Highly Efficient In-Band Cladding-Pumped 1593 nm All-Fiber Erbium-Doped Fiber Laser

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Abstract: A high power, high efficiency, Erbium doped fiber laser with in-band cladding pumping is demonstrated. Pump-limited, 103W output power is reported with a record efficiency of 75% with respect to the launched pump power.
OCIS codes: (140.3500) Lasers, erbium; (140.3510); Lasers, fiber

1. Introduction

High power fiber lasers operating near 1550 nm are of interest for many applications such as power-beaming, free-space communications and range finding, thanks to the "eye-safe" nature and good atmospheric transmission of this spectral region. Power scaling at these wavelengths has reached 300W in an Erbium-Ytterbium (Er-Yb) large mode area (LMA) fiber laser with cladding-pumping at 975nm [1]. Due to the large quantum defect of this pumping wavelength, an efficiency limited to 40% was recorded at low pump powers (<400W), dropping to 19% at higher pump power because of the saturation of the cross-relxation process between Yb and Er ions. Additional output power limiting factors for 915-980 nm pumped Er/Yb co-doped fiber lasers are well known to include a large thermal load, a limited dopant concentration and some self-lasing near 1 mm [2]. In-band pumping, an alternative solution offering high efficiencies and low thermal loads, is being promoted by the accelerating development of fiber coupled pump modules near 1535 nm, which now reach powers of 25W coupled in multimode fibers. However, in-band cladding pumping is limited by the low Er solubility in the silica matrix. For example, a 88 W cladding-pumped Yb-free LMA fiber laser has recently been demonstrated with an efficiency of 69% with respect to the absorbed pump power (~148 W absorbed out of 170W launched)[3]. Due to dopant concentration limitations, pump absorption was not optimal and the efficiency with respect to the launched pump can be estimated to be ~ 51%. On the other hand, an 18 W in-band core-pumped Er-Yb co-doped fiber laser has been demonstrated in a MOPA configuration with a high efficiency (~ 80%) showing low pair-induced quenching in these fibers [4]. However, further power scaling in a core-pumped configuration is not possible because of the limited power of the associated single mode pump diodes.

In this work, we propose a highly efficient Er-doped double-clad fiber laser optimized for high power scaling. Dopant concentration and fiber geometry were designed for optimal pump absorption using an in-band cladding-pumped scheme. We report a 75% efficiency with respect to the launched pump which is, to the best of our knowledge, the highest efficiency ever recorded for an all-fiber in-band cladding-pumped Er-doped fiber laser. The laser output power reaches 103W and was limited by the available pump power.

2. Experiment Setup

The main laser cavity (Fig. 1) consists of a double-clad Er-doped fiber that is cladding-pumped at 1535 nm. A set of 18 Er-Yb co-doped fiber lasers was fabricated and power combined to deliver 142 W at 1535 nm. This solution was adopted because the price of commercially available 1535 nm pump diodes is still prohibitive. Each Er-Yb pump laser, depicted in the zoom section of Fig.1, was pumped by two 970 nm fiber-coupled diodes and delivered 8W of output power. A cladding mode stripper (CMS) was used to eliminate residual 970 nm pump.

In the main laser cavity, a chirped fiber Bragg grating (FBG) written in a single mode undoped double-clad fiber is used as high reflector providing a 30 dB reflectivity over a 2 nm bandwidth. A flat cleave is used as a low reflectivity (4%) broadband mirror. The active fiber was designed to have 1.1 dB/m cladding absorption at 1535 nm. With an 18 m fiber length the total absorption was ~20dB. The second cladding, made of low index polymer, had a numerical aperture (NA) of 0.45. An Alumino-Phospho-Silicate glass matrix was used for the doped-core (17 μm diameter, NA=0.08) [5]. Yb was added to increase Er ion solubility and reduce quenching, without participating in the lasing transitions. Active fiber background losses were measured to be as low as 10 dB/km. The pump combiner was designed to combine 19 standard single mode fibers (SMF28) to a multimode 125 microns core (0.22 NA) output fiber. Combiner losses are evaluated to be <0.2 dB. The central branch is used for monitoring purposes.

