Utilizing Self-Seeding RSOA with Faraday Rotator Mirror for Colorless Access Network

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ABSTRACT

In this paper, we propose and demonstrate a self-seeding 1.2 GHz RSOA-based laser by employing 3.5 Gbit/s orthogonal-frequency-division-multiplexing quadrature-amplitude-modulation (OFDM-QAM) with bit-loading algorithm for upstream traffic in a colorless WDM-PON access. To achieve 3.5 Gbit/s traffic data rate and accomplish the forward error correction (FEC) threshold [bit error rate (BER) = 3.8×10^{-3}], a Faraday rotator mirror (FRM) is used to perform self-seeding operation in this experiment. Here, the power penalty is about 2.59 dB at the wavelength of 1550.0 nm wavelength in a 20 km single mode fiber (SMF) transmission. Moreover, the measured BER performances of proposed laser are also discussed and analyzed, while the fiber mirror (FM) is used to replace the FRM in this experiment.

Keywords: Self-seeding, RSOA, OFDM-QAM, Faraday rotator mirror

1. INTRODUCTION

Over past few years, a high performance and colorless optical network unit (ONU) has been an attractive solution for cost reduction in wavelength division multiplexing (WDM)-passive optical networks (PONs). Several technologies have been proposed to realize colorless operation. One is the use of a broadband light source (BLS) at a central office (CO) spectrally sliced by the remote node then the sliced light sources were modulated at each optical network unit (ONU)[1]. A broadband light source as well as continue wave (CW) originating from a central office is fed into the ONUs to inject into Fabry-Perot laser diodes (FP-LDs)[2] or to seed into reflective semiconductor optical amplifiers[3] (RSOAs) also have been investigated. However, these schemes not only require an additional light source but also suffer dispersion, Rayleigh backscattering, and broadband amplified spontaneously emission (ASE) noise from the broadband light source to limit transmission performance[4].

Self-seeding optical semiconductor technologies by utilizing reflectors to inject into FP-LDs[5] or RSOAs[6] are potential candidates for WDM access networks due to the benefits for immunizing crosstalk from backscattering. In particular, the self-seed RSOA is functionally equivalent to a tunable laser. However, the polarization dependent gain of the RSOA is a major issue to restrict transmission performance. To solve this problem, a Faraday rotator mirror was proposed to compensate the polarization effect by implementing a reflector. The experimental results indicated the performance of the Faraday rotator mirror was beneficial in the cases of improving BER fluctuation, in the non-return-to-zero (NRZ) modulation transmission[7].

In this demonstration, we propose and experimentally examine a self-seeding 1.2 GHz RSOA-based fiber laser by utilizing a faraday rotator mirror (FRM) to act as the reflected element. And utilizing optical orthogonal-frequency-division-multiplexing quadrature-amplitude-modulation (OFDM-QAM) format with bit-loading method can achieve around 3 GHz modulation bandwidth. Here, the 3.5 Gb/s OFDM data rate could be achieved below the forward error correction (FEC) threshold [bit error rate (BER) = 3.8×10^{-3}]. In the experiment, we also replace the FRM with a fiber mirror (FM) and compare the characteristic differences of transmission performance between the FRM and the FM.

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2. EXPERIMENT AND RESULTS

The experimental configuration of the proposed RSOA-based laser is shown schematically in Figure 1. The proposed fiber laser scheme consisted of a RSOA, a tunable band pass filter (TBF), a 95:5 and 1×2 optical coupler (CP), and an optical reflector. To compare the laser performance, the optical reflector is implemented either by a Faraday rotator mirror (FAM) or fiber mirror (FM). The 95 % output port of the 1×2 CP connects to the optical reflector in the proposed RSOA laser architecture. The TBF inside the cavity is employed to select various wavelength output. Then, the output wavelength of proposed laser is out of the 5 % port of CP. Before 20 km single-mode fiber (SMF) transmission, we used an erbium-doped amplifier to amplifier the optical signal. Finally, we detected and analyzed the optical signal after a preamplifier composed of another EDFA and a variable optical attenuator (VOA). The RSOA provide the 20 dB small signal gain, less than 3 dB PDG, and 10 dBm saturated output power when the bias current of the RSOA is 70 mA. The rotation angle of the FRM is 90° ± 2° at 1550 ± 6 nm.

