Chapter 16

Experimental Study of Fiber Laser Cavity Losses to Generate a Dual-Wavelength Laser Using a Sagnac Loop Mirror Based on High Birefringence Fiber

Manuel Durán-Sánchez, R. Iván Álvarez-Tamayo,
Evgeny A. Kuzin, Baldemar Ibarra-Escamilla,
Andrés González-García and Olivier Pottiez

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1. Introduction

Dual wavelength fiber lasers (DWFL) research has increased considerably in recent years due to the potential applications of these optical devices in diverse investigation areas. Interest of use of DWFL includes areas such as fiber sensors, wavelength division multiplexing, optical communications systems, optical instrumentation and recently in microwaves generation [1-4], among others.

DWFL are considered profitable optical sources because of their advantages such as low cost, easy and affordable optical structures, low losses insertion and space optimization. Principal issue to generate two simultaneous laser lines resides in the cavity losses adjustment. In DWFL designed with Erbium-doped fiber (EDF) as a gain medium there is a strong competition between the generated laser lines due to the EDF's homogeneous gain medium behavior at room temperature. To reduce the competition between the wavelengths, several techniques have been reported aiming to achieve stable multi-wavelength laser oscillations [5-8].

Moreover, fiber Bragg gratings (FBG) have been extensively used in DWFL cavities design due to their advantages as optical devices including easy manufacture, fiber compatibility, low cost and wavelength selection among others. FBG's wavelength selection property is commonly used as a narrow band reflector inside the laser cavity to generate a laser line at a specific wavelength. Several DWFL experimental setups using FBG's have been reported including use of a FBG written in a high birefringence or in a multimode fiber [6-11].

In a large majority of DWFL using EDF and FBG's, the laser cavity losses correspond to different generated laser lines at a specific wavelength position over the gain medium spectrum. The generated wavelength should be balanced to achieve two simultaneous laser lines. Consequently, both oscillation lines have the same pump threshold. Commonly the wavelengths adjustment is realized through arbitrary methods as use of polarization controllers (PC) and variable optical attenuators (VOA) [7, 12, 13]. With the progress on DWFL research studies have been followed two different pathways in order to enhance stability of the simultaneously generated laser lines by improving the cavity losses adjustment methods.

On the one hand, the research focuses on incorporating of cutting-edge devices in an effort to obtain more stable and efficient dual laser emissions. In such a way that these researching works reports the use of newly developed optical fibers such as photonic crystal fibers, leading to use optical devices that allow the exploit of nonlinear optics [14-16]. Most of the reported works on this area tend to have more complex designs and non-straightforward settings. By the other hand, a second pathway is in function of simplicity and optimization of laser cavity length, taking into account that a reduced cavity length implies a decrease of laser modes within the cavity, allowing, in a first instance analysis, a dual laser emission with lower instability, a simple adjustment of the competition between laser lines with a substantial reduction of implementation space that can improve the results repeatability [17, 18].

In recent years, obtaining of dual-wavelength laser emission does not represent an advance by itself in DWFL progress because the increasing need to analyze the behavior of the competition between the generated laser lines obtained by the cavity losses adjustment methods. Using arbitrary methods like adjustment by polarization controllers and variable optical attenuators do not allow a behavioral analysis of the competition between generated wavelengths because these methods do not have a measurable physical variable to characterize the adjustment and difficultly can provide repeatability in results.

The spectral selectivity of the interferometer is caused by birefringence that has to be introduced to the loop. A lot of effort has been made to suggest and investigate a variety of FOLM designs. Ma et al. [20] demonstrated polarization independence of the Hi-Bi FOLM. Liu et al. [21] reported a study of an optical filter consisting of two concatenated Hi-Bi FOLMs. Lim et al. [22] analyzed the behavior of an FOLM with a fiber loop consisting of two Hi-Bi fibers connected in series. The transmittance spectrum of the FOLM presents a periodic behavior with maxima and minima depending on the Hi-Bi fiber length and birefringence. For dual-wavelength lasers, low contrast offers the advantage of smoother cavity loss adjustment for the generated wavelengths where the principal mechanism of the adjustment of the cavity loss is the shift of the wavelength of the reflection maxima of the FOLM. The wavelength shift is achieved by the change of the temperature of the Hi-Bi fiber. This method allows generating two wavelengths with a well-controlled ratio between their powers [19].

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Moreover, the tuning of the laser generated wavelengths promises to be an advantage for DWFL microwave generation application making it possible through the tuning of separation between wavelengths. A simple method of wavelength tuning is related to the Bragg period modification of a FBG. Wavelength tunable DWFL were reported [16-19]. In most configurations the FBG's are used with Bragg wavelength shift by temperature change [23], compression or stretch [18, 24]. Most of the techniques reported before as a matter of fact realize an adjustment of the losses between the two wavelengths to achieve stable dual-wavelength generation. In spite of the numerous papers reporting dual-wavelength generation, to the best of our knowledge no investigations were reported on the relation between the losses for generated wavelengths that enables simultaneous dual-wavelength generation.

M. A. Mirza [25] in 2008 presented the theoretical and experimental analysis of the design of a Sagnac loop filter (SLF) with periodic output spectrum controlled by cascading a small birefringence loop (SBL) with a high birefringence loop (HBL) with a tuning of the amplitude and wavelength of the spectrum of the filter through mechanical rotation. In this work is mentioned that the proposed design may have potential application in the design of Erbium-doped fiber lasers for multiple wavelengths generation in the C band and also can be used as a tuning tool for competition between the generated laser lines.

H. B. Sun [26] published in 2010 a DWFL with wide tuning based on a Hi-Bi FOLM and the use of polarization controllers inside the loop for adjustment of the loss within the ring cavity proposed. The laser wavelength can be tuned flexibly within the range of 1525 nm to 1575 nm by adjusting the polarization controller. The separation between the two generated wavelengths is adjustable by changing the length of the Hi-Bi fiber of the FOLM loop. Also proves the modes stability of the two laser lines at room temperature with a variation of the peak output power of about 0.5 dB over 40 minutes of operation.

K. J. Zhou [27] in 2012 reported the use of an all-PM Sagnac loop periodic filter as a frequency selector in a Erbium-doped fiber ring laser. The laser with a 1 nm interval filter generates four simultaneous and stable wavelengths with equal frequency spacing to overcome the homogeneous broadening of Erbium-doped fiber as a gain medium at room temperature. Polarizer controllers are used inside the ring cavity to adjust the laser lines emissions. The experiment confirm that this kind of filter should be robust to environmental changes.

