OCDMA Light Source Using Directly Modulated Fabry–Pérot Laser Diode in an External Injection Scheme

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***Abstract*—This investigation proposes and experimentally demonstrates an optical code-division multiple-access (OCDMA) light source using a directly modulated Fabry–Pérot laser diode in an external injection scheme. This light source has an optical sidemode suppression ratio of over 27.5 dB and a pulsewidth of around 55 ps. Such a narrow pulsewidth has great potential for a two-dimensional OCDMA system. Additionally, the bit-error-rate performance with a $2^{31}-1$ pseudorandom bit sequence indicates the feasibility of this light source in a 2.488-Gb/s system application.**

***Index Terms*—Gain-switched Fabry–Pérot laser diode (FPLD), optical code-division multiple-access (OCDMA), semiconductor laser.**

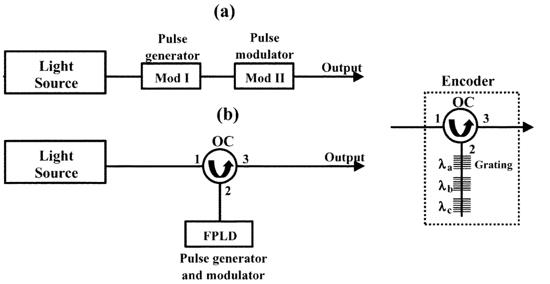

Fig. 1. Schematic diagram of (a) the general OCDMA light source and (b) the proposed light source. (Mod: electrooptic modulator. OC: optical circulator.)

I. INTRODUCTION

MULTIWAVELENGTH optical short pulse generation has recently attracted much interest because of its potential applications in wavelength-division-multiplexing, time-division-multiplexing, and optical code-division multiple-access (OCDMA) systems. The OCDMA system is an attractive technology for local access networks because of its security and privacy in transmission, asynchronous access capability, variable bit rate accommodation, and network scalability. Typical light sources for OCDMA systems may apply a multiwavelength laser or a broadband source and two electrooptic modulators: a faster one to carve the continuous wave into pulses, and a slower one to encode data, as shown in Fig. 1(a), to reduce multiple-access interference in OCDMA systems [1], [2]. However, this scheme requires precise synchronization between the pulse carving and data encoding, which is difficult to be implemented. In addition, the high cumulative loss, resulted from two consecutive optical modulators, wastes too much optical power in the passive-oriented OCDMA systems. Hence, a simple and cost-effective light source architecture for OCDMA applications is imperatively required.

A simple and economic approach to generate multiwavelength optical pulses can be achieved using a Fabry–Pérot laser diode (FPLD). OCDMA light sources using an FPLD with a fiber Bragg grating array have recently been proposed [3], [4]. Three-wavelength optical pulses with pulsewidths of around 70 ps and a sidemode suppression ratio (SMSR) of better than 20 dB were demonstrated. However, two electrooptic modulators also be used to modulate OCDMA pulses in the system [5].

This investigation experimentally studies a simple OCDMA light source using a directly modulated FPLD in an external injection scheme, as shown in Fig. 1(b). The directly modulated FPLD is used to modulate optical signal and generate optical short pulses simultaneously. The external injection of the FPLD is to assign user code by optical wavelength. Although the FPLD can be replaced by an electrooptic modulator which modulates the multiwavelength light source, the FPLD exhibits lower cost and can generate much shorter pulsewidth under gain-switching, thus increasing the time slots for data encoding in a two-dimensional OCDMA system. In this letter, the FPLD is modulated at 2.488 Gb/s in the return-to-zero (RZ) date format with a $2^{31}-1$ pseudorandom bit sequence (PRBS). The lasing wavelengths are externally injection-locked by a multiwavlength laser source. The SMSR is greater than 27.5 dB, and the pulsewidth is about 55 ps. Moreover, the pulsewidth could be further reduced by a high-speed FPLD [6].

II. EXPERIMENT AND RESULTS

Fig. 2 presents the experimental setup of the proposed system using a directly modulated FPLD. The system consists of a TO-Can packaged FPLD, a multiwavelength laser source, and an optical circulator. The TO-Can packaged FPLD is a commercially available light source at wavelength of 1550 nm with

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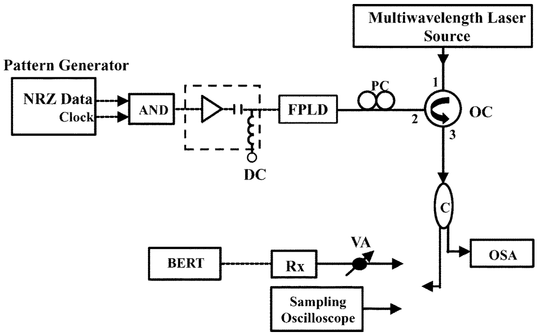

Fig. 2. Experimental setup. (C: 1 × 2 coupler. VA: variable optical attenuator. RX: optical receiver. BERT: BER tester.)

