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Stable and wavelength-tunable RSOA- and SOA-based fiber ring laser

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ABSTRACT

In this work, we propose and experimentally investigate a wavelength-tunable fiber ring laser architecture by using the reflective semiconductor optical amplifier (RSOA) and semiconductor optical amplifier (SOA). Here, the wavelength tuning range from 1538.03 to 1561.91 nm can be obtained. The measured output power and optical signal to noise ratio (OSNRs) of the proposed fiber laser are between -0.8 and -2.5 dBm and 59.1 and 61.0 dB/0.06 nm, respectively. The power and wavelength stabilities of the proposed laser are also studied. In addition, the proposed laser can be directly modulated at 2.5 Gbit/s quadrature phase shift keying-orthogonal frequency-division multiplexing (QPSK-OFDM) signal and 20–50 km single-mode fiber (SMF) transmissions are achieved within the forward error correction (FEC) limit without dispersion compensation. It could be a cost-effective and promising candidate for the standard-reach and extended-reach wavelength division multiplexed passive optical network (WDM-PON).

1. Introduction

Wavelength-tunable fiber lasers are important components for different applications, such as wavelength division multiplexed (WDM) fiber communication, optical sensor, optical instrument and equipment testing [1,2]. In general, the fiber lasers are consisted of wavelength selective elements (optical filters) and optical gain media [3–6] . The architecture of fiber lasers can be in linear or ring types [7,8]. Erbium-doped fiber amplifier (EDFA) [9], Raman amplifier (RA) [10], semiconductor optical amplifier (SOA) [11], reflective semiconductor optical amplifier (RSOA) [6], and hybrid optical amplifier [12] could also be used inside the cavity acting as gain medium for lasing. In order to achieve wavelength selectivity in fiber lasers, the fiber Fabry–Perot filter (FFPF), tunable bandpass filter (TBF), and fiber Bragg grating (FBG) were utilized inside the fiber cavity. However, due to the limited gain bandwidth of the amplifiers, the output power would drop rapidly in both sides of gain bandwidth [3,7,8].

In this work, a stable and continuous wavelength-tuning ring laser scheme using a C-band RSOA and a C-band SOA in the wavelength-tuning range of 1538.03–1561.91 nm is proposed and demonstrated. Using OFDM as the upstream data transmitters have been investigated in [13,14]. In [13], a centralized optical carrier was distributed from the optical line terminal (OLT) to the user optical networking unit (ONU). This scheme suffers from Rayleigh backscattering. In [14], high capacity upstream OFDM signal was achieved by modulating four individual distributed feedback (DFB) lasers located at the ONU. However in this scheme, the four wavelengths emitted by the DFB lasers were fixed, and the tunability was limited by thermal tuning. Hence, it cannot achieve colorless operation. Here, we proposed a cost-effective and widely tunable OFDM laser system. Here, the output powers in the wavelength range are between −0.8 and −2.5 dBm (power difference $\Delta P = 1.7$ dB). Besides, in the proposed fiber laser scheme, the output powers in the both sides of lasing range could not drop rapidly. The measured optical signal to noise ratio (OSNR) is between 59.1 and 61.0 dB. Finally, to characterize the stability and the transmission performance of proposed fiber ring laser, a 2.5 Gbit/s quadrature phase shift keying-orthogonal frequency-division multiplexing (QPSK-OFDM) signal is applied in RSOA of the proposed laser for directly modulation. The power penalties of 0.2 and 1 dB are observed at the bit error rate (BER) of 3.8×10^{-3} after 20 and 50 km single-mode fiber (SMF) transmissions, while the RSOA is operated at 80 mA, showing that the proposed ring laser could be a cost-effective and promising candidate for the standard-reach and extended-reach wavelength division multiplexed passive optical network (WDM-PON).

