that a phase shift of 58.9° can be obtained with a 0–2.4-V bias range. Measurement data also shows that the ECTL has a large loss, which is caused by the imperfect silicon conductor of the highly doped p^+ region. This highly doped region also affected by the characteristic impedance of the line, which was originally designed to be 50Ω at 10 GHz.

It is also noted that in a practical device, the thickness of the silicon strip can be considerably reduced. With a thinner wafer, the negative impact of reduced effective plate height (the second effect described in the previous section), will be removed. This will result in an increased phase range with the same voltage range reported above. Also, a thinner silicon strip will require less current and therefore lower power requirements. This ECTL has potential applications for making microwave and millimeter-wave electronically controlled devices, such as phase shifters, filters, resonators, and delay lines. Our goal, which is to produce an electronically controlled beam-steered antenna, will be presented in a subsequent paper.

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TUNABLE DUAL-WAVELENGTH LINEAR-CAVITY FIBER LASER BY USING AN EXTERNAL INJECTION-SEEDING SCHEME

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ABSTRACT: *In this paper, we propose and demonstrate a tunable dual-wavelength fiber laser by using an external injection-seeding scheme with a Fabry–Perot laser diode. The wavelength tuning range of this tunable dual-wavelength fiber laser is 12.6 nm, and the optical side-mode suppression ratio (SMSR) is more than 27 dB.* © 2004 Wiley Periodicals, Inc. Microwave Opt Technol Lett 40: 406–408, 2004; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.11394

Key words: *fiber laser; multiwavelength lasing; Fabry–Perot laser diode; and tunable laser*

1. INTRODUCTION

Multiwavelength fiber lasers have attracted much interest in the areas of optical communications, fiber sensors, optical signal processing, and optical instrument testing [1–5]. However, because of the large homogeneous broadening of the erbium-doped fiber (EDF) gain medium at room temperature, it is difficult to obtain stable simultaneous lasing with close wavelength spacing. Although a great deal of research has been focused on the technique by inserting filters and variable attenuators into the EDF laser cavity for multiwavelength oscillations at room temperature [3–5], the cavity loss corresponding to each wavelength needs to be balanced carefully in such arrangements. As a result, the lasing wavelengths are difficult to be controlled.

The Fabry–Perot laser diode (FPLD) for constructing an external injection-seeding scheme with a fiber Bragg grating has been proposed to generate a multiwavelength laser source [6–7]. In this paper, we demonstrate a novel and simple configuration of a tunable dual-wavelength fiber laser using a FPLD. The dual-wavelength output is implemented via the optical feedback control of the FPLD. The dual-wavelength output can be tuned flexibly by adjusting the tunable bandpass filter. Furthermore, in contrast with the conventional setup, our proposed scheme is easy to construct and low cost. The performance of the tunable dual-wavelength linear-cavity fiber laser operated at the optimal driving condition is reported. We also discuss the relationship between the FPLD driving current and the side-mode suppression ratio (SMSR).

2. EXPERIMENTAL SETUP

Figure 1 shows the proposed configuration of the tunable dual-wavelength fiber laser using an FPLD. In our experiment, the fiber laser consists of an EDF amplifier, an FPLD, a tunable bandpass filter (TF), and a fiber-loop mirror. The fiber loop mirror is used to construct an external linear cavity to provide feedback to the FPLD. The coupling ratio of the 2 × 2 coupler (C1) for the fiber loop mirror is 30:70. The lasing light emerging from this 2 × 2 coupler is obtained using a optical spectrum analyzer (OSA). A 980-nm laser diode (LD) pumps the EDF via a 980/1550-nm wavelength-division multiplexer (WDM) coupler. In addition, the EDF amplifier provides a 14-dB small-signal gain. The average 3-dB bandwidth of the tunable bandpass filter is 0.37 nm and its