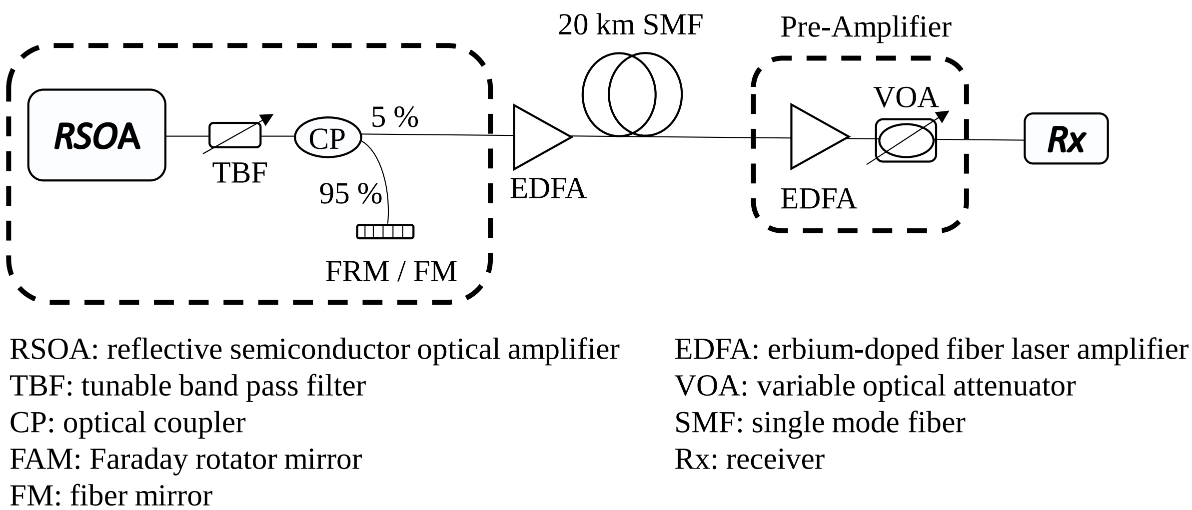

Figure 1. Experimental setup of the RSOA-based laser.

The OFDM symbol was encoded offline using MATLAB®. A serial binary stream was transformed into multiple parallel streams. Then, each parallel binary stream was mapped into specific QAM symbols. Inverse fast Fourier transform (IFFT) operation with 512 IFFT size was performed on the QAM symbols to generate the digital OFDM symbols. 1/32 cyclic prefix (CP) was inserted in each OFDM symbol to mitigate the dispersion induced performance degradation. The encoded digital OFDM symbol is transferred into an arbitrary waveform generator (AWG) and transformed into analogue electrical signal through a digital-to-analogue converter (DAC). 6 Gsample/s sampling rate and 8-bit DAC resolution was set for the AWG. 3.5 Gb/s total data rate can be achieved using bit-loading technology. A bias tee was used to combine the OFDM signal and the 70 mA direct current (DC) for directly modulating the RSOA operating at a temperature of 25 °C. At the receiver side, the optical signal was directly detected by a 10 GHz PIN photo-diode (PD) cascaded by a real-time oscilloscope with 20 Gsample/s rate for signal demodulation. The OFDM signal was decoded offline by reverse process of the encoder. The bit error rate (BER) of the signal is estimated by the QAM constellations distribution of each OFDM subcarrier

First, we demonstrated the stability of BER fluctuation by implementing the reflector by means of the Fiber Mirror and the Faraday rotator mirror. We set the received power at the input of pre-amplified receiver to –14 dBm, in order to ensure a minimum BER, and the wavelength was selected at 1550 nm by tuning the TBF. Figures 2(a) and 2(b) shows BER fluctuation during 10 minutes observing time with employing the FRM and the FM in the back-to-back (B2B) and after 20 km SMF transmission. As seen in Fig. 2(a), the average BER for using both the FAM and the FM were realized below the FEC threshold in the B2B transmission, but the BER changes dramatically between 10^{-2} and 10^{-4} in the situation of using the FM. In the 20 km fiber transmission, the average BER remains below the FEC threshold only in the situation of using the FRM and the BER oscillates slightly around within 10^{-3} as shown in Fig. 2(b). We could observed that the BER fluctuations are reduced both frequency and magnitude by implementing the FRM in the both B2B and 20 km SMF transmission. This behavior also can be indicated by comparing the OFDM constellation diagrams with bit-loading as shown in Figure 3.

