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A dual-wavelength tunable laser with superimposed fiber Bragg gratings

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Abstract
We report a dual-wavelength tunable fiber laser. The cavity is formed by two superimposed fiber Bragg gratings (FBGs) and a temperature tunable high-birefringence fiber optical loop mirror (FOLM). FBGs with wavelengths of 1548.5 and 1538.5 nm were printed in the same section of a fiber using two different masks. The superimposed FBGs were placed on a mechanical mount that allows stretch or compression of the FBGs. As a result of the FBG strain both lines are shifted simultaneously. Dual-wavelength generation requires a fine adjustment of the cavity loss for both wavelengths.

1. Introduction

Different methods have been proposed and demonstrated for generating dual or multi-wavelengths in fiber lasers. There are potential applications in a variety of research areas, such as fiber-based sensors, wavelength division multiplexing (WDM), optical communication systems and instrument testing among others [1–3]. Erbium-doped fibers (EDF) are attractive optical media for dual-wavelength generation providing compatibility with existing technology, wide gain bandwidth and simplicity. However, EDF is a homogeneous gain medium at room temperature, which leads to strong mode competition and difficulties for simultaneous generation of two or more laser lines. The most common way to ensure the stable generation of several lines consists of introducing different cavity losses for generating lines. Several methods to adjust the losses within the laser cavity to obtain simultaneous and stable laser emission have been proposed [4–6].

Fiber Bragg gratings (FBGs) are optical devices widely used in fiber laser design for wavelength selection due to their narrow band reflection. For dual-wavelength lasers an array of cascaded FBGs is usually used [2, 7]. Lasers using only one FBG with multiple reflection wavelengths, including FBGs written in few-mode or multimode fiber and FBGs written in high-birefringence (Hi-Bi) fiber, have also been reported [8, 9].

In this paper, we report a simple tunable dual-wavelength linear cavity fiber laser using superimposed FBGs written in the same point of an optical fiber segment allowing reflection at two different Bragg wavelengths. For loss adjustment we use a fiber optical loop mirror (FOLM) with a Hi-Bi fiber in the loop. Superimposed FBGs were placed on a mechanical mount that allows stretch or compression of the FBGs. The proposed fiber laser generates two simultaneous laser lines with equal or unequal output powers and tuning ability for both wavelengths, preserving the same separation between

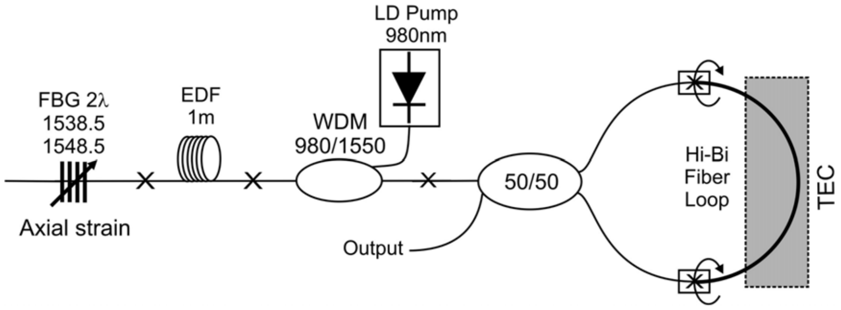

Figure 1. Experimental setup of the tunable and switchable dual-wavelength EDF laser.

the generated laser lines. The separation between wavelengths was 10 nm with 5.58 nm of tuning.

2. Experimental setup

Figure 1 shows a schematic of the laser. The linear laser cavity is formed by a FOLM consisting of a 50/50 coupler with output ports connected by a 28 cm Hi-Bi fiber, a 1 m EDF and two superimposed FBGs. FBGs with wavelengths of 1538.5 and 1548.5 nm were written in the same part of the fiber using two different masks. The superimposed FBGs were placed on a mechanical device that allows stretch or compression of the FBGs by a micrometric screw displacement. The maximum reflection of FBGs is 100%. The EDF is pumped through a 980/1550 WDM by a 70 mW laser diode. The output radiation was launched to a monochromator with a resolution of 0.2 nm, detected by a photodetector and monitored on an oscilloscope. The FOLM with the Hi-Bi fiber in the loop presents a periodic wavelength-dependent reflectivity.