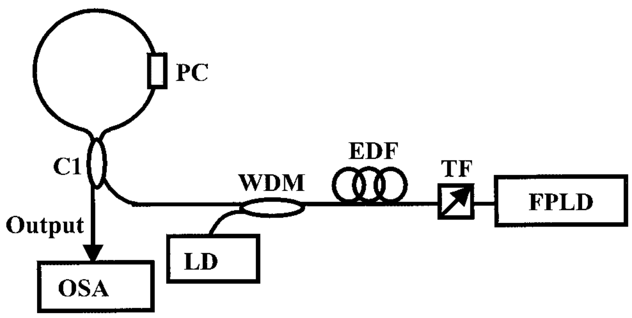

Figure 1 Experimental setup of the tunable dual-wavelength fiber laser with an FPLD (EDF: erbium-doped fiber, TF: tunable bandpass filter, WDM: 980/1550-nm WDM coupler, LD: 980-nm laser diode, FPLD: Fabry–Perot laser diode, C1: 2 × 2 coupler, PC: polarization controller, OSA: optical spectrum analyzer)

average insertion loss is 3.42 dB in the 1530–1560-nm wavelength region. The FPLD is biased at 28 mA and the temperature is set at 22°C. The central wavelength and mode spacing of this FPLD are 1547.94 nm and 0.78 nm, respectively. The threshold current of the FPLD is 18.5 mA.

3. RESULTS

The optical spectra of the fiber laser with the central wavelengths of the tunable bandpass filter located at 1548.68, 1549.07, and 1549.46 nm are shown in Figure 2 (a)–(c), respectively. The driving current is 28 mA. When the central wavelength of the tunable bandpass filter is close to one of the wavelengths of the FPLD lasing modes, the output of the FPLD is limited to this specific wavelength. Hence, the fiber laser only performs in single-wavelength operation, as shown in Figure 2(a) and (c). The SMSR of the single wavelength operation is 38 dB. Dual-wavelength output is observed when the central wavelength of the tunable bandpass filter is tuned approximately to the center of two of the FPLD lasing modes, as shown in Figure 2(b). The SMSR of the dual-wavelength operation is 29 dB. Figure 3(a) shows the output spectrum when the FPLD is biased at a 40-mA driving current. In this case, the SMSR is 27.5 dB. When the FPLD driving current is 50 mA, the SMSR is 26 dB, as shown in Figure 3(b). The optimal SMSR for the dual-wavelength output occurs when the FPLD is biased at 28 mA. As shown in Figure 4, this dual-wavelength fiber laser output exhibits good SMSR performance at more than 27 dB, and the wavelength tuning range, which is limited by the gain spectrum of the FPLD, is 12.6 nm. Nevertheless, we can assign the central wavelengths of different FPLDs to select the tuning range for practical application.

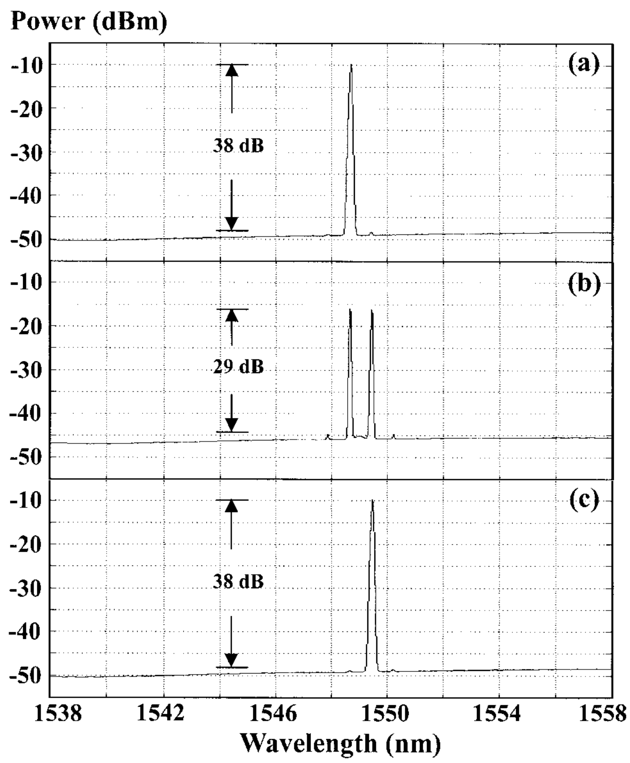

Figure 2 Output spectra of the fiber laser with the central wavelength of the tunable bandpass filter at (a) 1548.68 nm, (b) 1549.07 nm, and (c) 1549.46 nm, and the FPLD biased at 28-mA driving current