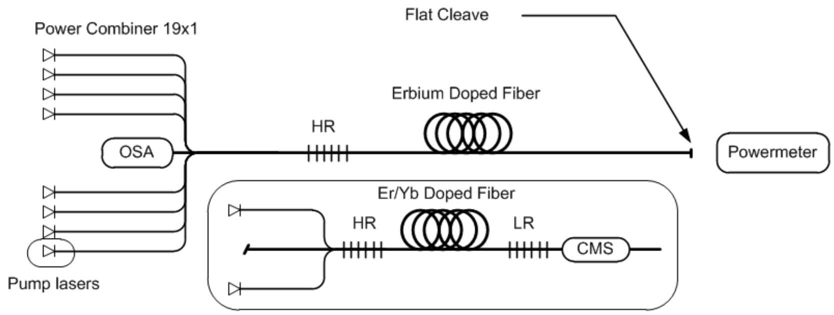

Fig. 1. Experimental setup

3. Experimental results

Fig. 2a shows the output laser power at 1593 measured as a function of launched pump power at 1535 nm. A 75% efficiency with respect to launched power is obtained without any sign of power saturation. The output spectrum displayed in Fig. 2b shows that the pump power is almost totally absorbed. The maximum output power was pump-limited and laser operation was stable (monitored continuously for more than an hour). The cavity was placed on an uncooled heat sink. Despite the high power level, unforced air-cooling is possible due to the high laser efficiency and the low fiber background losses. Fig.2b, measured at maximum power, displays an ASE level 50dB below the signal level. When setting the optical spectrum analyzer resolution bandwidth to 0.01 nm, the output laser spectrum shows some structure probably linked to non-uniformities of the FBG reflectivity.

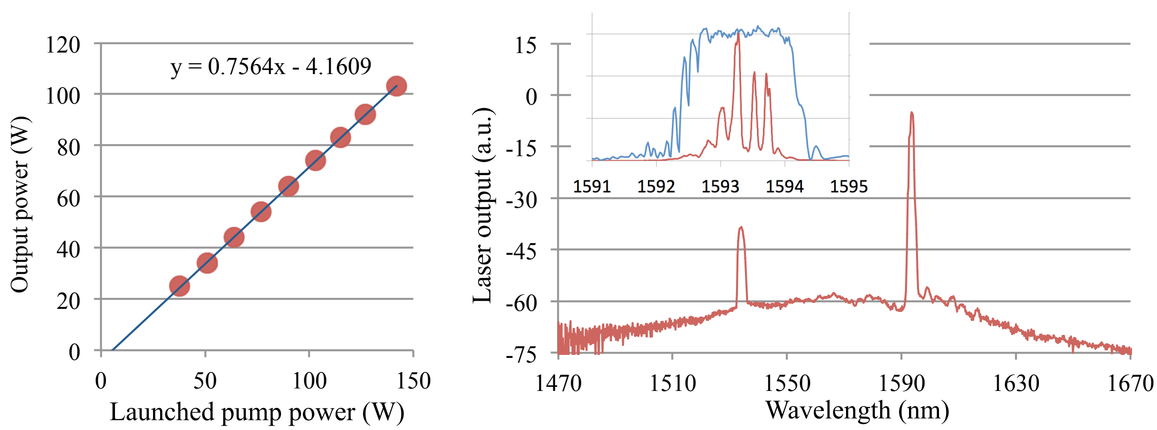

Fig. 2. A) Output power versus launched pump-power, and b) Output spectrum at 103W output power, the inset is the laser line (red) with a 0.01 nm resolution bandwidth and the FBG reflectivity spectrum (blue)

4. Conclusion:

A pump limited all-fiber Erbium-doped fiber laser with an output power of 103W is reported with a record efficiency of 75%. The Erbium-doped fiber was co-doped with Ytterbium only to reduce Erbium quenching in such a highly doped fiber. We believe that in-band pumping and Ytterbium co-doping are key ingredients for power scaling in the 1550 nm spectral band. We are currently working on a new highly doped single mode fiber design and we plan to further study its performance in a multi-hundred watts power level.

5. References

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