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Fine Adjustment of Cavity Loss by Sagnac Loop for a Dual Wavelength Generation[1]

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Abstract—We experimentally demonstrate a fine adjustment of cavity loss by Sagnac loop for a dual wavelength generation. The single or dual wavelengths are obtained by controlling the losses on both cavities through a fiber optical loop mirror (FOLM). Wavelength separation on the dual laser is 0.98 nm. The dual or single wavelength is obtained by changes in temperature in the order of 10^{-1}°C around the maximum in the FOLM. Also, we investigate energy fluctuations on signal level saturation effect in the cavity through different pumping power that act on the EDF, where we note that from the 60-mW pumping begins to generate dual-wavelength and 80-mW stabilizes.

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1. INTRODUCTION

Multiwavelength fiber lasers have attracted a great interest because they are considered to be cost-effective optical sources because of their various advantages such as multiwavelength operation, simple structure, low cost, and low insertion loss [1–6]. In particular, they have 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, 2]. The Erbium-doped fiber (EDF) is a homogeneous gain medium at room temperature, which leads to strong mode competition and unstable lasing of dual wavelength lasers. To achieve the oscillating dual wavelength generation in the fiber laser, versatile techniques have been proposed. Dual wavelength and switchable lasers were reported with the use of cascaded FBG cavities [3] a FBG written in a high birefringence (hi-bi) fiber [4] or in few-mode and multimode fibers [5]. When one of the mirrors is a FBG written in a Hi-Bi fiber the FOLM is frequently used as a second mirror [5–11]. Ahmad et al. [6] reported a high power multiwavelength setup based on cascaded FBGs and a bismuth based EDF configured with a Sagnac loop mirror to form a ring laser cavity. Yeh et al. [7] performed a switchable multiwavelength erbium fiber ring laser using Sagnac loop an Fabry–Perot laser diode. Liu et al. [10] implemented a switchable triple-wavelength EDF laser using a single FBG in a polarization maintaining fiber. Hu et al. [12] reported a switchable multi-wavelength fiber laser using a high-birefringence fiber loop mirror. Jia et al. [13] reported the use of a high birefringence fiber ring mirror for a multiwavelength selection. Liu et al. [14] demonstrate a tunable multiwavelength erbium-doped fiber laser based on a polarization-maintaining photonic crystal fiber Sagnac loop filter. All these methods require adjustment of the losses in the cavity with external means such as a variable optical attenuator (VOA) [3], an acousto-optical modulator (AOM) [12] and a polarization controller (PC) [3–12].

In this paper, we report a fine adjustment of cavity loss by the use of the FOLM with a Hi-Bi fiber in the loop. The transmission and the reflection of the FOLM present a sinusoidal wavelength dependence which can be shifted by controlling the temperature of the hi-bi fiber. The separation between the wavelengths in our laser is 0.98 nm. Both wavelengths were situated around the maximum of the FOLM reflection. The dual or single wavelength operation is obtained by changes of temperature by the order of 10^{-1}°C.

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[1] The article is published in the original.

2. EXPERIMENTAL RESULTS

The laser 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, a 10-m EDF, two FBGs and an optical attenuator (OA). The FBG1 has 55.4% maximum reflection at 1547.94 nm; the FBG2 has 59.75% maximum reflection at 1546.96 nm. The OA is obtained through curvature loss in a section of the fiber wounded over approximately 6 turns with a diameter of curvature of 5-cm. The number of turns was found experimentally to equalize roughly the loss of the cavity for the wavelengths corresponding to the FBG maxima. The fine loss adjustment is achieved by the FOLM. The EDF is pumped through a 980/1550 WDM coupler by a 50-mW laser diode. The coupler 1 with the 90/10 coupling ratio is used as the laser output. Only wavelengths reflected from FBG1 and FBG2 can be detected at this output. The output radiation was launched to a monochromator with the resolution of 0.2 nm, detected by a photodetector and monitored on an oscilloscope. The coupler 2 with the 50/50 coupling ratio is used to detect the light transmitted through FOLM. Both laser wavelengths and ASE can be detected at the output A.

