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# Tunable Dual-Wavelength Fiber Laser Based on a Polarization-Maintaining Fiber Bragg Grating and a Hi-Bi Fiber Optical Loop Mirror[1]

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**Abstract**—We demonstrate experimentally the operation of a linear cavity dual-wavelength fiber laser using a polarization maintaining fiber Bragg grating (PM-FBG) as an end mirror that defines two closely spaced laser emission lines. The PM-FBG is also used to tune the laser wavelengths. The total tuning range is ~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. The FOLM adjustment was performed by the temperature control of the Hi-Bi fiber.

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## 1. INTRODUCTION

Multi-wavelength optical fiber lasers attracted a lot of interest in recent years because of their potential applications in different research areas such as optical fiber sensors, wavelength division multiplexing communication systems and others [1–8]. However it is difficult to obtain stable dual-wavelength laser emission at room temperature using erbium-doped fiber (EDF) because EDF is a homogeneous gain medium. Various solutions were suggested to control the mode competition and increase stability. These include the use of an arrayed waveguide grating as a wavelength selector [9], intracavity loss optimization [10], use of self-injection Fabry–Perot laser diode [11], optimization of cavity elements [12], use of Hi-Bi optical loop filter [13] among others.

Fiber Bragg gratings (FBG) are used extensively in optical fiber lasers as narrow band reflectors [14–16]. Polarization-maintaining FBG (PM-FBG) written in a high birefringence (Hi-Bi) fiber recently attracted interest in the design of multi-wavelengths lasers [17–19] due to the existence of two wavelengths of reflection, one in each polarization axis of the fiber. This allows the generation of two simultaneous laser lines with well defined polarization.

The Bragg wavelength of a FBG can be shifted by temperature change [20], compression or stretch [21, 22], which allows the design of tunable fiber lasers. The wavelength of the PM-FBG can also be shifted by temperature control or strain allowing simultaneous tuning of both generated wavelengths.

In this paper, we report the experimental study of a linear cavity dual-wavelength tunable fiber laser using a PM-FBG. The PM-FBG was compressed/stretched allowing dual-wavelength total tuning range of ~8 nm. A Hi-Bi fiber optical loop mirror (FOLM) was used to adjust the cavity losses for the generated wavelengths to obtain stable dual-wavelength generation. The adjustment of the FOLM was performed by controlling the temperature of the Hi-Bi fiber in the loop with a precision around 0.1°C.

## 2. EXPERIMENTAL RESULTS

The proposed configuration is shown in Fig. 1. 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 with birefringence of $4.125 \times 10^{-4}$, a 10 m EDF, 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.

[1] The article is published in the original.

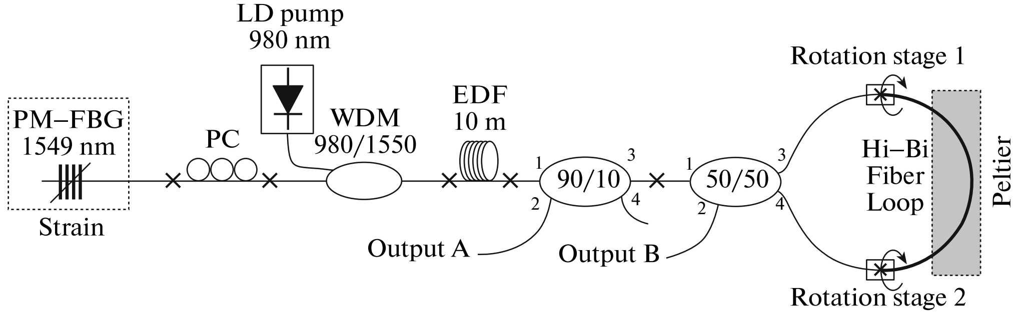


**Fig. 1.** Experimental schematic of the tunable and switchable dual wavelength EDF laser.

Both peaks have 99.5% maximum reflection. The EDF is pumped through a 980/1550 WDM by a 60-mW laser diode. The 90/10 coupler is used as the laser output (Output A). The output radiation was launched to a monochromator with 0.1 nm resolution, detected by a photodetector and monitored by an oscilloscope. Output B is used to monitor the light transmitted through the FOLM.