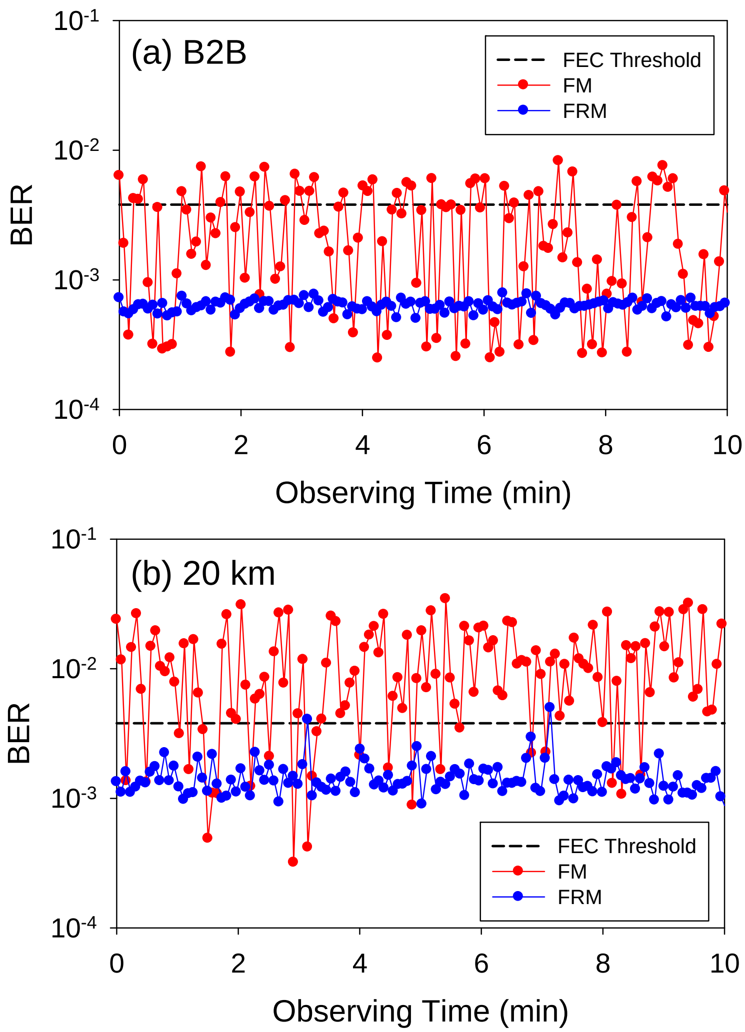

Figure 2. BER fluctuation during 10 minutes observing time with employing the FRM and the FM in the (a) back-to-back (B2B) and (b) 20 km SMF transmission.

Figure 4 reports the average BER as a function of received power for the wavelength at 1550 nm in the B2B and 20 km SMF transmission. We observed the BER could not achieve below FEC threshold in the case of utilizing FM as the reflector in the 20 km SMF transmission and the power penalty was about 2.59 dB in the case of using FRM at 1550 nm.

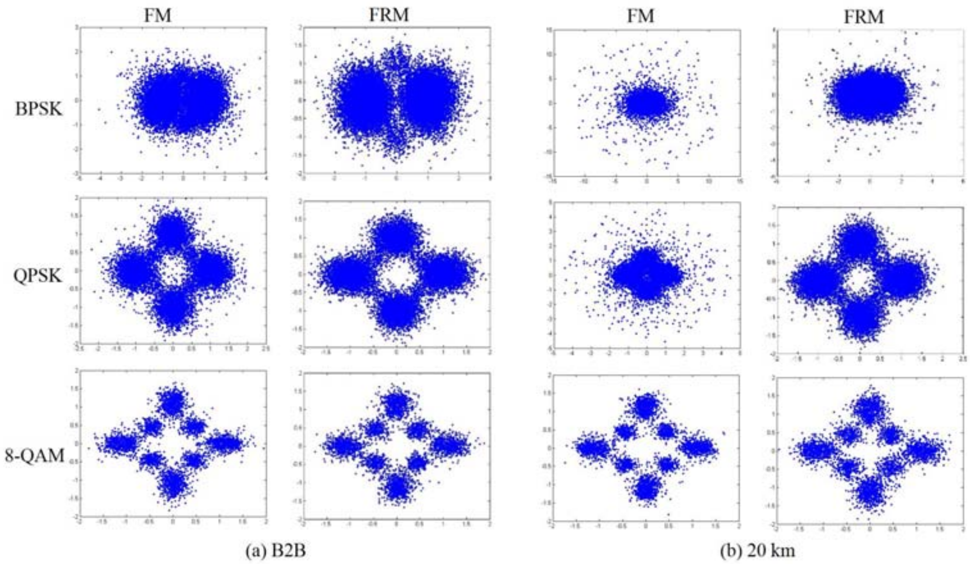

Figure 3. The OFDM constellation diagrams with bit-loading in the (a) B2B and (b) 20 km SMF transmission.

