

14 dB Gain, 1.3 μm Diode Laser Amplifier with Reshaping Capability Using Main-Mode Suppression and Injection Technique

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Abstract- A novel and cost-effective 1.3 μm diode laser amplifier with reshaping capability using main-mode suppression and injection technique is proposed. 14-dB gain and 10-Gb/s transmission over 60-km with power penalty < 0.84 dB are achieved.

I. INTRODUCTION

High-speed transmission system in 1.3 μm operation window features zero dispersion, but suffers from link-length obstacle due to the intrinsic attenuation limit of a single-mode fiber (SMF). Such limitation is expected to be eliminated by all-optical amplification. Several 1.3 μm amplification techniques have been presented, such as praseodymium doped-fiber amplifier (PDFA) [1], semiconductor optical amplifier (SOA) [2], and Raman amplifier (RA) [3], to provide a supplementary transmission window for the present EDFA-dominant system. However, owing to the issues of device cost and stability, it is still doubtful that whether these methods will meet the requirement for field deployment in local/metropolitan area networks (LANs/MANs). Recently, 1.5 μm all-optical 2R regeneration (re-amplification and re-shaping) modules based on two-mode injection-locked (TMIL) semiconductor laser diodes [4-6] have been intensively studied. This type of regenerator usually requires extra optical amplifiers to re-amplify the signal and to compensate the loss of re-shaping. However, we find that optical amplifiers are not necessities since the two mode injection-locked semiconductor laser itself, in principle, can simultaneously act as a regenerative laser amplifier and a waveform re-shaper if main-mode suppression and injection (MMSI) technique is employed. Therefore, in this paper, we propose and demonstrate the feasibility of a new and cost-effective 1.3 μm diode laser amplifier using MMSI technique. This new optical amplifier with reshaping functionality can offer a promising alternative for short and middle haul applications.

II. OPERATION PRINCIPLE

Figure 1 depicts the conceptual diagram of the proposed 1.3 μm diode laser amplifier using MMSI technique. A DFB-LD is initially side-mode injection-locked (SMIL) by a CW light at λ_p , with its free-running main mode highly suppressed, which may enhance the relaxation oscillation frequency (ROF). When a degraded signal S_{in} at wavelength λ_s , which has a power level exceeding the injection-locking threshold, is injected into this DFB-LD and its wavelength is fit into the locking range of the main mode, the S_{in} will be regeneratively amplified after passing through this DFB-LD. In the mean time, the mode frequencies of the DFB-LD will be red-shifted due to the carrier-induced refractive index change, which can help to pull the CW light out of the locking range and relieve the suppressing strength. If the S_{in} has the power level fallen below the injection-

locking criterion, it will experience nature loss when going through this DFB-LD. As a result, the DFB-LD by using a MMSI technique can simultaneously provide signal gain and reduce the accumulated noise over one and zero levels.

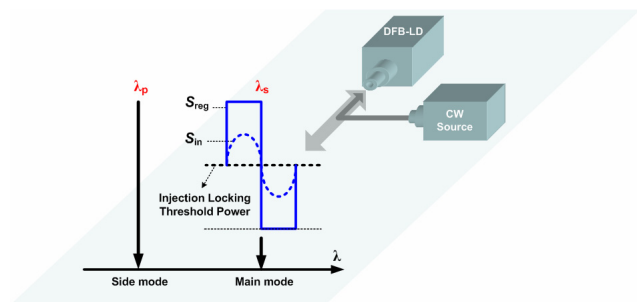


Fig. 1 Conceptual diagram of the proposed 1.3 μm diode laser amplifier using MMSI technique.

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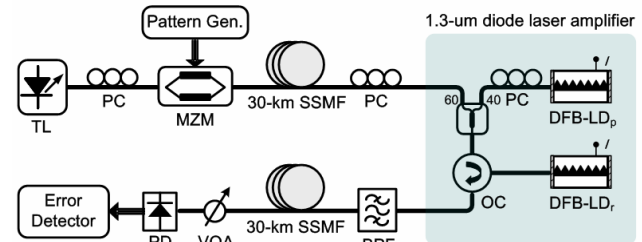


Fig. 2 The experimental setup for a 10 Gb/s straight line link over 60 km with the proposed 1.3 μm diode laser amplifier.

III. EXPERIMENTAL SETUP

Figure 2 illustrates the experimental setup for a 10 Gb/s straight line link with the proposed 1.3 μm diode laser amplifier. As shown in Fig. 2, the proposed laser amplifier was placed between two 30 km standard single-mode fiber (SSMF) spans. An optical transmitter, composed of a tunable laser (TL), a PC and a Mach-Zehnder Modulator (MZM), can emit a 10 Gb/s signal with $2^{31}-1$ PRBS test pattern at 1307.9 nm. After being transmitted over a 30 km SSMF span, the degraded signal was then fed into the proposed regenerator. This regenerator comprises an optical circulator (OC), a 60:40 coupler, a polarization controller (PC), and two DFB-LDs: DFB-LD_p, and DFB-LD_r. The DFB-LD_r was biased at 23.6 mA and had its temperature controlled at 13.64 °C to generate a main mode wavelength at 1307.9 nm. In addition, the DFB-LD_p, serving as an

external probe light source, was biased at 141 mA and 10.42°C to generate a CW light of 8 mW at 1300.8 nm. This CW light was combined with the input signal by a 60:40 coupler and injected into DFB-LD_r through OC. A thin-film CWDM bandpass filter (BPF), which has a 3 dB bandwidth of 10 nm, a central wavelength of 1311 nm, and an insertion loss of 0.35 dB, was employed at the output port of the laser amplifier to filter out the wanted signal. After signal regeneration, the output signal was propagated through another 30 km SSMF span, and transmitted to an optical receiver. To evaluate the performance of bit error rate (BER), an error detector is used after the optical receiver.