The FOLM acts as a broadband reflector with a periodic transmission spectrum with period of 20.8 nm. The change of the temperature of the Hi-Bi fiber results in the wavelength shift of the FOLM reflection spectrum. It allows fine adjustment of cavity loss for dual-wavelength generation. The operation of the tunable FOLM has been discussed in detail previously [23].

To adjust the laser cavity we set the temperature of the Hi-Bi fiber in the FOLM to have the transmission minimum (reflection maximum) at approximately 1549 nm where the PM-FBG reflection is centered. Figure 2 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.

The maxima of the FOLM reflection are close to 1 if a 50/50 coupler is used. However the minima can be adjusted between 1 and 0 by rotation of the splices between the Hi-Bi fiber and the coupler ports [23]. Figure 2a shows the FOLM transmission spectrum for a high contrast between minima and maxima of reflection. Figure 2b shows the FOLM transmission spectrum for a low contrast adjustment. The low contrast adjustment allows a smoother change of the FOLM reflection with temperature.

First we monitored the two laser lines at 1548.86 and 1549.18 nm at Output A and adjusted the PC 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. Instead of this we performed an adjustment of the temperature of the Hi-Bi fiber in the FOLM. Figure 3 shows the shift of the two wavelengths for different values of compression/stretch applied to the PMFBG. 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. The inset in Fig. 3 shows the oscilloscope trace of the signal at the FP output with no strain applied to the

