Hi-Bi Sagnac Interferometer Application for Wavelenght Tuning in CW and Actively Q-switched Erbium Fiber Laser

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Abstract: An experimental analysis for the use of a Sagnac interferometer with high birefringence fiber in the loop as generated laser wavelength tuning device in a ring cavity Erbium-doped fiber laser in continuous wave and pulsed actively Q-switched regimes is presented. The maximal tuning range of ~26.72 nm depends on the Sagnac interferometer wavelength spectrum period of ~30.32 nm. The wavelength tuning of the generated laser line is performed by wavelength displacement of Sagnac interferometer spectrum by temperature variations applied on the fiber loop. Experimental results of the laser spectrum in continuous wave and actively Q-switched operations, and Q-switched pulses characteristics are shown.

1 INTRODUCTION

Fiber Optical Sagnac interferometers (FOLM) had been successfully used as optical mirrors on design and implementation of fiber laser cavities. FOLM advantages include simple fabrication and design, low cost and high sensitivity. In particular, the Sagnac interferometer with high birefringence fiber in the loop (Hi-Bi FOLM) has been studied as an element that allows adjustment of the loss within the laser cavity in dual-wavelength fiber lasers using fiber Bragg gratings for wavelength selection (Durán-Sánchez et al., 2010). However, the Hi-Bi FOLM can also be an effective device for selection and tuning of the generated laser wavelength in lasers with single wavelength or multi-wavelength operation. (Huixtlaca et al., 2008); (González et al., 2010).

The Hi-Bi FOLM presents a periodical transmission spectrum that allows the obtaining of a reflected beam spectral selectivity within the cavity related with the birefringence and the length of the fiber loop. The Hi-Bi fiber loop birefringence change by temperature variations applied on the fiber loop causes a wavelength displacement of the Hi-Bi FOLM periodical spectrum. The Hi-Bi FOLM spectrum amplitude adjustment is achieved by adjusting the twist of the Hi-Bi fiber segment with coupler port fiber splices (Kuzin, 1999).

Moreover, the fiber lasers based on the use of erbium doped fiber (EDF) as a gain medium have been extensively studied and characterized in continuous wave (CW) (Ball and Morley, 1992), and pulsed actively Q-switch technique, (Delgado-Pinar et al., 2006); (Cuadrado-Laborde et al., 2010). These previous studies allow the use of the Hi-Bi FOLM for its experimental study as a generated laser wavelength tuning device within a laser cavity with well-known operating characteristics.

Furthermore, actively Q-switched technique application in fiber lasers for short pulses (in nanoseconds range) obtaining, have been studied due to their performance characteristic of higher energetic pulses obtaining with improved stability (Durán-Sánchez et al., 2015). With the onset of acousto-optic modulators (AOM) with fiber

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pigtailed connectors, the overall performance of laser has been improved. Pulsed fiber lasers by the actively Q-switched technique applications include LIDAR systems, medicine, optical fiber sensing, teraheartz generation, among others. Many of these applications require efficient pulsed laser emission with generated laser wavelength tuning over a significantly wide range and simple experimental setup designs. Reported tunable Q-switched fiber lasers generally use fiber Bragg gratings (FBG) for generated laser wavelength selection and tuning (Zhou et al., 2010); (Ahmad et al., 2013); (González-Garcia et al., 2015).

In this paper, an experimental analysis of generated laser wavelength tuning method by using a Hi-Bi FOLM is presented. The proposed method is implemented on a ring cavity Erbium-doped fiber laser operating in CW and actively Q-switched operation. The use of the Hi-Bi FOLM as a device for generated laser wavelength tuning represents a simple, effective, affordable and adaptable method to the requirements of specific wavelength laser emission in a wavelength range for fiber laser applications.

2 EXPERIMENTAL SECTION

2.1 Experimental Setup of Erbium-doped Fiber Laser

Figure 1 shows the experimental setup for the proposed fiber laser with CW and actively Q-switched operation. The ring cavity is based in the use of 3 m of EDF as a gain medium. The EDF is pumped with a 60mW laser diode at 980 nm through a wavelength division multiplexer (WDM).