This chapter proposes the application of a Sagnac fiber optical loop mirror with a high-birefringence fiber on the loop (Hi-Bi FOLM) used as a spectral filter to adjust finely the laser cavity losses, reducing the competition between generated laser wavelengths by temperature variations on the FOLM fiber loop. This control allows characterizing the competition behavior with temperature variations to achieve a better adjustment to obtain dual-wavelength laser emission. The appropriate choice of the angles of both ends of the Hi-Bi fiber allows a reflection minimum between 0 and 0.9 without substantial wavelength shift. The reflection maximum is always equal to 1 [19].

In this chapter the application of an all-fiber Hi-Bi FOLM to balance the losses within a dual-wavelength fiber laser is presented. An analysis of the losses is performed by charactering the FBG's reflections over the transmission spectrum of the FOLM when the laser wavelengths are generated, allowing the study of the fine adjustment of the FOLM transmission spectrum wavelength shift by temperature variation in the Hi-Bi fiber loop of the FOLM necessary to achieve dual-wavelength laser emission.

2. Numerical analysis of Sagnac Hi-Bi FOLM for dual-wavelength laser application

Numerically analysis for variation of the transmission spectrum of a Hi-Bi FOLM with the twist of the fiber in the loop can be an important tool for dual-wavelength fiber lasers design. The Hi-Bi FOLM shown in Figure 1 consists of a fiber coupler with a coupling ratio of $\alpha/1-\alpha$, which is assumed to be independent of wavelength. The output ports (3 and 4) are fusion spliced to a Hi-Bi fiber with arbitrary angles between the axes of the Hi-Bi fiber and the axes of the coupler ports. The segments where the Hi-Bi fiber is spliced to the coupler ports are placed on rotation stages. The Hi-Bi fiber is placed on a thermoelectric cooler to shift the wavelength dependence of the filter transmission. A light beam with electric field E_i enters through port 1; the transmitted beam with electric field E_T exits from port 2.

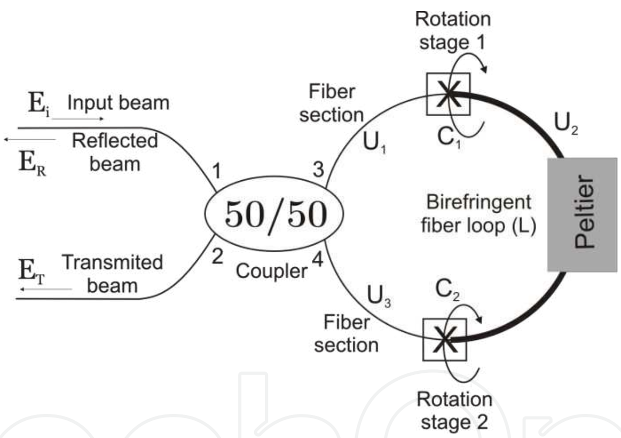

Figure 1. High birefringence fiber optical loop mirror

To calculate the transmission of the FOLM, we used the approach developed by Mortimore [28]. For a single input field E_i, a transmitted field E_T is given by:

$$E_T = \begin{pmatrix} E_{Tx} \\ E_{Ty} \end{pmatrix} = \begin{pmatrix} (2\alpha-1)J_{xx} & (1-\alpha)J_{xy}+\alpha J_{yx} \\ -\alpha J_{xy}-(1-\alpha)J_{yx} & (1-2\alpha)J_{xx} \end{pmatrix} \begin{pmatrix} E_{ix} \\ E_{iy} \end{pmatrix}, \quad (1)$$

where the J matrix is calculated as the product of matrices corresponding to all elements in the loop:

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$$J = U_1 \cdot C_1 \cdot U_2 \cdot C_2 \cdot U_3, \tag{2}$$

where matrices U_1 and U_3 represent the coupler ports; the matrices C_1 and C_2 represent the coordinate rotation accounting for the angles between the axes of the Hi-Bi fiber and those of the coupler ports at the splices; finally, the matrix U_2 represents the Hi-Bi fiber. The analysis of the matrices that form the Jones matrix for the Hi-Bi FOLM is presented in detail in reference [19], where matrices U_1, U_2 and U_3 take into account linear birefringence of the fibers and the circular birefringence caused by the fiber twist angle. Matrices C_1 and C_2 transform the Jones vectors from the Cartesian system related with the axes of the port to that related with the axes of the Hi-Bi fiber.

Transmission spectrum of the Hi-Bi FOLM is a periodic function whose period is given by the following expression:

$$\Delta\lambda = \frac{\lambda^2}{B \cdot L}, \tag{3}$$

where B is the fiber loop birefringence, L the fiber loop length and λ the wavelength.

The values of the transmission minima are defined by the coupling ratio and are equal to, the transmission maxima however depends on the rotation of the rotational stages and can be adjusted in the range between $(2\alpha - 1)^2$ and 1 [29]. The adjustment of the values of the transmission maxima can be useful in particularly for dual wavelength laser application. However the rotation of the rotational stages also moves the wavelengths of the maxima and minima.

The numerical simulation for calculated transmission spectrum was performed. The coupler ports with a length of 0.5-m and a beat length of 6 m was used. The length of the Hi-Bi fiber is equal to 28 cm with a beat length of 3.6×10^{-3} m. The angles $\theta_1 = 0.5\pi$ and $\theta_2 = 0.3\pi$ were taken arbitrarily. To obtain the transmission maximum equal to 1 the angles ϕ_1 and ϕ_2 were adjusted with $\phi_2 = -0.8\pi$. Figure 2 shows transmission spectra for angle φ_1 variations in the range between 0 and 1.087π. Transmission maximum depends on the period $\phi_1 = 1.087\pi$. Here we can see than the adjustment of the transmission maximum by angle ϕ_1 variations also causes a wavelength shift of the transmission spectra that depends on the birefringence of the coupler ports.

Figure 3 shows the wavelength as the angle ϕ_1 is varied for different beat lengths of the coupler ports with the same simulation parameters. In a range of the angle ϕ_1 approximately between 0.2π and 0.8π the wavelength shift is less than 1 nm. The wavelength shift is more pronounced for larger birefringence of the coupler ports.

