

Transmission improvement of vertical cavity surface emitting lasers at 4×2.5 Gbit/s under a semiconductor optical amplifier with external light injection technique

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Abstract. A 10-Gbit/s wavelength-division-multiplexing (WDM) transport system over a 50-km single-mode fiber (SMF) transport based on vertical cavity surface emitting lasers (VCSELs) and a semiconductor optical amplifier (SOA) with an external light injection technique is proposed and demonstrated. Improved bit error rate (BER) performance is observed under direct modulation of four channels at 2.5 Gbit/s, attributed to the SOA light injection technique to reduce the SOA-induced distortion and crosstalk. © 2005 Society of Photo-Optical Instrumentation Engineers. [DOI: 10.1117/1.1849731]

Subject terms: semiconductor optical amplifier; vertical cavity surface emitting laser; wavelength division multiplexing.

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1 Introduction

Current wavelength-division-multiplexing (WDM) transport systems are composed of distributed feedback (DFB) laser diodes and erbium-doped fiber amplifiers (EDFAs) throughout a fiber link.^{1,2} Directly modulated vertical cavity surface emitting lasers (VCSELs) look promising as low-cost light sources for high-speed digital optical communication systems.^{3,4} 1.55- μm VCSELs have been selected as suitable candidates for WDM transport systems not only because the wavelength matches the low-loss window of the fiber, but also the use of an optical amplifier makes long-haul transport possible. Compared with EDFA, the use of a semiconductor optical amplifier (SOA) as an

optical amplifier is very attractive, since it can be integrated with other devices on the same substrate. In WDM transport systems with SOA, if the SOA is gain saturated, then the gain of any channel will be influenced by the intensity of other channels, causing distortion and crosstalk in the system. Thereby, it is important to reduce the distortion and crosstalk induced by the gain saturation of SOA.^{5,6} In this work, a cost-effective architecture is proposed for deployment in WDM transport systems, as demonstrated by the VCSELs and SOA with an external light injection technique. Improved bit error rate (BER) performance was observed under direct modulation of four channels at 2.5 Gbit/s (2.5 Gbit/s/ $\lambda \times 4\lambda$).

2 Experimental Setup

Figure 1 shows the experimental setup of our proposed 10-Gbit/s WDM transport system over a 50-km single-mode fiber (SMF) transport based on VCSELs and SOA with an external light injection technique. Four VCSELs (VCSEL 1 through 4) are directly modulated by a pseudorandom binary sequence (PRBS) pattern generator of $2^{23}-1$ at 2.5 Gbit/s, with 70-ps rise/fall times. Four VCSELs were selected with wavelengths of 1533.47 (λ_1), 1541.35 (λ_2), 1549.32 (λ_3), and 1557.36 (λ_4) nm, respectively. The output power level of each VCSEL was -3 dBm, at a bias current of 4.9 mA. The 3-dB roll-off was at 3 GHz. These four wavelengths are multiplexed with a WDM multiplexer (MUX) and launched into the SOA. The SOA has a maximum fiber-to-fiber gain (28.4 dB) at a bias current of 300 mA, low gain ripple (± 0.5 dB), and low polarization dependence (<1.5 dB). The light from the injection light source is injected into the SOA through a 3-dB optical coupler and a polarization controller (PC). The wavelength of the injected light is 1580 nm (λ_5) where the SOA has a small gain such that large optical power can be injected into the SOA without causing large gain reduction. After transmission over a fiber link of 50 km, the received optical signals are demultiplexed by a WDM demultiplexer (DEMUX), and detected using four digital optical receivers with 70-ps rise/fall times. The OC-48 digital signal is fed into the OC-48 BER tester for BER analysis.

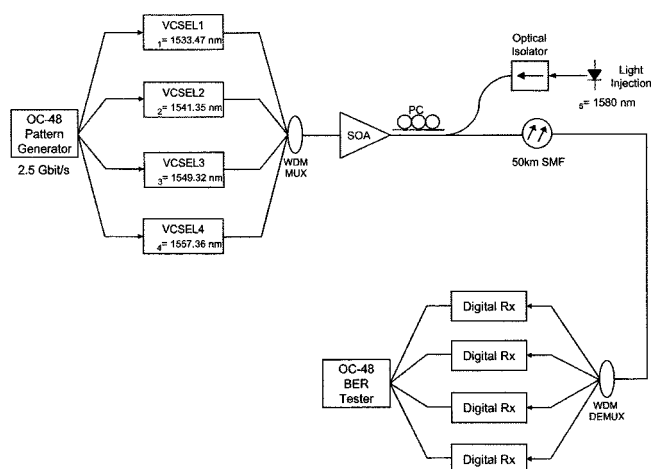


Fig. 1 The experimental setup of our proposed 10-Gbit/s WDM transport system.

