Investigation of switching-window in a gain-transparent UNI configuration

Lijun Li (李利军), Ming Chen (陈 明), and Ge Fan (范 戈)

State Key Lab of Advanced Optical Communication Systems and Networks,
Shanghai Jiao Tong University, Shanghai 200030

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Switching-window in an interferometric configuration of a gain-transparent ultrafast nonlinear interferometer (gt-UNI) is investigated numerically. The phase change is observed in detail. To assess the performance of switching window, the integrated contrast ratio (ICR) is introduced. For the data pulse with the bit width of 6.25 ps and with the energy of 60 pJ, respectively, the ICRs in different situations are simulated using modified nonlinear Schrödinger equation (MNLSE) considering of the carrier depletion pulsation (CDP), carrier heating (CH), and spectral-hole burning (SHB). The results show that the maximum ICR is located at the optimum position of the semiconductor optical amplifier (SOA) that is determined by the width and energy of the control pulse.

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Optical time division multiplexing (OTDM) system is the trend for terrestrial optical communication[1]. Demultiplex technique is one of the key techniques in a practical OTDM system. The all-optical switch is preferred in the demultiplexer. There are three kinds of all-optical switches based on cross-phase modulation (XPM) effect in semiconductor optical amplifiers (SOAs): the gain-transparent semiconductor laser amplifier in a loop mirror (gt-SLALOM) switch, the gain-transparent Mach-Zehnder interferometer (gt-MZI) switch, and the gain-transparent ultrafast nonlinear interferometer (gt-UNI) switch[2]. According to Schubert *et al.*[2], gt-SLALOM switch shows a considerably lower demultiplexing performance comparing to the other two switches from the point of the integrated contrast ratio (ICR) values. Toptchiyski *et al.* have investigated the switching windows in a gt-SLALOM configuration where the spectral profile of the gain through the implementation of a finite-impulse response (FIR) filter is taken into account[3]. In this letter, we investigate the switching windows in a gt-UNI configuration. Here the modified nonlinear Schrödinger equation (MNLSE) is used to get the traveling fields. One of the two assumptions we taking in this work is that in the spectral transparency region of the SOA the data signal will experience no gain and no noise, even though an overall attenuation of about 10—15 dB (depending on the injection current) was found experimentally[4]. The other one is that the nonlinear phase change at the data wavelength in the amplifier is identical to that of the control wavelength, which is supported by experiments[5].

In the gt-UNI with a copropagating control pulse the signal pulse is split into orthogonal polarization components. The signal components are combined with a control pulse via a 50/50 fiber coupler. The control pulse induces refractive index and gain nonlinearities in the SOA. Because the control pulse temporally overlaps the delayed signal component, it imparts a differential phase and amplitude modulation to the two signal components due to subpicosecond components of the refractive index and gain nonlinearities such as carrier depletion pulsation (CDP), carrier heating (CH), and spectral-hole burning (SHB). Both orthogonal signal components experience the same phase-shifts due to long-lived refractive index nonlinearities when the control pulse is not present. The difference of them is mostly determined by the control pulse when the control pulse is present. The two signal components are then recombined in birefringent fiber and are subsequently interfered in a fiber polarizer. The control pulse is filtered out using a band pass filter. A polarization controller (PC) is used to bias the interferometer by adjusting the relative phase delay of the signal components.

The switch is gated by optical control pulse. The transmittance function T_{demux} of the switching-window at demux port is defined as the ratio of the data output to the data input power[3]:

$$T_{\mathrm{demux}} = \frac{1}{4}\left(1 + \mathrm{e}^{-2b_N\Delta\Phi} - 2\mathrm{e}^{-b_N\Delta\Phi}\cos\Delta\Phi\right), \tag{1}$$

where, $\Delta\Phi$ is the phase difference of the two data signals and b_N is the fitting CDP factor. With the assumption of the attenuation neglected, the T_{demux} is simplified as

$$T_{\mathrm{demux}} = \frac{1}{2}\left(1 - \cos\Delta\Phi\right), \tag{2}$$

which is helpful to investigate the effect of the phase change.

To define a value that characterizes the performance of a switching-window, the overall shape of the switching-window has to be considered. Therefore, we introduce the ICR as

$$\mathrm{ICR} = 10\log\frac{\int_{\Delta t_{\mathrm{bit}}} T_{\mathrm{int}}(t)\mathrm{d}t}{\int_{\Delta t_{\mathrm{out}}} T_{\mathrm{int}}(t)\mathrm{d}t}, \tag{3}$$

where $T_{\mathrm{int}}(t)$ is the transmittance of the intrinsic switching window. For a data signal with a repetition frequency $V_{\mathrm{line}} = kV_{\mathrm{base}}$ (k multiplex factor), $\Delta t_{\mathrm{bit}} = 1/V_{\mathrm{line}}$ and $\Delta t_{\mathrm{out}} = 1/V_{\mathrm{base}} - \Delta t_{\mathrm{bit}}$ denote the integration periods for the switched and unwanted switched channels, respectively.

The shape of the window is affected by the phase change. The parameters of the SOA we used are the same as those of Ref. [3] and the energies of the input control pulse with the width of 6.25 ps full-width at half-maximum (FWHM) are 20, 30, 50, and 160 pJ, respectively. The phase change of the control pulse at the end of the SOA is shown in Fig. 1, where we find that the range of the phase change is approximately covered around a circle 2π, which is the essential to form a rounded switching-window with three statuses (closed, open, and then closed again). While the attenuation is small enough, the width of the window is determined by the slope of the phase change and the on-off ratio is determined by the phase change range. The sharp slope and wide phase change are preferred. So as shown in Fig. 1 the higher energy of the control pulse, the better performance of the switching-window.

