Numerical and experimental investigation of erbium (III) ion doped fluoride glass fiber laser operation at threshold

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***Abstract*—Lanthanide ion doped, fiber lasers are characterized by high brightness, circular beam shape, tuning ability and short pulse generation. In this contribution, we study experimentally and numerically near threshold operation of a erbium (III) ion doped fluoride glass fiber laser which operates near 2800 nm. The results obtained are useful for engineers developing novel fiber lasers, as the results help in detecting the onset of stimulated emission.**

Keywords—Fiber lasers, time domain analysis, laser threshold

I. Introduction

The erbium (III) ion doped, fluoride glass, fiber laser is an important milestone in the development of fiber lasers operating in the mid-infrared wavelength region. It is, at the moment, still the only fiber laser capable of delivering near 3000 nm a nanosecond pulse with peak power exceeding 10 kW and M^2 near 1 [1]. Further, this laser can be conveniently pumped using a 980 nm laser diode with a double-clad. fiber, cross-sectional arrangement and it reaches output powers exceeding 10 W near 3000 nm [2].

Currently, the main effort in the development of mid-infrared fiber lasers is focused on reaching wavelengths exceeding 4000 nm [3,4]. An important element of this effort is the correct identification of lasing, coming from a newly developed, laser setup. An erroneous identification of lasing may result in a misdirection of the fiber development effort, which can be very costly.

In this paper, we focus on the study of the temporal behavior of output light coming from an erbium (III) ion doped fluoride glass fiber laser. We focus exclusively on the output wavelengths near 2800 nm. In our study, we combine both experimental methods and numerical modelling.

II. Experimental Setup and Numerical Model

The experimental setup is presented in Fig.1. The pump light emitted by a 980 nm laser diode is focused on the coupling facet of the erbium (III) ion doped fluoride glass fiber. It propagates through the fiber and is reflected of the air / glass interface at the other end of the cavity. The 2800 nm light is collected from the fiber end opposite to the launch end and delivered to the detector, and oscilloscope to record the temporal traces of the laser output. The pumping laser diode is modulated directly from a current drive.

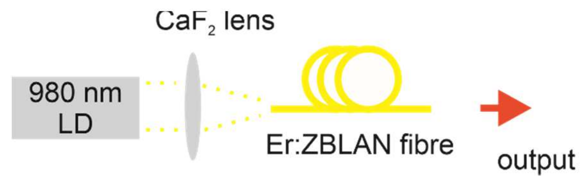

Fig. 1. Experimental setup of an erbium (III) ion doped fluoride glass fiber laser.

The one dimensional time domain, numerical model used in this study relies on the finite difference method to convert a set of partial differential equations, that govern the photon distribution within the laser cavity, to a set of ordinary differential equations. These latter equations are then solved, together with rate equations describing the level populations, in MATLAB programming environment [5]. The simulation parameters have been taken from [6]. The numerical calculations have been performed on a standard PC with 13th Gen Intel(R) Core(TM) i5-1335U 1.30 GHz processor using Windows operating project.

III. Results

The length of the fiber used in the laser cavity assembled according to Fig.1 was 0.7 meters. The laser cavity was terminated by the cleaved ends of the fiber where a reflectivity of 4 % is assumed. The fiber was double-clad. The core diameter was 15 µm, the inner-cladding double D diameter was 240/260 µm, while the doped core erbium III ion concentration was 70000 ppm. The pump laser diode operated at 980 nm and was coupled into a 100 mm pigtail, undoped fluoride fiber. We assumed that the pump power coupled to the erbium (III) ion doped fiber, had losses attributed only to the 4 % Fresnel reflection at the air-glass interface of the fiber end. The pump laser diode was modulated with a near square waveform having the repetition frequency of 10 Hz. The pulse rise and fall time was approximately 1 µs, while the pulse ramp time was: T_{on} = 50 ms followed by 50 ms of off time (Fig.2).