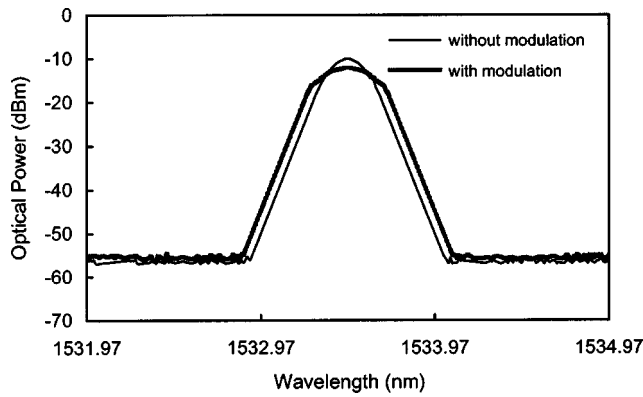


Fig. 2 The output spectra of VCSEL1 with and without 2.5-Gbit/s modulations.

3 Experimental Results and Discussions

The output spectra of VCSEL1 with and without 2.5-Gbit/s modulations are shown in Fig. 2. VCSEL1 was operated in a single longitudinal mode with a side-mode suppression (SMSR) of 45 dB, and the 3-dB linewidth was found to be about 0.21 nm. When applying a PRBS modulation of 1 V at 2.5 Gbit/s, the SMSR was reduced to 43 dB and the 3-dB linewidth was broadened to 0.34 nm.

The measured BER curves of the λ_1 channel against received optical power with and without light injection are plotted in Fig. 3. At a BER of 10^{-9} , without light injection, the received power level was -24.2 dBm; with -7 dBm light injection, the received power level was -26.6 dBm; with -3 dBm light injection, the received power level was -30.8 dBm. Improvement of 2.4- and 6.6-dB receiver sensitivities were obtained with increments of the injected light. Such improvement of the receiver sensitivity is due to the use of a light injection technique to reduce the SOA-induced distortion and crosstalk. The back-to-back BER curve is also given in Fig. 3 for comparison. At a BER of 10^{-9} , the power penalty is measured to be about 1.6 dB between the back-to-back case and the -3 dBm injection one. The difference in slope of the back-to-back BER characteristic is attributed to the fiber dispersion (17 nm/ps·km) and the chirp of directly modulated VCSELs.

The BER performance might be affected by the crosstalk from the adjacent channels; however, crosstalk effect can be reduced due to large channel spacing ($\Delta\lambda_{1,2} = 7.88$ nm, $\Delta\lambda_{2,3} = 7.97$ nm, and $\Delta\lambda_{3,4} = 8.04$ nm). With -3 -dBm light injection, we transmit a single wavelength (λ_1) only; an identical BER curve is measured (\blacktriangle). It indicates that no effect of crosstalk between channels is observed. There is no difference in BER performance for

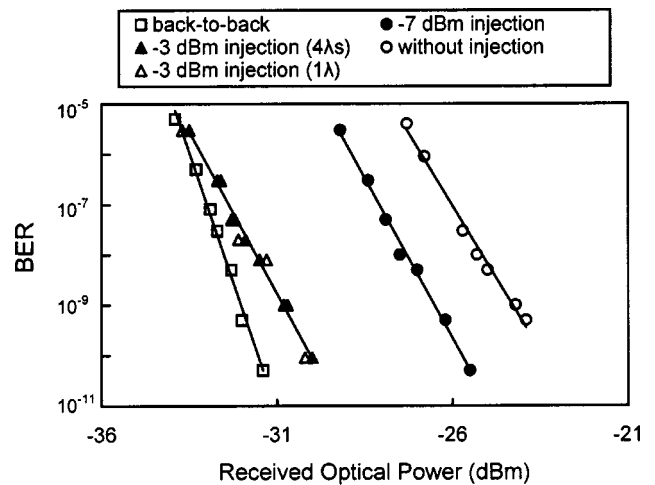


Fig. 3 The measured BER curves of the λ_1 channel against received optical power.

single wavelength or four wavelength WDM system transmission.

4 Conclusions

We propose a 10-Gbit/s WDM transport system based on VCSELs and SOA with an external light injection technique. This WDM transport system has the transmission capacity of 10 Gbit/s (2.5 Gbits/ $\lambda \times 4\lambda$) and a 1.6-dB power penalty (SOA with -3 -dBm injection) at a BER $< 10^{-9}$, compared to back-to-back transport.

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