Experimental study and comparison of three innovative high power CW polarised all-in-fibre laser designs

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Ytterbium linearly polarised fibre lasers are of great interest in many domains such as second harmonic generation, material processing, medical or scientific applications. Previous works have demonstrated different methods to realize polarised fibre lasers. Here we present and compare three continuous-wave all-in-fibre polarised laser configurations. Each laser employs an innovative fibre-based solution, namely a chiral grating polariser, and two different polarising fibres. The lasers deliver up to 27 W at 1084 nm with a polarisation extinction ratio higher than 17 dB. Compared with other techniques, the laser structure is simple and does not require specific external stabilisation, making these technologies very promising.

Introduction

Among fibred products available on the market to linearly polarise an optical source, most of them are limited in terms of handling optical power. These devices are therefore not adapted for high power polarised all-in-fibre lasers. Previous works have demonstrated different methods to realize high power linearly polarised fibre lasers. An efficient method uses narrow linewidth cross-matched Fibre Bragg Gratings (FBG) for polarisation selection [1]. This method requires fine tuning and control of the wavelength of one of the two FBG. Other methods are based on integrating a polarisation dependent loss element into the fibre laser cavity. This can be, for instance, a tilted FBG [2], a large mode area coiled fibre [3], or a polarising photonic crystal fibre [4]. In this paper, we present an experimental study and comparison of three innovative high power continuous wave linearly polarised all-in-fibre Fabry-Perot lasers.

Innovative polarisation filtering

The three laser designs that we present here employ innovative components to filter the polarisation in the laser cavity and force linearly polarised emission. The first design uses a chiral grating polariser. This device is fabricated by the company Chiral Photonics and is based on the very interesting properties of twisted fibres.

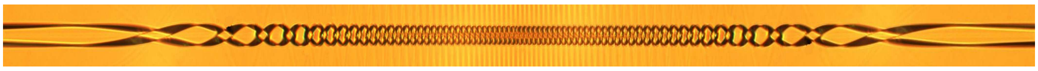

Figure 1: Picture of the twisted fibre used in the chiral polariser

In adiabatically twisted single-mode birefringent fibres, polarisation transformation and scattering are synchronised [5]. This implies that light can be transmitted or scattered out of the twisted fibre depending on its state of polarisation. Therefore under the condition that the twist is first accelerated (Fig.1) and then decelerated, in-fibre

broadband polarisation filtering can be obtained. The Polarisation Extinction Ratio (PER) of the polariser we used is higher than 32 dB and the insertion losses are around 1.8 dB on the range 1055-1105 nm.
The second and third laser configurations are based on single polarisation fibres respectively from Corning (SP1060) and Fibercore (HB1060Z). These birefringent fibres permit to filter one of the two polarisations all along the propagation. The Corning SP1060 fibre has a special design: an elliptical core between two very close air holes filtering one polarisation state when light is propagating along the fibre. This polarisation filtering effect can be obtained over a broad bandwidth (~35 nm) and the efficiency depends on the length and the bend diameter of the fibre used. The Fibercore HB1060Z fibre exhibits single polarisation guidance over a wide polarising bandwidth (> 100 nm) thanks to the very high birefringence (Beat length of 0.7 mm @ 633 nm) obtained with a special bowtie design. Compared to the Corning product, this fibre is all-solid, making splices with standard PM fibres easier.

Experimental laser designs

The three lasers that we realized are based on all-in-fibre Fabry-Perot (FP) structure with Polarisation Maintaining (PM) fibres (Fig.2). We directly inscribed FBG in the core of single-mode PM fibres (core diameter of 5 µm) with a phase mask technique. The Highly Reflective FBG (HR-FBG) were inscribed on double-clad fibres to permit the guiding of both the multimode pump and the signal. These devices had reflectivities higher than 99% over 1 nm at 1084 nm. The Low Reflectivity FBG (LR-FBG) were inscribed on single clad fibres since these devices were placed at the output of the laser, where multimode pump guiding is no more required. The reflectivity of these output FBG was typically 5% over 3 nm at 1084 nm.