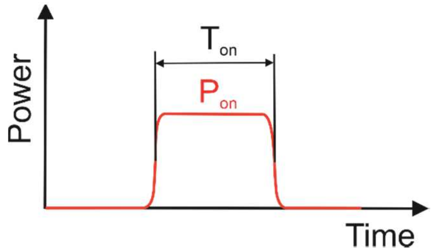

Fig. 2. Laser pump diode pulse shape.

Fig. 3 shows the measured dependence of the fiber laser output power on time, at selected values of the pump power P_{on} (Fig.2). Below threshold (black trace in Fig.3), the output waveforms differ qualitatively from those collected above threshold (blue and green color in Fig.3). Above threshold at the pulse leading edge, the pulse was preceded by a significant overshoot of the output power [7]. On the trailing edge a noticeably slower decay below threshold was observed. This is because below threshold the light decay time is equal approximately to the upper lasing level life time while above threshold it is in principle determined by the lasing cavity photon lifetime, though for a specific experimental setup (cf. Fig.1) it is limited by the pump pulse switch-off time. It is noted that there is a non-zero output power intensity recorded before the pumping pulse arrival, which is due to thermal radiation background incident upon the detector. This background light was extracted from experimental results during the postprocessing of measured results.

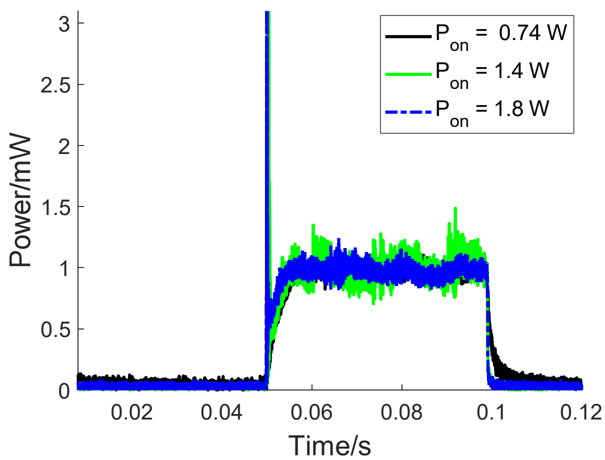

Fig. 3. Measured output pulse shapes at selected values of the pump power.

Fig. 4 shows the numerically calculated dependence of the fiber laser output power on time at selected values of the pump power. Similarly to the experimental results, the numerical results have been rescaled to one for the ramp (P_{on} in Fig.2) so that the attention can be focused on the shape of each waveform. It is interesting to note that the model reproduces the waveforms with a distinct leading peak which is observed above threshold. Concerning the trailing edge, similarly to experimental results a distinctly longer light decay is observed below threshold. Further, there are oscillations observed experimentally that are not reproduced by the model. This discrepancy can be attributed to wavelength hopping, as observed in [7]. Also, the numerically calculated waveform at 0.74 W pump power has a significantly larger delay than the one observed experimentally. This requires further investigation.

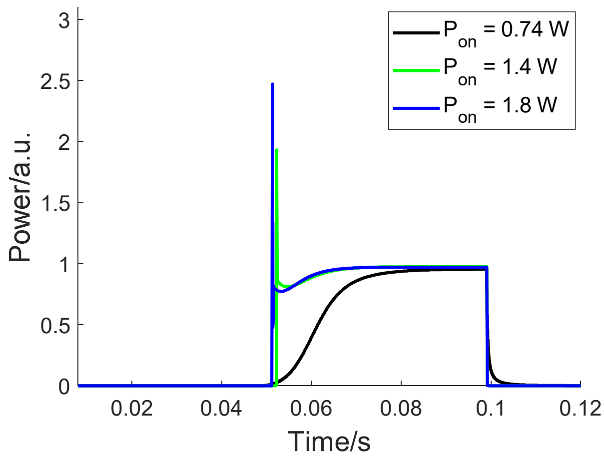

Fig. 4. Numerically calculated output pulse shapes at selected values of the pump power compared with an experimentally obtained pulse shape.

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