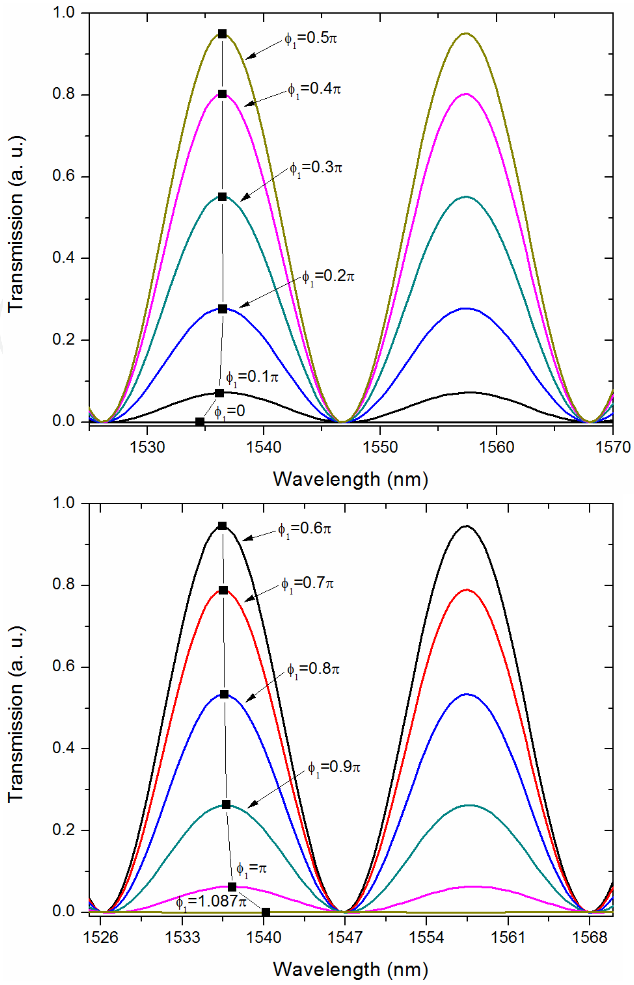

Figure 2. FOLM transmission spectra as a function of angle ϕ_1 with fixed ϕ_2.

The Hi-Bi FOLM transmission spectra amplitude adjustment causes a shift of the maximum/minimum in the reflection spectrum that is undesirable for dual-wavelength laser applications. However, the appropriate choice of the angles of both ends of the Hi-Bi fiber allows a reflection minimum between 0 and 0.9 without substantial wavelength shift. The twist of the fiber offers a simple way to change the ratio between the reflection maximum and minimum that provides a useful and simple method for the FOLM contrast adjustment.

3. Sagnac Hi-Bi FOLM charactization for dual-wavelength laser application

For the experimental investigation we introduce the basic experimental setup used. The all-fiber Fabry-Perot cavity laser is limited at one end by two Bragg gratings and at the opposite end by a Hi-Bi FOLM. Figure 4 shows the configuration where the laser gain medium is EDF with a length of 10-m. The two FBGs at one end of the cavity have 55.4% of maximum reflection at 1547.94 nm and 1546.96 nm to 59.75% respectively. The optical attenuator (OA) is

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achieved through the introduction of bend loss between the FBG's in a fiber section wounded approximately 6 turns in a circular piece with a 5-cm diameter. The adjustment of the turns was experimentally obtained at a point where both wavelengths (corresponding to FBG1 and FBG2 maxima) compete for the gain of the active medium. With this method we are roughly adjusting the losses within the cavity. The fine cavity loss adjustment is achieved by the FOLM formed by a 3dB optical coupler (Coupler 2) with the output ports interconnected through a high birefringence fiber with 28-cm length.

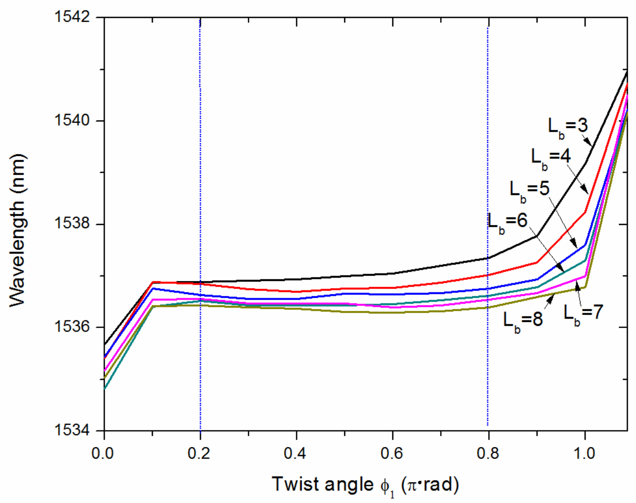

Figure 3. Dependence of the wavelength shift of the transmission maximum on the angle ϕ_1 for different beat lengths L_b.

The EDF is pumped by a 50-mW laser diode at 980-nm through a 980/1550 wavelength division multiplexer (WDM). Coupler 1 is a 90/10 coupling ratio optical coupler used to measure the 10% laser output at Output B, detecting only reflected wavelengths from FBG1 and FBG2. The output signal is launched to a 0.2-nm resolution monochromator, detected by a photodetector and monitored by an oscilloscope. Output A is used to measure the FOLM transmission spectrum at low pump power (below the threshold). Both laser wavelengths and ASE can be detected at this output.

The splices were placed into rotation stages to adjust the transmission of the FOLM. The Hi-Bi fiber temperature is controlled by temperature controller with a precision of 0.1 °C for the purpose of tuning the wavelength of the transmission spectra. The Hi-Bi fiber loop is placed on a thermoelectric cooler (TEC) whose temperature can be adjusted in the range between room temperature (about 25 °C) and 9 °C.

Measure of Hi-Bi FOLM transmission at temperatures in a range between 9 and 20°C was performed. Figure 5 shows the Hi-Bi FOLM transmission for Hi-Bi fiber loop temperatures of 9 and 11°C measured at Output A for low pump power. As it can be seen the transmission curve is shifted towards longer wavelengths when the temperature is decreased however the period remains equal to 20.8-nm. The contrast adjustment by rotation angles twist is near to the maximal contrast.

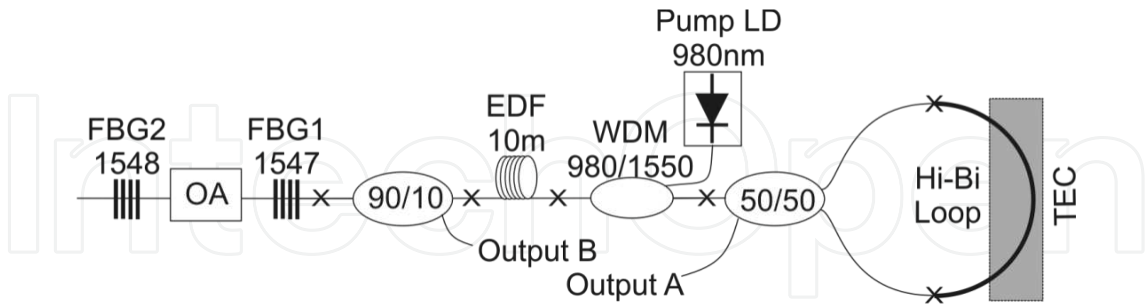

Figure 4. Experimental setup for the dual-wavelength fiber laser.