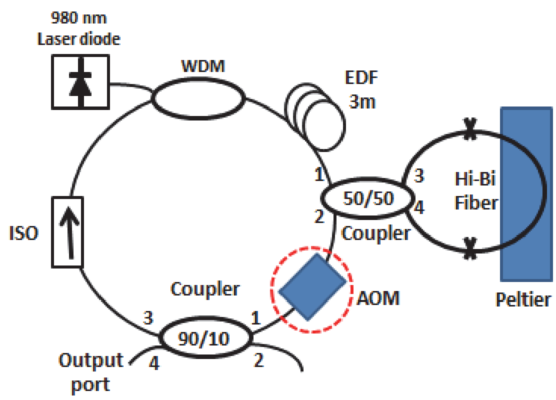

Figure 1: Proposed ring cavity Erbium-doped fiber laser experimental setup.

The Hi-Bi FOLM consist of a 50/50 optical coupler with output ports (ports 3 and 4) interconnected by ~19 cm of high birefringence (Hi-Bi) fiber with birefringence of 4.22×10^{-4}. The Hi-Bi fiber is placed on a Peltier device which applies temperature variations driven by an electronic temperature controller/meter. The cavity is completed by an optical isolator for beam propagating direction establishment within the cavity, an acousto-optic modulator driven by a RF signal generator for actively Q-switching technique application, and a 90/10 optical coupler port 4 is used to measure the laser spectrum by an optical spectrum analyser (OSA), and for pulses measurements by a photodetector and a oscilloscope.

2.2 Hi-Bi FOLM Transmission Spectrum Characterization

The Hi-Bi FOLM acts as a spectral filter with a periodic transmission spectrum. The wavelength period is determined by the Hi-Bi fiber loop length, the signal wavelength and the Hi-Bi fiber birefringence (Álvarez-Tamayo et al., 2010). With a Hi-Bi fiber length of 19 cm, the calculated wavelength period for the Hi-Bi FOLM transmission spectrum is ~30 nm.

The splices between coupler output ports and Hi-Bi fiber are placed in rotation stages for Hi-Bi FOLM transmission spectrum amplitude adjustment (Kuzin, 1999). The reflection maxima depends on Hi-Bi fiber birefringence axes orientation (Durán-Sánchez et al., 2010). With the proper rotation adjustment on the Hi-Bi fiber with the FOLM output ports splices, the maximum transmission of the Hi-Bi is achieved.

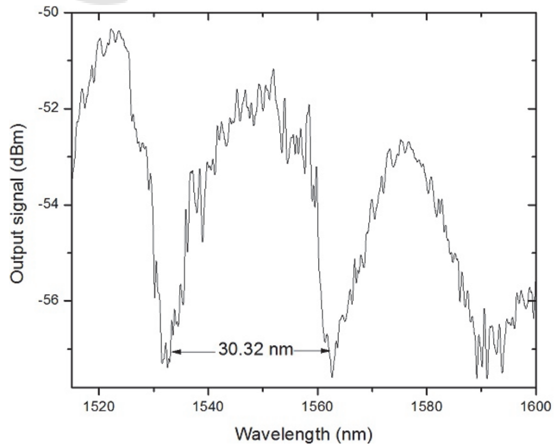

Figure 2: Hi-Bi FOLM measured transmission spectrum.

Figure 2 shows the measured Hi-Bi FOLM transmission spectrum in the proposed experimental setup. Measurements were performed with the cavity opened between the 50/50 coupler and the AOM connection with low pump power (around 30mW) at the 50/50 unconnected coupler port (coupler port 2) with an OSA. As it can be observed, the measured Hi-Bi FOLM transmission spectrum exhibits a periodical function with a wavelength period of ~30.32 nm.

The Hi-Bi FOLM transmission spectrum exhibits wavelength period differences (observable between each period), attributed to the amplified spontaneous emission (ASE) of the EDF amplification used as input signal.

