Multiwavelength and Switchable Erbium-Doped Fiber Lasers

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ABSTRACT:

In this work, an experimental stability comparison between two different switchable Erbium-doped fiber lasers (EDFL) is carried out. Both topologies use fiber Bragg grating reflectors in order to select the emission wavelengths and two 2x4 optical switches. By adjusting the switches combinations, the lasers can be switched among the sixteen different wavelength lasing configurations. An output power instability analysis with time for both topologies was performed. The experimental results confirm that the topology based on a serial configuration offers a better stability and higher optical signal to noise ratios (OSNR) than the one based on a parallel configuration.

Key words: Erbium lasers, fiber Bragg gratings, fiber lasers, ring lasers, switchable laser.

1.- Introduction

Multiwavelength erbium doped fiber lasers (MEDFL) have attracted attention due to their potential applications in both sensing and telecommunication fields (wavelength-division multiplexing, fiber-optic sensors, optical spectroscopy, etc) [1].

An important aspect to take into account of the MEDFL is their output power instability and mode competition [2]. These instabilities can degrade the performance characteristics of a sensor array based on a tunable ring laser interrogation scheme. The design parameters optimization of these lasers, such as erbium doped fiber (EDF) length and the coupling ratio can reduce these undesirable effects [3]. Moreover, in this work the authors experimentally demonstrate that an appropriate election of a ring laser configuration can improve considerably the characteristics of these lasers.

In particular, a comparison between two different MEDFL topologies is carried out. The first topology is based on the parallel connection of the FBGs using optical circulators and the second one consists on a serial configuration. Experimental results of time stability of the two MEDFL are also presented and analyzed. Both studied structures show a good temporal stability for four wavelengths. As is reported in literature ring lasers with more than 2 [4] or 3 [5] wavelengths are instable. Our structures show also good time stability for even 4 wavelengths without cooling the EDF to 77 K with liquid nitrogen as mentioned in [6].

2.- Experimental set-up

In this work, two different Erbium-doped fiber ring laser (EDFRLs) configurations are experimentally studied and compared. The experimental setups of the proposed EDFRLs are shown in Fig. 1(a) and (b), for a parallel and serial topology respectively.

The first set up comprises a C-band EDFA module, two 2x4 optical switches, a 1x4 and a 4x2 optical couplers. The gain of the amplifier for the wavelength band of utilization (i.e. 1540nm) for a single-wavelength state was about 11.5dB and 13.5dB for an input power of 55mw and 90mW respectively.

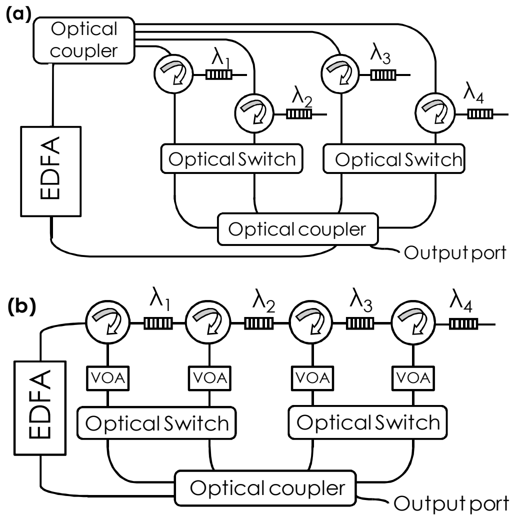

Fig. 1: (a) Experimental set-up for the MEDF ring laser parallel (a) and serial (b) topology

Several previous studies show that, in order to simplify these kind of setups, polarization maintaining (PM) components can be eliminated because of not having significant impact on the output power stability [3], [8]. Also, the polarization dependent loss value of these optical switches is so low (about 0.02dB) that inserting PM components was not necessary.

We used two compact lightwave electromechanical switches model 86060C from Agilent Technologies. Two input switch diagram is shown in Fig. 2. In these switches, the two input arms move together to connect either input channel to an output channel.

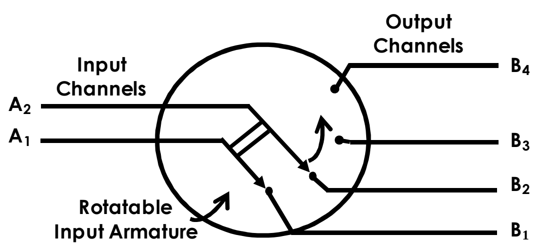

Fig. 2: Two input switch diagram

This enables that the ring cavity laser can be made to operate in all possible single-, dual-, three- and four-wavelength states by appropriately adjusting the switches' combinations, and using just two of the four output ports. These devices, when using as single-mode switches, have a typical insertion losses of 0.7±0.025 dB and an optical return loss of 62 dB. In addition to this, due to the high isolation they show (-100dB), isolators were not necessary in order to avoid the spatial hole-burning effect.

