Active Q-switching of a fiber laser using a modulated fiber Fabry-Perot filter and a fiber Bragg grating

Rodolfo Martínez Manuel[1*], J J M Kaboko[2], and M G Shlyagin[3]

[1]Centro de Investigaciones en Óptica, A.C. Photonics, Prol. Constitución 607, Fracc. Reserva Loma Bonita Aguascalientes, 20200, México;

[2] University of Johannesburg, Electrical and Electronic Engineering Science Dept. Auckland Park, 2006,Republic of South Africa;

[3]Centro de Investigación Científica y de Educación Superior de Ensenada, Ensenada, Baja California, C.P. 22860 México.

E-mail: rodolfom@cio.mx

Abstract

We propose and demonstrate a simple and robust actively Q-switched Erbium-doped fiber ring cavity laser. The Q-switching is based on dynamic spectral overlapping of two filters, namely a fiber Bragg grating based filter and a fiber Fabry – Perot tunable filter. Using 3.5 meters of Erbium-doped fiber and a pump power of only 60 mW, Q-switched pulses with a peak power of 9.7 W and a pulse duration of 500 ns were obtained. A pulse repetition rate can be continuously varied from a single shot to a few KHz.

Keywords: Q-switched fiber laser; fiber Fabry – Perot tunable filter; Erbium-doped fiber.

1. Introduction.

Q-switching technique is a well-known method to generate laser light pulses with a short time duration and high peak power. Lasers based on fiber-optic cavities exhibit significant advantages when compared to the bulk-cavity lasers, like simplicity, robustness, small volume and low cost. Different techniques for developing actively Q-switched fiber lasers have been demonstrated.

From the beginning, the most popular active Q-switching techniques made use of electro-optic and acousto-optic modulators [1]. Fiber-coupled optical modulators are also widely used in Q-switched fiber lasers. However, electro-optic modulators are temperature and polarization sensitive. Also, electro-optic and acousto-optic modulators require special controllers for a correct operation. Insertion losses of these components are considerably high due to the non-fiber nature of these modulators.

All-fiber Q-switched lasers based on diverse switching mechanisms, such as all-fiber phase modulators [2], all-fiber acoustically modulated attenuator [3], and microsphere resonator [4], have been reported. Another reported technique to switch the Q factor of a fiber laser cavity is based on tuning the reflection bands of fiber Bragg gratings (FBGs) used as laser mirrors; stretching and relaxing the FBG using acousto-optic modulators [5], piezoelectric actuators [6] and magnetostrictive transducers [7]. Despite its simplicity, these techniques have some limitations such as unwanted strain in the FBG as it is normally attached to the modulator, as well as the speed of the deformation applied to the fiber Bragg grating for tunning purpose; it is very easy to damage the fiber Bragg grating if it is stretched and relaxed at a high rate. To avoid these unwanted effects, another reported configuration includes a Fabry-Perot filter and an in-line abrupt-tapered Mach-Zehnder filter [8]; no tune of a FBG is needed, the cavity is switched as the spectral transmittance of the filters overlap on/off. However, the tapered fiber makes the configuration fragile. The Mach-Zehnder fiber filter is manufactured using highly Erbium-Ytterbium co-doped fiber. In this configuration the extinction ratio (switched-in/switched-off power ratio) of the laser is only 17.1 dB, and in order to increase it, a special attention while manufacturing the Mach-Zenhder filter is crucial [8].

Q-switched fiber lasers are important for a variety of applications including remote sensing and distributed fiber-optic sensors based on linear reflection from multiplexed FBG-based interferometers and/or Rayleight backscattering [1]. For application in fiber optic sensors, among the most important required parameters of the laser are the high contrast of output light pulses (extinction ratio), narrow bandwidth of the output light and possibility to switch rapidly the output wavelength or dual-wavelength operation [9,10].