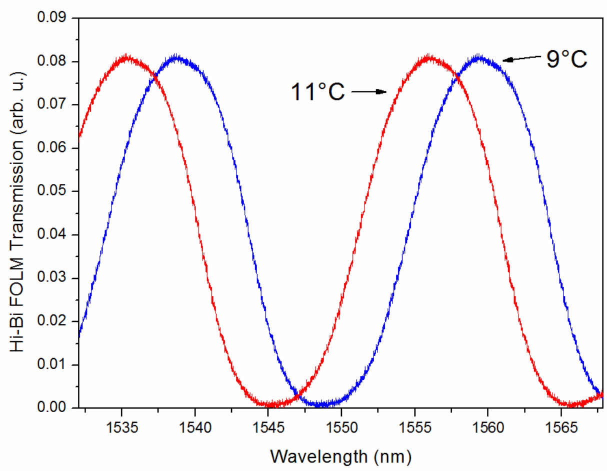

Figure 5. Hi-Bi FOLM transmission spectra wavelength shift by fiber loop temperature variation.

The wavelength dependence shift of the FOLM transmission on Hi-Bi fiber loop temperature is shown on Figure 6. The wavelength shift is well fitted by a linear dependence with a slope of -1.71 nm/°C shown with dashed line, which yields a temperature period equal to 13 °C.

Figure 7 shows output signal spectrum at the output A for the fiber Sagnac loop with a pump power of 25-mW, which is below the threshold for generating laser amplification. The measurement was performed with a temperature of 22.7 °C. Rotation angles adjustment is close to a minimum FOLM spectra output with ϕ_1=40^o (angle which we take as zero for rotation ϕ_1, we rotate 180° in ϕ_1 from this position of the rotator C_1) and ϕ_2=120^o reference to the axis of laboratory table. With fixed ϕ_2, rotation is performed in ϕ_1 with a 15° step.

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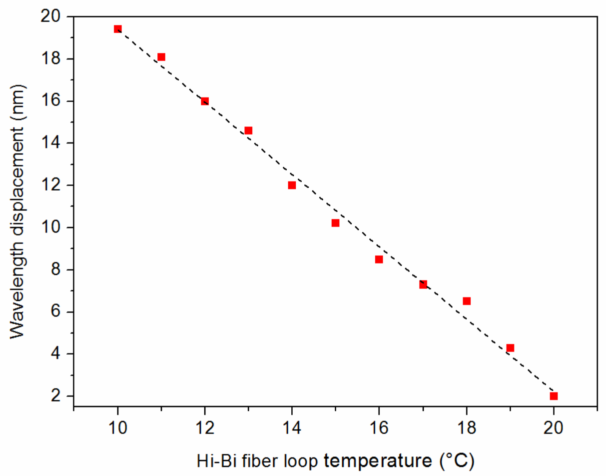

Figure 6. Wavelength displacement for Hi-Bi fiber loop temperature variations.

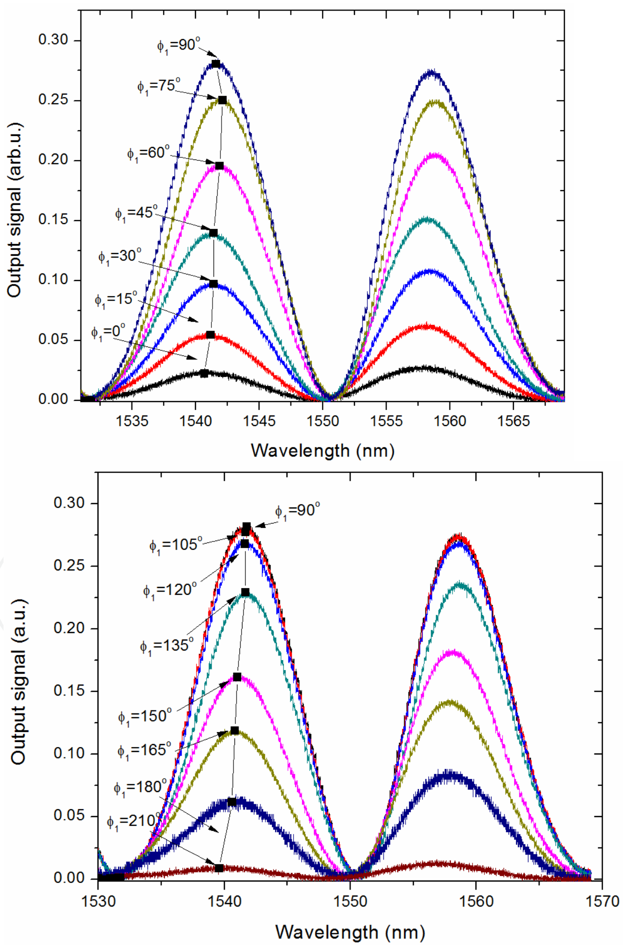

Figure 7. Spectrum at the FOLM output for different angles ϕ_1 with fixed ϕ_2.

The FOLM transmission presents periodic wavelength dependence with a period of 20.8 nm. It can be seen that the position of the maximum is shifted when the angle ϕ_1 is changed. The maximum is connected by a solid line in Figure 7. However, the period remains the same.

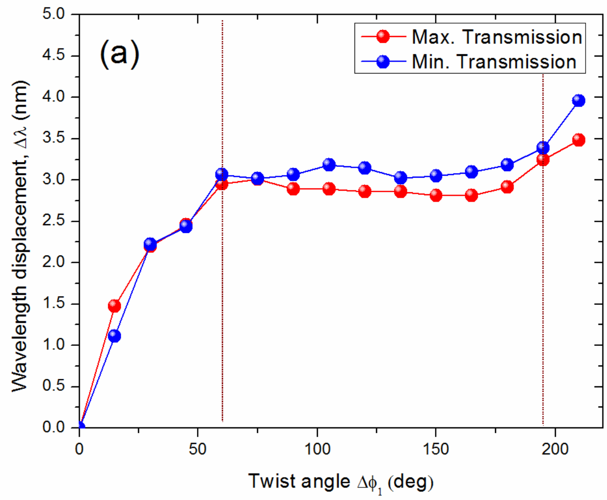

Figure 8. Dependence of wavelength shift of the transmission maximum and minimum on the angle ϕ_1 with ϕ_2=55°.