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2. Experiments and results

Fig. 1 shows the experimental setup of proposed wavelength-tunable fiber ring laser. The proposed fiber laser is consisted of a C-band SOA, a C-band RSOA, a 3-port optical circulator (OC), a 1×2 optical coupler (CP), a polarization controller (PC), and a C-band tunable bandpass filter (TBF). The SOA used is commercial available (GIP, OAU116BB128001A). Its gain is around 9 dB. In this measurement, the SOA is fixed at 120 mA pumping current and the bias current of RSOA is operated at 50, 60 70 and 80 mA respectively. Here, the TBF is used inside a ring cavity for wavelength tuning. The 3-dB bandwidth, tuning range and insertion loss of TBF are 0.4 nm, 30 nm (1530–1560 nm) and ~6 dB, respectively. Furthermore, the OC inside the fiber loop could result in the counter-clockwise signal propagation. The PC is used to adjust the polarization status for maintaining the maximum output power. To observe the tuning wavelength and output power of proposed fiber laser, an optical spectrum analyzer (OSA) and power meter (PM) are used respectively. The resolution of the OSA is 0.06 nm. As shown in Fig. 1, a ring laser cavity is formed, in which the gain media are the SOA and RSOA. The TBF selects the desired wavelength within the gain bandwidth of the SOA. Then the signal will launch into the RSOA, which is modulated by data; hence the optical signal can be modulated. The OC makes sure the optical signal travels in the clockwise direction. Finally the modulated optical signal can be observed at the output port of the laser via a CP. The cavity length of the laser is estimated around 34.5 m.

Fig. 2 presents the output wavelength spectra of proposed fiber ring laser in the wavelength range of 1538.03–1561.91 nm, when the bias currents of the SOA and RSOA are 120 and 80 mA respectively. The tunability of the laser is continuous, and the wavelength tuning is performed by using the TBF. The observed peak power of lasing wavelength is between −3.9 and −2.8 dBm in this wavelength range. The observed background noise of lasing wavelength is below −61 dBm. Owing to cascading the SOA and RSOA inside the fiber cavity, the effective gain bandwidth range is enhanced and the output power of lasing wavelength in both sides of the spectrum could not drop rapidly as seen in Fig. 2. However, other schemes [3,7–8] would have a rapid drop of output power in both sides of the spectrum.

Fig. 3 shows the measured output power and OSNR in the lasing wavelengths from 1538.03 to 1561.91 nm. As shown in Fig. 3, the measured minimum and maximum output powers are −2.5 and −0.8 dBm at 1559.88 and 1541.03 nm respectively. The maximum power difference (ΔP) is 1.7 dB in the lasing wavelength range. Besides, the observed OSNR could be larger than 59.1 dB in this wavelength range. The maximum difference of OSNR measured is 1.9 dB, as illustrated in Fig. 3. Besides, using the technique described in ref. [15], the relative intensity noise (RIN) of the proposed laser is -79.5 dB/Hz.

Then, a 2.5 Gbit/s QPSK-OFDM modulation format is applied onto the RSOA of the ring laser for directly signal modulation.

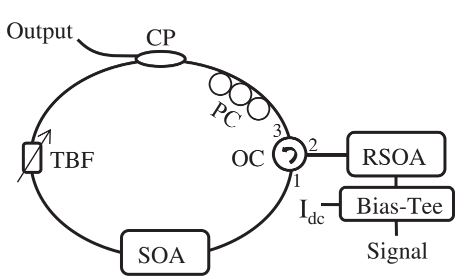

Fig. 1. Experimental setup of proposed stable and CW wavelength-tunable fiber ring laser.

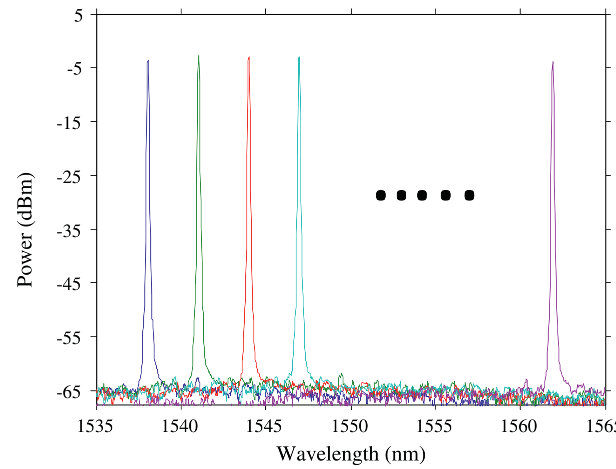

Fig. 2. Output wavelength spectra of proposed fiber ring laser in the wavelength range of 1538.03–1561.91 nm, when the bias currents of SOA and RSOA are 120 and 80 mA.