In this work, we present a method to actively switch the Q factor of an all-fiber laser cavity which has potential to be very useful for applications in optical fiber sensors.

2. Experimental Setup.

In the proposed configuration, Q-switching in the laser cavity is based on dynamic spectral overlapping of two filters, namely FBG based filter (reflection spectra) and fiber Fabry-Perot (F-P) tunable filter (transmittance spectra). When the spectra of the two filters overlap, the filter system has the maximum transparency; then, the laser cavity has minimal losses and it can release the stored energy in the form of the giant impulse. Otherwise, the laser cavity is considered to be opened and storing energy. In this configuration, no dynamic strain is applied to the FBG filter; the tunable F-P filter is used to dynamically change its spectral transmittance to actively switch the Q factor of the all-fiber ring cavity. Short pulses, stable (or tuned) in wavelength and with high extinction ratio can be generated with this configuration.

The proposed experimental configuration of the active Q-switched fiber ring laser is schematically shown in figure 1. In this fiber laser system, a laser diode emitting light at 980 nm is used as a pump source for the fiber laser. The pump light is coupled into the ring cavity through a wavelength division multiplexer (WDM). The gain medium of the laser is an Erbium-doped fiber (EDF). The pump light absorbed by the EDF assists in generation of spontaneous emission of light in the 1550 nm range. A specific spectral band of this spontaneous emission light is then reflected from the fiber Bragg grating (FBG) and travel to the fiber F-P tunable filter through the circulator. The reflectivity of the FBG is approximately 98% at 1550 nm. When the reflection band of the FBG overlaps with the transmittance band of the fiber F-P tunable filter, the light reflected from the FBG is allowed to oscillate in the cavity and the laser releases an accumulated energy in form of a single pulse. In this sense, the FBG defines the emission wavelength of the fiber laser. The unidirectional operation of the fiber ring laser is guaranteed by the three-port circulator.

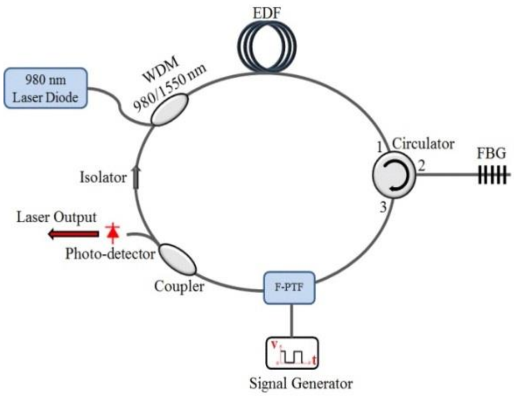

Figure 1. Schematic setup of Erbium-doped fiber ring laser with active Q-switching.

The spectral position of the F-P transmittance band is controlled by applied voltage. Therefore, it can be dynamically tuned by a signal from a standard low-power signal generator. By this way, the cavity Q-factor can be easily modulated. The F-P filter has a characteristic bandwidth of 200 pm; a free spectral range and the finesse are approximately of 40 nm and 200, respectively; the bandwidth of the FBG reflection spectrum is of 150 pm. Both spectra as shown in figure 2.

