Polarised high power fibre lasers by combining low birefringence fibres and point-by-point Bragg gratings

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Abstract – We present a novel scheme for obtaining highly linearly polarised, high power fibre lasers. The technique exploits the natural birefringence of point-by-point written Bragg gratings, which constitute the frequency selective feedback elements of the lasers.

Introduction

Fibre Bragg gratings (FBGs) are an ideal candidate for frequency selective feedback elements for fibre laser sources because they simplify the laser geometry by minimizing the need for external bulk optics such as dichroic dielectric mirrors while offering narrow linewidths. Point-by-point (PbP) FBGs, in particular, have recently been used in several laser systems offering even greater benefits of ultra-narrow linewidths (of the order of 15 pm), great stability at high power operation and power scalability to the 100 W level [1, 2]. Another feature of these gratings is their ability to linearly polarise a fibre laser constructed from a low birefringence fibre. This was first observed with the realization of a fully linearly polarised distributed feedback (DFB) fibre laser with an extinction ratio of > 40 dB [3] and a very low output power of 180 µW. However it is well known that it becomes increasingly difficult to maintain linearly polarised output when power scaling these devices. Indeed, attempts to scale the output power to the Watts level have yeilded a modest result, of a partially linearly polarised (60 %) high power fibre laser, by using a different configuration [2]. Clearly, the implications of creating a high power linearly polarised fibre laser with a low birefingence fibre and a PbP FBG as the frequency selective feedback element and polarisation discriminator are profound. In this study we show that if care is taken in selecting the grating parameters and the cavity arrangement it is possible to obtain highly linearly polarised (88 %) fibre lasers with up to several Watts of output power. We explain the properties of PbP FBGs that affect the polarisability of the lasers and compare and contrast the performance of different laser configurations.

Background

The PbP technique for writing FBGs with ultrafast IR radiation was first demonstrated in 2004 [4]. The PbP technique refers to the use of a single tightly focused femtosecond pulse into the core of an optical fibre in order to modify the refractive index of the core locally

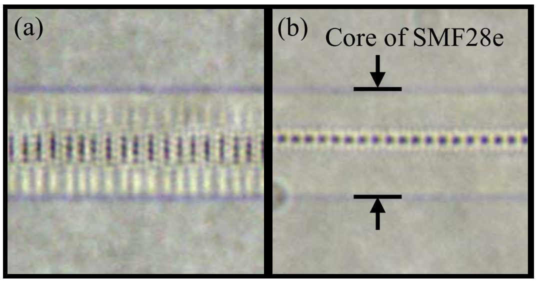

Fig. 1. Femtosecond laser induced refractive index modulations in the core of SMF 28e fibre. (a) Side view; (b) Top view.

and hence create one fringe of the grating. By translating the optical fibre at a velocity synchronized with the repetition rate of the femtosecond laser it is possible to build up a structure consisting of many refractive index modulations and hence periods that will inevitably have a stop band at the required wavelength. A typical picture of a PbP FBG is shown in Figure 1. The refractive index modulations are significantly smaller than the cross sectional area of the core of an optical fibre and are cylindrical in shape. In the presence of the high optical field of the tightly focused (1-1.5 µm beam waist) femtosecond pulse, the glass matrix, in this case silica, becomes ionized, and a filamentation effect is believed to take place which creates the cylindrical refractive index modulations that consist of 4-5 spheroids that are ~ 400–600 nm in diameter [5]. This yields a refractive index modulation which is ~ 5–7 µm in height and 0.5 µm in diameter as seen in Fig. 1. Since the refractive index modulations are voids or near the threshold for void formation, the fringes have a strong refractive index contrast. These strong, asymmetric refractive index modulations lead to unequal insertion loss for the two primary states of polarisation and induce a birefringence to the propagating mode [6]. Owing to these two affects, lasing in a particular polarisation state is favoured.

Specifically tailoring the birefringence and polarisation dependant loss is important in realizing highly linearly polarised fibre lasers. Therefore the parameters that are believed to influence the polarisability of a fibre laser include:

- *Grating length and order* - these will influence the polarisability of a laser as they determine the number of refractive index modulations and hence the induced birefringence to the propagating mode.

