High Power Splice-less Fiber Laser at 2825 nm

Yiğit Ozan Aydın*, Vincent Fortin, Réal Vallée and Martin Bernier
Centre d'Optique, Photonique et Laser (COPL), Université Laval, Québec City, Québec G1V 0A6, Canada
**yigit-ozan.aydin.1@ulaval.ca*

Abstract: We report the demonstration of a passively cooled 2825 nm splice-less erbium-doped fluoride fiber laser delivering 20 W output power in continuous wave operation. This result represents the highest mid-IR output power obtained from a splice-less laser cavity.
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1. Introduction

Fiber lasers operating around 3 µm have made significant progress in the last ten years. Since the advent of high quality double-clad fibers, reliable, compact and high efficiency mid-IR laser sources have been reported [1-3] and are now good candidates for applications such as laser surgery [4], IR countermeasures [5] and spectroscopy [6]. High power 3 µm-class fiber lasers are generally based on the $^4I_{11/2} \rightarrow {}^4I_{13/2}$ erbium transition in fluoride glasses, where the upper level is directly pumped using commercial InGaAs laser diodes around 976 nm. This transition is efficient in heavily doped fluoride glasses (>5% mol.) thanks to an energy transfer upconversion (ETU) process based on ($^4I_{13/2}$, $^4I_{13/2}$) $\rightarrow$ ($^4I_{9/2}$, $^4I_{15/2}$) ion transitions. However, such heavily erbium-doped fluoride fiber lasers are often power limited because of their high heat generation due to high pump absorption, large quantum defect and poor thermal properties of fluoride fibers compared to silica fibers. In addition, since fluoride glasses have very low melting temperatures, all intracavity components based on fluoride fibers such as fiber Bragg gratings (FBGs), end caps and fusion intra-cavity splices require proper thermal management. In recent high power demonstrations at up to 30W [7], highly reflective (HR) FBGs were written in the core of a mode matching single mode passive fiber to reduce its heating which could make it shift outside the reflective band of the output (LR) FBG. However, this approach requires splicing of single-mode fluoride fibers, a challenging process which also increases the round-trip losses of the cavity.

In this work, we report a simplified demonstration of a passively cooled 20 W splice-less fiber laser cavity at 2825 nm. To eliminate the intracavity splices and greatly simplify the laser assembling, both FBGs are written into the core of the gain fiber, through the polymer coating, using an optimized FBG inscription process. To further limit the heating of the HR-FBG, the laser cavity is first backward pumped (counter-propagation scheme) at 976 nm. A fourfold increase in output power is obtained compared to previous splice-less laser cavity reports [8, 9].

2. Experiment

The experimental setup of the laser is shown in Fig.1a. A 6.5 m length of 7 mol.% erbium-doped zirconium fluoride double clad fiber provided by Le Verre Fluoré is used as the gain medium of the laser cavity. The core has a 15 µm diameter and a numerical aperture (NA) of 0.12. The fiber cladding has a truncated circular geometry with a numerical aperture of 0.46 and diameter of 260 µm. It is pumped by a pump source composed of four multi-mode laser diodes operating at approximately 976 nm and combined in a tapered fused bundle. The combined diodes provide about 120 W of total continuous output power into a 220/240 µm, 0.22 NA multi-mode silica fiber. The pump beam is coupled in the doped fiber through a ZnSe aspheric lens (L2, f=12.7 mm) with a launching efficiency of 65%. The same lens is also used to collimate the laser beam. Both LR- and HR-FBGs are written directly in the core of the erbium fluoride fiber using femtosecond pulses at 800 nm and a phase mask, as described in [10]. The highly reflective input FBG has a reflectivity of 99% while the output LR-FBG has a reflectivity of 5%. Differently from previous demonstrations which have the FBGs written in the doped fiber, the fiber jacked was not removed during the grating writing process to significantly facilitate the laser assembling, thanks to recent advances in FBG writing through the coating using near-infrared femtosecond pulses [11]. The output fiber tip was capped with a short segment of coreless AlF_3 fiber (length of 500 µm) from Fiberlabs in order to slow down the OH diffusion in the fiber core and to decrease the broadband feedback. AlF_3 end capping is even more important for a backward pumped cavity because the pump beam causes additional thermal load on the output fiber tip. The end cap was placed into a copper V-groove and fixed with a low index fluoroacrylate polymer to provide pump guiding from the backward side. In addition, an ultra-pure nitrogen flux was blown on the fiber tip to slow down its degradation. The doped fiber and its FBGs were passively cooled on an aluminum spool with V-grooves. A thin layer of UV-curable low-index fluoroacrylate polymer was also applied on the fiber assembly to ensure a good thermal contact with the spool.