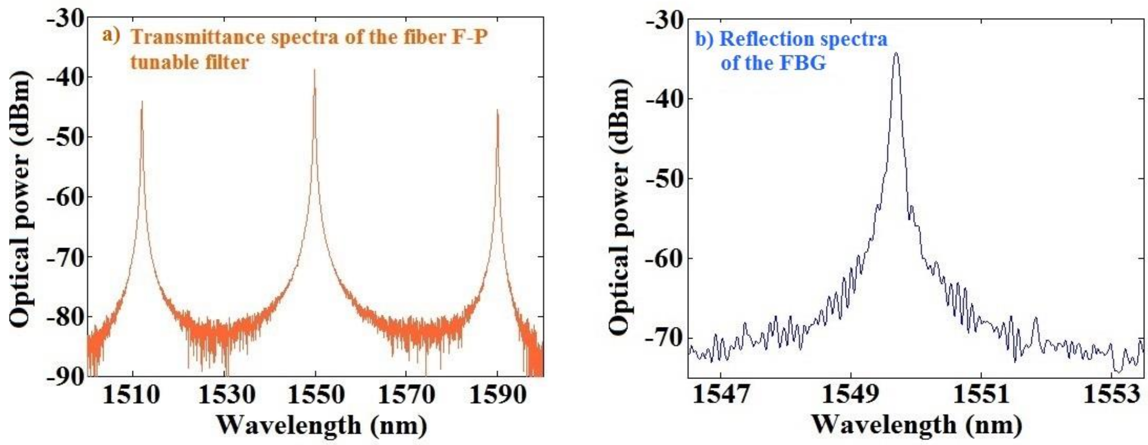

Figure 2. Spectra of the two implemented filters, a) transmission spectrum of the F-P filter; b) the reflection spectrum of the FBG.

An output coupler is used to extract the optical pulses from the fiber cavity. For output pulse measurements, a photo-detector in combination with a digital oscilloscope was used. In experiments, for characterization of the system, we applied Sin-like signals to the filter at different frequencies but with the same amplitude. An example of a train of generated light pulses is shown in figure 3; the standard deviation of peak power was less than 1%.

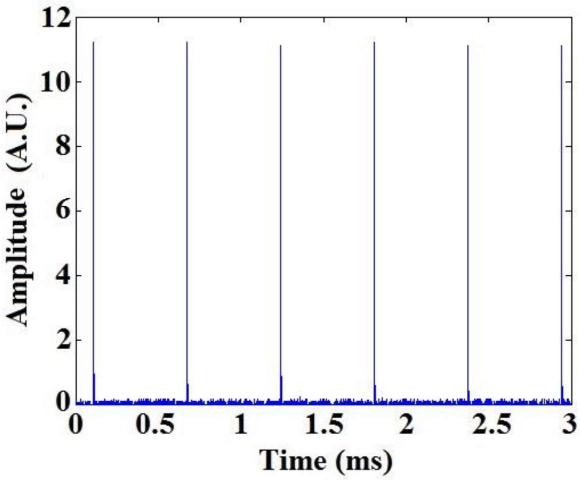

Figure 3. Train of the light pulses at the fiber laser output.

An additional optical isolator is used in the cavity in order to minimize impacts of optical reflections from interfaces of optical components, and in particular, to diminish the amplified spontaneous emission (ASE) reflected from the F-P filter towards the laser output. That permitted to increase significantly output pulse extinction ratio.

3. Experimental Results

Implementing the described system, two Erbium-doped fibers having different Erbium ion concentration were tested as active medium for the laser system. The fiber-one was with Erbium ion concentration of 960 ppm and the fiber-two with an Erbium ion concentration of 2200 ppm, with absorption coefficients of 12.4 dB/m and 23.4 dB/m at 980 nm, respectively. Experiments with different lengths of the Erbium-doped fibers were performed. With obtained experimental data presented in figure 4, an optimization of the active fiber length for a given pump power was performed in order to get the maximum output peak power from the laser system. In all the experiments, the output power of the pump diode laser was of 60 mW. The scanning frequency was of 1 KHz.

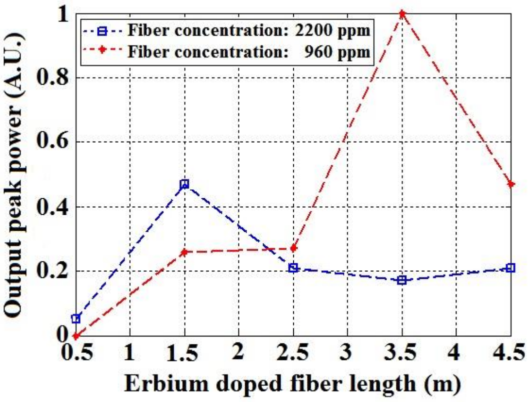

Figure 4. Dependence of the laser output peak power on the length of the Erbium-doped fibers with different ion concentration.