The transmission minima depend only on the coupling ratio of the coupler α and are equal to $(1 - 2\alpha)^2$. However, the transmission maxima depend on the orientation of the birefringence axes of the Hi-Bi fiber. The period of transmission is equal to 22.3 nm. The birefringence of the Hi-Bi fiber is highly sensitive to temperature changes which cause a shift of the FOLM reflection spectrum. We found that the transmission curve is shifted towards longer wavelengths when the temperature is decreased, but the period remains the same. The contrast between maxima and minima of the FOLM reflection spectrum was adjusted by twisting the splices between the Hi-Bi fiber loop ends and 50/50 output coupler ports. We report a more detailed analysis of the FOLM behavior for dual-wavelength laser application in [7, 10]. The Hi-Bi fiber is placed on a thermoelectric cooler (TEC) whose temperature can be adjusted in the range between room temperature and 9 °C.

3. Experimental results and discussion

For a FOLM with a 50/50 coupler, we can describe the reflection at temperature t and wavelength λ as:

$$R = \frac{\gamma}{2}\left(1 + A\cos\left(\frac{2\pi}{\Lambda}(\lambda - \lambda_0) + \frac{2\pi}{T}(t - t_0)\right)\right), \quad (1)$$

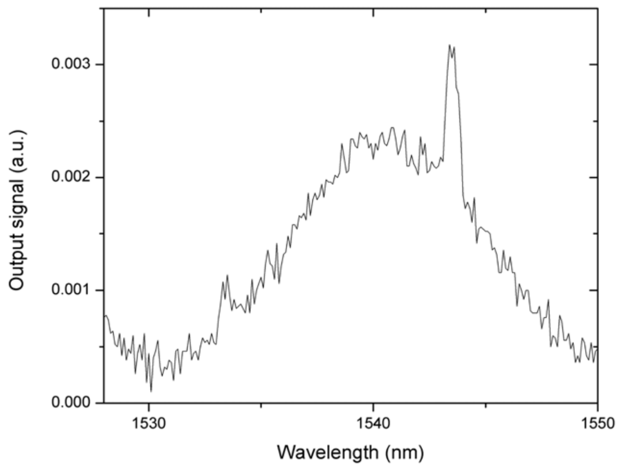

Figure 2. FOLM transmission spectrum measured at output.

where λ_0 and t_0 are the wavelength and temperature at which the FOLM has the maximal reflection and Λ and T are the measured wavelength and temperature periods, respectively. The coefficient γ stands for the losses in the FOLM caused by splices between coupler ports and the Hi-Bi fiber. The constant A defines the contrast between the maximum and minimum reflection of the FOLM. It can be adjusted by twisting the Hi-Bi fiber using the rotation stages. An interesting feature of the proposed configuration is the possibility of fine adjustment and measurement of the ratio $R(\lambda_2)/R(\lambda_1)$ required for dual-wavelength generation.

Figure 2 shows the spectrum at the output with a pump power of 15 mW, which is below the threshold for laser generation. The measurements were done at the temperature of 15.3 °C at which we have found the dual-wavelength generation (details will be discussed below). In figure 2 we can also see the reflection of the FBGs with wavelengths centered at 1538.5 and 1548.5 nm. The best fit of the measured transmission with equation (1) was obtained for $\Lambda = 22.3$ nm, $T = 13$ °C.