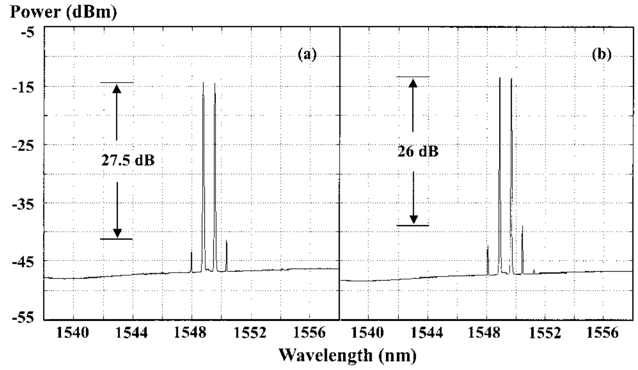

Figure 3 Output spectra of the tunable dual-wavelength fiber laser with FPLD biased at (a) 40-mA driving current and (b) 50-mA driving current

4. CONCLUSION

To summarize, we have proposed a novel and simple scheme of a tunable dual-wavelength fiber laser. This tunable dual-wavelength output is implemented by using a self-seeded FPLD. A tunable bandpass filter is used within the linear cavity to select the lasing wavelength. Because of the FPLD self-seeded mechanisms in

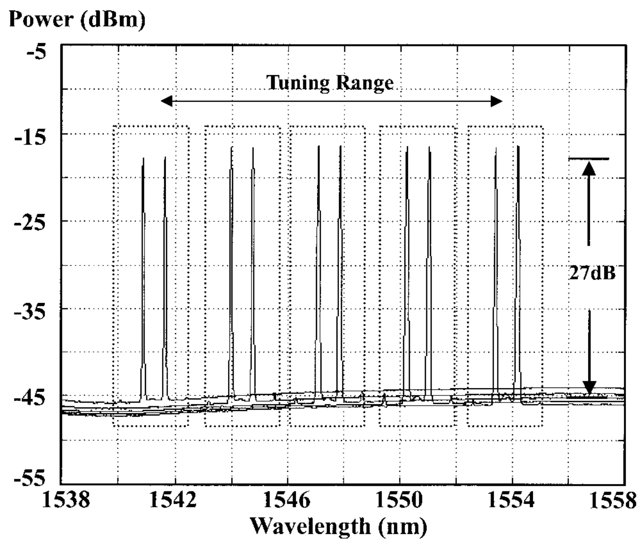

Figure 4 Output spectra of the tunable dual-wavelength linear-cavity fiber laser with FPLD biased at 28-mA driving current

combination with the tunable filter function, the linear-cavity fiber laser can stably lase two wavelengths simultaneously and can be easily tuned dynamically. The relationship between the FPLD driving current and the SMSR of this dual-wavelength laser were also discussed.