- *Inscribing pulse energy* - will affect the shape and refractive index contrast of the fringes of the grating and therefore the birefringence induced to the propagating mode.
- *The position of the FBG* with respect to the core will affect the overlap between the light and the grating and could induce asymmetries in the core if incorrectly positioned.
- Finally the *cavity length* used does have an influence on the polarisability of the laser. This is because the fibre used is a low birefringence fibre that acts to depolarise the laser over longer lengths.

Experiments

The two cavity arrangements that were explored are depicted below in figure 2.

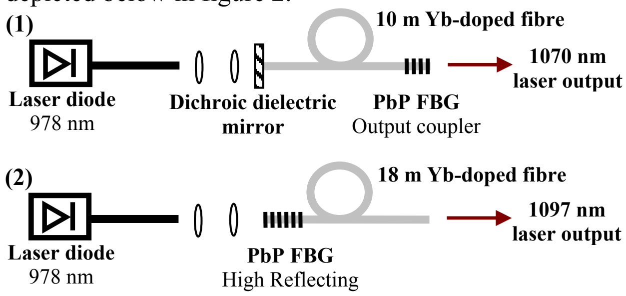

Fig. 2. Two cavity configurations used. The light grey lines depict the single-mode-core Yb-doped, hex-shaped double clad fibre laser used. (1) With a PbP FBG as the output coupler. (2) With a PbP FBG as the high reflector. The dielectric mirror was high reflecting at 1070 nm and highly trasnmitting at 978 nm.

The PbP FbGs were inscribed as described above with pulse energies between 150–220 nJ. The period of the FBGs was set to 3rd order for 1 micron light but the Bragg wavelength was altered to target the peak in the gain for the respective cavity lengths. The fibre coupled laser diode used, offered a maximum of 30 W of pump light at 978 nm.

Using configuration (1), gratings of lengths 10, 8, 5, 2, 1.5 & 1 mm were inscribed inturn into the active core of the fibre in order to observe the effect on the state of polarisation emitted from the laser. The pulse energy was maintained at 150 nJ for all FBGs. It was determined that lengths shorter then 2 mm did not have enough feedback to promote lasing action. For all the other grating lengths the laser was observed to be partially polarised with the percentage of light in a single state of linear polarisation for each grating length summarised in Table 1.

Grating length (mm)	10	8	5	2
% linearly polarised (low P)	67	56	88	88
% linearly polarised (high P)	60	56	78	79
Maxiumum Power	2.8	3.9	3.6	4.4

Table 1. Percentage of light in a single state of linear polarisation at low/high power for various FBG lengths.

It can be seen that the 2 shorter gratings promoted lasing action with as much as 88 % of the light in a single state of linear polarisaion at low power levels, and up to 79 % of the light linearly polarised for power levels of ~ 4 W. Although the pulse energy, grating order and cavity length were kept constant the results shown in table 1 are a convolution of differnet parameters. The variations seen in the amount of linearly polarised light for different formats is mainly attributed to grating length but also errors in the spatial location of the refractive index modulations within the core from grating to grating. This changes the overlap and hence interaction of the fundemantal mode of the laser with the grating and therefore affects the polarisation of the laser. Nevertheless, significant improvements in the amount of linearly polarised light at high power levels have been obtained using the PbP FBG as the output coupler.

Using configuration (2), many fibre lasers with various grating lengths, orders, inscribing pulse energies were fabricated. The best result for this laser geometry was 69 % of the light in a single state of linear polarisation for a fibre length of 18 m. This level of polarisability was observed at an output power of 7 W.

Conclusions

PbP FBGs induce a birefringence and a polarisation dependant loss to the propagating mode due to their morphology and strong refractive index contrast. These two features can be exploited to create linearly polarised fibre lasers. Parameters that affect the level of polarisation of a fibre laser with a PbP FBG include grating length, order, inscribing pulse energy, position of the FBG with respect to the core and cavity length. We demonstrated an 88 % and 78 % linearly polarised output at low and high power (4.4 W) respectively from a fibre laser utilising the cavity configuration with the PbP FBG as the output coupler.

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