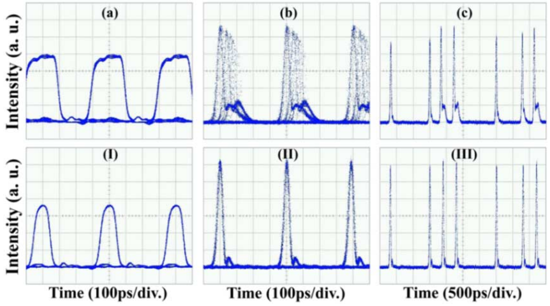

Fig. 3. Given an electrical waveform with a 200-ps pulsewidth from the AND gate: (a) eye diagram of electrical RZ data; (b) eye diagram of optical RZ data from the FPLD without laser injection; (c) specific optical data pattern from the FPLD without laser injection. Given an electrical waveform with a 100-ps pulsewidth form the AND gate: (I) eye diagrams of electrical RZ data; (II) eye diagrams of optical RZ data from the FPLD without laser injection; (III) specific optical data pattern from the FPLD without laser injection. (Color version available online at http://ieeexplore.ieee.org.)

2.5-GHz bandwidth. For short pulse generation and modulation, a 2.488-Gb/s nonreturn-to-zero (NRZ) with $2^{31}-1$ PRBS and a synchronous clock are fed into an electrical AND gate to generate appropriate electrical waveform and is then directly applied to the FPLD. The AND gate is used to convert NRZ electric signal into an RZ data format. The duty cycle of the RZ data can be adjusted at the AND gate. Fig. 3(a) and (I) shows the eye diagrams of the RZ data waveforms from the output of the AND gate with pulsewidths of 200 and 100 ps, respectively. When the FPLD is operated without laser injection and directly modulated with pulsewidths of 200 and 100 ps in the RZ data format, the corresponding optical eye diagrams are shown as (b) and (II), respectively. Fig. 3(c) and (III) presents the specific optical data patterns from the FPLD without laser injection. A longer electrical pulsewidth, namely 200 ps, output from the AND gate results in a larger amplitude and a timing jitter fluctuations at the output of the FPLD. To improve the optical outputs, a suitable electrical waveform can be employed to make the carrier density at the starting point of each bit equal [7], [8]. The narrow electrical data pulse (100 ps) can generate distortionless and even narrower optical pulses (37 ps) caused by the gain-switching mechanism. Accordingly, the FPLD is modulated with a pulsewidth of 100 ps in RZ data format to generate multiwavelength pulses.

In this investigation, the multiwavelength laser source comprises three distributed feedback (DFB) lasers and is employed as an external-injection light source to the FPLD. A polarization controller is utilized to control the polarization state of the injected light and to optimize the output SMSR. When the central wavelengths of DFB lasers are at the wavelengths of FPLD's lasing modes, optical pulses at the three injection wavelengths can be produced. The injection wavelengths are 1546.02, 1555.25, and 1564.62 nm, and the injection power at each wavelength is around −6.5 dBm in this experiment. The laser output is split by a 1 × 2 coupler (C) with a splitting ratio of 50 : 50 and an optical spectrum analyzer (OSA) and a sampling oscilloscope is applied to simultaneously monitor the optical spectrum and corresponding eye diagrams. Fig. 4 illustrates the output spectra of the directly modulated FPLD with and without laser injection. The measured worst SMSR exceeds 27.5 dB when the central wavelengths of the DFB lasers coincide at the three FPLD lasing modes. Moreover, as shown in Fig. 5, we took the BER measurements for the directly modulated FPLD with and without laser injection, where the corresponding pulsewidths are 55 and 37 ps, respectively. An additional 0.5-dB penalty is observed with longer pulsewidth due to its larger duty cycle in RZ format [9]. This system performance verifies the feasibility of the 2.488-Gb/s system using this cost-effective light source.

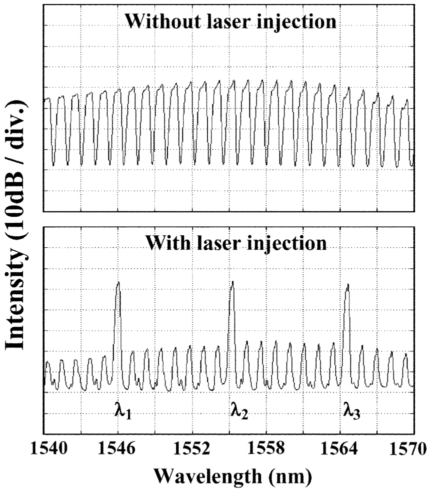

Fig. 4. Output spectra of the directly modulated FPLD without and with laser injection.

