All-Fiber Gain-Switched Laser at 2.8 Microns

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Abstract: We present an all-fiber gain-switched laser at 2.8 microns that generates 37 µJ, 250 ns pulses at a repetition rate up to 150 kHz. Such source is promising for generating high-power supercontinuum in the mid-IR.
OCIS codes: (140.3510) Lasers, fiber; (140.3538) Lasers, pulsed; (140.3500) Lasers, erbium

1. Introduction

Mid-infrared pulsed lasers, like those presented in [1–4], are interesting prospects for applications in medicine, material processing and defense and security [5–7]. They can also lead to the generation of mid-IR supercontinuum for spectroscopic applications. For such purpose, the required pumping laser sources must produce high peak powers and energies while being robust and reliable. These properties can be achieved by adopting an all-fiber design such as demonstrated with silica fiber lasers [4,8,9]. However, until now, due to the lack of fused fluoride fiber components and modulators, pulsed mid-infrared laser sources have been designed with free space optics making them liable to the surrounding atmosphere, and which ultimately have limited their overall robustness and power scalability. An interesting approach to generate ns pulses in an all-fiber implementable design is by gain-switching the laser cavity with a temporally controlled pulsed pumping. Gorjan et al have demonstrated such an approach at 2.8 µm using an erbium-doped fluoride glass fiber, diode pumped at 976 nm [3]. They reported output peak powers of 68 W with pulses of 305 ns at a repetition rate of 100 kHz. Nevertheless, their demonstration was limited to an average output power of 2W given the free-space design of their laser cavity.

In this contribution, we present a compact, stable and rugged all-fiber gain-switched laser based on heavily erbium-doped fluoride fiber and fiber Bragg gratings. We reported stable pulsed laser emission at 2.8 µm with 5 W of average output power, 360 W of peak power and pulse durations of 230 ns. The performances, limitations and potential improvements of this laser will be discussed as well as its potential applications.

2. Experimental Setup

The experimental laser setup presented in Fig. 1 is based on a similar all-fiber architecture that achieved a maximum average output power of 30 W in continuous operation at 2.94 µm as reported in [10]. The laser setup consists of a 4.85 m length of double-clad fluorozirconate fiber (*Le Verre Fluoré*) with a 7 mol. % erbium-doped core (Ø = 15 µm, NA = 0.12) and a circular inner cladding (Ø = 260 µm, NA > 0.46) truncated by two parallel flats. The fiber is pumped by two combined laser diodes that deliver a peak pump power of 55 W at 980 nm. The multimode silica fiber delivering the pump power is spliced to the fluoride fiber which, combined to the use of intracore fiber Bragg gratings [11], provides the all-fiber design. The feedback in the cavity is provided by two fiber Bragg gratings (FBGs) that have been written directly through the coating of the erbium-doped fiber to preserve the mechanical integrity of the laser assembly. The high reflector input coupler (HR) has 98% reflectivity at 2825.5 nm with a FWHM bandwidth of 0.6 nm. The low reflector output coupler (LR) has 16% reflectivity at 2825.4 nm with a FWHM bandwidth 0f 2.4 nm.

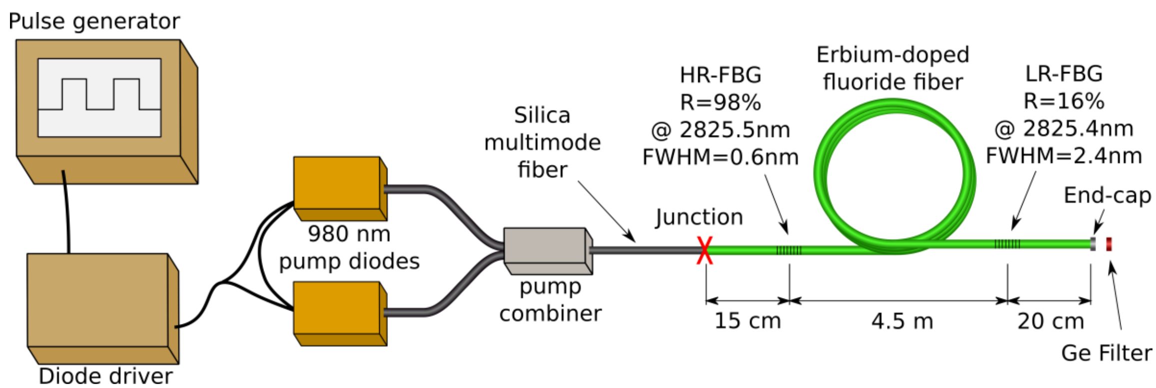

Fig. 1. Schematic of the experimental setup used for the all-fiber gain-switched laser at 2825nm

The laser output is protected by an AlF_3 fiber endcap to prevent degradation of the fiber tip due to high average and peak powers. A germanium filter is used at the laser output to suppress the residual pump power. The high-speed electronics which controls the pump diodes comprise a pulse generator (DG-535, *Stanford Research Systems*) for tuning the duration and the repetition rate of the pump pulses combined to a diode driver (PCO-6131, *Directed Energy*) that modulates the intensity of those pulses. The pulse intensity is fixed at the maximum operation current of the diodes ($I \approx 11$ A) to obtain the highest peak power.