At each strain applied to the FBGs we tuned the temperature of the Hi-Bi fiber to achieve dual-wavelength generation, and for this temperature λ_0 and t_0 were measured to use in equation (1). Then we used equation (1) to determine the FOLM reflection $R(\lambda_1)$ and $R(\lambda_2)$ for the wavelengths λ_1 and λ_2 corresponding to FBG1 and FBG2, respectively. In

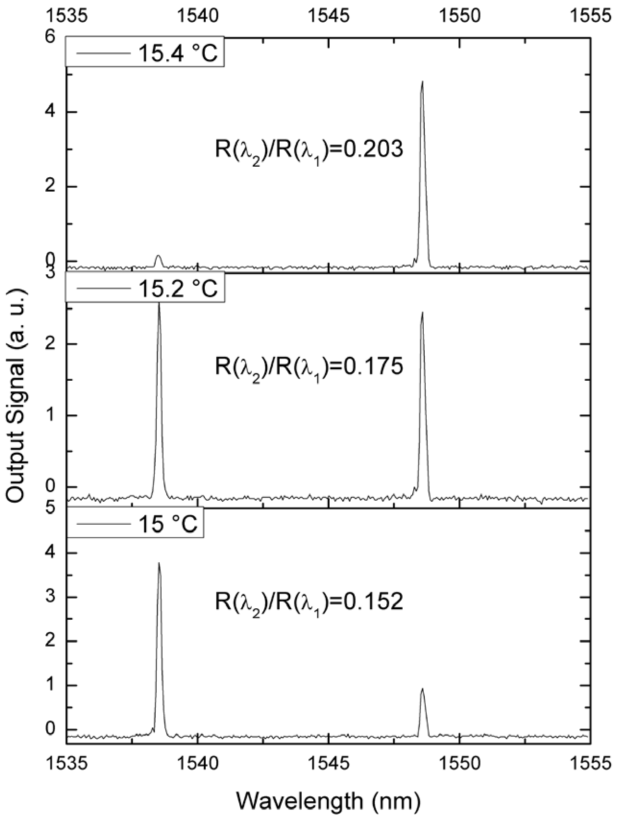

Figure 3. The laser spectra at a Hi-Bi fiber temperature equal to 15.2 °C (equal power of laser lines), and temperatures equal to 15.4 and 15.2 °C. The ratios between the FOLM reflections for λ_2 and λ_1 are shown in the figures for each temperature.

our measurements we set the maximum of the transmission spectra to 0.9. The calculated constant A for this adjustment is equal to $9/11$.

Figure 3 presents the laser output spectrum at different temperatures of the Hi-Bi fiber in the FOLM without strain applied to the FBGs. Laser wavelengths are displayed at 1538.5 nm and 1548.5 nm. At a temperature of 15.2 °C two peaks with equal amplitudes were observed. At a temperature of 15 °C two peaks are still observed; however, the amplitude of the peak with the shorter wavelength is higher than that of the peak with the longer wavelength. The increase in temperature to 15.4 °C results in a higher amplitude of the peak with the longer wavelength. As can be seen, the laser operation range is about 0.4 °C. For each temperature we calculated the ratio between reflection of the FOLM for long and short wavelengths, $R(\lambda_2)/R(\lambda_1)$. As can be seen dual-wavelength operation is observed for the range of $R(\lambda_2)/R(\lambda_1)$ between approximately 0.15 and 0.2.

Figure 4 shows the laser wavelengths for different strains applied to FBGs using the micrometric screw. The maximum stretch was 80 μm with intervals of 10 μm. The relation between micrometric displacement and wavelength shift of the FBG is around 0.79 nm/10 μm. The maximum wavelength shift was 5.58 nm. As can be seen, the measured data have an approximately linear behavior. The separation between laser lines is 10 nm independent of strain. The temperature

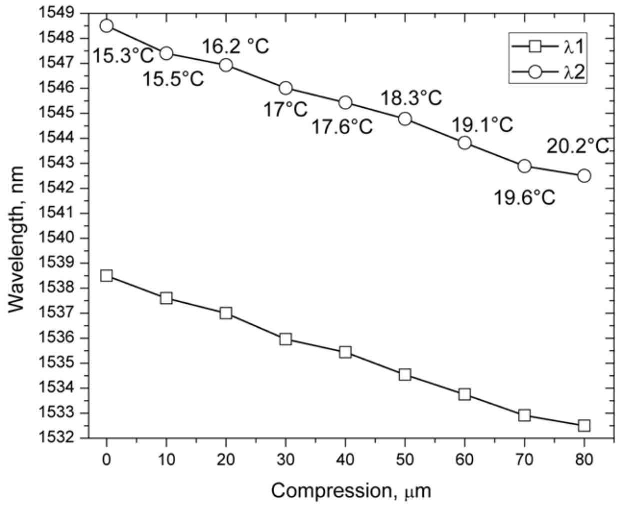

Figure 4. Dual laser wavelength shift with respect to axial compression of the FBG at different temperatures.

of the Hi-Bi fiber in the loop of the FOLM required for dual-wavelength generation is shown in figure 4 for each compression.