3 RESULTS AND DISCUSSION

3.1 CW Fiber Laser Operation on Wavelength Tuning

Spectrum measurements of the generated CW laser tuned wavelengths by Hi-Bi FOLM fiber loop temperature variations is presented in Figure 3. The experimental results were measured with a pump power of 60mW at the 90/10 coupler port 4 (output port) with an OSA. For the CW laser operation, the AOM was removed from the experimental setup shown in Figure 1 by closing the ring cavity between the 50/50 coupler port 2 with the 90/10 coupler port 1. As it is shown, the generated laser line is tuned in a wide wavelength range of ~26.72 nm, from 1551.58 nm with Hi-Bi fiber loop temperature of 29.5°C to 1578.3 nm at 11.94°C. The Hi-Bi FOLM wavelength spectrum period corresponding to the longer wavelength limit for Erbium amplification spectrum has preference to generate laser emission.

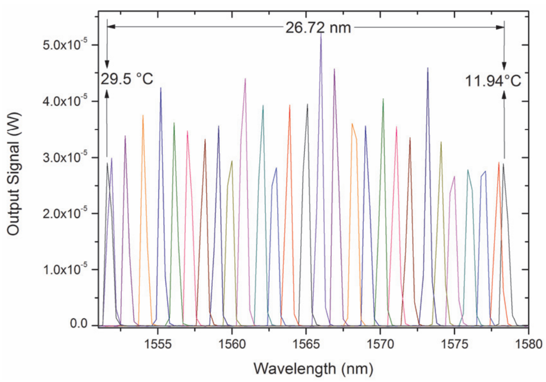

Figure 3: Measured CW laser line wavelength spectra tuned by Hi-Bi FOLM fiber loop temperature variations.

As it is observed, the generated laser line exhibits amplitude variations depending on the tuned wavelength. This instability is significantly attenuated by increasing the pump power.

The laser wavelength tuning on the Hi-Bi FOLM fiber loop temperature variations can be linear fitted with a slope of approximately -1.47 nm/1°C.

Figure 4 shows the generated laser lines in both wavelength tuning limits (1551.58 and 1578.30 nm). As can be observed, in the wavelength tuning limits a simultaneously generated laser lines occurs at wavelength separation of ~30.32 nm, corresponding to the Hi-Bi FOLM transmission spectrum period. At the tuning limit, another Hi-Bi FOLM transmission period is competing for the laser wavelength generation.

The use of FBGs for generated laser wavelength tuning is based in the mechanical strain application resulting in the grating physical deformation. This method usually allows the laser line tuning in a narrow wavelength range (less than 10nm) due to the possibility of irreversible damage of the FBG. Moreover, the proposed laser wavelength tuning method is performed by optical means. Since it is not a tuning method by mechanical deformation, wide tuning wavelength range only depends on the EDF amplification spectrum wavelength range and the Hi-Bi FOLM spectrum wavelength period.

Therefore, the maximal laser wavelength tuning range depends on the Hi-Bi FOLM transmission spectrum period and is reduced (to 26.72 nm) by the dual-wavelength laser operation generated in the limits, which is produced where competition for lasing of two different periods occurs.

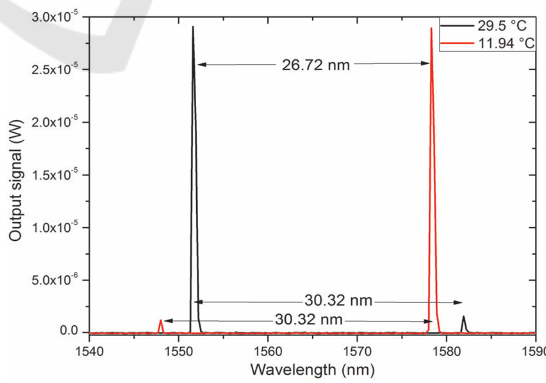

Figure 4: Generated CW laser lines at both wavelength tuning limits.

3.2 Tunable Actively Q-switched Fiber Laser Operation

With the experimental characterization of wavelength tuning by temperature variations of Hi-Bi FOLM fiber loop obtained in CW laser operation, laser performance with generated wavelength tuning in pulsed regime by the actively Q-switched technique is obtained.

Similar results of laser output spectrum measurements for CW regime (Figure 3) were obtained in actively Q-switched laser operation for the experimental setup shown in Figure 1. Experimental results presented in terms of generated laser wavelength tuning on Hi-Bi FOLM fiber loop temperature variations are shown in Figure 5.