The 1x4 optical coupler was used to incorporate four FBGs into the laser cavity, creating a star or parallel topology. Optical power inside the ring is thus divided into four branches of approximately equal power. It also allows the simultaneous lasing of the four wavelengths selected by the FBGs. The 4x2 coupler is used for collecting the four arms signals and for extracting part of the optical output laser from the ring to the output port. Each one of these braches incorporates a FBG for selection of the lasing wavelengths. An optical circulator is used in each branch to insert the FBGs reflected signals into the ring. In this configuration four circulators were used to direct the signal inside the ring, ensuring unidirectional operation and therefore avoiding the spatial hole-burning effect. Because of this, and also due to the high isolation level of the optical switches, inserting isolators was not necessary. The operation wavelengths of the FBGs have been located in the flat region of the erbium gain profile in order to ease the power equalization of the channels. In this test, gratings of 1531, 1532.5, 1534, and 1535.5 nm have been used, each one showing about 0.3nm at -3dB bandwidth and about 97% of reflectivity. All the free terminations of the system have been immersed in refractive-index-matching gel to avoid undesired reflections.

By using this structure we can select the emission wavelength of the laser, obtaining, when the number of wavelengths are less than four, better output power levels, OSNRs and stability in comparison with a non-switchable multiwavelength laser. In these ring lasers, one of the major problems is correctly adjusting the cavity losses on each wavelength in order to achieve oscillation of the system in all the desired channels. The oscillation threshold power for each wavelength is different due to the nonflat shape of the erbium fiber gain profile; as a consequence, individual loss control for each wavelength is required in order to ease the power equalization.The second fiber laser experimentally analyzed is a serial configuration where optical circulators are used to redirect the FBGs reflected signals to the different inputs of the switches (Fig. 1(b)). As in the previous configuration, the utilization of circulators ensures the unidirectional operation.

The reflected wavelengths at the FBGs are directed to the corresponding input branch of the switches using a specific circulator for each FBG. This configuration gives a parallel output from the serial array of gratings, which allows using the switches to obtain a switchable laser. Another advantage of this new topology in comparison with the typical in-line filtering topology, where the FBG and VOA of each channel are placed consecutively, is the ease of the individual control of each channel because we can place the VOAs before the different inputs of the switches. Thus we have individual control of the attenuation of the power of each lasing wavelength without affecting directly the other ones. After the switches, a 2x4 coupler is used again for collecting the four outputs from the switches and for extracting part of the optical output laser from the ring to the output port. In order to check the improvement of the OSNR and the output power level of this structure, the results for several lasing combinations of the four wavelengths selected by the FBGs were studied and analyzed.

An output power instability study at room temperature and an optical signal-to-noise (OSNR) comparison of these configurations (single-, dual-, three- or four-wavelength lasing operation) was carried out. The spectral characteristics of the lasers were measured using an optical spectrum analyzer (OSA) at the output port with 0.1 nm resolution.

3.- Results

By using the set up shown in Fig 1(a), the laser can be switched among the four different lasing wavelengths, lasing one, two, three or four wavelengths simultaneously. By reducing the number of lasing wavelengths we also increase the output power and stability values of the remaining ones, because we reduce the gain competition among the different wavelengths. The pump power used was 90 mW at 980 nm in this case.

As can be seen in Fig 3(a), a single-wavelength laser with an output power of around -13 dBm and OSNRs (measurement of the ratio of signal power to noise power in an optical channel) of about 62 dB can be obtained. This figure shows only one of the four possible lasing wavelengths that can be generated by doing that, all of them showing the same characteristics. Fig. 3(b) corresponds to a three-wavelength switch operation, also showing one of the four possible lasing wavelengths combinations. The power obtained from each of the output channels was around –19 dBm and the three lasing wavelengths showed OSNRs about 58 dB.