The FOLM with the hi-bi fiber presents a periodic wavelength-dependent reflectivity. The transmission minima depends only on the coupling ratio of the coupler and are equal to $(1-2\alpha)^2$, where α is the coupling ratio of the coupler. However the transmission maxima depend on the orientation of the birefringence axes of the hi-bi fiber. To adjust the transmission maxima the fiber segments where the hi-bi fiber is spliced with a standard single mode fiber of the coupler ports were rotated to align properly the axes angles. At the best alignment the maximum transmission of the FOLM is equal to 1 if splice losses are neglected. The hi-bi fiber is placed on a cooler whose temperature can be adjusted in the range between room temperature and 9°C. The birefringence of the hi-bi fiber is highly sensitive to temperature changes which cause a shift of the FOLM reflection spectrum. An electronic control was designed to allow fine temperature adjustment with the accuracy up to 0.1°C.

We have measured the transmission of the FOLM at temperatures in the range between 9 and 20°C. Figure 2 shows the transmission of the FOLM for temperatures of 9 and 11°C that are close to the temperature of dual wavelength generation (12.1°C, details will be discussed below).

As it can be seen the transmission curve is shifted towards longer wavelengths when the temperature is decreased however the period remains equal to 20.5 nm.

The dependence of the wavelength shift on temperature is shown in Fig. 3. The wavelength shift is well fitted by a linear dependence with a slope of −1.71 nm/°C.

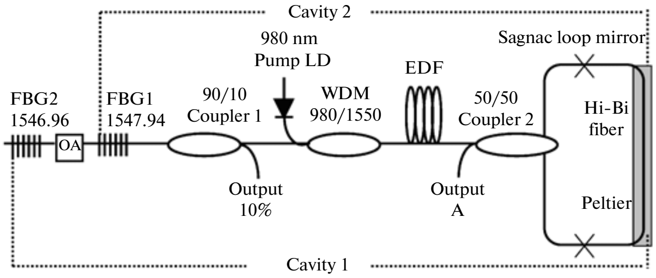

Fig. 1. Experimental configuration of the switchable dual wavelength EDF.

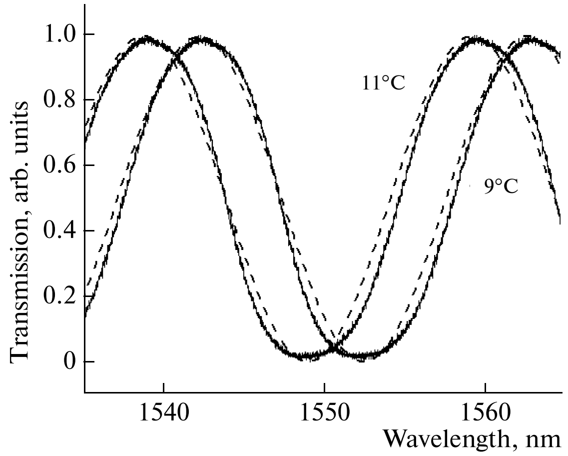

Fig. 2. Transmission of the FOLM; solid line—experimental result, dashed line—calculated transmission.

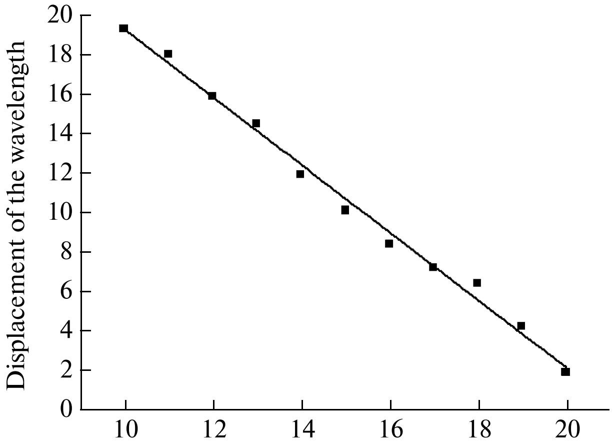

Fig. 3. Displacement of the wavelength with respect to changes of temperature.