Figure 8 shows the wavelength shift of the maximum and the minimum of transmission due to the variation of the ϕ_1 angle for an angle ϕ_2 adjustment to 55°. The angle ϕ_1 was referred as 0 in the same manner as for Figure 7. The experimental dependences show a behavior similar to that obtained in simulations in Figure 3. It can be seen that there exists a range of the angle from about 60° to 180° where the dependence of the wavelength shift is almost flat with variations of less than 0.5-nm (corresponding to only a few percent of the transmission period).

The FOLM is used to adjust the loss of the cavity for wavelengths λ_1 and λ_2 corresponding to the FBG1 and FBG2 to obtain dual-wavelength operation. The application of the FOLM for dual-wavelength lasers was reported for the first time in Ref. [30].

4. Dual-wavelength fiber laser cavity loss fine adjustment by Sagnac Hi-Bi FOLM

Figure 8 presents the laser spectrum for different temperatures of the Hi-Bi fiber with the experimental setup shown in Figure 4. Laser output is measured in Output B for a pump power of 50-mW. The temperature of the Hi-Bi fiber was chosen to have a maximum of reflection of the FOLM close to the wavelengths of maximal reflection of the FBG's. Rotation stages fiber twist is set near to the 70% of FOLM transmission spectrum amplitude contrast.

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A change of the temperature moves the maxima of FOLM transmission and so changes the ratio between the reflections for λ_1 and λ_2.

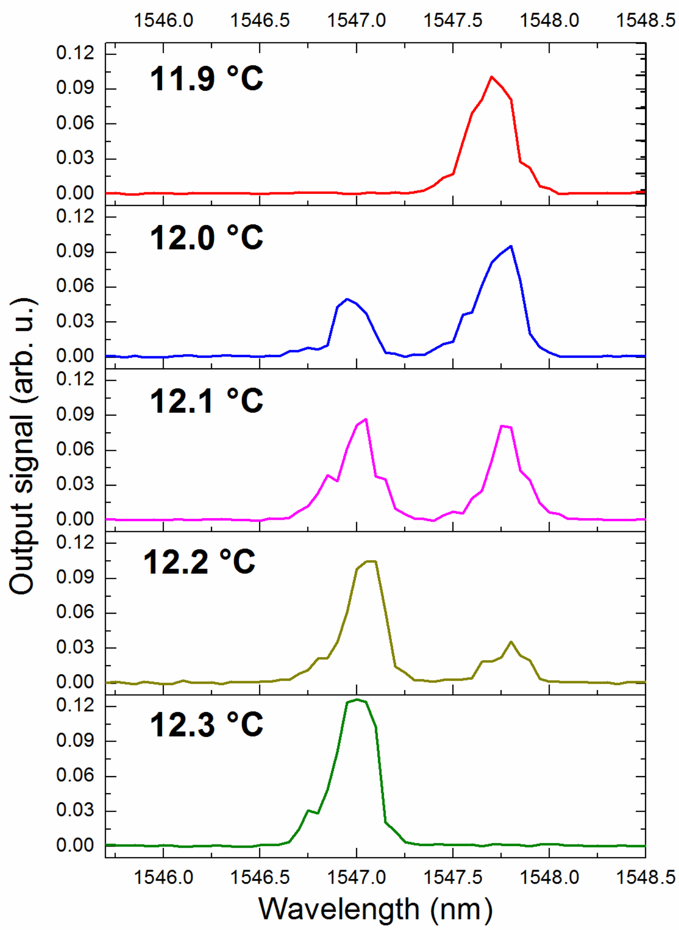

Figure 9. Measured output laser spectra for different Hi-Bi FOLM fiber loop temperatures.

As can be seen at the temperature of 12.0 °C two peaks are still observed however the amplitude of the peak with shorter wavelength is less than that of the peak with longer wavelength. At the temperature of 12.1 °C two peaks with equal amplitudes were observed. The increase of temperature to 12.2 °C results in a lower amplitude of the peak with longer wavelength. Finally for the temperature shift larger than 0.2 °C only one wavelength is generated by the laser, the shorter wavelength at 12.3 °C and for the longer wavelength at 11.9 °C.

Here we show the usefulness of the adjustment of the values of the reflection maxima by tuning the angles of the rotation stages. Figure 10a shows the laser transmission spectra obtained with the FOLM at high contrast between maxima and minima of reflection, while Figure 10b shows the results obtained with low contrast with the change of contrast achieved through a rotation of the rotational stages. In the results with lower contrast (Figure 10b) the dependence of the reflection on the temperature is slower, then, the range of temperatures over which dual-wavelength generation is observed is larger than in Figure 10a, providing higher tolerance with respect to the temperature stability. In figure 10a the FOLM spectrum was adjusted to have the highest contrast between the reflection maximum and minimum with ϕ_1=120°. In figure 10b results, the FOLM spectrum was adjusted to have a low contrast with ϕ_1=30°.

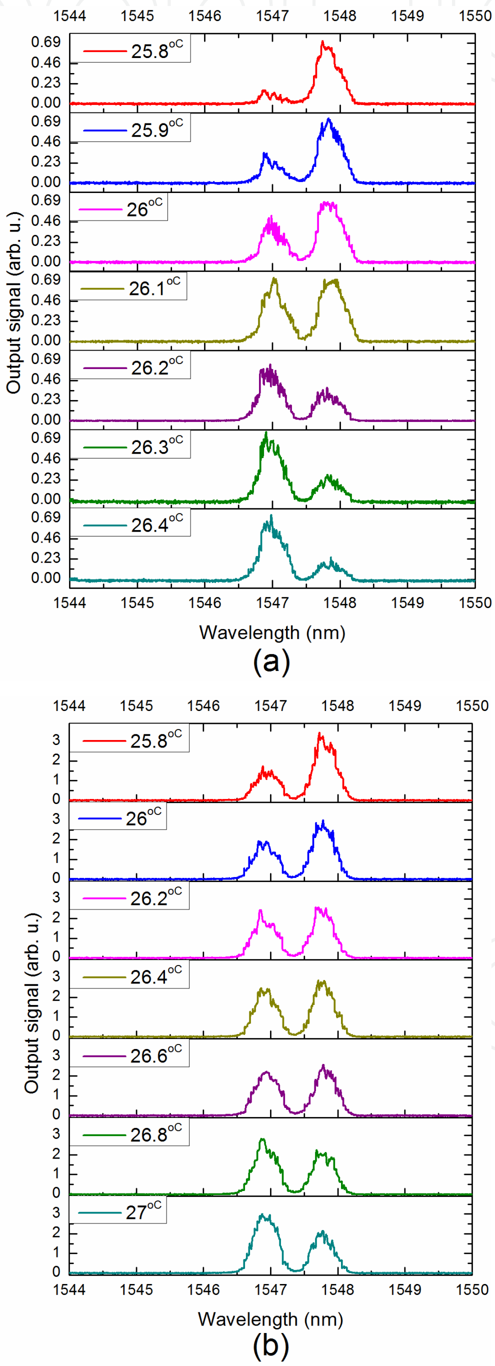

Figure 10. Laser output spectra at different temperatures with different contrasts.