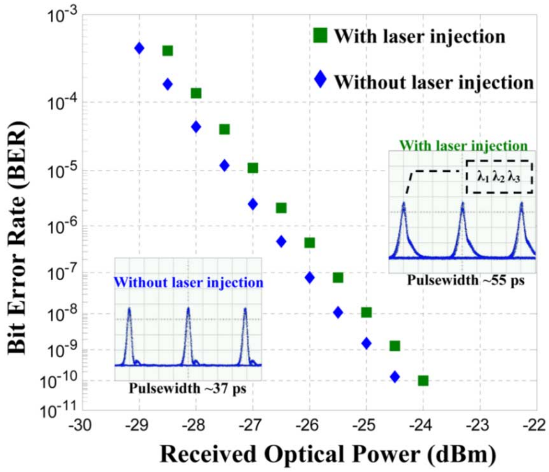

Fig. 5. BER curves from the directly modulated FPLD without and with laser injection. (Color version available online at http://ieeexplore.ieee.org.)

To further demonstrate the feasibility of such a light source in OCDMA application, we constructed an OCDMA encoding

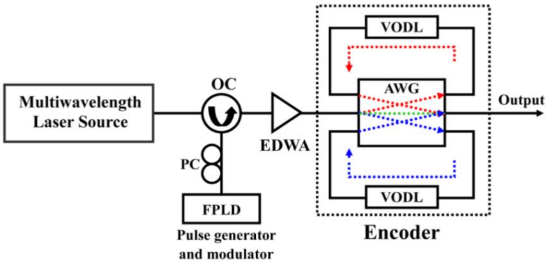

Fig. 6. Two-dimensional OCDMA encoding system using the directly modulated FPLD. (AWG: array waveguide grating. VODL: variable optical delay line. EDWA: erbium-doped waveguide amplifier.) (Color version available online at http://ieeexplore.ieee.org.)

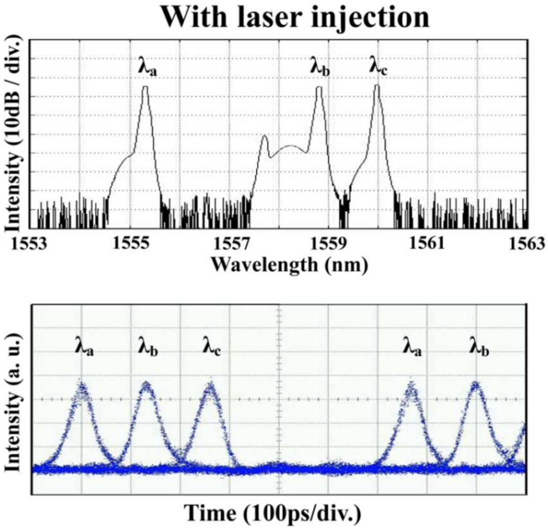

Fig. 7. Spectrum and eye diagram of the directly modulated FPLD with laser injection. (Color version available online at http://ieeexplore.ieee.org.)

system with this light source. Fig. 6 shows the two-dimensional OCDMA encoding system using the directly modulated FPLD. The two-dimensional OCDMA encoder comprises an array waveguide grating and two variable optical delay lines. Figs. 7 and 8 show the spectra and eye diagrams of the directly modulated FPLD with and without laser injection, respectively. The improvement in output performance can be seen when laser injection is employed. The eyes of different wavelengths are all clearly opened and are with equal output chip power. While without laser injection, the optical pulses have larger amplitude fluctuation due to the mode partition noise in the FPLD [10]. Since the optimized output power of the light source will greatly improve the system performance and efficiency in an OCDMA system [11], an erbium-doped waveguide amplifier in the light source not only can act as an optical amplifier but also optimize the optical power in the OCDMA network.

III. CONCLUSION

A cost-effective OCDMA light source is proposed and experimentally demonstrated. This multiwavelength pulsed light source is implemented by using a directly modulated FPLD incorporated with external laser injection. The SMSR exceeds 27.5 dB, and the pulsewidth is around 55 ps at a standard data rate of 2.488 Gb/s. Measurements of BER indicate that the developed system is appropriate for use in 2.488-Gb/s systems. The performance of the FPLD modulated used in an OCDMA encoding system is also displayed. With the combination of gain-switching and external light injection, a low-speed FPLD can possibly be employed in a two-dimensional OCDMA system.

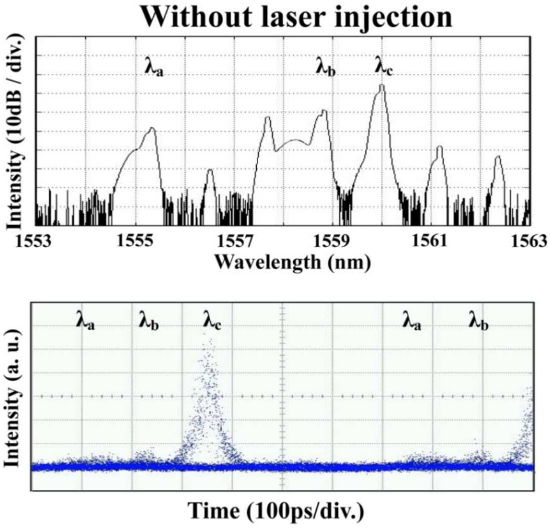

Fig. 8. Spectrum and eye diagram of the directly modulated FPLD without laser injection. (Color version available online at http://ieeexplore.ieee.org.)

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