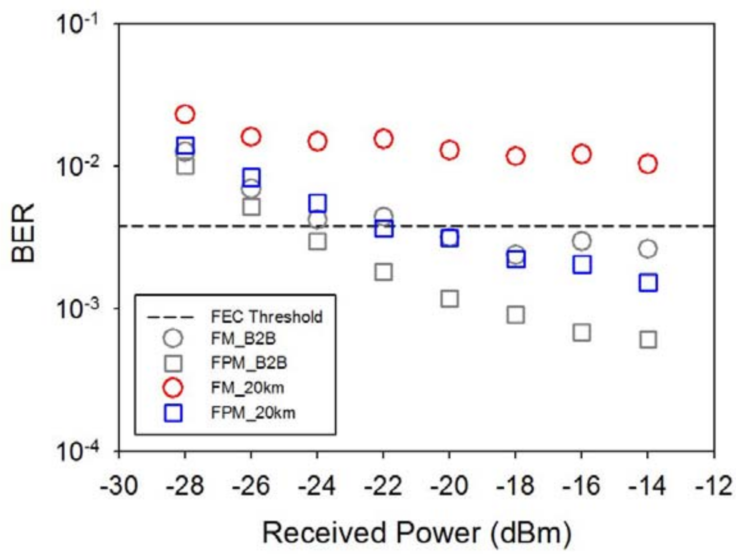

Figure 4. The average BER measurement of self-seeding RSOA-based laser by implementing a reflector by means of FRM and FM at 1550 nm in the B2B and 20 km fiber transmission.

Due to the fact that the polarization rotation for the Faraday rotator mirror is 90° ± 2° at 1550 ± 6 nm. We selected six channels at 1542.5 nm, 1545 nm, 1547.5 nm, 1550 nm, 1552.5 nm, and 1555 nm of the proposed laser without fiber transmission. The optical signal for the six channels are detected at the 5 % output of the CP and are analyzed by an optical spectrum analyzer (OSA) with 0.1 nm resolution bandwidth (RBW) and −80 dBm sensitivity, as shown in figure 5. The output power variation of proposed RSOA laser is measured within 0.48 dB among the six channels. Here, we examined the BER over 10 minutes by setting the receiver power at −14 dBm in order to achieve an average BER below 3.8×10^{-3} (FEC threshold). Then we computed the BER fluctuation defined as the standard deviation of sampled BER normalized the average BER value for each channel. The experiment results indicate the BER fluctuation is tending down around 1550 nm and a maximum value is 0.42 at 1542.5 nm. The results are reported in Figure 6.

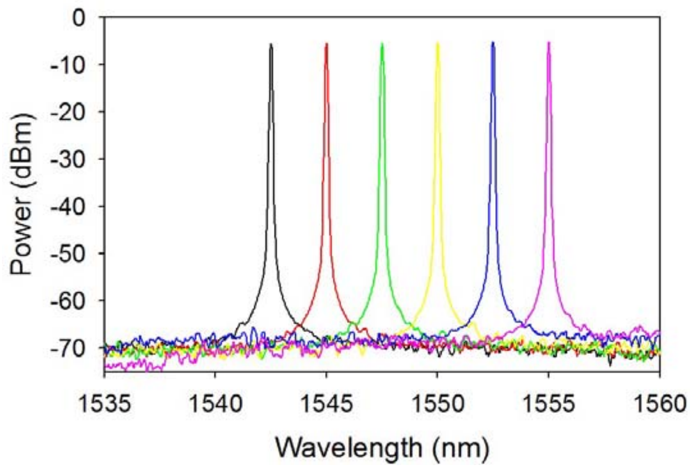

Figure 5. The optical spectra for the proposed self-seeding RSOA-based laser at 1542.5, 1545, 1547.5, 1550, 1552.5 and 1555 nm.