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Figure 11 shows the measured power of the two laser lines for the same FOLM adjustment as for Figures 10a and 10b for the maximal transmission amplitude point. Insets in the figures show reflection of the FOLM used for each measurement. We can see that the temperature tolerance of the dual-wavelength operation for the case shown in Figure 11b is much higher than the temperature tolerance for the case shown in Fig. 11a.

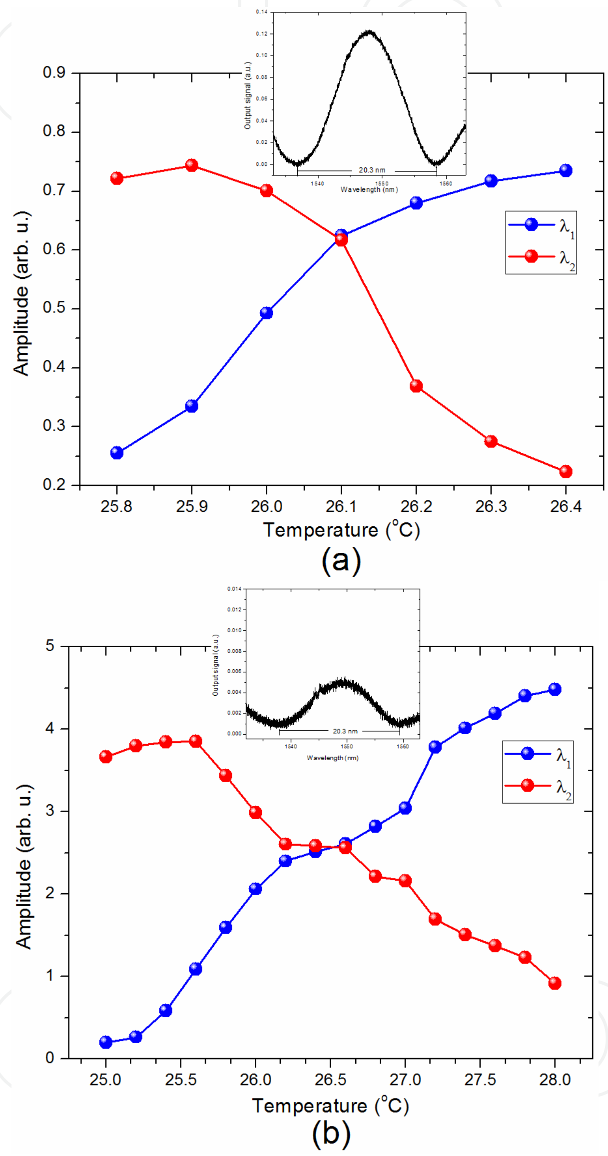

Figure 11. Power at wavelengths λ_1 and λ_2. (a) Highest contrast between reflection maxima and minima, (b) low contrast between reflection maxima and minima.

For dual-wavelength lasers, low contrast offers the advantage of smoother cavity loss adjustment for the generated wavelengths where the principal mechanism of the adjustment of the cavity loss is the shift of the wavelength of the reflection maxima of the FOLM. The wavelength shift is achieved by the change of the temperature of the Hi-Bi fiber. This method allows generating two wavelengths with a well-controlled ratio between their powers.

5. Tunable dual-wavelength fiber laser with Sagnac Hi-Bi FOLM and a polarization-maintaining FBG

Here, experimentally operation of a linear cavity dual-wavelength fiber laser using a polarization maintaining fiber Bragg grating (PM-FBG) is presented. PM-FBG is used as an end mirror that defines two closely spaced laser emission lines and it is also used to tune the laser wavelengths. The total tuning range is around 8 nm. The laser operates in a stable dual-wavelength mode for an appropriate adjustment of the cavity losses for the generated wavelengths. The high birefringence (Hi-Bi) fiber optical loop mirror (FOLM) is used as a tunable spectral filter to adjust the losses as can be seen before in topics 3 and 4 [31].

The experimental setup used is similar to in figure 4 and it can be seen in figure 12. The linear laser cavity is formed by the Hi-Bi FOLM analyzed before and a PM-FBG mounted in a mechanical device allowing compression/stretch and a polarization controller (PC). The PM-FBG spectrum presents two peaks with separation of 0.3-nm centered at 1549 nm. Both peaks have 99.5% maximum reflection. The 90/10 coupler is used as the laser output (Output A). The output radiation was launched to a monochromator with 0.1-nm of resolution, detected by a photodetector and monitored by an oscilloscope. Output B is used to monitor FOLM transmission spectra.

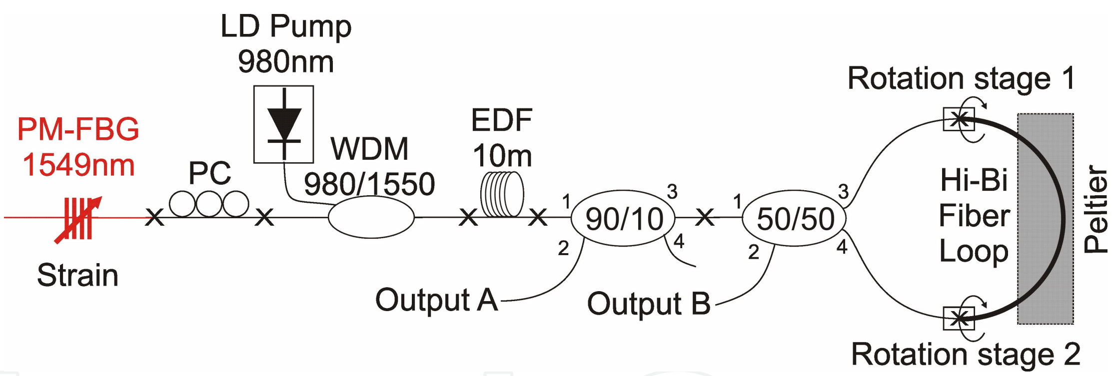

Figure 12. Tunable dual-wavelength fiber laser with PM-FBG experimental setup.

