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Compact Narrow Linewidth Actively Q-Switched Er–Yb Double-Clad Fiber Laser

Berenice Posada-Ramírez [1], Manuel Durán-Sánchez [2], Ricardo I. Alvarez-Tamayo [3], Jared Alaniz-Baylón [1], Guillermo Salceda-Delgado [4], Evgeny A. Kuzin [1] and Baldemar Ibarra-Escamilla [1,*]

[1] Instituto Nacional de Astrofísica, Óptica y Electrónica, Luis Enrique Erro 1, Sta. María Tonantzintla, Puebla 72824, Mexico; b.posada@inaoep.mx (B.P.-R.); jared.alaniz@inaoep.mx (J.A.-B.); ekuz@inaoep.mx (E.A.K.)

[2] CONACyT—Instituto Nacional de Astrofísica, Óptica y Electrónica, Luis Enrique Erro 1, Sta. María Tonantzintla, Puebla 72824, Mexico; maratonista80@hotmail.com

[3] CONACyT—Universidad Autónoma de Nuevo León, Av. Universidad S/N San Nicolás de los Garza, Nuevo León 66451, Mexico; alvarez.tamayo@hotmail.com

[4] Universidad Autónoma de Nuevo León, Av. Universidad S/N San Nicolás de los Garza, Nuevo León 66451, Mexico; gusademo@gmail.com

* Correspondence: baldemar@inaoep.mx; Tel.: +52-222-247-2940

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Abstract: Actively Q-switched laser operation of a narrow linewidth compact fiber laser based on an Er–Yb double-clad fiber is presented. The laser linewidth as a function of the repetition rate and the Q-switched pulses characteristics for different pump powers are experimentally analyzed. Stable Q-switched laser operation with spectral laser linewidth of 73 pm in a repetition rate range from 90 to 270 kHz is obtained. The minimum pulse duration of 178 ns, maximum peak power of 30.5 W, and maximum pulse energy of 5.4 μJ are observed. The maximum average power reached is 1.1 W.

Keywords: fiber lasers; Q-switched lasers; Er–Yb double-clad fiber; fiber Bragg gratings

1. Introduction

In recent years, fiber lasers operating in the 1550 nm wavelength region are widely studied because of their properties such as high gain, eye-safe laser emission, and single-mode operation, among others [1–3]. Since Erbium/Ytterbium double cladding fiber (EYDCF) came out, different approaches of fiber lasers were reported in order to reach high efficiency and high power emission [4–6]. In this regard, Q-switched EYDCF lasers (EYDCFL) have been of increasing interest for applications in which short pulses (a few nanoseconds) with high peak power and high pulse energies are required. Q-switched EYDCFL are used for industrial processing, remote sensing, instrumentation, and medical applications in which laser emission at different wavelengths, short pulse duration, and wide repetition rate operation range are often required. In order to achieve short laser pulses, Q-switching is performed by passive and active techniques. The passive Q-switching is based on the use of a saturable absorber such as fiber with graphene or carbon nanotube deposits [7–11] and un-pumped segments of active fiber [12,13]. In this case, the repetition rate of the generated pulses is determined by the pump power which limits the controlling of the laser pulses characteristics and the output power reached. The active Q-switching technique for laser pulses generation requires the use of an external modulator to obtain pulsed laser operation. In contrast to passive Q-switched lasers, when an active Q-switching technique is applied, the pulse characteristics can be modified independently of the pump power by using an electronic pulses generator, allowing the proper controlling of the laser pulses for the required laser application [14–17]. In this regard, the use of EYDCF to design active Q-switched fiber lasers has been underexploited. As far as we know, besides what has been reported by our investigation group [5,13,17], Zhang et al. [18] reported an all-fiber actively Q-switched ring cavity fiber laser based on Er/Yb co-doped fiber which demonstrated the improvement of power efficiency when EYDCF is used, however, the pulsed operation reported is in a narrow and low repetition rate range from 10 to 25 kHz. In this paper, we experimentally demonstrate a simple and compact actively Q-switched fiber laser operating in the 1550 nm waveband. The laser performance is based on the use of EYDCF used as a gain medium. The proposed EYDCFL is an all-fiber configuration which represents an improvement of the previously reported approaches regarding use of bulk components, simplicity of design and ease of construction with similar (and in some cases improved) operation parameters such as power efficiency, repetition rate range, and pulse energy; compared with the previously reported approaches. Is worth mentioning that the proposed EYDCFL was designed, implemented, and experimentally studied in terms to obtain a specific application as a reliable pump power source for thulium-doped fiber laser investigations. However, the proposed configuration can be of interest for its application in areas such as optical communications, optical instrumentation, remote sensing, and nonlinear optics investigation operating in the 1.55 µm wavelength band.