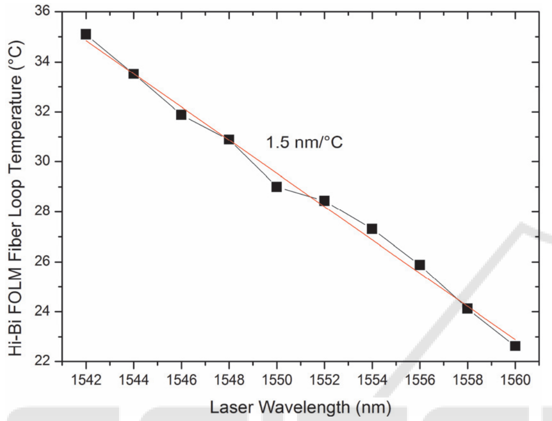

Figure 5: Actively Q-switched laser line wavelength tuning on Hi-Bi FOLM fiber loop temperature variations.

A group of ten measurements of laser line wavelength tunings are shown in a wavelength range from 1542 to 1560 nm corresponding to Hi-Bi fiber loop temperature variations from 22.62 to 35.12°C. As it is shown, the obtained laser lines are generated in a different wavelength range in comparison with the laser lines obtained in CW. With the AOM including within the cavity, the cavity losses are adjusted modifying the Hi-Bi FOLM transmission spectrum amplitude for each wavelength period. As a result, the generated laser emission is shifted to another preferred Hi-Bi FOLM spectrum period in a different wavelength range.

The Q-switched laser wavelength on Hi-Bi FOLM fiber loop temperature variations can be linear fitted with a slope of 1.5 nm/1°C. Therefore, no significant variation in wavelength tuning on loop temperature slope between CW and Q-switched laser operations is observed.

Figure 6 shows the pulse profiles for Q-switched fiber laser operating for different repetition rates. Measurements were performed at output port with a photodetector and monitored in an oscilloscope. The repetition rate was varied from 20 to 45 kHz where Q-switched pulses are observed. The pulses were obtained with a generated laser wavelength at 1560 nm with 22.6°C of Hi-Bi fiber loop (room temperature). The results shown typical actively Q-switched pulses behaviour, with the increase of the repetition rate the pulse increases the build-up delay time and pulse widens as pulse amplitude decrease.

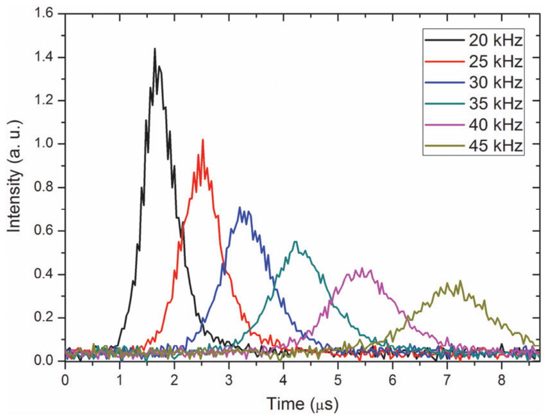

Figure 6: Actively Q-switched pulses profile on repetition rate variations for generated laser wavelength at room temperature.

Pulse duration and pulse energy for different repetition rates are presented in Figure 7. Measurements were performed with the same actively Q-switched laser operation characteristics shown in Figure 6.

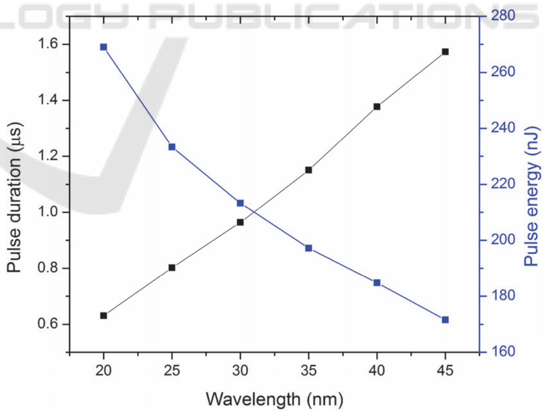

Figure 7: Pulse duration and pulse energy on repetition rate variation for generated actively Q-switched laser wavelength at room temperature.