Using 3.5 meters length EDF with 960 ppm ion concentration, the Q-switched fiber laser exhibits twofold rise of the maximum output peak power than one obtained using the EDF with 2200 ppm ion concentration. Many factors can influence the maximum ouput power in the Q-switched mode. The length of the doped fiber is important and strongly affects the output peak power. The results presented in Figure 4 indicate that for a given pump power the highest output peak power is obtained using a 3.5 m of EDF (960 ppm), while using 2.5 meters of the same fiber the output peak power is only 25 % of maximum value, and with 4.5 meters of the fiber the peak power is reduced to 46%. So we selected 3.5m long 960ppm fiber for other experiments. A further optimization of course can lead to better laser parameters. However, for proof-of-concept experiments we could get promising results.

Using the 3.5 meters of the 960 ppm ion concentration fiber in the laser cavity, we measured dependence of peak power and pulse duration on the scanning frequency of F-P filter. Results of these measurements are presented in figure 5. The velocity of the F-P wavelength tuning depends on frequency of the electrical signal. At low frequency, less than one kHz, the transmittance spectrum of F-P filter overlaps with the FBG spectrum too slowly. Lasing starts before the filter system achieve the maximum transmittance; this makes the pulses of the system to have less peak power, longer time duration and even to generate more than one pulse per scanning cycle. With increase of the scanning rate, the peak power is getting maximum at the frequency of 1 KHz and then reduces monotonically. At the same time, duration of light pulses is getting minimum value of 500 ns at the frequency of 1.5 KHz and then increases. Such a behaviour we attribute to low power of the pump diode laser. At high frequency, period between pulses becomes shorter than time required for cavity gain getting its maximum. The output coupling ratio in this experiment was 90% of light out. Nevertheless, even with only 60 mW of pump power, the laser parameters such as pulse frequency, maximum peak power and minimum pulse duration are acceptable for some applications in fiber-optic sensors [11] where the length of the sensing fiber is a limiting factor for the pulse repetition rate.

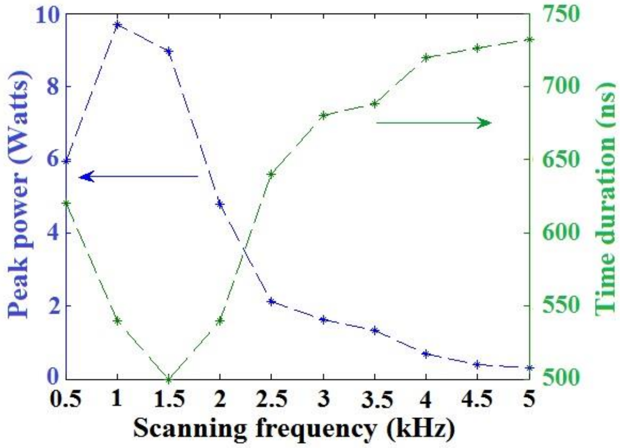

Figure 5. Peak power and time duration of the light pulses as a function of the F-P scanning frequency.

The F-P filter can support even more than 5 kHz of scanning frequency; however in our configuration with low-level pump power the output peak power decrease drastically with the increase of scanning frequency, as shown in figure 5.

The extinction ratio of the output laser is measured to be more than 40 dB. Results are shown in figure 6. These measurements were taken in a CW regime of the laser operation; this is, when the reflectance spectrum of the FBG overlaps with the transmission line of the F-P filter (ON) and then when the F-P transmission line is tuned away of the FBG wavelength and high losses are introduced into the laser cavity (OFF). This high extinction ratio is achieved due to the high isolation in the ring cavity; if the optical isolator is removed from the cavity, the extinction ratio is reduced to 20 dB. The high extinction ratio in the output of the laser is very important for applications in distributed fiber sensors, especially when a long multi-kilometre sensing fiber is required.