2. Experimental Setup

The experimental setup of the proposed actively Q-switched EYDCFL is shown in Figure 1. The EYDCFL has a Fabry–Perot configuration. The gain media is a 3.3 m long EYDCF (CorActive DCF-EY-10/128) (CoreActive High-Tech Inc., Québec, QC, Canada) with core absorption of 85 dB/m at 1535 nm, diameter of 10 µm, NA of 0.20; and first cladding with absorption of 2 dB/m at 915 nm, diameter of 128 µm, and NA > 0.45. The EYDCF is pumped by a 25 W multimode laser source at 976 nm (Focusligth FL-FCMSE55) (Focuslight Technologies Inc., Xi'an, Shaanxi, China) through a pigtailed beam combiner 2 + 1 × 1. An intracavity pigtailed acousto-optic modulator (AOM, Gooch & Housego Fibre-Q T-M200-0.1C2J-3-F2S) (Gooch & Housego PLC, Ilmister, UK) driven by a radio frequency (RF) signal is used to generate Q-switched pulses. The cavity is formed between the 4% Fresnel reflection from the normal cleave of the unconnected AOM fiber end in one side and a homemade fiber Bragg grating (FBG) with 99% reflection at 1548.3 nm spliced to the EYDCF end in the opposite side. The measured bandwidth of the FBG at −3 dB is of 209 pm, which contributes to the linewidth narrowing of the laser emission. The unconnected end of the FBG (output 1) is used to measure the laser spectrum by using an optical spectrum analyzer (OSA, Yokogawa AQ6375) (Yokogawa Corporation of America, Newnan, GA, USA) with a wavelength range from 1200 to 2400 nm and resolution of 50 pm. In the output 1, the laser pulses are also detected by a photodetector and observed in an oscilloscope. The unconnected port of the AOM (output 2) is used to measure the laser average output power by a thermal power sensor (Thorlabs S146C, 900–1650 nm, 20 W) (Thorlabs Inc., Newton, NJ, USA) and a power meter console (Thorlabs PM100D) (Thorlabs Inc., Newton, NJ, USA).

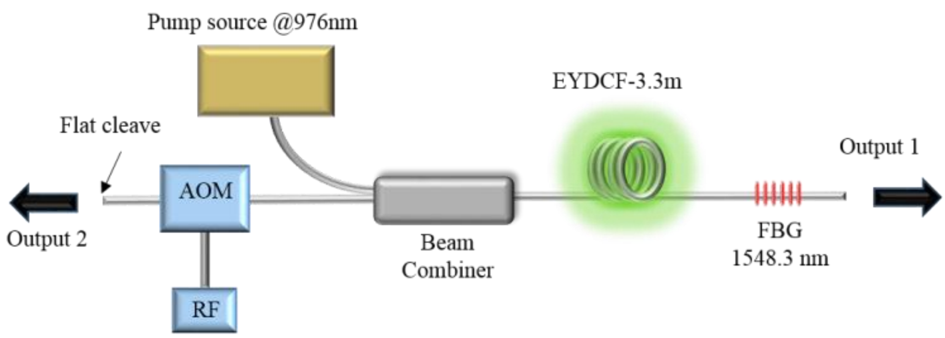

Figure 1. Experimental Setup of the actively Q-switched EYDCFL.

