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Microarticle

Passively Q-switched 0.24 mJ ring laser based on anisotropic tapered fiber

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ABSTRACT

We report on a passively high-power Q-switched ring laser based on the active polarization-maintaining double-clad tapered Yb^{3+}-doped fiber (APM-T-DCF) as gain media. It generates 0.24 mJ pulse trains which consist of Q-switched pulses each with the energy of about 48 μJ and up to 385 W of peak power. Q-switched regime was achieved by tuning the optical feedback polarization state and band pass filtering. For the best of our knowledge, for the first time, we demonstrate Q-switched fiber ring laser based on APM-T-DCF.

Introduction

Ytterbium (Yb) -doped tapered double clad fibers have been shown to be efficient gain media with the inherent suppression of nonlinear effects for amplifier systems operating near 1 μm [1]. APM-T-DCF is a nonregular optical fiber with core NA typically less than 0.1 and special geometric longitudinal profile that core diameter increases adiabatically over the length of the fiber. It allows to achieve extremely large mode field diameter up to 80 μm at the output with preserving polarization state and near single mode composition [2]. Unidirectional increasing of absolute active media volume as the core diameter increasing towards the direction of signal propagation provides effective amplification of signal. At the same time that non-regularity of core violates condition of phase synchronism consequently enlarging nonlinear effects (SBS, SRS, TMI) thresholds. These advantages make APM-T-DCF an ideal gain medium for high power short-pulse fiber amplifiers [1]. Different types of T-DCF were shown in recently published papers [1–3]. Their efficiency in amplification schemes and linear Q-switched mJ-class laser schemes [3] leaves no doubt. However, the same advantages mentioned above, in accordance with their essense, make APM-T-DCF more effective medium for a unidirectional bypass ring laser cavity in the contrast with linear laser schemes. Nonetheless Q-switched ring fiber cavities based on APM-T-DCF is completely novel approach for modern science. Pulsed fiber lasers are widely applicable for different areas in industry, medicine and science. Here Q-switched fiber lasers occupy a separate position due to the possibility of obtaining pulses with relatively long duration and high energies. In comparison with actively Q-switching schemes where saturable absorbers or modulators are common [4], passively Q-switching allows to organize laser cavity usually with less elements consequently less losses and therefore cheaper [5]. It was previously shown that regular large mode area fibers are suitable for active medium of passively Q-switched ring laser cavity. Moreover, ring laser cavities are highly promising in the future for obtaining the ultrashort pulses [6].

Experimental results and discussions

Principal scheme of optical laser cavity is depicted in Fig. 1a. Yb-doped active polarization maintained tapered double clad optical fiber is used as an active medium. The length of APM-T-DCF is 4,75 m. The polarization state preserves due to the presence of stress-inducing rods inside of APM-T-DCF forming PANDA-type cross section. The absorption of the pump at 976 nm in the active fiber core is about 700 dB/m. Core diameter is gradually increasing from near single mode size of 12 μm at the narrow end to 50 μm at the wide end along the entire length of APM-T-DCF. Core to cladding ratio is 1:10 and numerical aperture of core is 0.08. Fig. 1b demonstrates the change in the diameter of the fiber cladding along the length. The pump of APM-T-DCF is organized using multimode diode operates at 976 nm into the cladding of narrow part through $(2 + 1) \times 1$ pump combiner. The signal fiber of pump combiner is 10/125 μm polarization maintaining double clad fiber and pump ports are formed by 105/125 μm 0.22NA optical fibers. Collimating L1 and

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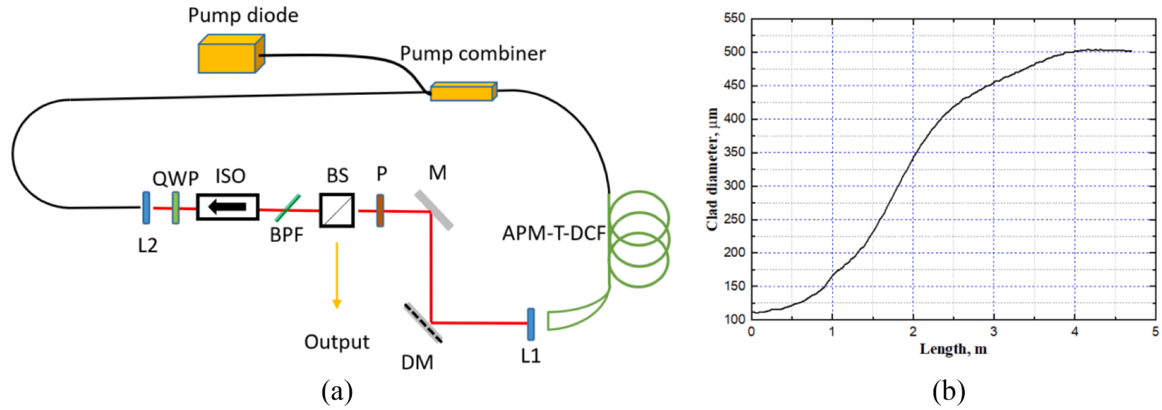

Fig. 1. (a) Scheme of Q-switched ring laser with active Yb-doped polarization maintaining tapered double-clad fiber (APM-T-DCF); (b) Longitudinal geometric profile of Yb-doped APM-T-DCF.