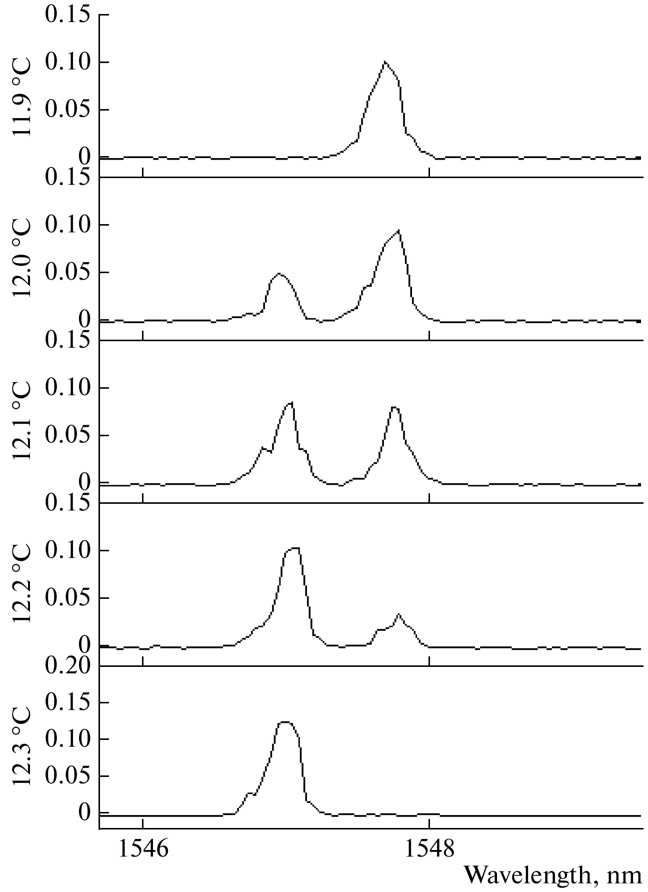

Fig. 4. Measured output spectra of the laser at different temperatures.

Figure 4 presents the spectra of the laser output at different temperatures of the hi-bi fiber in the FOLM. At the temperature of 12.1°C two peaks with equal amplitudes were observed. 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. 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 the longer wavelength at 11.9°C. The interesting feature of the proposed configuration is the possibility to determine very exactly how the ratio $R(\lambda_1)/R(\lambda_2)$ has to be changed to switch the laser from the single-wavelength operation at λ_1 to the dual wavelength operation and then to the single-wavelength operation at λ_2.

We investigate the stability of the oscillations of the dual wavelength saturation effect on the signal level in the cavity through different pumping powers acting on the EDF. In Fig. 5 we show the energy fluctuations of the lasing wavelengths with different pumping powers. Figure 5a shows the fluctuations of energy with a pumping power of 60-mW in the EDF for several measurements at intervals of 5 min. Furthermore, when the pump energy is less than 60-mW, oscillations of the dual lasing wavelength is not obtained. Figure 5b shows the fluctuations of energy for pumping powers of 60, 70, 80, 90, and 100-mW for repeated measurements every 2 min. It is noted that from 80-mW dual wavelength lasing is shared more stable.

3. CONCLUSIONS

We experimentally investigated the emission behavior of a dual wavelength EDF laser with the linear cavity formed by two FBGs and the FOLM with the hi-bi fiber in the loop. The temperature control of the hi-bi fiber allows fine adjustment of the ratio between the cavity loss for λ_1 and λ_2. Using this adjustment we were able to change the generation mode 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

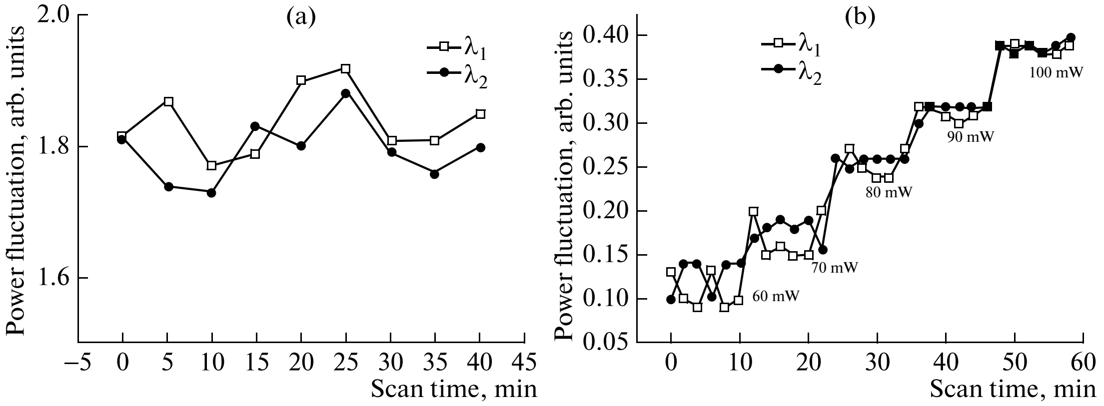

Fig. 5. Stability of the dual wavelength saturation effect through different pumping power in the EDF.

λ_2. We also investigate the power fluctuations for different pumping powers in the EDF, where we note that from 60-mW pumping begins to generate dual-wavelength and 80-mW is stabilized.

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