3. Results and Discussion

In Figure 2, the EYDCFL spectrum and output power in continuous wave (CW) operation is shown. The experimental results were obtained without the AOM within the laser setup. The unconnected port of the beam combiner was normal cleaved, acting as a 4% reflector to limit the cavity. The aforementioned fiber end is also used as output 2 to measure the output power of the laser. Figure 2a shows the output laser spectrum measured with the OSA. The laser wavelength is generated at a central wavelength of 1548.3 nm with full width at half maximum (FWHM) linewidth of 82 pm. The maximal pump power applied in CW was 11.4 W (maximal pump power for CW laser operation results). The output power dependence on the pump power applied is shown in Figure 2b. The lasing threshold is ~0.5 W of pump power. With the maximal pump power application the output power achieved being 4.32 W, with an efficiency slope of 38%.

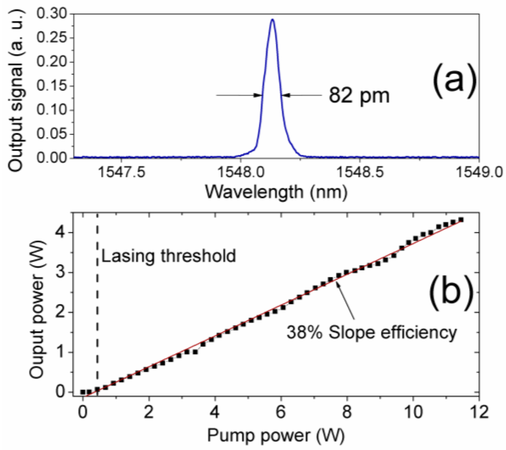

Figure 2. EYDCFL in CW operation, (**a**) laser line spectrum and linewidth, (**b**) Output power vs. pump power.

The laser spectrum linewidth evolution as a function of the repetition rate in actively Q-switched operation is discussed in Figure 3. The measurements were obtained with a pump power of 6.5 W. Figure 3a shows the laser output spectrum at the repetition rate limits in which stable Q-switched pulses are observed. With the minimal repetition rate of 85 kHz (blue curve), the spectral FWHM linewidth is 92.2 pm while a linewidth of 73 pm is achieved with a maximal repetition rate of 155 kHz (red curve). The laser line wavelength corresponds to the central wavelength of the FBG of 1548.3 nm. Figure 3b shows the spectral linewidth evolution due to the repetition rate variation. The laser spectral width exhibits a narrowing from 93 to 73 pm as the repetition rate is increased from 85 to 155 kHz.

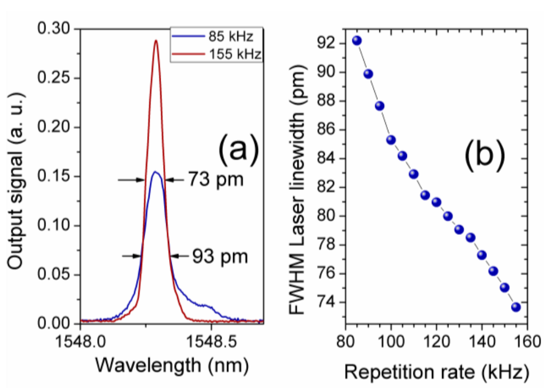

Figure 3. EYDCFL spectral linewidth evolution in Q-switched operation, (**a**) laser spectrum and linewidth at the repetition rate limits, (**b**) linewidth narrowing on repetition rate increase.