The estimated pulse energy and the measured pulse duration are presented in a repetition rate from 20 to 45 kHz. The maximal pulse duration of 1.57 μs is obtained at the maximal repetition rate of 45 kHz where the pulse maximal widening is observed. The maximal pulse energy of 269 nJ is obtained with the minimal repetition rate of 20 kHz. With the repetition rate increase, pulse duration increase and pulse energy decrease, as it is observed. The obtained results show a typical performance of actively Q-switched pulses generation.

Figure 8 shows the measured pulse durations on repetition rate variations for actively Q-switched pulses obtained in different generated laser wavelength tunings. Measurements were performed in a repetition rate from 20 to 50 kHz. A group of ten pulse durations was obtained for laser wavelengths tuned from 1542 to 1560 nm each 2 nm. Pulse duration increase with the repetition rate increasing is observed. As it is shown, the pulse widens increase for longer laser generated wavelength tuned. As a result, the maximal pulse duration of 1.67 µs is obtained at maximal repetition rate of 50 kHz for the laser emission tuned to 1560 nm. The maximal pulse duration obtained with a repetition rate of 50 kHz varies with the laser wavelength tuned in a range from 1.31 to 1.67 µs, however, for the minimal repetition rate of 20 kHz, the pulse duration varies in a narrower range from 482 to 648 ns. Although an increase of pulse duration with longer laser wavelength tuned is observed, the behaviour tendency in not clearly defined.

Estimated pulse energy in function of repetition rate variations for different laser wavelengths tuned on actively Q-switched laser operation is shown in Figure 9. The pulse energy was estimated for the same pulse measurements obtained in Figure 8. The results show a pulse energy decrease with the increase of the repetition rate, a typical actively Q-switched pulses performance.

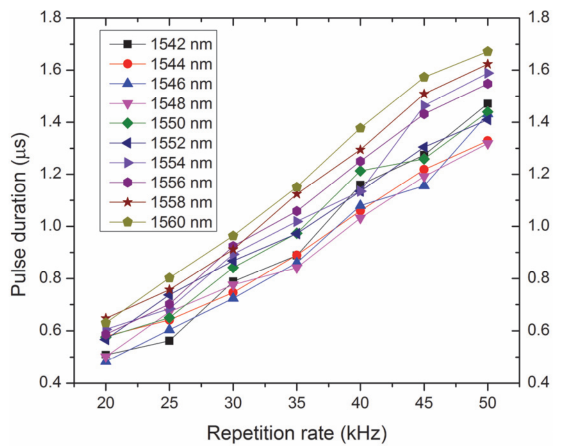

Figure 8: Pulse duration on repetition rate variations of different wavelength tunings for actively Q-switched laser operation.

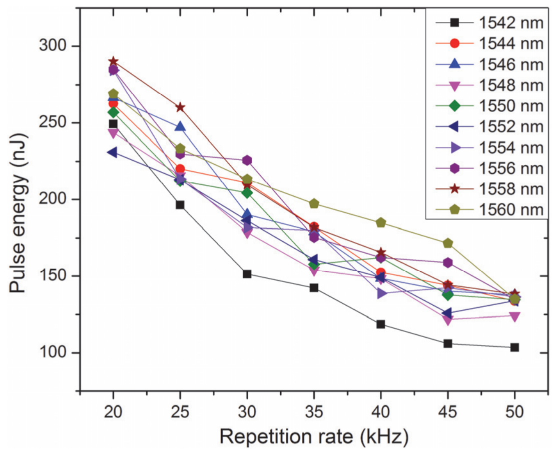

Figure 9: Pulse energy on repetition rate variations of different wavelength tunings for actively Q-switched laser operation.

The maximal pulse energy of 290 nJ is obtained with the minimal repetition rate in which stable Q-switched pulses are observed of 20 kHz and with the generated laser wavelength emission at 1558 nm. The maximal pulse energy (with repetition rate of 20 kHz) on different laser wavelength tunings varies in a range from 231 to 290 nJ. In agreement with the results obtained for pulse duration shown in Figure 8, a tendency of increase in pulse energy is also observed for longer tuned wavelengths; however, the increase is not clearly noticed between each wavelength tuning. The actively Q-switched laser performance of increasing of pulse duration and pulse energy with longer wavelengths tuned is not consistent at each variation of the repetition rate; however, it is noticed as a global tendency observed from figures 8 and 9 experimental and estimated results.

