All-Optical Flip-Flop Memory by Using two coupled Polarization Switches

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An all-optical flip-flop memory with separate set and reset inputs is presented. The flip-flop is formed from two coupled polarization switches that are operated by utilizing the nonlinear polarization rotation in semiconductor optical amplifiers. The concept of the system is explained and experimental results are presented, demonstrating that a contrast ratio of over 20 dB between output states and a switching power of less than –3 dBm can be obtained. The all-optical flip-flop can be utilized in all-optical packet switches.

Introduction

All-optical packet switches have been considered as an important part for the future all-optical access node [1]. A crucial component of the all-optical packet switch is an all-optical flip-flop memory [2]. In this paper an all-optical flip-flop memory with separate optical set and reset inputs is described. Optical flip-flop memories can be realized from two coupled nonlinear optical elements. An all-optical flip-flop memory that is made from two coupled lasers is published in [3] and an all-optical flip-flop memory that is realized from two coupled Mach-Zehnder interferometers (MZIs) is presented in [4]. The last configuration allows ultra-fast operation. In this paper, we demonstrate an all-optical flip-flop memory that is made from two coupled nonlinear polarization switches. This all-optical flip-flop implementation has a simple structure, separate set and reset inputs and large input wavelength range. Moreover, this all-optical flip-flop has similar properties as the one that is based on two coupled MZIs [4]. However this implementation is easy to realize by using commercially available pigtailed components and shows stable operation without photonic integration. We demonstrate the feasibility of the concept and we show that the contrast ratio between output states of flip-flop is over 20 dB while the switching power is less than –3 dBm.

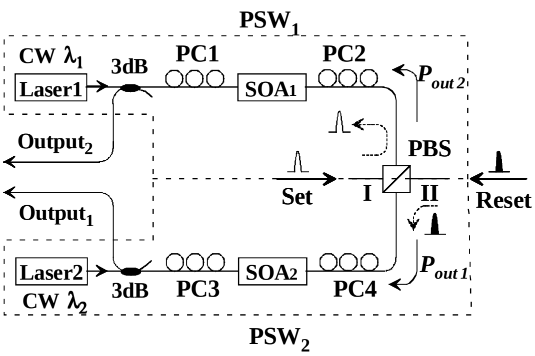

Figure 1

Figure 1. The configuration of the all-optical flip-flop based on two polarization switches. CW: continuous wave, PSW: polarization switch, PC: polarization controller, SOA: semiconductor optical amplifier, PBS: polarization beam splitter, $P_{out\ 1}$ is the output of PSW_1 and $P_{out\ 2}$ is the output of PSW_2.

System concept

The all-optical flip-flop concept is depicted in Figure 1. It consists of two coupled polarization switches (PSWs). The PSW, that acts as a logic AND gate [5], is made from a laser source, a semiconductor optical amplifier (SOA), two polarization controllers and a polarization beam splitter (PBS). A laser emits a continuous wave (CW) probe beam at wavelength λ_1 that is fed into a SOA. The SOA output is sent into a PBS. The system contains two polarization controllers. The first polarization controller is used to adjust polarization of the input signal to be approximately 45 degrees to the orientation of the SOA layers, while the second polarization controller is used to adjust the polarization of the amplified SOA output with the orientation of the PBS. The SOA can be saturated by injection of a high intensity pump (control) signal. The solid curve in Figure 2 shows the typical (experimental) PBS output as a function of the intensity of the saturating control light. It follows that a control beam of sufficient intensity, can suppress the PSW output. This effect is caused by the additional birefringence that is introduced in the SOA by the control light [6], which causes the TE and the TM modes of the probe beam to experience a different refractive index. At the PBS, the two modes combine coherently. If the phase difference between the two modes is an odd multiple of π, the PSW output is suppressed. Note that the curve of Figure 2 is similar to the one presented in [4] in which the suppressed output of an active MZI is discussed.

Similar as in [4], an optical flip-flop can be realized by coupling two identical PSWs as shown in Figure 1. The first PSW, hereafter to be called PSW_1, outputs light that is injected into the second PSW (to be called PSW_2). Hence, the light that outputs PSW_1 acts as a saturating control signal that can suppress PSW_2 and the light that outputs PSW_2 can act as a saturating control signal to suppress PSW_1. The solid curve in Figure 2 represents the intensity $P_{out\ 1}$ of the light that outputs PSW_1 as a function of the intensity $P_{out\ 2}$ of the light that outputs PSW_2. The system is set in such a way that the maximum output intensity $P_{out\ 1}$ equals the intensity of the control light $P_{out\ 2}$ that is required to suppress PSW_1. Since the PSWs are identical, the solid curve is complementary to the dashed curve that represents the intensity of the light that outputs PSW_2. At point A, PSW_1 is dominant and PSW_2 is suppressed while at Point B, PSW_1 is suppressed and PSW_2 is dominant. Both A and B can be shown stable states of the system, Point S can be shown to be an unstable point [3].