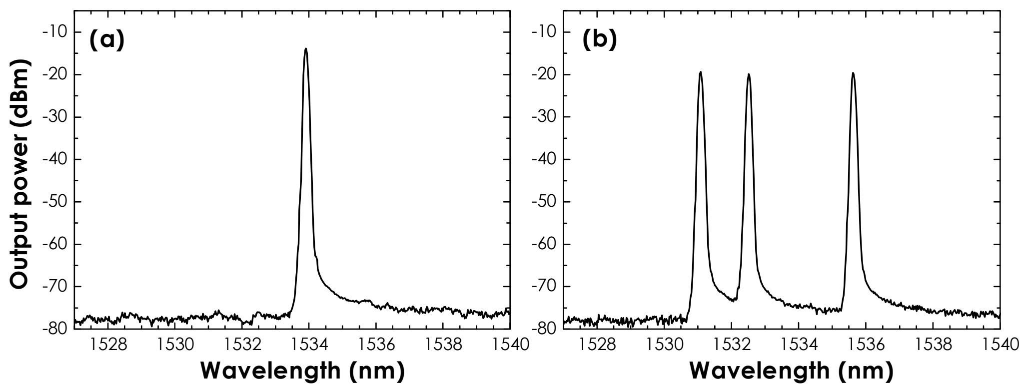

Fig. 3: Output spectrum of the MEDFRL with (a) single-wavelength and (b) three-wavelength lasing configuration by using the parallel topology

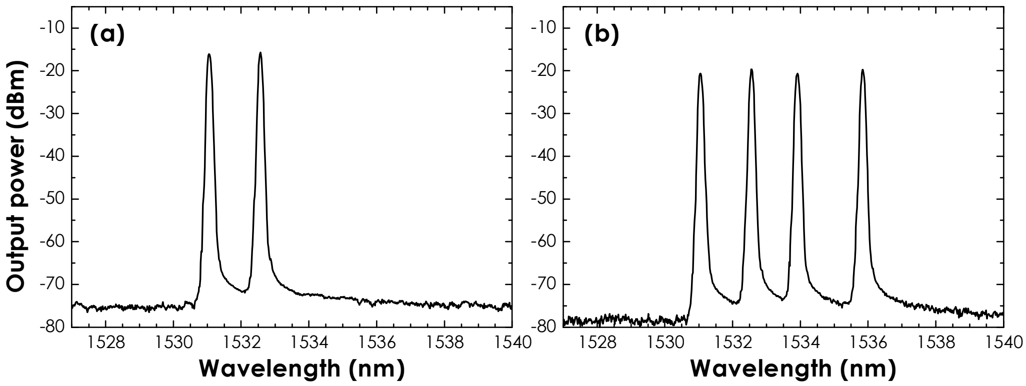

Fig. 4: Output spectrum of the MEDFRL with (a) dual-wavelength and (b) four-wavelength lasing configuration by using the serial topology.

By using the set up shown in Fig 1(b), the laser can be also switched between the four different lasing wavelengths, some of these possible combinations can be observed from Fig 4(a) and (b). These figures show only two possible lasing wavelength permutations that can be generated by appropriately adjusting the switches' combinations. In this case, we obtained a pump power improvement (reduction) in comparison with the previous laser of Fig. 1(a).

The optical efficiency (output power divided by launched pump power) achieved with the serial topology is about 48% better than that with the parallel topology. The reason is that pump power needed for the first studied topology is almost twice as the second one (90mW, compared with 55mW for the serial topology). This is due to the serial topology that reflects the four amplified wavelengths in each recirculation along the optical path. However, parallel topology losses in each branch the optical power of the three remaining amplified wavelengths that not fit with the corresponding FBG reflecting band.

In this case, output power levels of around -12 dBm, -16 dBm, -19 dBm and -20 dBm were obtained for a single-, dual-, three- and four-wavelength lasing configurations respectively. Nonuniformity of the channel-to-channel output power is smaller than 0.8dB when the four-wavelength lasing configuration is used. Regarding to the OSNR, the obtained values for these lasing configurations were about 62 dB, 59 dB, 58 dB and 57 dB also in that order.

The output power and the wavelength of the lasers can suffer some changes with time. Because of that the output power and the signal wavelength stabilities are both experimentally measured on both fiber laser topologies. In this work, the instability is defined as the output power and wavelength variations (measured in dB and nm) for a given interval of time and a specific confidence level (CL), that is the probability value associated with a confidence interval, given as a percentage [7]. In these experiments a confidence level of 99% was used. Each configuration was tested 50 times during 500 seconds. The measured data were recorded once each ten seconds. This can be observed in Fig 5(a), where the output spectrum for a dual-wavelength laser in a parallel topology was analyzed every ten seconds.

The signal wavelength instability was also measured for this dual-wavelength laser in a parallel topology. Just as it was expected bearing in mind previous results in non-switchable lasers [3], these values were lower than 0.03nm when a pump power of 90mW was used in a topology like this.

This process was repeated for all the possible wavelength lasing combinations. For this first configuration based on a parallel topology, Table 1 shows some of the output power instability results for several lasing combinations for one, two, three or four FBGs of the single-, dual-, three- or four-wavelength lasers respectively, when time increases.

