MIX-PI: Photonic Inverter Based on a Monolithic Diode Laser with Injection Locking and Cross Gain Modulation Effects Employed

Masahiro Tsuchiya, Yutaka Takita, and Masato Kishi

Department of Electronic Engineering, the University of Tokyo, and CREST, JST
7-3-1 Hongo, Tokyo 113-8656, Japan
Tel: +81-3-5841-6679, Fax: +81-3-5841-8563, e-mail: tsuchiya@ktl.t.u-tokyo.ac.jp

It is worthwhile to explore for simple and compact optoelectronic devices having the all-optical signal regenerating and reshaping functions since it is highly advantageous to bring those functions cost-effectively into the future photonic networks. We have studied the effects of optical injection into a mode-locked monolithic laser diode (MLLD) device of dual optical modes, and found out *its digital action*, i.e. a sensitive and abrupt optical inverter action which could lead to the regenerating and reshaping functions. Indeed, its static input/output (I/O) curve exhibits extremely abrupt switching characteristics in the μW regime, which look fairly similar to those of inverters in electrical logic circuits. We also confirmed its dynamic action for a 155.52 Mb/s NRZ PRBS data stream. We named this scheme as MIX-PI (photonic inverter based on a monolithic diode laser with injection locking and cross gain modulation (XGM) effects employed) taking its phenomenological and structural aspects into consideration and believe that it is potentially attractive for practical applications in photonic networks.

The MIX-PI scheme is shown in Fig. 1 (a). Note that the inverter consists of one active device only, i.e. MLLD, besides an optical circulator and an optical band-pass filter. This configuration is exceptionally simple among photonic inverters ever reported [1-4]. Its distributed Bragg reflector bandwidth is rather narrow and, therefore, only two modes (M1 and M2) appeared at two respective wavelengths λ_1 and λ_2 in a rather asymmetric manner as shown conceptually in Fig. 1 (b). The mode spacing is approximately 36 GHz. The wavelength of the inverter input λ_{in} was set slightly shifted from λ_1 and M2 is defined as the inverter output.

Measured static I/O characteristics are shown in Fig. 2. An ideally abrupt switching action was obtained. The switching occurs abruptly in the (b) - (c) range of extremely low input power P_{in} from 5 to 7 μW, which is sandwiched by the fairly flat regions (a) - (b) and (c) - (d). The reshaping function is expected to bring about by the abruptness and the threshold power is the lowest ever reported as far as we know. One can see also that the output power P_{out} of the high level is 70 μW and 10 times higher than the threshold, indicating a possible regenerating function.

The following model and mechanisms can explain those characteristics. The flatness in the (a) - (b) region is caused by the dominant mode competition between M1 and the input. The abrupt switching feature in the (b) - (c) range can be due to the combination of injection locking and XGM; the locking of M1 to the input is established, leads to an abrupt increase of P_1 and, consequently, suppresses M2 rapidly through XGM. P_{out} is kept fairly low, almost zero, in the (c) - (d) range, which is due to the sufficient reduction of M2 gain.

We have clarified its dynamic aspect also. The measured photo-detected output data signals for 155.52 Mb/s NRZ PRBS input indicate clear opening in the eye-pattern and confirm the inverter operation at this bit rate. The frequency dependence was measured for the inverted optical bit-pattern and the measured cut-off frequency is 1.8 GHz, which is rather low and corresponds approximately to the estimated relaxation frequency of the MLLD device. We have applied this scheme to a distributed feedback laser diode with additional optical injection for the dual-mode operation and similar I/O characteristics were confirmed with a higher cut-off frequency.

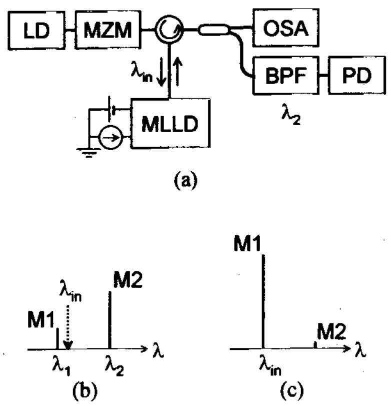

Fig. 1. (a) Experimental setup. The two states of an inverter operation, namely, high and low levels are explained by schematically drawn optical spectra in (b) and (c), respectively. M1 and M2 are lasing modes of MLLD. LD: laser diode, MZM: Mach-Zehnder modulator, MLLD: mode-locked laser diode, OSA: optical spectrum analyzer, BPF: band-pass filter, PD: photo detector, λ_1 = 1563.67 nm, λ_2 = 1563.97 nm, λ_{in} = 1564.71 nm.

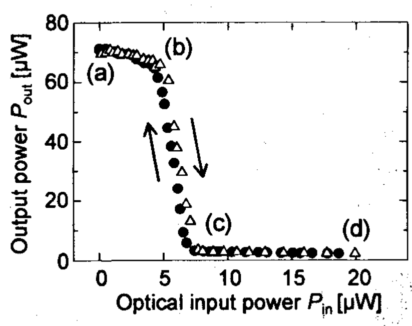

Fig. 2. Optical input/output characteristics of the photonic inverter. The axes are corrected numerically by taking account of the optical loss caused at the circulator and the fiber-laser coupling.

References

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