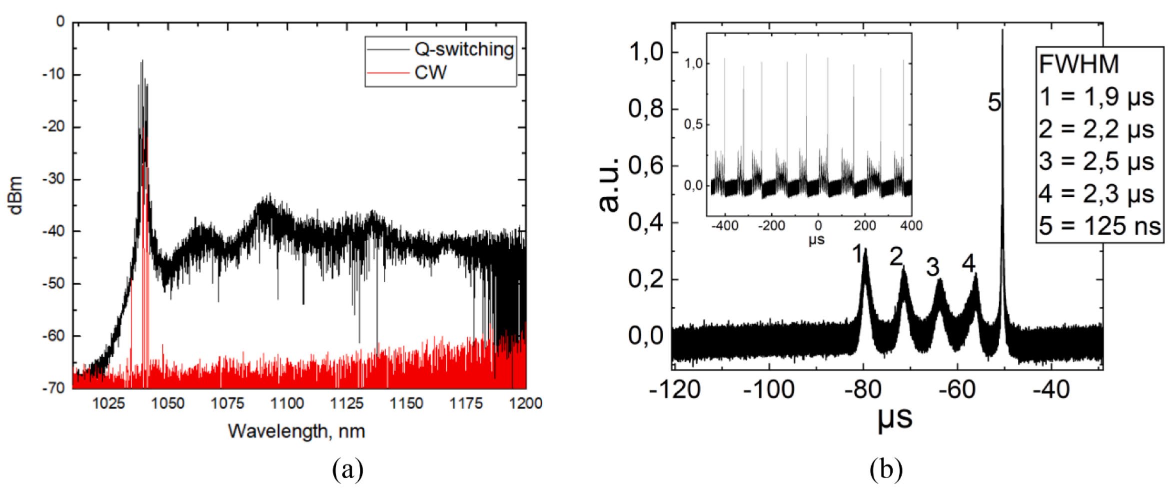

Fig. 2. (a)Spectra of the Q-switched (black curve) and CW (red curve) operation; (b) Output Q-switched pulses train, inset - the corresponding oscilloscope trace. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

focusing L2 aspherical lenses are used, correspondingly, to output radiation from wide end of APM-T-DCF and to couple radiation into the input signal fiber of pump combiner. Short pass dichroic mirror (DM) filters of residual pump radiation. Second silver mirror (M) is used to adjust proper angle of free space beam propagation. A linear polarizer (P) and quarter-wave plate (QWP) is used to control the polarization state of the light beam inside the cavity. And the polarization-dependent isolator (ISO) ensures the unidirectional propagation of laser beam. The 90% of optical power is output by a non-polarizing beamsplitter cube placed between P and a bandpass filter (BPF). Precise tuning of spectral filtration is performed by adjusting of the BPF tilt angle according to interferometric principles. An optical spectrum analyzer and a 4 GHz oscilloscope with a 5 GHz photodetector are used to measure the pulsed signal parameters. The output average power is also detected by an optical power meter. With the random tilt angle of BPF and rotation angle of QWP laser operates in continuous wave regime with spectrum Fig. 2a (red line). The lasing threshold in CW regime was achieved at 4 W of pump power and CW operation was maintained for all pump powers with inappropriate angles of BPF and QWP. Q-switching regime of laser operation starts at certain tilt and rotation angles and is maintained in the narrow ranges of them. Precise tuning of the transmission spectral band and the polarization state inside the cavity allows to control Q-switching regime parameters in particular a duration of the laser pulses [7]. Typical Q-switched laser spectrum is shown in Fig. 2a (black line) and oscilloscope trace of pulses is shown in Fig. 2b. These both spectra in Fig. 2a were achieved with maximum tested pump power of 11.6 W. Slope efficiency of constructed laser in Q-switched regime is achieved about 22%. The high pulse train energy of about 0.24 mJ and peak power of generated pulses, after Q-switching regime started, leads to arising of an additional radiation at a longer wavelength range mostly corresponding to stimulated Raman scattering in singlemode part of optical scheme. The maximum directly detected average optical power is 2.77 W including all spectral components. Most of the power of about 86% is carried in pulsed laser line spectral region with central wavelength about 1043 nm. Repetition rate of the pulse trains (Fig. 2b) is about 10 kHz measured for minimum achieved duration of the highest pulse of 125 ns. Also Fig. 2b shows that the optical pulse train contains additional components at the repetition rate of approximately 128 kHz corresponding to the processes of Q-switching regime formation. All of the pulses in the train carry almost the same energy of 48 μJ in accordance with the integration over time. Consequently, peak power of the first pulses are about 25 W and up to 385 W for last nanosecond one.

Conclusions

In this paper we demonstrated passively Q-switched ring laser APM-T-DCF-based cavity scheme which allows to control optical feedback precisely using spectral and polarization tuning components. The trains of pulses with duration from 125 ns to 2.5 μs carry about 0.24 mJ in total and 48 μJ of each pulse was achieved at 10 kHz repetition rate. The characteristic feature of this scheme is the possibility of adjusting the state of polarization and the central wavelength inside the laser cavity.

These results are promising to establish stable mode-locking regime with high peak power.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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