3. Results

The temporal profile of the pump pulse and the synchronized laser pulse are measured with a 1ns rise time MCT detector (*Kolmar Technologies*) and are presented in Fig. 2. The best results were obtained when the pump pulse is turned off once the laser pulse is emitted. This prevents generation of secondary pulses and increases the stability of the gain-switched emission regime. For this laser setup, the laser pulses have an average duration of 230 ns. The pulses also feature a mode-lock resembling pattern with a period of 45 ns which corresponds to the time required for one cavity round-trip [4]. This pattern has been observed in previous gain-switched thulium fiber lasers emitting around 2 µm [4], which represents an interesting feature capable to boost the output peak power by a factor of 2. A higher peak pump power could give access to even higher laser peak powers.

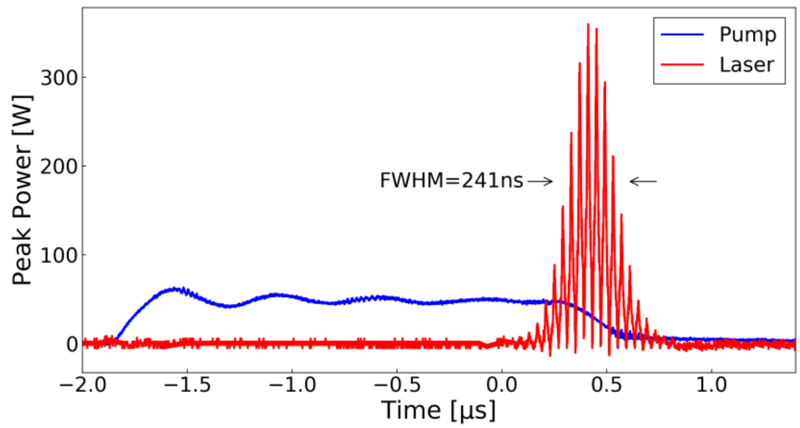

Fig. 2. Measured pump/output pulses for peak pump power of 55 W at a repetition rate of 80 kHz.

The peak power and energy per pulse were also characterized for different repetition rates, as presented in Fig. 3. The most stable regime is observed at 80 kHz, where the generated pulses reach a maximum peak power of 360 W and an energy of 37 µJ. Pulse-to-pulse instabilities of around 10% were observed which are mostly caused by the diode driver output current instabilities and pulse duration variations.

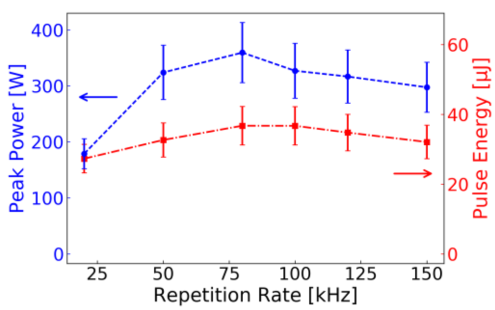

Fig. 3. Peak power as a function of the repetition rate. The maximum peak power of 360W and energy of 37µJ is obtained at 80kHz.

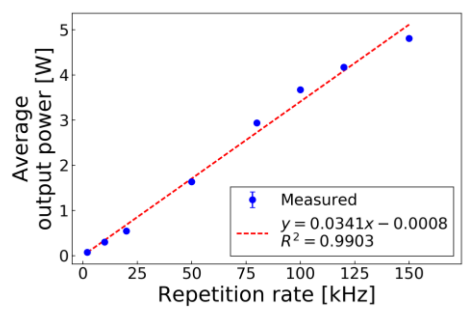

Fig. 4. Average output power of the laser as a function of the repetition rate

As shown in Fig. 4, the maximum average output power delivered by this all-fiber laser cavity is 4.8 W at a repetition rate of 150kHz. Considering the corresponding average pump power of 15.5 W, the laser slope efficiency of the laser reach 31%. No significant degradation to the laser's output characteristics were observed even after a few weeks of operation thanks to the all-fiber design.

4. Conclusion

We demonstrate an all-fiber gain-switched fluoride glass fiber laser emitting at 2.825 μm. The fiber laser operates in the gain-switch regime at a repetition rate adjustable between 25 kHz and 150 kHz with a maximum average output power of 4.8 W. The maximum estimated output peak power and energy per pulse are 360 W and 37 μJ respectively. By using a more stable diode-driver with shorter rise time and higher pump peak powers, the performances of this source could be further increased to the kW peak power regime, which is promising for the development of high-end applications such as supercontinuum generation for remote sensing or direct processing of biological tissues.

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