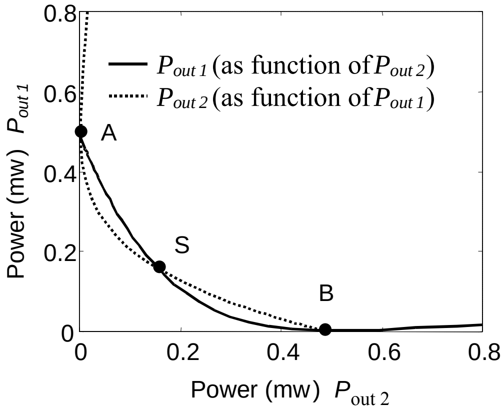

Figure 2

Figure 2. Intensity $P_{out\ 1}$ of the light that outputs PSW_1 as a function of the intensity $P_{out\ 2}$ of the light that outputs PSW_2 (solid curve). Intensity $P_{out\ 2}$ of the light that outputs PSW_2 as a function of the intensity $P_{out\ 1}$ of the light that outputs PSW_1 (dashed curve). It is clear that the two curves are complementary.

The system of two coupled PSWs can function as an optical flip-flop as follows. The state of the flip-flop can be determined by observing the amount of light at the PSW outputs. In State 1, PSW_1 dominates and suppresses PSW_2, while in State 2 PSW_2 dominates and suppresses PSW_1. To switch the flip-flop between the states, light can be injected in the PSW that dominates (that is the one injecting the most light into the other PSW) via the set state or the reset ports. The injected light reduces the light exiting the dominant PSW, which allows the suppressed PSW to increase its light output and become the dominant PSW.

Experiment and results

The all-optical flip-flop is implemented as in Figure 1. Laser 1 and Laser 2 emit CW light at wavelength λ_1=1549.32 nm and λ_2=1550.92 nm respectively, however, it is not essential to bias the PSWs with light at different wavelengths. The output power is –3.34 dBm for Laser 1 and –3.05 dBm for Laser 2. The SOAs were manufactured by JDS Uniphase and employ a strained bulk active region. SOA_1 is biased with 163.97 mA of current and SOA_2 is biased with 161.86 mA of current. The PBS has four ports and an extinction ratio of 30 dB. PSW_1 and PSW_2 are coupled to each other via the PBS.
The steady state PSW output intensity versus the intensity of the input light is presented in Figure 2 as discussed in the previous section. The two states of the flip-flop are shown as point A and point B. The dynamic operation of the flip-flop is demonstrated by toggling the state of the flip-flop by injecting a regular sequence of optical pulses into the PSW that was currently the master. The pulses had a wavelength of 1552.52 nm and a duration of 150 ns. The pulses were injected in the master once every 1.85 μs through the set and reset port (see Figure 1). Figure 3 shows the oscilloscope traces of optical pulses and the optical output power of flip-flop at each wavelength. In Figure 3a, optical pulses are injected into PSW_1 via Port I of PBS (see Figure 1) to set the flip-flop in State 2. Figure 3b shows the optical pulses that are injected into PSW_2 via Port II of PBS (see Figure 1) to reset the flip-flop in State 1. The optical peak power of the pulses in Figure 3a is –3.91 dBm and –4.35 dBm in Figure 3b. Figure 3c and Figure 3d presents the dynamic output of flip-flop at $output_1$ and $output_2$. The switching between flip-flop states every 1.85 μs can clearly be observed. Furthermore, it is visible that the flip-flop state is stable in the time between changing states. Also the contrast between State 1 and State 2 was investigated by using an optical spectrum analyzer. It turned out that contrast ratio between the two states of the flip-flop is over 20 dB, as shown in Figure 4.

