polymer jacket of a fluoride fibre using the direct-write technique with a Bragg wavelength (λ_B) of 2.88 μm. This approach avoids the use of expensive phase masks, complicated stripping and recoating procedures required in the normal FBG fabrication process. We then used these FBGs to demonstrate a broadly tunable mid-IR Ho^{3+}-Pr^{3+} co-doped ZBLAN fibre laser operating in the continuous wave (CW) regime. We achieve an overall tunability of 37 nm spanning from 2. 85 μm to 2. 887 μm by mechanically applying tension and compression to the robust FBG.

2. Fibre Bragg Grating fabrication

An efficient fabrication methodology was used to inscribe a mechanically strong FBG into the core of a double-clad fluoride fibre through its polymer jacket using the direct-write technique [5]. In this experiment, the fibre used was a 1 m long active double clad fluoride fibre (FiberLabs Inc.). The fibre diameter including the polymer jacket was 480 μm with an inner cladding diameter of 125 μm, outer cladding diameter of 210 μm, a core diameter of 13 μm and an NA of 0.13 which ensures single-mode operation at 2.88 μm.

During the inscription process, femtosecond laser pulses centered at 800 nm were focused by a 40x dry objective into the core of the optical fibre. A Type-I [6] FBG was written using 270 nJ, 115 fs pulses at 1 kHz repetition rate provided by a Ti-Sapphire laser. The fibre was mounted on a computer controlled translation stage to inscribe a square wave pattern along the core of the fibre. The amplitude of the square wave was selected to cover the entire core diameter during the fabrication process. Fig. 1(a) depicts a schematic representation of the fabrication process and a microscopic image of the femtosecond laser inscribed pattern in the core of the fibre.

3. Tunable mid-IR all-fibre laser

The experimental setup for the wavelength tunable Ho^{3+}-Pr^{3+} co-doped ZBLAN fibre laser is depicted schematically in Fig. 1(b). A high power 1150 nm laser diode was used to pump the active fibre. An anti-reflection coated CaF_2 lens with a focal length of 20 mm was used to focus the pump beam into the double-clad active fibre. The input end of the fibre was perpendicularly cleaved and the 4% Fresnel reflection acted as a low reflectivity broadband mirror. The other end had the high reflectivity FBG centered at 2880 nm, thereby forming a Fabry-Perot laser cavity. Applying compression or tension on the FBG changes the effective period Λ of the grating ($\lambda_B = 2\Lambda n_{\text{eff}}$) to tune the lasing wavelength. The output spectrum of the laser was captured using an optical spectrum analyzer.

In this experiment, the laser was initially centered at 2.88 μm with a line width of 105.29 pm, slope efficiency 15% and 0.25 W of output power before applying the compression and tension to the FBG of physical length 15 mm. To stretch

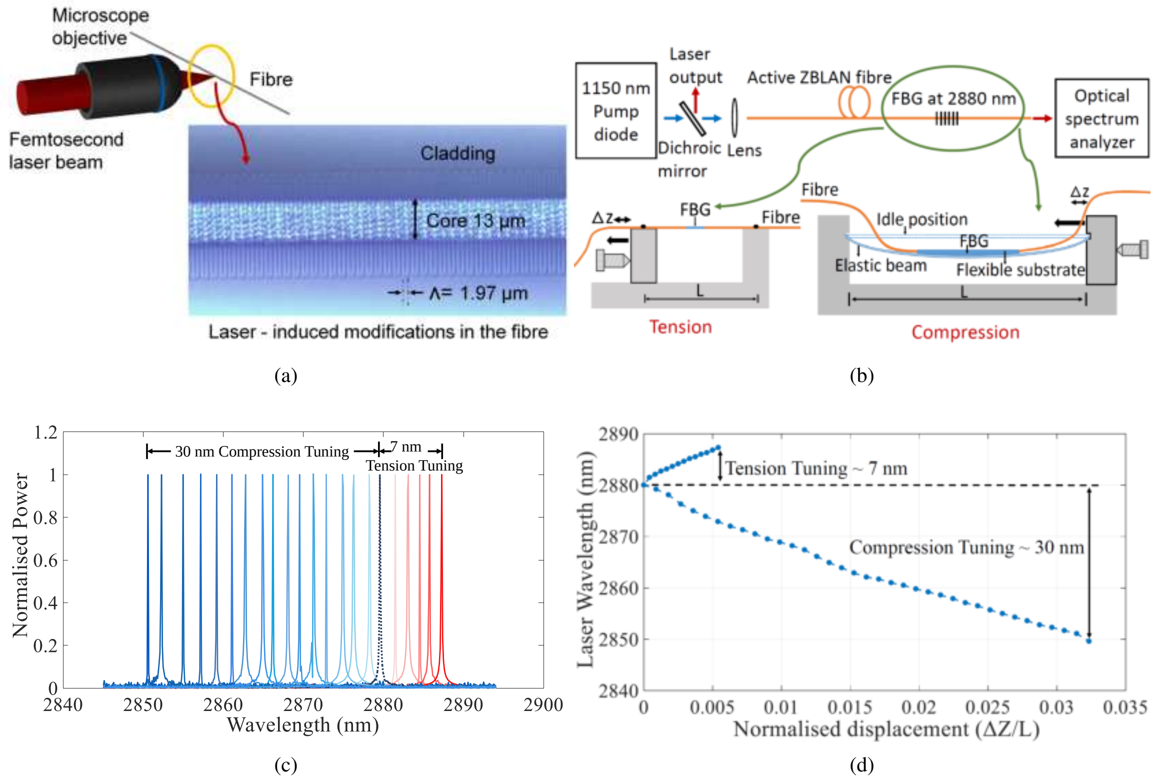

Figure 1. (a) Femtosecond laser direct-write setup and microscopic image of the FBG (b) Experimental setup (c) Spectra of the shifted laser output peaks. Note that the laser linewidth across the entire tuning range was less than 112 pm (d) Measured tuning range of the tunable laser source

the FBG, we fixed one end of the grating to a stationary stage and the other end to a translation stage as demonstrated in Fig.1 (b). A fast drying epoxy fixed the ends to the fibre holders. Axial tension was applied to the FBG by adjusting the micrometer screw. Stretching the fibre produced a linear red-shift of 7 nm at the laser wavelength as illustrated in Fig. 1(c). During the compression measurements, it was essential to compress the fibre along its axis to prevent buckling. This was accomplished by embedding the fibre with the FBG on an elastic steel beam of length l = 16.5 cm, width w = 1.2 cm and thickness h = 0.1 cm using a flexible substrate having a low Young modulus of 1.03 GPa, held between a fixed and a movable end. The inward translation of the movable block deformed the beam into an arc shape [7]. As shown in Fig. 1(c) the maximum blue-shift in the laser wavelength achieved by compression measurements was 30 nm. Fig. 1(d) depicts the wavelength shift of the CW laser with respect to the normalized displacement, $\Delta z/L$. Note that subsequent breakage of the FBG limits the tuning range in both the cases.

In conclusion, to the best of our knowledge, this is the first inscription of a FBG through the polymer coating of a doped double-clad fluoride fibre without a phase mask. A stable, 37 nm wavelength tunable FBG-based CW fibre laser was demonstrated by applying tension and compression to the mechanically robust FBG.

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