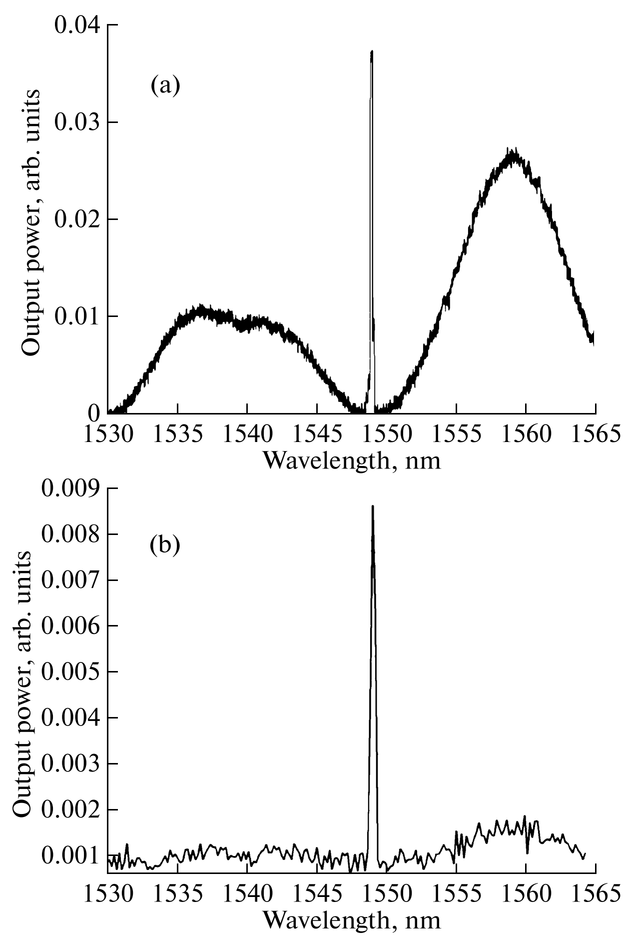


**Fig. 2.** Signal at the output B. (a) High contrast adjustment. (b) Low contrast adjustment.

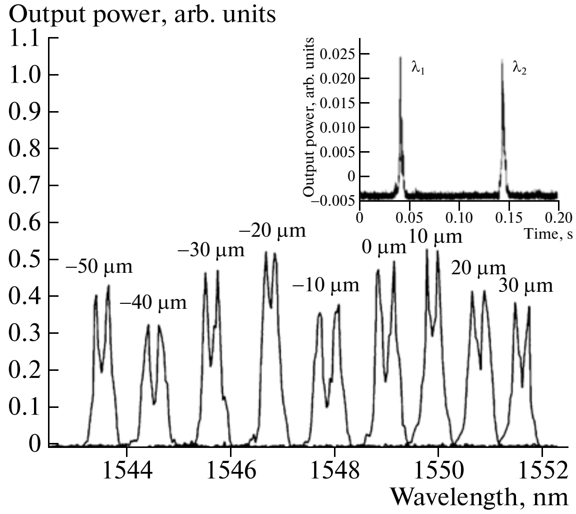


**Fig. 3.** Fiber laser spectra at the compressed/stretched PM-FBG. Micrometer screw positions are shown in the graphics; negative values are assigned to the compression, positive to the stretch.

PM-FBG. We see 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. We measure the total power by the inability to measure the optical power of each line separately, and then the experimental setup was set for dual laser emission for measurement.

To apply axial compression or stretch we used 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 maximum 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 4 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.

Our experimental setup allows estimating a reflection change for shorter and longer wavelengths of the PM-FBG under compression/stretch. Figure 5 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 (1549 nm). 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.

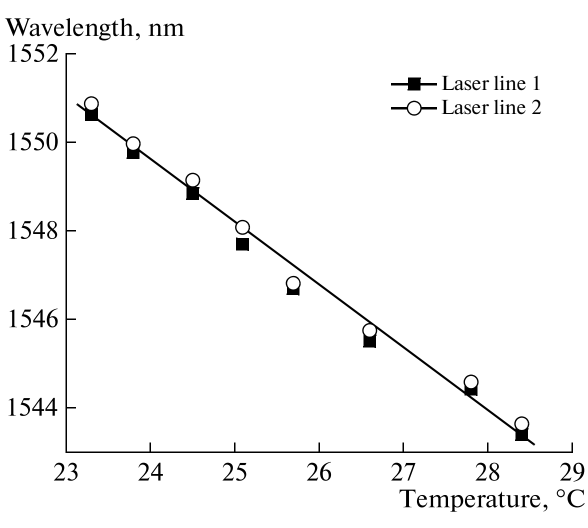


**Fig. 4.** Temperature of the FOLM required for dual-wavelength laser operation at stretched/compressed PM-FBG.

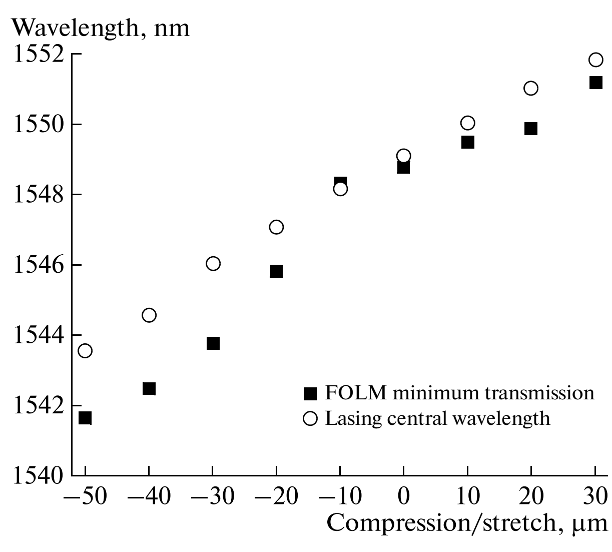


**Fig. 5.** Wavelengths of the FOLM minimum transmission and lasing central wavelengths at the stretched/compressed PM-FBG.

## 3. CONCLUSIONS

We have demonstrated experimentally the operation of a tunable linear cavity dual-wavelength fiber laser at room temperature using a PM-FBG and a FOLM. The laser operated in stable dual-wavelength mode. The PM-FBG was compressed and stretched axially for tuning the laser wavelengths. The temperature control of the FOLM Hi-Bi fiber loop was used to adjust the losses inside the cavity. The required temperature precision is of the order of $10^{-1}$°C. The use of the temperature controlled FOLM makes the adjustment of dual wavelength operation simple and straightforward. The total tuning range was ~8 nm with a laser lines separation as small as ~0.3 nm.

## ACKNOWLEDGMENTS

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