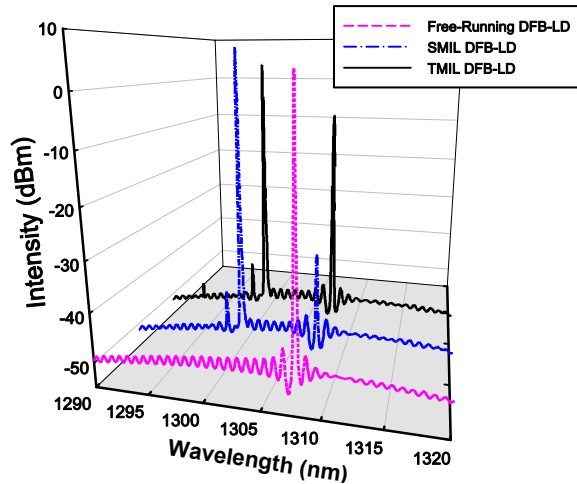


Fig. 3 The measured optical spectra of the DFB-LD_r at the port 3 of OC in Figure 2 for free-run, SMIL and TMIL operations.

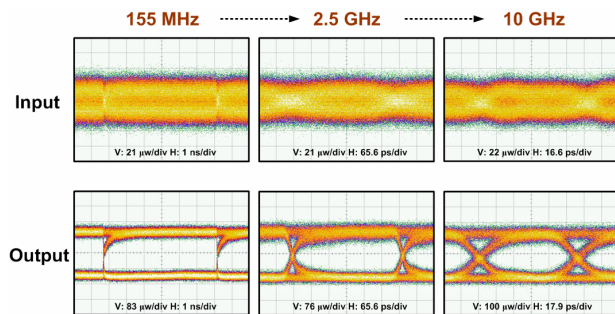


Fig. 4 Data-rate transparency up to 10 GHz of the proposed 1.3 μm diode laser amplifier.

IV. RESULTS AND DISCUSSIONS

Figure 3 shows the optical spectra of the DFB-LD_r at the port 3 of OC in Figure 2 for free-run, side-mode injection-locked (SMIL) and two-mode injection-locked (TMIL) operations. As shown in Fig. 3, the free-running DFB-LD_r had an output power of 3.91 dBm at 1307.9 nm, and a side-mode suppression ratio (SMSR) over 46.0 dB. When the SMIL is operated by injecting a 1300.8 nm CW light, the main mode peak was highly suppressed by 34.9 dB. When a 1307.9 nm signal with average power of -20.3 dBm was injected at the port 1 of OC, it was resonantly amplified up to -6.17 dBm with a reshaped waveform at port 3 of OC. This small signal gain of 14.13 dB from the port 1 to the port 3 of OC can compensate the losses of a 30 km SSMF and a 60:40 coupler. A small four-wave mixing spike at 1293.72 nm,

resulting from the beating of two mode signals, was also observed in Figure 3 for TMIL operation. Figure 4 demonstrates the data-rate transparency characteristic of the proposed 1.3 μm diode laser amplifier. The measured results indicate that the proposed regenerator can restore the eye patterns to wide-open from seriously distorted input ones for data rates from 155 MHz to 10 GHz. Figure 5 shows the 10 Gb/s bit error rate (BER) performance of the proposed 1.3 μm diode laser amplifier with reshaping capability for the experimental setup in Figure 2. The power penalties at BER = 10⁻⁹, compared with back-to-back case, were 0.47 and 0.84 dB after transmission over 30 km and 60 km, respectively. The insets illustrate the measured eye diagrams of the signal for (a) back to back, and (b) regenerated at 30 km. The inset (b) shows that the regenerated signals have extinction ratio (ER) of 10.19 dB.

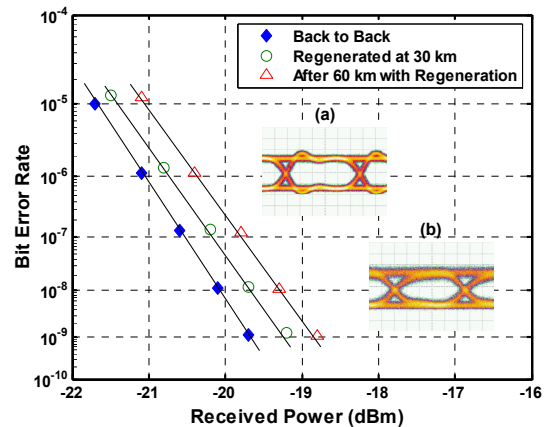


Fig. 5 BER performance of the proposed 1.3 μm diode laser amplifier at 10 Gb/s. The insets are the measured eye diagrams of the signal for (a) back to back, and (b) regenerated at 30 km.

V. CONCLUSION

This work demonstrates the feasibility of a 1.3 μm diode laser amplifier by using the main-mode suppression and injection locking (MMSI) technique. 1.3 μm regenerative amplification of 14.13 dB gain and the data-rate transparency up to 10 Gb/s have been achieved. In addition, a 10 Gb/s transmission link over 60 km with power penalty < 0.84 dB has also been demonstrated. This low cost diode laser amplifier with reshaping capabilities is promising for the future applications on short and middle haul networks.

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