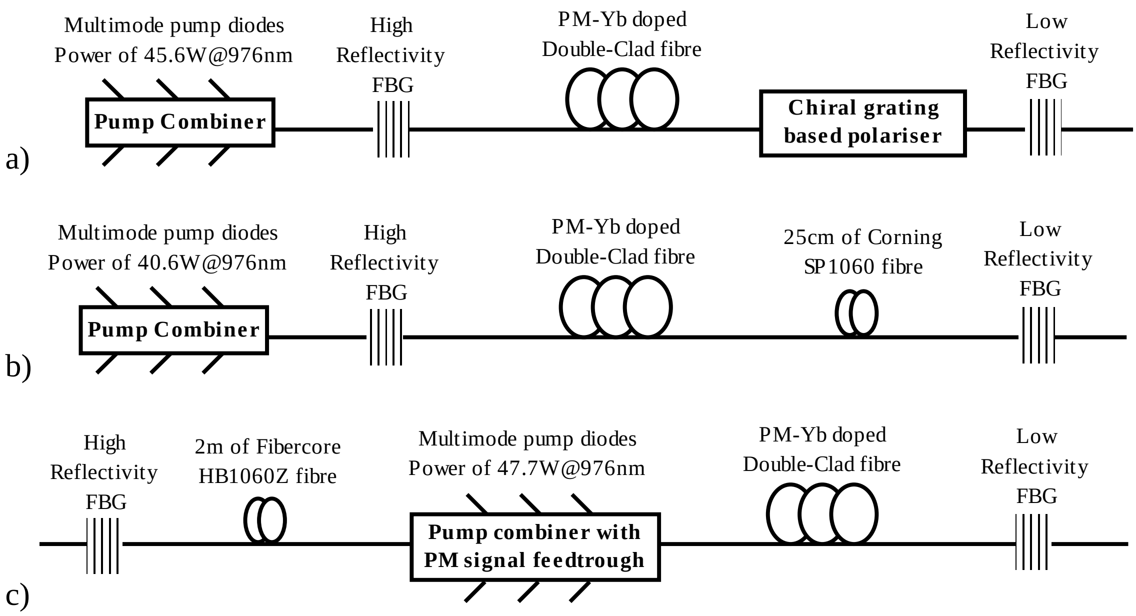

Figure 2: Designs of the 3 experimental linearly polarised fibre lasers: a) Laser with chiral polariser, b) Laser with Corning SP1060 fibre, c) Laser with Fibercore HB1060Z fibre

In configurations "a" and "b" the pump combiner is placed outside of the laser cavity and the polarising component (Chiral grating polariser or SP1060 fibre) is placed

between the end of the doped fibre and the LR-FBG. The polariser is provided with PM980 fibre on each side so it is easy to splice without inducing extra-losses, but concerning the SP1060 fibre, the best result that we obtained was about 0.3 dB loss per splice with PM980 fibre.
For the third (c) design, we used another type of combiner which had a PM fibre for the signal. This design permits to limit the impact of the losses due to the splices of the HB1060Z fibre (about 0.25 dB per splice) by placing it close to the HR-FBG. Indeed when the device is placed on this side of the laser cavity, insertion losses will not have a direct impact on the output power compared to the opposite situation. Others advantages of the "c" design are firstly that double clad fibre is no more required for the HR-FBG and secondly that the output of the combiner is directly spliced to the input of the doped fibre which limits the pump losses. But, unfortunately, this kind of combiner also induces losses of about 1 dB on the PM signal that limits the advantages of this design and the gain on the laser efficiency. Concerning the coiling of the single polarisation fibres, we obtain the best results for coiling diameters of 20 cm and 10 cm for the SP1060 and HB1060Z fibres respectively.