Pout Instability (dB)	λ_{FBG}=1531nm	λ_{FBG}=1532.5 nm	λ_{FBG}=1534 nm	λ_{FBG}=1535.5 nm
one FBG	0.35 dB			
two FBGs	0.85 dB	0.61 dB		
three FBGs	1.16 dB	1.18 dB	1.18 dB	
four FBGs	2.02 dB	1.82 dB	2.62 dB	2.56 dB

Table 1. Output power stability for the single- (one FBF), dual- (two FBGs), three- (three FBGs) and four-wavelength (four FBG) lasers using a parallel topology.

Pout Instability (dB)	λ_{FBG}=1531nm	λ_{FBG}=1532.5 nm	λ_{FBG}=1534 nm	λ_{FBG}=1535.5 nm
one FBG	0.03 dB			
two FBGs	0.26 dB	0.31 dB		
three FBGs	0.55 dB	1.01 dB	0.72 dB	
four FBGs	1.06 dB	1.58 dB	1.36 dB	1.63 dB

Table 2. Output power stability for the single- (one FBF), dual- (two FBGs), three- (three FBGs) and four-wavelength (four FBG) lasers using a serial topology.

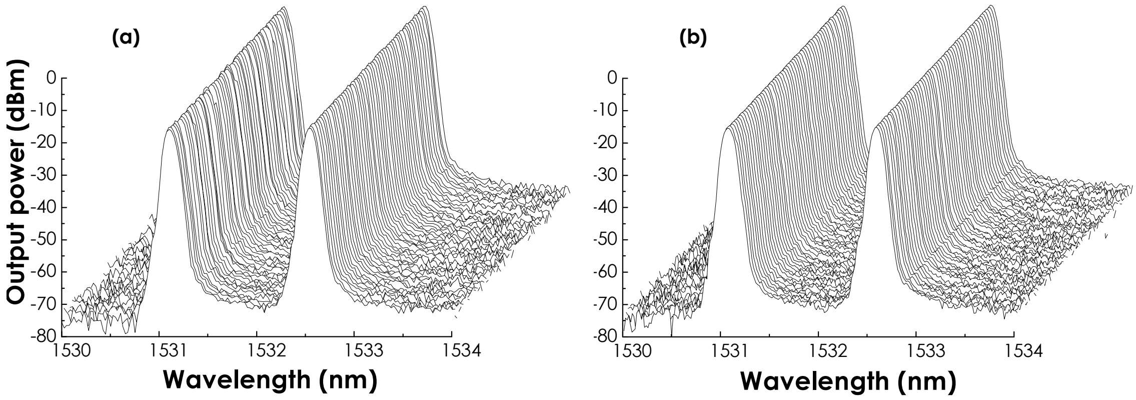

Fig. 5: Fiber laser output spectrum for a dual-wavelength laser in a parallel (a) and serial (b) topology scanned every 5s (50 times repeated scans)

An example of the experimental results of the output power instability of EDFRLs based on a serial topology is shown in Fig. 5 (b). As can be shown in this figure the power instability is reduced considerably with this new laser configuration. The pump power used was also reduced to 55 mW.

Once again this process was carried out for the same wavelength lasing combinations than before. For this second configuration based on a serial topology, Table 2 shows the output power instability for one, two, three or four FBGs of the single-, dual-, three- or four-wavelength lasers respectively, when time increases. For a second time the signal wavelength instability was also measured for this dual-wavelength laser in a serial topology. For this configuration, the wavelength instability values decreased, moreover the wavelength instability is reduced almost half as the parallel topology. If a comparison between these two tables is carried out, we can conclude that the power instability results using the serial topology are much better than the obtained by means of the parallel one. For instance, when a single-wavelength output power laser variations are contrasted, the results improved to be more than 10 times better using the serial configuration than the parallel one.

If a comparison between these results is carried out we can conclude that the structure based on a serial topology is better in terms of output power stability than the first one besides less pump power is needed to get the same output power levels than the parallel one, but, just as it was expected, when the number of laser wavelengths increases, the output power instability increases as well.

4.- Conclusion

An experimental stability comparison between two different four-wavelength switchable lasers has been demonstrated. By appropriately adjusting the possible combinations of two 2x4 optical switches, the ring cavity laser can be made to operate in the single-, dual-, three- or four-wavelength states. We have characterized their power stability and OSNR. Both topologies use fiber Bragg grating reflectors in order to select the emission wavelengths. In this work the authors experimentally demonstrate that an appropriate election of a ring laser configuration can improve considerably the characteristics of these lasers, although they were implemented with the same components, showing better stability performance or even less pump power needed in one or another case. From the experimental results, it is found that the EDFRL based on a serial configuration of FBGs using circulators presents a better output power stability than the EDFRL based on a parallel configuration. Another important aspect of this new configuration is that the improved output power stability is obtained with less pump power.

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