Passive Q-switching Dynamics of SBS/Er Fiber Laser

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We investigated self-starting quasi-periodic pulsation in Er-doped fiber laser at 30-80 mW pump power. Pulsation occurred at a quite stable repetition rate in the range of 300-500 µs and peak power of 50-200 W with ~50 % fluctuation. Commonly we observed a small pulse with duration of 50 - 200 ns and peak power of 0.5 - 5 W followed by gigantic Q-switched pulse with duration of 10 - 50 ns. The comparison of experimental oscilloscope traces with theoretically predicted ones proved that pulsation was caused by cooperative dynamics of Rayleigh backscattering and stimulated Brillouin scattering in fiber.

Introduction

Recently a novel mechanism for passive Q-switching in fiber lasers based on cooperative dynamics of linear Rayleigh backscattering (RS) and Stimulated Brillouin Scattering (SBS) has been reported [1]. The matter of the mechanism [2,3] is the following. Rayleigh backscattering of the light propagating in the laser cavity creates additional distributed feedback in the fiber cavity leading to a very effective linewidth narrowing. This in turn creates the conditions for SBS in the fiber. The growth of SBS then causes a series of avalanche processes leading to Q-switching. Until now, passive Q-switching caused by the above-mentioned mechanism has been realized experimentally but with pump powers higher than 2 W [4,5]. At so high pump levels, the laser dynamics is complicated by a multiplicity of competing nonlinear effects [6] impeding both the recognition of initial RS-SBS process leading to Q-switching and comparison of experimental and theoretical results.

In this paper, we report our experiments with Er-doped fiber lasers pumped by low-power 980 nm laser diode. Pulsation operational mode caused by RS-SBS mechanism was successfully observed at pump power levels of 30 - 80 mW.

Experiment

In the experiment, the laser employed in refs. [1-4] was realized with the use of an Er-doped fiber pumped by 980 nm laser diode with maximal output power of 100 mW (Fig.1.). The laser consists of a linear fiber cavity, comprising 90% reflecting fiber Bragg grating (FBG), Er-doped fiber, piece of single-mode fiber (SMF), and a single-mode fiber ring resonator (RR) attached to the cavity through a 10/90 single-mode fiber coupler. The laser is pumped by a laser diode through a WDM coupler, which is inserted between Er-doped fiber and SMF. If backreflection from the output end of the extra fiber is suppressed, feedback in the linear fiber cavity occurs due to reflection from FBG and backreflection caused by RS or SBS in the fiber ring resonator. The laser output radiation from both output 1 and output 2 is detected simultaneously by two photodiodes. The signals from photodiodes are digitized and recorded by oscilloscope for further analysis. The temporal resolution of the detection system is less than ~ 1 ns.

Laser dynamics was investigated for laser configurations with two different length of the linear cavity (8 m for basic configuration and 44 m for configuration with long linear part of cavity).

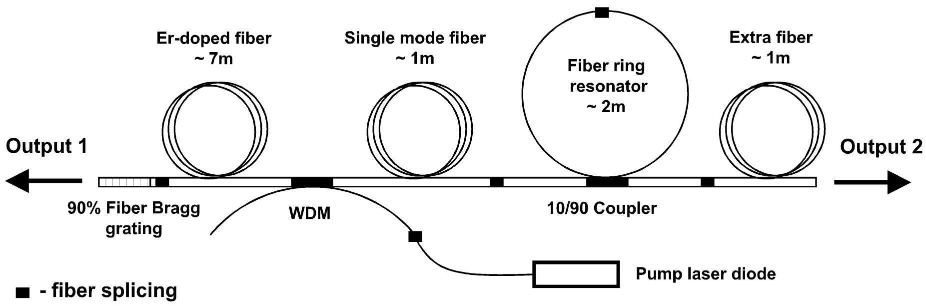

Figure 1. Experimental setup (lengths of fibers are indicated for the basic configuration).

The laser could operate in pulsed mode, when the free end of the extra fiber (EF) was cut at angle to eliminate backreflection from this fiber end. At pump power of 90 mW, self-starting generation of pulses occurred (Fig. 2, a) at a quite stable repetition rate in the range of 300-500 µs and peak power estimated to 10 W for basic configuration (and to 200 W for configuration with long linear part of cavity) with ~50% fluctuation. Careful angled cutting of the fiber end allowed us to reduce backreflection from the fiber end and to decrease the threshold down to 70 mW. The pulse generation was achieved with threshold pump power as low as 30 mW when the laser was affected by a weak acoustic signal. It is important to note that the way of starting did not influence the pulsation parameters (peak power, repetition rate, pulse duration), which were mainly determined by the laser configuration and pump power level.

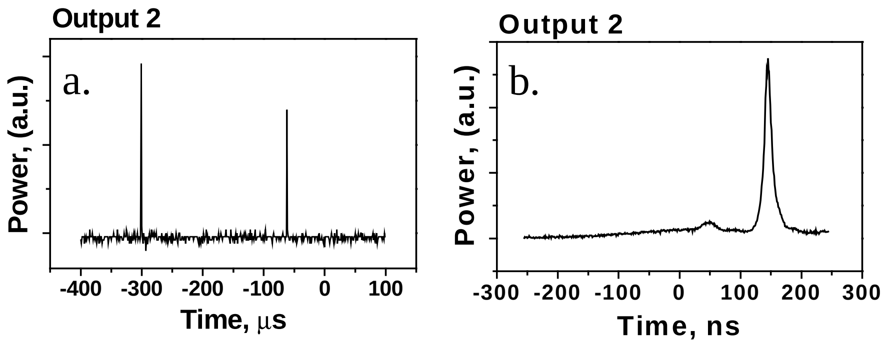

Figure 2. Typical oscilloscope traces recorded at pump power of 80 mW (basic laser configuration, a - large x-scale, b – small x-scale).