Experimental results

The Figure 3 presents the power characteristics and spectra of the three lasers that we tested. Concerning the design "a" with the chiral grating polariser, the maximum output power obtained is 17.1 W with a spectral linewidth of 0.8 nm and is limited by the pump power (efficiency of 37%). The PER is higher than 17 dB. The low efficiency of the laser (without polariser the efficiency reached 70%) can be explained by the high intra-cavity losses induced by the polariser (1.8 dB). At full power, the estimated optical power at the input of the polarizer is 27 W, which is much higher than the acceptable power of in-line fibre polarisers using bulk optics. Chiral grating polarisers are very interesting components because they combine a lot of advantages: high PER, high acceptable power, broad bandwidth, easy to splice with standard PM fibre.

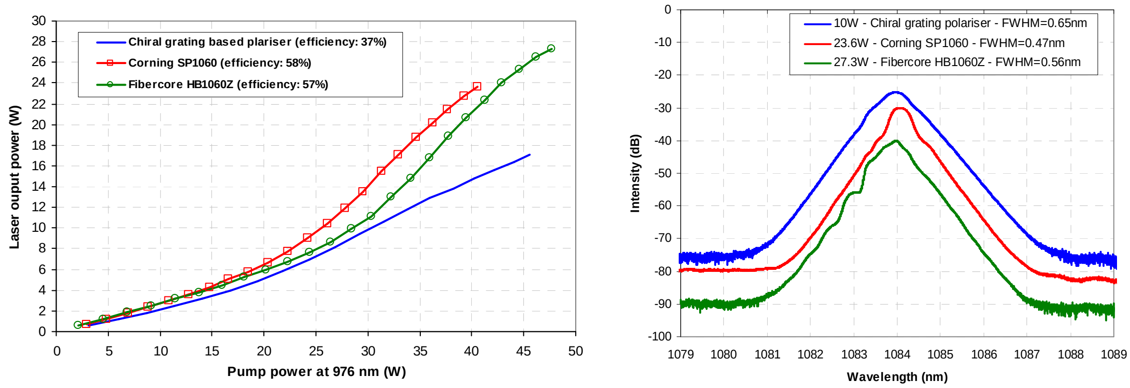

Figure 3: Output power characteristics and spectra of the 3 laser designs tested

With the laser design "b" based on the Corning SP1060 fibre, the maximum output power obtained is 23.6 W with a spectral linewidth at Full-Wave-Half-Maximum (FWHM) of 0.47 nm and the efficiency at full power (58%) is higher than for the previous design. The PER is higher than 16 dB. The Corning single polarisation fibre permits to obtain higher power with good laser efficiency but, from an experimental

point of view, this fibre is not easy to use. In fact, splices with standard PM fibre are not easy to realise and the fibre need very precise bend management to prevent burning.
The laser design "c" with the Fibercore HB1060Z fibre, permits to obtain a maximum output power of 27.3 W with a spectral linewidth of 0.56 nm and an efficiency at full power of 57%. The PER is higher than 18 dB. The Fibercore single polarisation fibre is more interesting than the Corning one because splices with standard fibres are easier and the polarising bandwidth is stable whatever the coiling diameter.
Regarding the spectra, they are all centred at 1084 nm but we observe some differences on the spectral shape and linewidth. The differences of spectral shape between the two designs using polarising fibres are mainly related to the shape of the FBG that we used. We assume that the increase of the spectral linewidth (0.8 nm instead of 0.5 nm) of the laser using the chiral grating polariser is mainly due to nonlinear effects. In fact, the core diameter of the twisted fibre in the polariser is smaller than the one in standard PM980 fibre which favours four wave mixing for instance.

Conclusion

We present in this paper, three innovative designs of high power CW linearly polarized all-in-fibre lasers. All the presented lasers are based on Fabry-Perot cavity design and each one uses an intra-cavity polarisation dependent element that forces the laser emission to be linearly polarised. The three polarising elements used are chiral grating based polariser, Corning SP1060 and Fibercore HB1060Z single polarisation fibres. The maximum output power obtained is 27 W for the laser using Fibercore single polarisation fibre. All the designs are interesting because they are simple and permit to obtain high power with good PER without need of external stabilisation. Chiral grating polariser and single polarisation fibres and very promising technologies for high power polarised all-in-fibre applications.

References

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