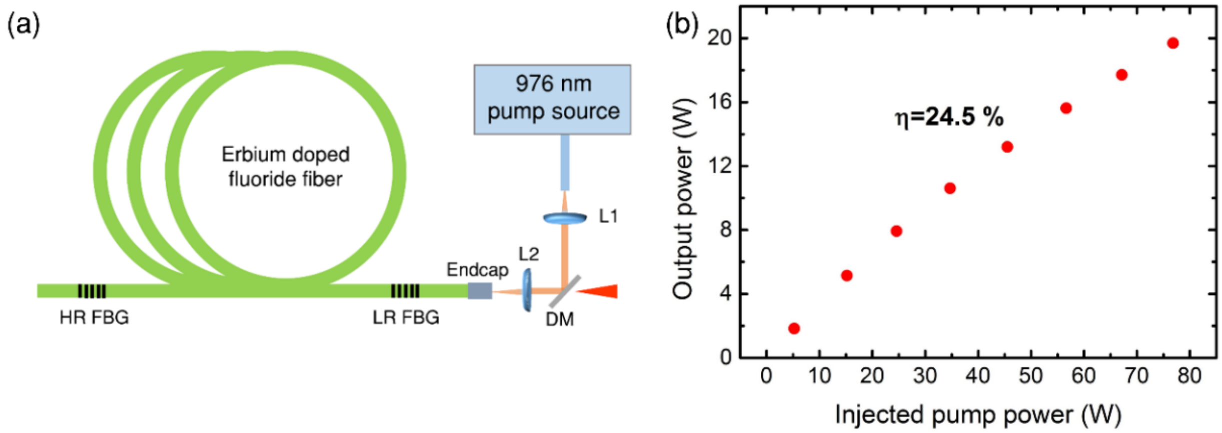

Fig.1. (a) Experimental setup of the monolithic laser at 2825 nm (HR-FBG, highly reflective grating (R=99%); LR-FBG, lowly reflective grating (R=5%); DM, dichroic mirror; L1, L2, coupling lenses). (b) Output power as a function of the launched pump power.

3. Results and discussion

The output power of the laser as a function of launched power was measured with a thermopile detector (Fig.1b). A 19.8 W output power is reached when the cavity pumped with 76.8 W of launched pump power around 976 nm. The laser starts to oscillate directly at 2825 nm and its emission wavelength slightly drifts (-15 pm/W) as the power is increased due to the thermal shift of the HR Bragg wavelength. A 24.5% slope efficiency is obtained with respect to launched pump power which is typical for such erbium laser emitting near its gain maximum [8, 12]. The temperature evolution of the fiber tip and first meters of gain fiber were therefore monitored with a thermal imaging camera. The power scaling potential of such splice-less cavity will be discussed as well as the different potential solutions to the endcap degradation problem.

4. Conclusion

In conclusion, we have demonstrated an erbium-doped fluoride glass fiber laser delivering a maximum output power of 19.8 W at 2825 nm using a simple splice-less design. We believe it is the highest output from a mid-infrared fiber laser cavity without intracavity splices. This study represents a significant advance for further power scaling of erbium-doped fiber lasers emitting near 3 µm.

5. References

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