From Fig. 2 we can find that there exits an optimum position in the length of SOA where the window is closed at pre- and post-sides as expected. Here the energy of control pulse is 5 pJ. The width of pulse phase change is going wide since the control pulse is amplified along the SOA. In other words, the density of pulse phase change increases due to the amplification. However, the pulse change at mid-pulse is becoming small and consequently the entirely opening position of window is moving behind.

The time shift between the control pulse and switching-window is shown in Fig. 3. With the energy of control pulse increasing, the degree of shift increases, which is due to the sharper phase change slope of higher energy. On the other hand, the range of phase change being wider along SOA causes the time shift decreasing. Ranging from 380- to 470-μm SOA, the differences of shift for control pulses with different energies (20, 50, 80, and 160 pJ) are 0.46, 0.39, 0.37, and 0.32 ps, respectively, the reason of which is that the speed of time shift is small for strong control pulse compared with the relatively weak one. This time shift should be noticed and compensated properly for OTDM demux.

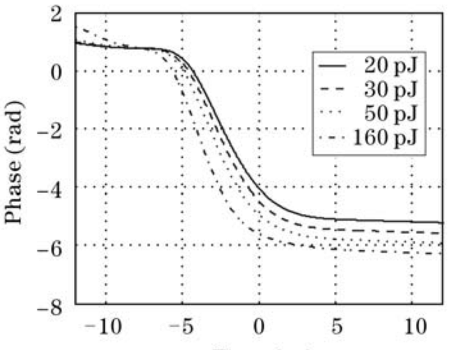

Fig. 1. Phase change of control pulse across SOA with different energies.

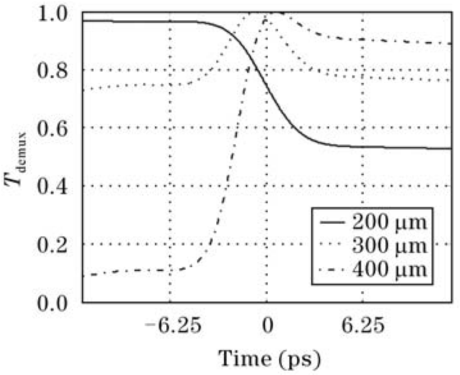

Fig. 2. Switching-windows at different position along SOA.

Nearly at the 440-μm SOA, there are maximum values of ICR for all conditions as shown in Fig. 4. The optimum position is moving up to near 440-μm SOA and the optimum ICR is raising up to 3.43 dB with the energy increasing and then shifting back again. Figure 5 shows the ICR while the width of control pulse is ranging from 4 to 12.5 ps with the energy of 60 pJ. The maximum value is also 3.43 dB when control pulse width is 10 ps at 410-μm SOA.

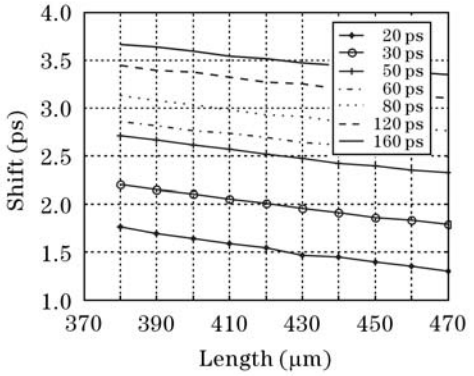

Fig. 3. The time shift between the control pulse and switching-window.

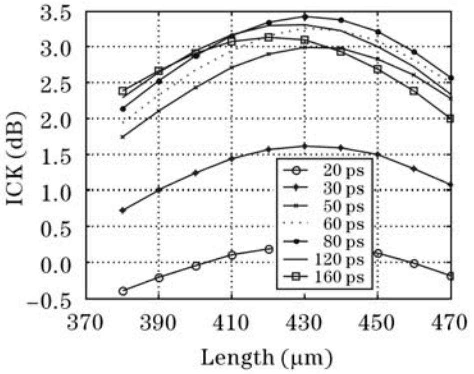

Fig. 4. Evaluation of switching windows with different control pulses for the gt-UNI.

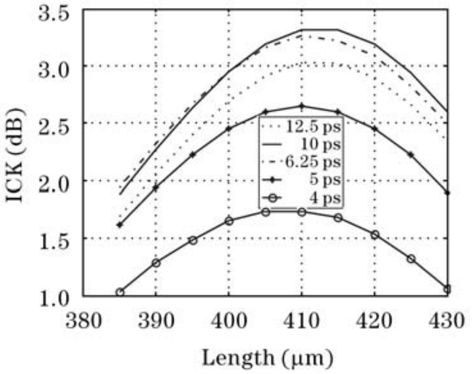

Fig. 5. Evaluation of switching windows with different control pulses for the gt-UNI.

The performance of switching-window in gt-UNI based on SOA is investigated in detail. For the control pulse of 6.25 ps the shift between the window and control pulse can reach up to several picoseconds. This significant shift can be reduced using weak control pulse. In the simulation the maximum value of ICR is 3.43 dB when the energy of control pulse is 80 pJ.

L. Li's e-mail address is llj@sjtu.edu.cn.

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