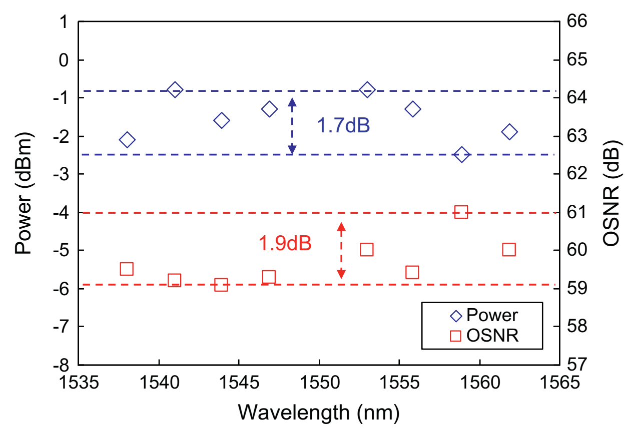

Fig. 3. Measured output power and optical signal to noise ratio (OSNR) in the lasing wavelengths of 1538.03–1561.91 nm.

The RSOA is designed to have a direct modulation bandwidth of ~ 1 GHz. The QPSK-OFDM signal and the DC current are combined and applied to the RSOA via a bias-tee (BT). Here, the baseband electrical OFDM upstream signal is generated by an arbitrary waveform generator (AWG) using the Matlab® program. The signal processing of the OFDM transmitter constructs by the serial-to-parallel conversion, QPSK symbol encoding, inverse fast Fourier transform (IFFT), cyclic prefix insertion, and digital-to-analog conversion (DAC). Here, the 63 subcarriers of QPSK-OFDM format occupy ~1.25 GHz modulation bandwidth with a fast-Fourier transform (FFT) size of 128 and cyclic prefix of 1/32. Hence, a 2.5 Gbit/s total data rate is obtained. Then, the lasing wavelength signal would be direct-detected via a 9 GHz PIN receiver, and the received OFDM signal is captured by a real-time sampling oscilloscope for signal demodulation. In order to demodulate the vector signal, the off-line DSP program is employed. And the demodulation process contains the synchronization, FFT, zero forcing equalization, and QPSK symbol decoding. As a result, the bit error rate (BER) could be obtained from the measured signal-to-noise ratio (SNR).

In this measurement, the bias current of SOA is fixed at 120 mA, while the RSOA is operated at the DC bias current of 50, 60, 70, and 80 mA, respectively. The lasing wavelength is tuned at 1553.0 nm for performance testing. Fig. 4(a)–(c) show the bit error rate