In contrast with previous experiments, the laser dynamics was more simple and slower. Using digital oscilloscope we could recognize different stages of the Q-switching pulse formation process and investigated each of them experimentally in details. Commonly we observed a small pulse with duration of 50 - 200 ns and peak power of 0.5 - 5 W followed by gigantic Q-switched pulse with duration of 50 ns (for basic configuration and of 10 ns for configuration with long linear part of cavity) (Fig.2,b). No extra echo pulses following the main pulse were observed. It was concluded that no nonlinear effect except SBS influenced on the laser dynamics. Therefore, we could compare in details the experimentally observed laser dynamics with the theoretical behavior as predicted by the RS-SBS model.

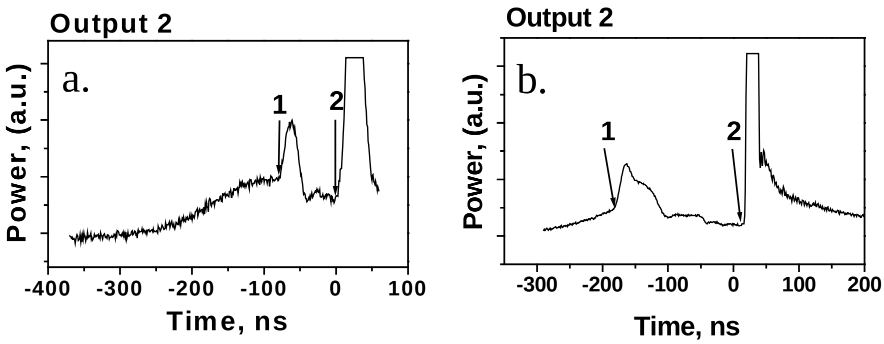

Figure 3. Fine structure of laser pulses at pump power of 80 mW (a - basic laser configuration, b – configuration with long linear cavity).

Fine structures of small and gigantic pulses were investigated for both laser configurations. On this way certain relations between fine structure of the pulses and laser parameters were found. Several stages of the pulse formation can be clearly recognized in the oscilloscope traces of the output 2 (Fig.3). Initially, the power grows exponentially with a characteristic time of ~ 70 ns. Then inflection in the curve happens and the growth becomes slower. At the time indicated by arrow 1 in fig.3(b) (point 1), a small pulse is generated before the gigantic pulse that appears at point 2. In a complete agreement with theoretical predictions, by varying the laser cavity length we observed two qualitatively different laser behaviors in pulses mode. In the experiment with 8 m cavity configuration gigantic pulse had duration 40 – 80 ns and peak power less than 50 W. Fronts of the small and gigantic pulses were separated in time by the cavity round trip time (Fig.3, a). When the length of cavity had been increased up to 44 m fronts of the small and gigantic pulses were separated by the time, which is smaller than the cavity round trip time, and gigantic pulses became more powerful with peak power 200 W and duration 10 – 15 ns (Fig.3, b).

Theory

Numerical simulations of the RS-SBS process in fiber laser were performed (Fig.4). Simulations were based on the set of dynamical SBS/RS equations [7,8]. Comparison of experimental and theoretical results allowed us to recognize different stages of pulse formation process, namely, lasing due to Rayleigh backscattering, appearance and growth of the first order SBS Stokes radiation (point 1) and the second order Stokes radiation (point 2), lasing suppression due to saturation of the population inversion in Er-doped fiber by the SBS Stokes radiation. So, we concluded that pulsation was caused by the RS-SBS Q-switching mechanism [1-3].

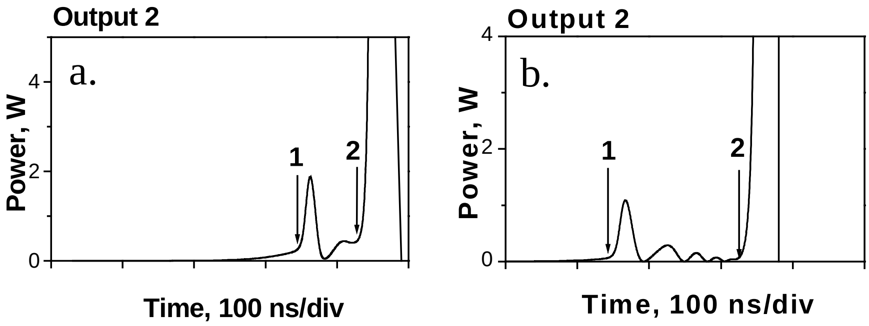

Figure 4. Computer simulated traces of the total radiation from output 2 (a - basic laser configuration, b – configuration with long linear cavity).

Conclusion and acknowledgments

In conclusion we have successfully demonstrated passive Q-switching in a Er-doped fiber laser configuration at very low pump power. We have investigated the laser dynamics and described a number of specific features of the temporal behavior that accompanied the generation of gigantic pulse. We proved that pulsation was caused by the RS-SBS Q-switching mechanism that was exploited early but only with high-power fiber lasers. ore than 100 W peak power pulses with duration of ~ 10 ns have been observed at pump power of only 80 mW. Such a light source, which could be very flexible, may be useful for many applications.

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