Figure 4 shows the Q-switched pulses evolution as a function of the pump power. The measurements were obtained at a fixed repetition rate of 140 kHz with a pump power variation in a range from 3.1 to 7.7 W, where the maximal pump power for Q-switched laser operation was set to 7.7 W in order to avoid damage of the fiber components. The generated pulse trains exhibit a shift toward shorter times over the AOM triggering time window. The observed pulses behavior impact in the pulses characteristics which depend on the launched pump power. The experimentally obtained time shift of the pulses trains as a function of the pump power is discussed from Figure 4a, in which a single pulse peak, taken as a reference is depicted. As it can be observed (and also noticed from Figure 3a), the time shift is more pronounced when low pump power is applied and is quasi-stabilized with higher pump powers, far above from the lasing threshold. Figure 4b shows the measured laser average output power and pulse duration as a function of the pump power. As it can be expected, with the increase of the pump power, the average output power increases as the pulse stretches. With the maximal pump power of 7.7 W, the maximal average power of 640 mW and the minimal pulse duration of 160 ns are obtained.

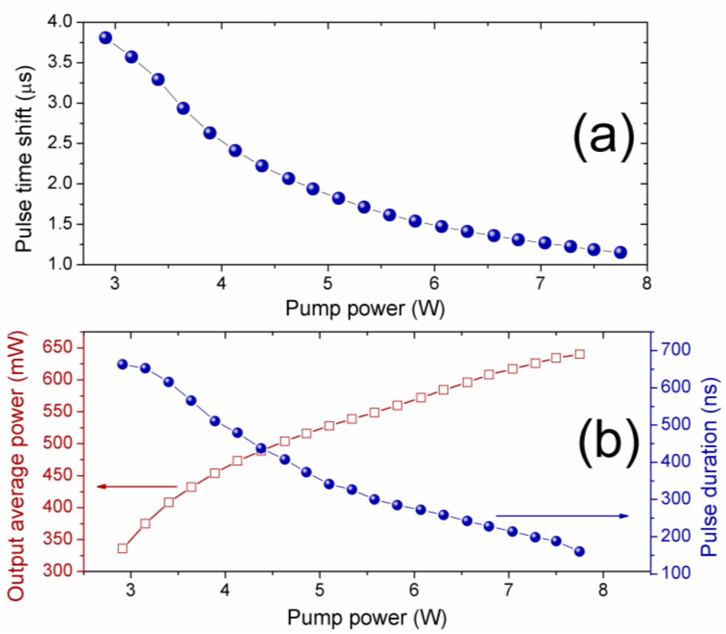

Figure 4. EYDCFL Q-switched pulses evolution as a function of the pump power, (**a**) Pulse time shift, (**b**) Output average power and pulse durations.

In Figure 5, the measured pulse duration and the estimated pulse energy as a function of the repetition rate of the actively Q-switched EYDCFL are shown. The experimental results were obtained with the maximal pump power limited to 7.7 W to avoid damage on the fiber components. The pulse energy was estimated from the measured average power and the repetition rate. As it can be expected, the generated laser pulses exhibit typical pulse characteristics of the actively Q-switched lasers. With the increase of the repetition rate from 90 to 270 kHz, the pulse duration increases from 178 to 520 ns as the pulse energy decreases from 5.42 to 4.08 μJ. When the repetition rate is decreased above 90 kHz, Q-switched pulses with spurious emission are generated.

Figure 6 shows the measured average power and the estimated peak power as a function of the repetition rate where stable Q-switched pulses are observed. With the increase of the repetition rate, the average power increases and the peak power decreases (as it can be expected because the pulses widen). The maximal output average power of 1.1 W is achieved with the maximal repetition rate of 270 kHz while the maximal peak power of 30.52 W is obtained with the minimal repetition rate of 90 kHz.