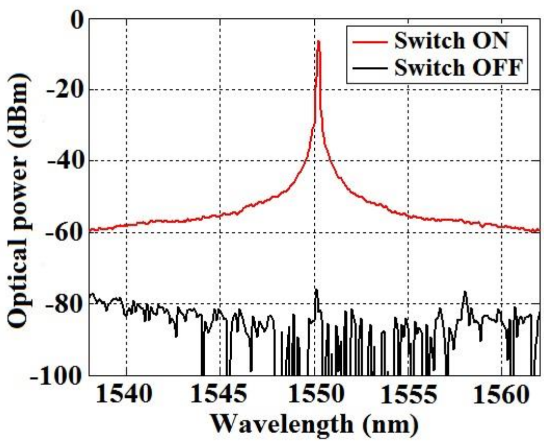

Figure 6. Spectra of output laser light for switch-on and switch-off.

A higher extinction ratio value is expected in a pulsing regime of the laser due to the nature of the Q-switching effect, accumulated energy released in a form of pulse.

The configuration presented here can be modified to emit train of pulses at different wavelengths by using several FBGs, reflecting a different wavelengths. This feature can be of special interest for applications in fiber-optic sensors.

4. Conclusions

We have proposed and experimentally investigated a new simple configuration of an active Q-switched Erbium-doped fiber ring laser based on a tunable Fabry-Perot filter and reflective FBG. The peak power characteristics of the laser has been studied with respect to the length of Erbium doped fiber and the doping concentration, as well as the scanning frequency.

Based on experimental investigation, optimization of the laser configuration was performed to maximize the output peak power of the laser at a low pump power of 60 mW. It was shown, that the peak power and pulse duration are strongly dependent on pulse frequency rate. The laser peak power of 9.7 W was obtained using 3.5 m of Erbium-doped fiber with ion concentration of 960 ppm, at 1 KHz of the pulse repetition rate and 90% of light coupled out. The laser pulse duration of 500 ns at the wavelength of 1550 nm was obtained at the same pulse repetition rate. The simplicity of this Q-switching technique and its principle of operation make it suitable for being extended in more complex set-ups including multi-wavelength fiber laser for sensing applications.

References:

[1] Wang Y and Xu C Q 2007 *Progress in Quantum Electronics* **31** 131-216

[2] Sheu F W and Kang J J 2007 *Optics Communications* **278** 132-137

[3] Huang D W, Liu W F and Yang C C 2000 *IEEE Photon. Technol. Lett.* **12** 1153-55

[4] Kieu K and Mansuripur M 2006 Opt. Lett. **31**, 3568-70

[5] Cuadrado-Laborde C, Delgado-Pinar M, Torres-Peiró S, Díez A and Andrés M V 2007 *Opt. Commun.* **274** 407-411

[6] Cheng X P, Tse C H, Shum P, Wu R F, Tang M, Tan W C and Zhang J 2008 *J. Lightwave Technol.* **26** 945-951

[7] Pérez-Millán P, Díez A, Andrés M V, Zalvidea D and Duchowicz R 2005 *Opt. Express* **13** 5046-51

[8] Chen N K, Feng Z Z and Liaw S K 2010 *Laser physics letters* **7** 363-365

[9] Durán-Sánchez M, Álvarez Tamayo R I, Pottiez O, Ibarra-Escamilla B, Hernández-García J C, Beltran-Perez G and Kuzin E A 2015 *Laser Physics Letters* **12** 025102

[10] González-García A, Ibarra-Escamilla B, Pottiez O, Kuzin E A, Maya-Ordoñez F M and Duran-Sánchez M 2015 *Laser Physics Letters* **25** 045104

[11] Bao X and Chen L 2012 *sensors* **12** 8601-8639