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ENHANCEMENT OF BRILLOUIN STOKES POWERS IN MULTIWAVELENGTH FIBER LASER UTILIZING BAND-PASS FILTER

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ABSTRACT: *We report an increased number of stokes when used with a band-pass filter in multiwavelength Brillouin erbium-doped fiber laser (BEFL). A total of 15 Stokes were achieved as compared with seven in a system without the band-pass filter. The efficiency of generating Brillouin Stokes improved due to the suppression of out-of-band amplified spontaneous emission in the BEFL. The band-pass filter provides a specific range of lasing window that coincide with the Brillouin pump signal. The flatness of the Brillouin stokes is also improved in the proposed design.* © 2004 Wiley Periodicals, Inc. Microwave Opt Technol Lett 40: 408–410, 2004; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.11395

Key words: *fiber laser; Brillioun scattering; multiwavelength fiber laser*

INTRODUCTION

Despite the detrimental effect of stimulated Brillouin scattering (SBS) in long-distance optical communications [1, 2], SBS has found applications in many areas, such as selective carrier amplification [3], distributed fiber-optic temperature sensing [4], char-

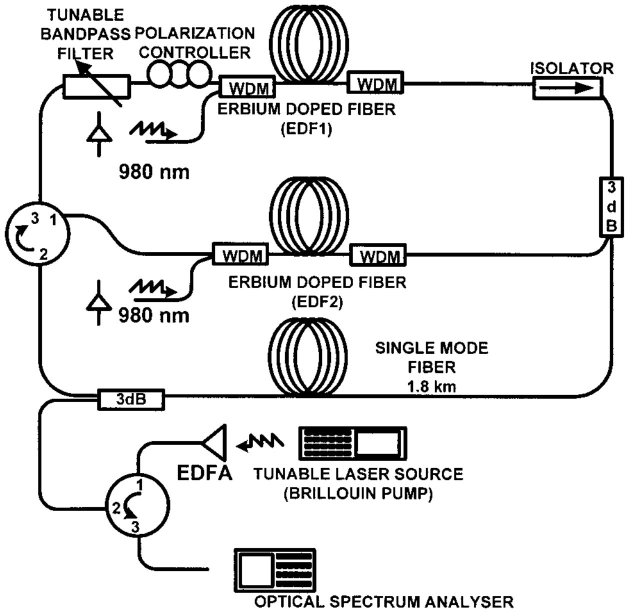

Figure 1 BEFL with band-pass filter

acterization of fiber optic strain [5], and Brillouin fiber lasers (BFLs) [6, 7].

Research on BFLs has been going on for some time, beginning with its first report in [8]. BFL requires a critically coupled resonator and cavity matching of the pump signal in order to achieve efficient operation. These stringent requirement can be overcome by using a hybrid ring laser, which combines Brillouin and erbium-doped fiber (EDF) gain [9], known as Brillouin/erbium fiber laser (BEFL). By combining both gains, the fiber laser will have some properties of BFLs, but the gain from the EDF will allow significant output powers to be achieved. Further improvement on this configuration allows for the generation of multiwavelengths output from the fiber laser. While research in this field has been concentrated to produce the highest number of stoke lines, to our best knowledge, no one has studied the inclusion of a band-pass filter within the multiwavelength BEFL setup.

In this paper, we investigate the effect of a tunable band-pass filter with respect to the number of Stoke lines generated by the BEFL. The effect of amplified spontaneous emission can be suppressed by the band-pass filter and, therefore, the competition of lasing modes can be reduced.

EXPERIMENTAL SETUP

The configuration of the BEFL used in our experiment is illustrated by the experimental setup shown in Figure 1. The laser system comprises of two 3-dB couplers, which redirect a portion (50%) of the BEFL signal to the internal cascaded cavity within the laser ring and re-inject a portion of the signal back to the outer laser ring. A 980/1550-nm wavelength division multiplexer is used to allow pumping of 980-nm DFB lasers to the EDFs and to "dump" the residual 980-nm signal from the EDFs. The length of EDF1 is 8 m with an Er^{3+} ion concentration of 440 ppm used as the gain medium. The approach adopted by Nam Seong Kim [10] to enhance the number of Stokes through the inclusion of a second EDF (EDF2) within the feedback loop of the main BEFL ring is also deployed in the proposed system. The length of EDF2 is 12 m from the same type of EDF mentioned above. A spool of 8.8-km single-mode fiber (SMOF) is included in the laser ring to produce the Stoke-shifted signal, which provides a frequency shift of ap-