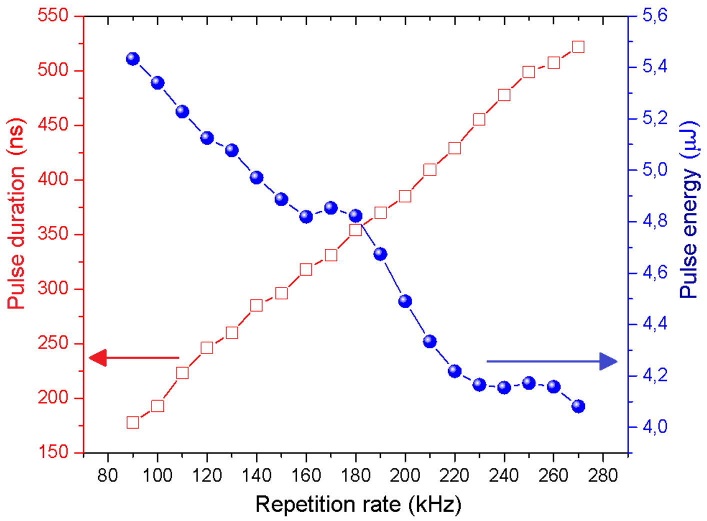

Figure 5. Pulse duration and pulse energy as a function of the repetition rate of the Q-switched laser pulses.

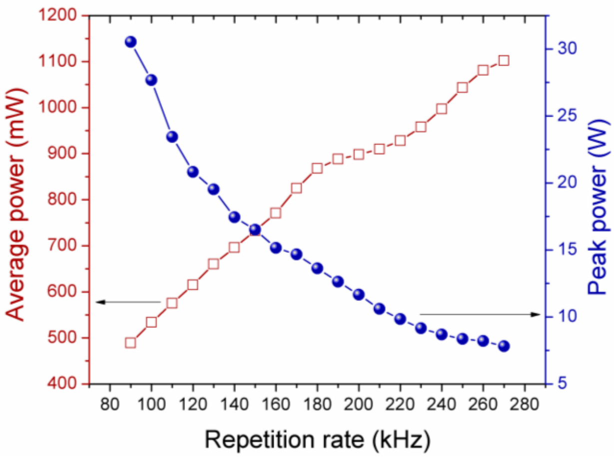

Figure 6. Q-switched laser average output power and peak power as a function of the repetition rate.

The proposed configuration exhibits competitive CW and actively Q-switched operation characteristics compared with the previously reported investigations. The obtained results experimentally demonstrate the reliability of the proposed EYDCF laser. The high-power efficiency slope in CW operation of 38%, as it can be expected, exhibits advantages of the use of EYDCF as a gain medium in fiber lasers operating in the 1.55 μm waveband. Compared with the previously reported investigations of actively Q-switched EYDCF lasers in which the laser linewidth is around 200 pm [5,13,17,18], the obtained linewidth was narrowed to 73 pm. The Q-switched laser operation shows stable pulse trains in a high repetition rate in a wide range from 90 to 270 kHz, which represents an improvement compared with the low and narrow range of repetition rate from the reported investigations where the maximum repetition rate in which stable Q-switched pulses is around 140 kHz with a maximum repetition rate range of ~100 kHz [5]. The estimated pulse energy of 5.42 μJ was improved in comparison with the previous works in which the maximal pulse energy of ~1.6 μJ is reported [13].

4. Conclusions

In conclusion, we experimentally demonstrated the actively Q-switched laser operation of a compact EYDCFL with narrow linewidth (less than 100 pm) at the wavelength of 1548.3 nm. Experimental analysis of the linewidth variation as a function of the repetition rate and the Q-switched pulse evolution as a function of the pump power were discussed. With the maximal pump power applied of 7.7 W, the Q-switched laser generates stable pulses in a repetition rate range from 90 to 270 kHz. Laser efficiency in CW of 38% with maximal average power in Q-switched regime of 1.1 W was obtained. Pulses with a maximal pulse energy of 5.42 μJ, maximal peak power of 30.52 W, and minimal pulse duration of 172 ns were achieved. The proposed configuration was demonstrated as a reliable actively Q-switched laser setup for different potential applications (such as remote sensing, nonlinear optics, and optical instrumentation, among others) because of its construction simplicity, compactness, and relatively low cost of fabrication.

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Conflicts of Interest: The authors declare no conflict of interest.

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