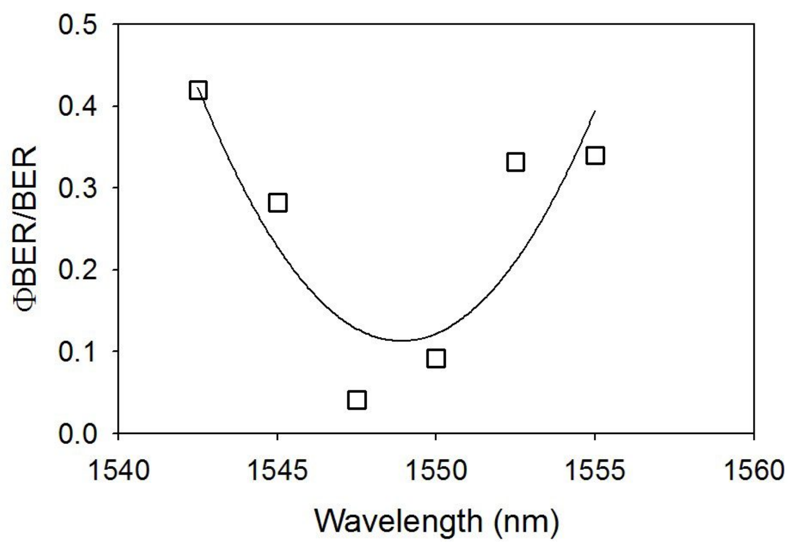

Figure 6. Stability at 1542.5, 1545, 1547.5, 1550, 1552.5 and 1555 nm.

Finally, we further investigated the performance for the different wavelength of the proposed self-seeding RSOA-based laser by implementing 20 km SMF transmission. We observed that the power penalty is larger at the 1542.5 and 1550 nm, but smaller around 1550 nm. As indicated in Figure 7, the maximum value and minimum values for the power penalty are 8.77 and 0.01 dB at 1542.5 and 1552.5 nm, respectively. It is worth that when the tuning wavelength of the proposed fiber laser exceeds the range between 1542.5 and 1555 nm, the average BER could not achieve below the FEC threshold after 20 km SMF transmission, the same as using the reflector by means of FM. As we mention before, the Faraday rotator mirror was design to rotate the polarization at 1550± 6 nm. When we operate out of the polarization match range which leads to polarization mismatch and fails to achieve FEC threshold after 20 km transmission just like using the FM. We believe the whole C-band could be achieved 3.5 Gb/s OFDM transmission by using a FRM provided 90° rotation in the C-band.

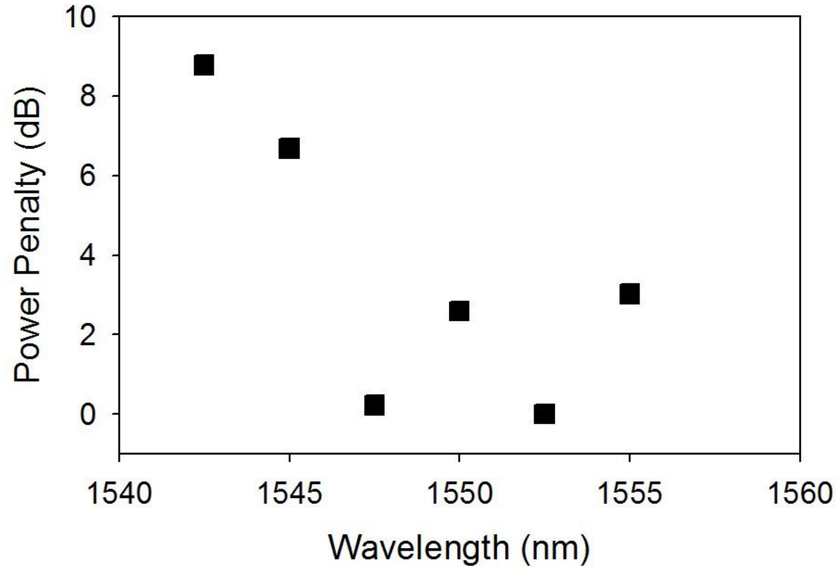

Figure 7. Power penalty as function of wavelength.

3. CONCLUSION

In summary, we proposed and investigated a self-seeding RSOA-based laser for colorless access networks by implementing an optical reflector by means of a Faraday mirror. We demonstrated the BER could be achieved below FEC threshold by employing 3.5 Gb/s OFDM with bit-loading when a wavelength was selected properly by tuning TBF. We also replaced the Faraday mirror with a fiber mirror for comparing the stability of the BER fluctuation. We found the implementation of Faraday mirror was beneficial in the case of reducing the frequency and magnitude for BER fluctuation. We observed that the BER fluctuation and the power penalty depended on the wavelength due to the effective range of polarization rotation provided by the Faraday rotator mirror. We believed the whole C-band could be achieved 3.5 Gbit/s data rate transmission by employing OFDM with bit-loading when a Faraday rotator mirror (FRM) was employed for the whole C-band.

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