The laser cavity is set to have the transmission minimum at approximately 1549 nm where the PM-FBG reflection is centered by temperature variations of the Hi-Bi FOLM fiber loop.

Figure 13 shows the reflection spectrum of the PM-FBG and ASE at Output B for a pump power near the laser threshold (around 25-mW) and a temperature of 24.5 °C. No strain is applied to the PM-FBG then, PM-FBG reflection peak is centered at 1549 nm.

Figure 13a shows the FOLM transmission spectrum for a high contrast between minima and maxima of reflection. Figure 13b shows the FOLM transmission spectrum for a low contrast adjustment. The low contrast adjustment allows a smoother change of the FOLM reflection with temperature such that this is the adjustment of contrast used in measurements of the generation of laser lines.

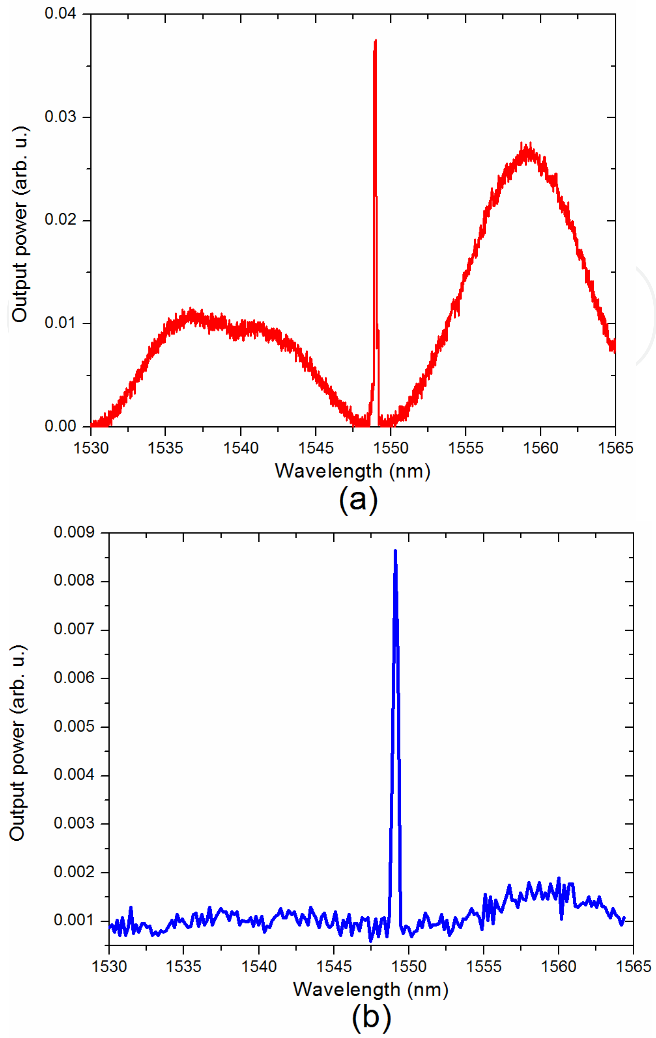

Figure 13. Measured Hi-Bi FOLM transmission spectra at Output B. (a) High contrast adjustment. (b) Low contrast adjustment.

For dual-wavelength generated laser lines measurement, both laser lines at 1548.86 and 1549.18 nm are monitored at Output A. Adjust of PC allows to obtain stable dual wavelength generation. However the compression/stretch of the PM-FBG causes the loss of the dual wavelength generation and further adjustment of the PC is required. The adjustment of the PC however is not a straightforward procedure. An adjustment of the temperature of the Hi-Bi fiber in the FOLM was performed then. Figure 14 shows the shift of the two wavelengths for different values of compression/stretch applied to the PM-FBG. Micrometer screw positions are shown in the graphics; negative values are assigned to the compression, positive to the stretch.

The resolution of the monochromator was not sufficient to measure the bandwidth of lines. To be sure that we have two well separated laser lines we monitored the output also with a scanning Fabry–Perot.

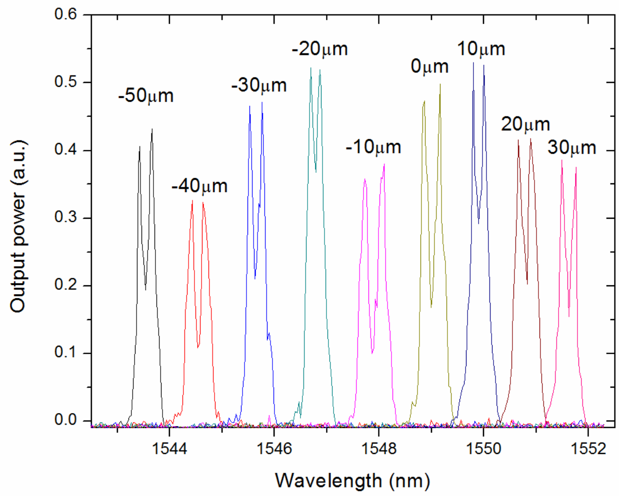

Figure 14. Fiber laser spectra at the compressed/stretched PM-FBG.

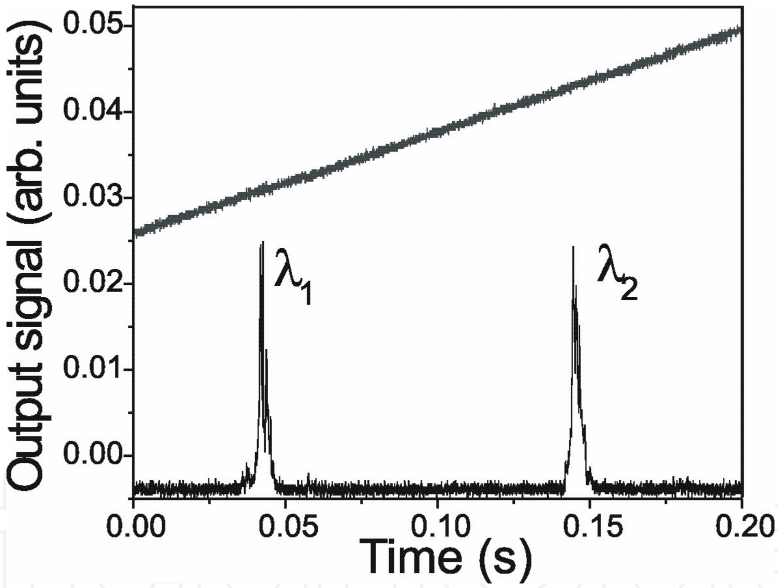

Figure 15. Output signal from the Fabry-Perot scanning with no strain applied to the PM-FBG.

