Splice-less Erbium All-fiber Laser Using FBGs Written Through the Coating

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Abstract: Using fiber Bragg gratings written directly in the gain fiber through the polymer coating, we demonstrate a scalable and extremely simple erbium fiber laser emitting over 20 W of power at 1610 nm.
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1. Introduction

Powerful laser sources operating in the 1.5 to 1.7 µm "eye-safe" wavelength emission range are of interest for numerous applications, ranging from LIDAR to spectroscopy. Simultaneously, all-fiber laser sources offer great robustness and compactness for deployment in the field. As such, the pursuit of performant erbium fiber lasers, which emit efficiently in this spectral band, has drawn increasing scientific interest, and the simplification of such sources is of great appeal for large-scale commercial applications.

Several demonstrations of all-fiber erbium lasers have been reported in the past. Jebali *et al.*, for instance, have reached a high output power of 264 W at 1585 nm by in-band pumping of an erbium-ytterbium co-doped fiber [1]. However, they employed a complicated pumping scheme involving the combination of 36 pump lasers at 1535 nm to achieve this result. A simpler approach has been demonstrated by Kotov *et al.*, who amplified a 1585 nm signal to 103 W using a singly-doped erbium fiber [2]. Still, such an amplifier required a 4 W seed laser to operate, and its lack of reflectors limits its scalability. A known way of further simplifying the laser cavity design is to use fiber Bragg gratings (FBG) written directly in the gain fiber to sustain the laser effect. Indeed, a previous demonstration by Wikszak *et al.* has used one such FBG to generate 38 mW at 1554.5 nm from an erbium fiber laser [3]. However, this design still relied on some free-space coupling, and its low power output has not since been improved upon.

In this presentation, we show how FBGs written in the gain fiber can be used to design a performant single-pump, monolithic and splice-less erbium fiber laser emitting at 1610 nm. Writing the FBGs through the fiber's polymer coating greatly simplifies the assembling process of the cavity, making this design ideal for large-scale production. The characteristics of the assembled laser cavity and the FBGs used for this work are described below.

2. Experiment and Results

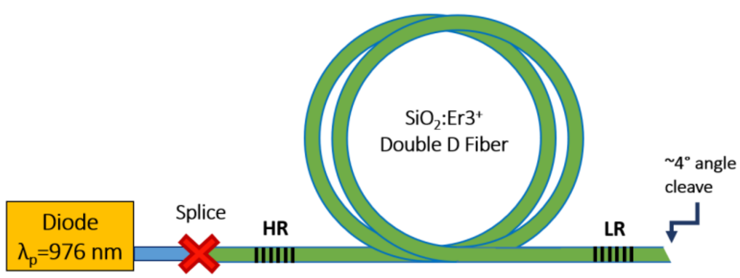

Fig. 1. Schematic of the laser cavity used for this work. HR and LR designate a highly reflective or lowly reflective FBG, respectively. Both FBGs are written in the gain fiber while maintaining the polymer coating intact. The fiber measures L=62 m from HR to LR.

Figure 1 shows the laser cavity used for this work. As can be seen, the use of FBGs written directly in the gain fiber effectively eliminates the need for free-space or spliced components, allowing the whole cavity to fit inside the fiber itself. The design can be broken down into three main constituents: the pump, the fiber and the FBGs.

The pump is an nLight element e18 wavelength-stabilized multimode diode emitting over 120 W of power at 976 nm through an 105/125 µm (core/clad) pigtail fiber, allowing precise targeting of the absorption band of erbium. It is spliced directly to the laser cavity, resulting in power-scalable clad-pumping of the single-mode gain fiber.

The gain fiber itself was fabricated with a combination of MCVD and solution doping, and drawn using in-house facilities. Its technical specifications are summarized in table 1. The fiber cladding is made of pure silica, while the core is doped with two different ions: erbium to sustain the laser effect, and aluminum to improve erbium solubility and limit cluster formation. The concentrations of both dopants were selected based on previous work by

Kotov *et al.* [2]. In order to limit the propagation of poorly-interactive circular modes and improve pump absorption, the preform was polished on two sides before drawing, effectively giving the fiber a “double-D” shape. The tip is cleaved at an angle to limit Fresnel reflections at the output.

Table 1: Characteristics of the gain fiber

Core diameter	Cladding diameter	Er_2O_3 concentration	Al_2O_3 concentration	Cutoff wavelength	α_{clad} @976 nm	α_{core} @1200 nm
16 µm	129 µm	0.03 mol. %	1.2 mol.%	1480 nm	43.5 dB/km	23.1 dB/km

The FBGs are written directly in the gain fiber through the polymer coating using femtosecond pulses at 800 nm and the phase-mask technique, with the procedure detailed in previous work [4]. A peak wavelength of 1610 nm is selected for maximum laser efficiency based on in-lab experiments, and the spectra of both the HR and LR FBGs are presented as inset on figure 2. HR and LR reflectivity are respectively 99.6% and 1% at the signal wavelength, values that optimize laser efficiency. In order to limit the decay of the FBGs with time, both were annealed at a temperature of 150ºC for a 10 minutes duration after writing. The use of such a low annealing temperature was necessary to avoid damaging the polymer coating of the fiber.

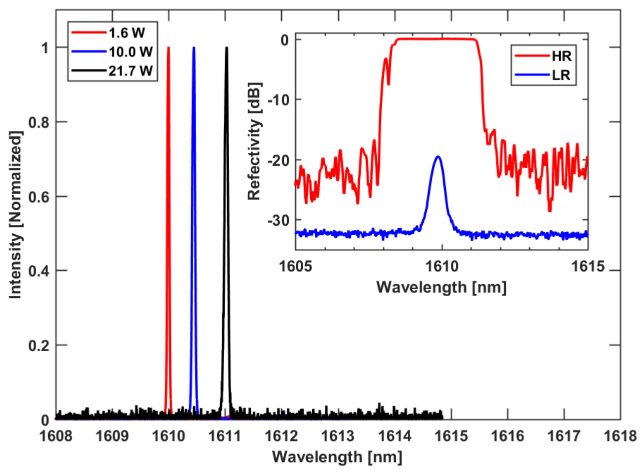

Fig. 2. Fiber laser signal spectra at different output powers. The inset shows FBG reflection spectra.

Figure 2 also shows the spectrum of the laser signal. The signal has a narrow linewidth of 0.07 nm at the maximum output power of 21.7 W, achieved with 19.6% slope efficiency with respect to launched pump power. Single-mode operation was confirmed via a beam quality measurement (M^2=1.01). To our knowledge, this the most powerful laser of its kind reported so far. Efficiency could still be improved in future work by increasing core size and tweaking dopants concentration. A significant drift in peak wavelength is observable due to the heating up of the FBGs as power increases: this behavior could be impeded by proper heat management and constraining of the LR, which was passively resting on an aluminum plate for temperature monitoring during this experiment and reached over 50ºC at maximum output.

3. Conclusion

We have demonstrated how FBGs written through the polymer coating can be used to design a performant splice-less erbium fiber laser, emitting above 20 W at 1610 nm. This is the highest power reported from an erbium fiber laser with this configuration. The simplicity of the design makes it ideal for large-scale production.

4. References

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