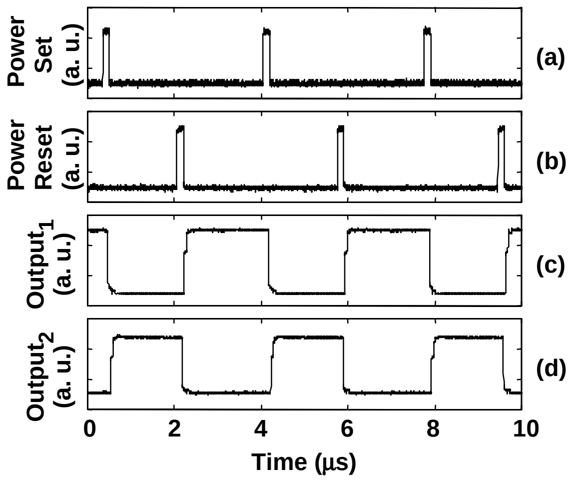

Figure 3

Figure 3. Dynamic output of the flip-flop showing switching between states every 1.85 μs. The upper panels (Figure 3a and Figure 3b) are the traces of the external optical pulses at wavelength 1552.52 nm. The lower panels (Figure 3c and Figure 3d) are the dynamic output of flip-flop at $output_1$ (λ_1=1549.32 nm) and $output_2$ (λ_2=1550.92 nm).

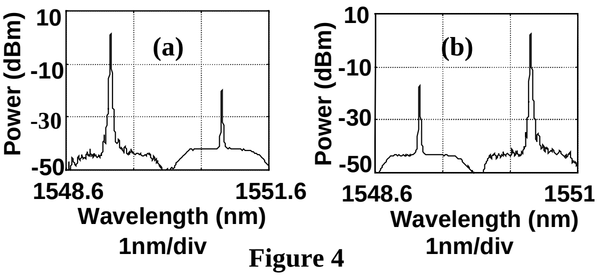

Figure 4

Figure 4. Spectral output at each state of the flip-flop. Figure 4a represents State 1 (wavelength λ_1 1549.32 nm dominant), and Figure 4b represents State 2 (wavelength λ_2 1550.92 nm dominant).

Conclusions

An all-optical flip-flop memory based on two coupled polarization switches has been demonstrated. The contrast ratio between output states of the flip-flop is over 20 dB and the optical switching power is less than –3 dBm.

The speed of this flip-flop is determined by the speed of the PSW and the propagation distance between two SOAs. In the experimental setup, approximately 12 meters of fiber is used between the two SOAs, which implies that about at least 100 ns are required for the states of the flip-flop to change. However, integrated versions of the flip-flop could reduce the distance two SOAs to several millimeters. In this case, the speed of flip-flop is dominated by the speed of the PSW. It has been demonstrated that the PSW can operate at 10 GHz [7], thus we expect the flip-flop can reach similar speeds. Finally, we remark that the curves presented in Figure 2 are similar to the ones presented in [3] which reveals that a PSW acts as a Mach-Zehnder interferometer where the role of the different light paths is now realized by independently operating TE and TM modes of the optical field.

Acknowledgment

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References

[1] O. Boyraz, J.W. Lou, K.H. Ahn, Y. Liang, T.J. Xia, Y.H. Kao and N. Islam: “Demonstration and performance analysis for the off-ramp portion of an all-optical access node”, *Journal of Lightwave Technology*, vol. 17, pp. 998-1010, 1999.

[2] M.T. Hill, A. Srivatsa, N. Calabretta, Y. Liu, H. de Waardt, G.D. Khoe, and H.J.S. Dorren: “1x2 optical packet switch using all-optical header processing”, *Electronics Letters*, vol. 37, pp. 774-775, 2001.

[3] M.T. Hill, H. de Waardt, G.D. Khoe, and H.J.S. Dorren: “All-optical flip-flop based on coupled laser diodes”, *Journal of Quantum Electronics*, vol. 37, pp. 405-413, 2001.

[4] M.T. Hill, H. de Waardt, G.D. Khoe, and H.J.S. Dorren: “ Fast optical flip-flop by use of Mach-Zehner interferometers”, *Microwave Optical Technology Letters*, vol. 31, pp. 411-415, 2001.

[5] H. Soto, C.A. Diaz, J. Topomondzo, D. Erasme, L. Schares and G. Guekos: “All-optical AND gate implementation using cross-polarization modulation in a semiconductor optical amplifier”, *IEEE Photonics Technology Letters,* vol. 14*,* pp. 498-500, *2002.*

[6] R. J. Manning, A. Antonopoulos, R. Le Roux and A. E. Kelly, “Experimental measurement of nonlinear polarization rotation in semiconductor optical amplifiers”, *Electronics Letters*, Vol. 37, pp. 229-231, 2001.

[7] M. F. C. Stephens, A. E. Kelly, D. Nesset, A. Wonfor, and R.V. Penty: “Demonstration of time demultiplexing from 40Gb/s to 10Gb/s via polarization switching in a semiconductor optical amplifier”, *in Proceedings CLEO/Europe ‘98*, 1998, pp. 383-383.