Figure 15 shows the oscilloscope trace of the signal at the FP output with no strain applied to the PM-FBG. As can be seen there are two well separated lines with separation of 0.34 nm. The free space of FP shown in the inset is equal to 0.6 nm. The total power inside the cavity is about 1-mW and was measured at the output A through a photodetector and an optical power meter.

Axial compression or stretch was applied by using a micrometric screw mechanical system. The maximum compression applied was 50 µm causing a maximum wavelength displacement of 5.5 nm. The corresponding wavelengths shift rate is about 1.1 nm/10 µm. The maxi-

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mum stretch was 30 µm, causing a wavelength shift of about 2.58 nm, which corresponds to a rate of 0.86 nm/10 µm. The total laser wavelength shift is 8.09 nm with average rate of 1 nm/10 µm approximately. For each compression/stretch of the PM-FBG we adjusted the temperature of the Hi-Bi fiber to obtain dual-wavelength generation.

Figure 16 shows the temperature required for dual-wavelength generation. As one see the dependence is well fitted linearly with a slope of –1.39 nm/°C so the adjustment procedure is very simple and straightforward.

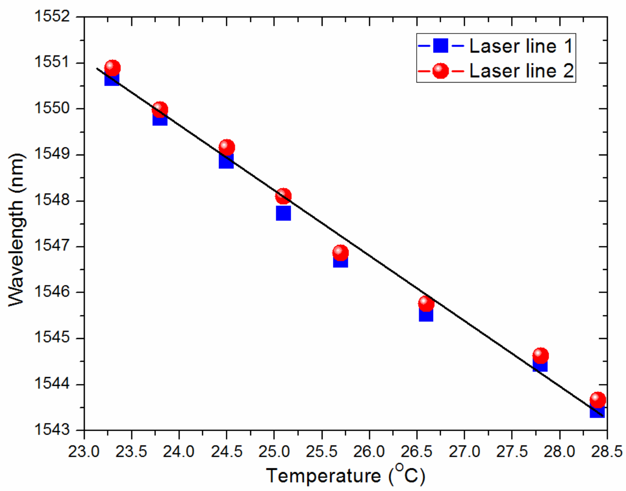

Figure 16. Required Hi-Bi FOLM temperature for dual-wavelength laser operation at stretched/compressed PM-FBG.

This method allows to estimate a reflection change for shorter and longer wavelengths of the PM-FBG under compression/stretch. Figure 17 shows the FOLM minimum transmission wavelength and the central wavelength of the dual line laser. If the wavelength of the FOLM minimum transmission coincides with the central wavelength of the laser, the reflection of the FOLM is equal for both wavelengths. We observe this for compression/stretch around 0.

To have dual wavelength generation under compression or stretch the minimum of the FOLM transmission (corresponding to maximum reflection) has to be displaced to shorter wavelength with respect to the central lasing wavelength, which means that the FOLM reflection for the shorter wavelength line is slightly higher than the reflection for the longer wavelength.

From this we can conclude that the reflection of the PM-FBG for shorter wavelength line became slightly smaller at compression/stretch than for the longer wavelength line.

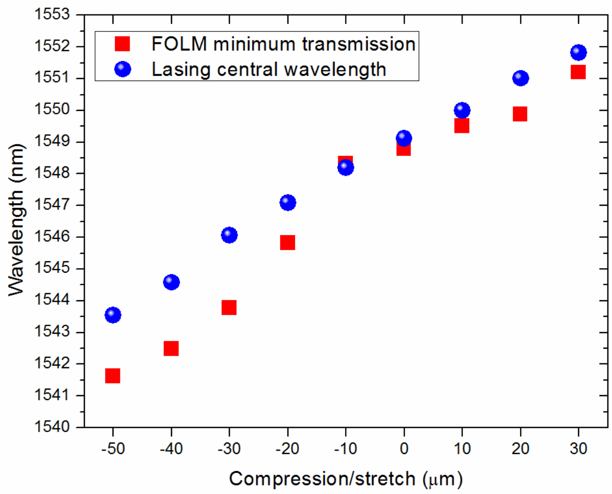

Figure 17. Wavelengths of the FOLM minimum transmission and lasing central wavelengths at the stretched/compressed PM-FBG.

6. Conclusions

In the first part we present numerical and experimental analysis of a high birefringence fiber optical loop mirror (Hi-Bi FOLM) to use in lasers with dual wavelength. The adjustment in the amplitude spectrum because of the reflectivity was considered as a tool for the dual wavelength laser stability. This is accomplished by adjusting the angles in one of the ports of the FOLM where we in which we may have a minimum and maximum of reflectivity the laser cavity. Also that we can select the best performing region in terms of period, amplitude spectrum of the FOLM and by temperature we can shift the wavelength in the FOLM and equalize the two wavelengths required to generate a laser with dual wavelength emission.

In the second part we propose to apply the FOLM to generate a laser with dual wavelength emission. We propose and demonstrate experimentally a laser with dual wavelength and stable, we can make the laser having laser emission at single or dual wavelength by adjusting the temperature in the loop FOLM and we demonstrate how to improve the stability of the laser by adjusting the amplitude using the optical fiber twisters in the FOLM.

In the third part we explain the implementation of the FOLM to generate tunable dual wavelength using a polarizer maintaining fiber Bragg grating (PM-FBG). We propose and demonstrate experimentally a tunable wavelength laser. The tuning range was 8.06-nm; this tuning was achieved by stretching and compressing the PM-FBG. For each tuning was only necessary to adjust the temperature in the FOLM. As a result of this application of the FOLM to generate a dual wavelength laser, we present two simple configurations that can be used for future applications.

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Author details

Manuel Durán-Sánchez[1], R. Iván Álvarez-Tamayo[2], Evgeny A. Kuzin[3], Baldemar Ibarra-Escamilla[3], Andrés González-García[3] and Olivier Pottiez[4]

1 Mecatrónica, Universidad Tecnológica de Puebla (UTP), Puebla, México

2 Facultad de ciencias físico-matemáticas Benemérita Universidad, Autónoma de Puebla (BUAP), Puebla, México

3 Departamento de Óptica, Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE), Puebla, México

4 Departamento de Fibras Ópticas, Centro de Investigaciones, en Óptica (CIO), León, Guanajuato, México

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