The use of the FOLM for loss adjustment allows the investigation of tolerance of dual-wavelength generation to the ratio between the cavity losses at λ_1 and λ_2. Figure 5(b) shows reflections of the FOLM for λ_1 and λ_2 required for dual-wavelength generation calculated using equation (1). Figure 5(a) shows the ratio $R(\lambda_2)/R(\lambda_1)$. At low FBG compressions both laser lines are situated on the plateau of the EDF amplification and we can see that the reflection for short wavelength is higher than that for long wavelength. When $R(\lambda_1)$ is approaching the amplification peak of the EDF spectrum (around 1533 nm), reflection $R(\lambda_2)$ increases and reflection $R(\lambda_1)$ decreases with compression.

4. Conclusions

We experimentally investigated the emission of a tunable dual-wavelength laser with a linear cavity formed by superimposed FBGs and a FOLM with a Hi-Bi fiber in the loop. Tunable superimposed FBGs were placed on a mechanical mount that allows stretching or compression of the FBGs. The temperature control of the FOLM Hi-Bi fiber loop allows fine adjustment of the ratio between the cavity loss at λ_1 and λ_2. Using this adjustment we were able to change the mode of operation of the laser from single wavelength to stable dual-wavelength generation with equal powers for λ_1 and λ_2 or to stable dual-wavelength generation with unequal powers at λ_1 and λ_2. We have measured the change of the ratio $R(\lambda_2)/R(\lambda_1)$ between the FOLM reflection for λ_1 and λ_2. When both lines are situated on the plateau of the EDF amplification the reflection of longer wavelengths was always higher than the reflection for shorter wavelengths.

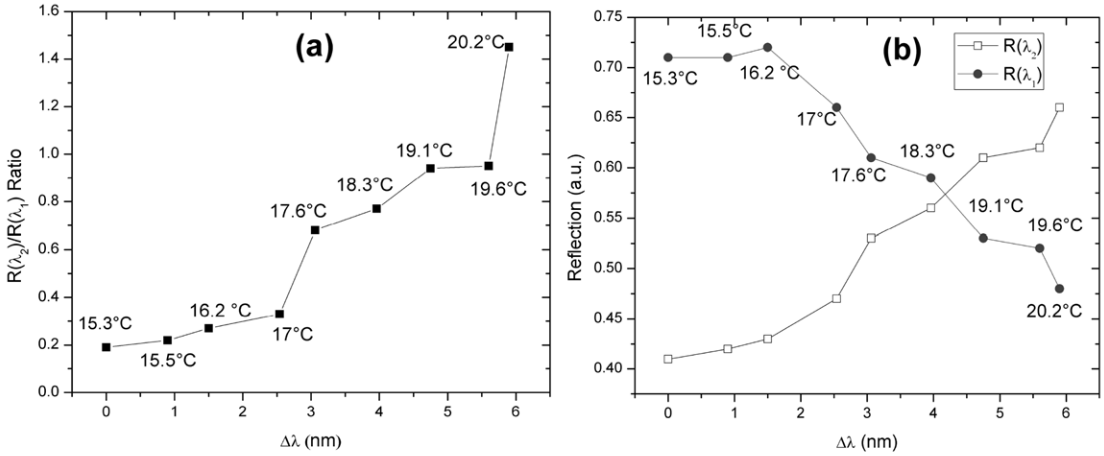

Figure 5. Calculated reflection at different compressions: (a) reflection ratio; (b) reflections $R(\lambda_2)$ and $R(\lambda_1)$.

Acknowledgments

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