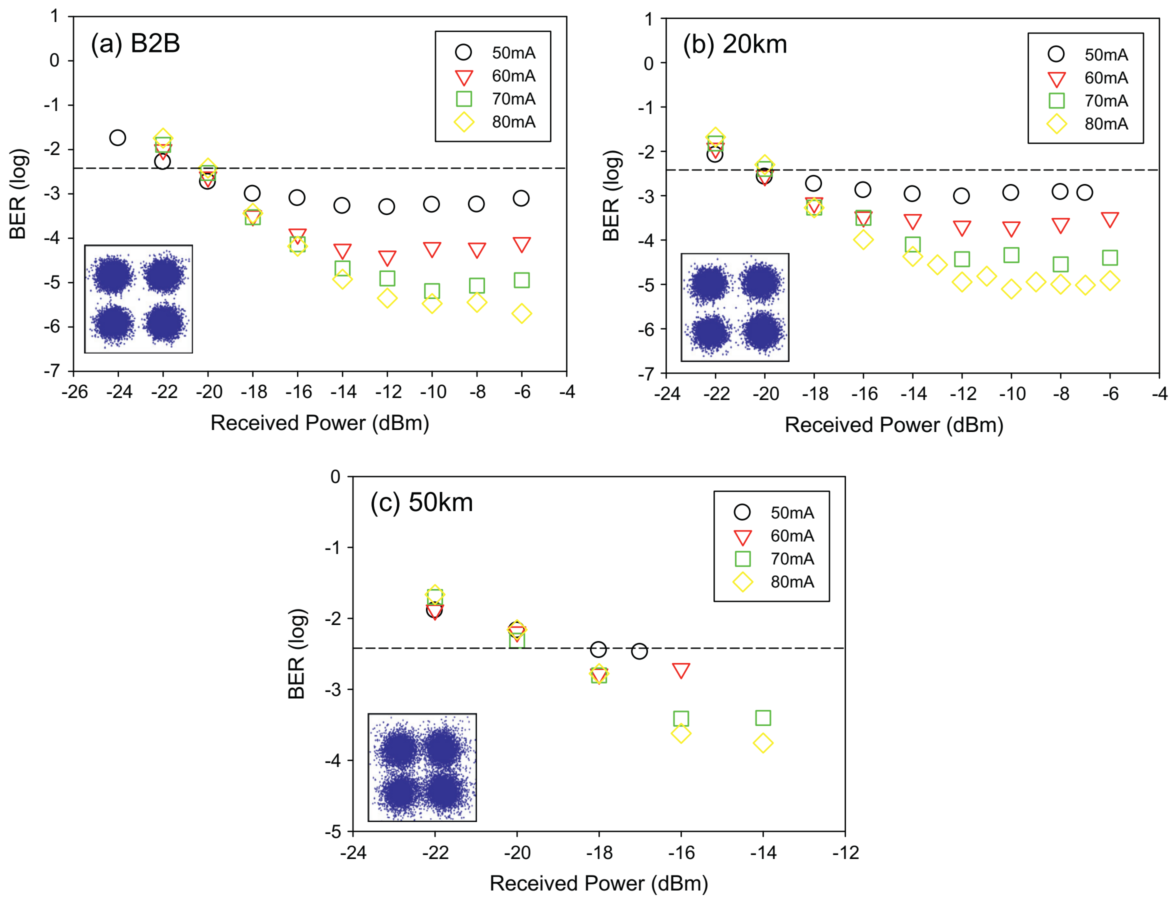

Fig. 4. BER performances of proposed laser (a) at the B2B and (b) after 20 and (c) 50 km fiber transmissions, respectively, when the RSOA is operated at 50, 60, 70 and 80 mA. And the insets are corresponding constellations at the FEC threshold.

(BER) performances of proposed laser at the back-to-back (B2B) status and after 20 and 50 km fiber transmissions, respectively, when the RSOA is operated at 50, 60, 70 and 80 mA. And the insets of Fig. 4(a)–(c) are corresponding constellations at the BER of 3.8×10^{-3} [the forward error correction (FEC) threshold] under the B2B and after 20 and 50 km SMF transmissions, respectively, when the SOA and RSOA are 120 mA and 80 mA. As shown in Fig. 4(a) and (b), the optical power penalties are 0.5 and 3.3 dB (RSOA@50 mA); 0.6 and 1.8 dB (RSOA@60 mA); 0.3 and 1.2 dB (RSOA@70 mA); and 0.2 and 1 dB (RSOA@80 mA), respectively, after 20 km and 50 km SMF transmissions at FEC threshold. In addition, the optical sensitivities of received powers are listed in Table 1, at the B2B and after 20 and 50 km fiber transmissions, respectively, when the RSOA is operated at 50, 60, 70 and 80 mA and SOA is fixed at 120 mA. At the B2B status and after 20 km fiber transmission, by increasing the bias current of RSOA gradually, the received powers are also increased, as shown in Table 1. However, when the bias current of RSOA is increased after 50 km fiber transmission, the optical received sensitivities could be enhanced. That is to say, the received power and penalty can be improved after 50 km fiber transmission, when the bias current of RSOA is increased to 80 mA, as seen in Table 1.

Table 1
Observed sensitivities at the B2B and after 20 and 50 km fiber transmissions, respectively, when the RSOA is operated at 50, 60, 70 and 80 mA and SOA is fixed at 120 mA.

RSOA	Sensitivity @ BER of 3.8×10^{-3}		
	B2B	20 km	50 km
50 mA	−21.3 dBm	−20.8 dBm	−18.0 dBm
60 mA	−21.0 dBm	−20.4 dBm	−19.2 dBm
70 mA	−20.6 dBm	−20.3 dBm	−19.4 dBm
80 mA	−20.3 dBm	−20.1 dBm	−19.3 dBm

3. Conclusion

We have proposed and demonstrated a stable and continuous wavelength-tuning ring laser scheme using the C-band RSOA and C-band SOA in the wavelength-tuning range of 1538.03–1561.91 nm. Here, the output powers in the wavelength region were obtained between −0.8 and −2.5 dBm (ΔP = 1.7 dB). Moreover, utilizing the proposed fiber laser scheme, the output powers in the both sides of lasing range could not drop rapidly. And the measured OSNR was between 59.1 and 61.0 dB. Furthermore, to characterize the lasing wavelength performance of proposed fiber ring laser, a 2.5 Gbit/s QPSK-OFDM signal was applied in RSOA for directly modulation in SMF transmissions of 20–50 km. According to the different fiber transmission lengths, the RSOA could be operated at various bias currents for signal propagation. When the fiber transmissions were short-reach (∼20 km) and long-reach (∼50 km), the RSOA could operate at the bias current 50 and 80 mA, respectively. Therefore, the power penalties of 0.5 and 3.3 and 0.2 and 1 dB are observed at the BER of 3.8×10^{-3} after 20 and 50 km fiber transmissions, while the RSOA was operated at 50 and 80 mA respectively.

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