4 CONCLUSIONS

In this manuscript, it is experimentally demonstrated the use of a Hi-Bi FOLM as reliable, effective and simple device to achieve a method for generated laser wavelength tuning for ring cavity fiber laser experimental setups. The results were obtained for laser CW regime and for pulsed regime by the active Q-switched technique.

The tuning range of the laser wavelength depends on the Hi-Bi FOLM wavelength transmission period. With the proposed Hi-Bi FOLM, the tuning range is 26.72 nm in which single wavelength emission is generated. In the tuning limits, incipient dual-wavelength laser generation is observed with separation between generated laser lines corresponding to the Hi-Bi FOLM period of 30.32 nm.

The preferred wavelength transmission period of the Hi-Bi FOLM transmission spectrum in which the laser wavelength is generated depends on the losses inside the laser cavity, which, together with the EDF amplification spectrum modify the Hi-Bi FOLM transmission spectrum to generate ideal conditions where laser wavelength is emitted. This wavelength is tuned by displacement of the Hi-Bi FOLM transmission spectrum through temperature changes application on the FOLM Hi-Bi fiber loop.

Laser wavelength tuning on Hi-Bi FOLM fiber loop temperature variations slope of -1.47 nm/1ºC in CW operation and -1.5 nm/1ºC in active Q-switched operation is observed. For pulsed operation by the active Q-switched technique, changes are observed in the pulse characteristics depending on the generated laser wavelength. Pulse duration and pulse energy increase when the laser emission is obtained at longer tuned wavelengths.

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REFERENCES

Huixtlaca, I., Beltrán, G., Castillo, J,. Muñoz, S., 2008. *IEEE Journal of Quantum Electronics, 44*, 49-55.

González, A., Pottiez, O., Grajales, R., Ibarra, B., Kuzin, E. A., 2010. *Laser Physics, 20*, 720-725.

Durán-Sánchez, M., Flores-Rosas, A., Álvarez-Tamayo, R. I., Kuzin, E. A., Pottiez, O., Bello-Jimenez M., Ibarra-Escamilla B., 2010. *Laser Physics, 20* (5), 1270-1273.

Kuzin, E.A., Cerecedo-Nuñez, H., Korneev, N., 1999. *Optic Communications, 160*, 37-41.

Ball, G. A., Morley, W. W., 1992. *Optics Letters, 17* (6), 420-422.

Delgado-Pinar, M., Zalvidea, D., Diez, A., Perez-Millán, P., Andrés, M. V., 2006. *Optics Express, 14* (3), 1106-1112.

Cuadrado-Laborde, C., Diez, A., Cruz, J. L., Andrés, M. V., 2010. *Laser Phyics Letters, 7* (12), 870-875.

Durán-Sánchez, M., Álvarez-Tamayo, R. I., Pottiez, O., Ibarra-Escamilla B., Hernández-García, J. C., Beltrán-Pérez, G., Kuzin, E. A., 2015. *Laser Physics Letters, 12* (2), 025102 (6pp).

Zhou, D-P., Wei, L., Dong, B., Liu, W-K., 2010. *IEEE Photon. Technol. Letters, 22* (1), 9-11.

Ahmad, H., Zulkifli, M. Z., Muhammad, F. D., Zulkifli, A. Z., Harun, S. W., 2013. *Journal of Modern Optics, 60* (3), 202-212.

González-García, A., Ibarra-Escamilla, B., Pottiez, O., Kuzin, E. A., Maya-Ordoñez F. M., Durán-Sánchez, M., 2015. *Laser Physics, 25* (4), 045104 (5pp).

Álvarez-Tamayo, R. I., Durán-Sánchez, M., Pottiez, O., Kuzin, E. A., Ibarra-Escamilla B., Flores-Rosas, A., 2010. *Applied Optics, 50* (3), 253-260.