Three-state all-optical memory based on three-coupled polarization switches

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An all-optical memory with three states is presented. The optical memory is realized from three-coupled identical nonlinear polarization switches. The state of the optical memory is determined by the wavelength of the memory's output light. In each state, only one wavelength is dominant. The concept is explained and experimental results are presented that demonstrate that a contrast ratio of over 20 dB and a switching power of around 8 dBm can be obtained. This concept can be extended for an all-optical memory with a large number of states, which is crucial to realize 1×N all-optical packet switches.

Introduction

All-optical memories, which are key components in all-optical packet switches, attract the interest of researcher [1]. A 1×2 all-optical packet switch that contains a two-state optical memory is demonstrated [2]. In principle, the number of the memory's states determines the number of output states of the packet switch. Therefore, all-optical memories with more states are crucial for 1×N all-optical packet switches. In this letter we describe an all-optical memory that has three states and this concept can be extended for an optical memory with a large number of states. A two-state optical memory can be realized from two coupled nonlinear optical elements. Examples are an all-optical memory that is made from two coupled lasers [1], an all-optical memory that is realized from two-coupled nonlinear polarization switches [3][4], and an all-optical memory that is made from two coupled Mach-Zehnder interferometers [5]. In this letter, we demonstrate that it is possible to construct a three-state optical memory based on three-coupled nonlinear identical polarization switches. The state of the optical memory is determined by the wavelength of the memory's light output. In each state, only one wavelength is dominant. This all-optical memory implementation has separate inputs to set the memory in a particular state. We demonstrate the feasibility of the concept and we show that the contrast ratio between output states of the memory is over 20 dB and the switching power is around 8 dBm.

System concept

The all-optical memory concept is depicted in Figure 1. It consists of three-coupled nonlinear polarization switches (PSWs). Each PSW is made from a laser source, a semiconductor optical amplifier (SOA), two polarization controllers (PCs) and a polarization beam splitter (PBS). A PBS is shared by the three PSWs as shown in Figure 1. In each PSW, a laser emits a continuous wave (CW) probe beam that is fed into a SOA. The SOA output is sent into the PBS.

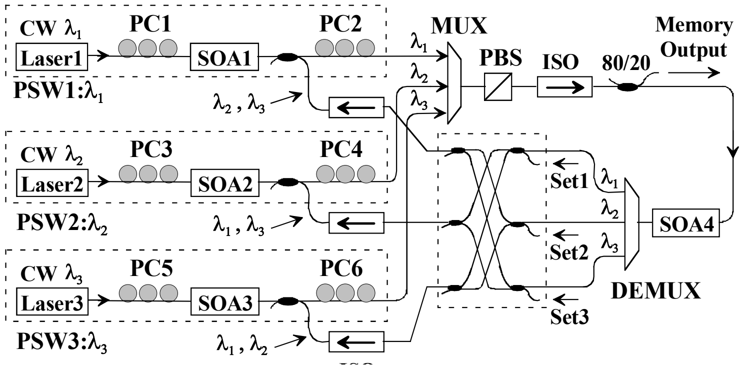

Figure 1. *The configuration of the all-optical memory based on three-coupled polarization switches (PSWs). Each PSW shares a common polarization beam splitter (PBS). ISO: optical isolator, MUX: optical multiplexer.*

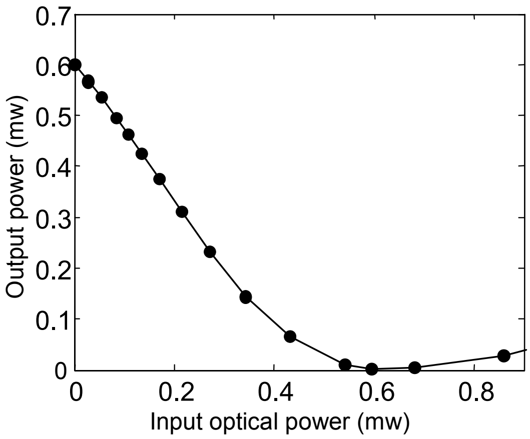

Figure 2. *The output power of PSW_1 at PBS versus the input power to the pigtail of SOA_1.*

The operation principle of a single PSW is described in [3][4]. Figure 2 shows the typical (experimental) PBS output as a function of the intensity of the saturating external light. It follows that an external light with sufficient intensity, can suppress the PSW output. This effect is caused by the additional birefringence that is introduced in the SOA by the external light [4], which causes the TE and the TM modes of the probe beam to experience a different refractive index. If the phase difference between the two modes is π, the PSW output is suppressed.

Two identical PSWs can be coupled each other to make a two-state all-optical memory [3]. In such a configuration one PSW acts as the master PSW, which suppresses the output of the other PSW (the slave). Due to the symmetry of the master-slave configuration, the role of master and slave can be interchanged by injecting external light into the dominant PSW.

The concept in [3] can be extended to a three-state optical memory. In Figure 1, three identical PSWs are coupled to each other to construct a three-state optical memory. The output of each PSW has to be coupled into the other two PSWs, but not into itself. To realize this, each PSW outputs different wavelength and be combined at the PBS output. 20% of the combined light is coupled out of the system by using an 80/20 coupler, which acts as the memory output. The other 80% of the combined light is firstly fed into SOA_4 to be amplified and then be separated by a demultiplexer (DEMUX). The outputs of the demultiplexer with different wavelength are combined and dispensed to each PSW via a small network that is made from 3 dB couplers, as shown in the dashed-box on the right-hand side in Figure 1. This small network is set such a way that the output of each PSW with distinguished wavelength is fed back into the other PSWs but not into itself. The amplification by SOA_4 ensures that the light injected in each PSW is sufficient to suppress the PSW output. Since the system is symmetric, all the PSWs can suppress the output of other PSWs, and thus each PSW can become dominant. Therefore, the memory has three possible states, depending on which PSW is dominant. In each state, only one PSW dominates and the other PSWs are suppressed, thus only one wavelength is dominant. For instance, in State 1, PSW_1 dominates and suppresses the output of the other PSWs.

To select the state of the memory, external light can be injected via one of set ports, as shown in the Figure 1. The external light is firstly sent through a small network that is described above. This network can dispense the external light into some specific PSWs, depending which input port is used. The external light from one set port can set the memory in a particular state. For instance, the external light from Set 1 Port can set the memory in State 1 (PSW_1 dominates and λ_1 is dominant). The external light that is injected into Set 1 Port, is distributed into the all the PSWs except PSW_1. Thus the saturating external light stops or reduces the light exiting from the PSWs in which the external light is injected, no matter if these PSWs are dominant or suppressed. As a consequence, PSW_1, in which no external light is injected, increases its output light and become dominant to suppress the other PSWs. This state remains after the external light is removed.

Experimental results

The three-state all-optical memory is implemented as in Figure 1. All the couplers in the experiment are 50/50 couplers except one 80/20 coupler that is indicated in the Figure 1. Laser 1, Laser 2 and Laser 3 emit CW light at wavelength λ_1=1550.92 nm, λ_2=1552.52 nm and λ_2=1554.13 nm respectively, The output power is –4.71 dBm for Laser 1, –4.75 dBm for Laser 2 and –4.65 dBm for Laser 3. The SOA (JDS Uniphase) injection currents were 157 mA for SOA_1, 151 mA for SOA_2 and 150 mA SOA_3 respectively. SOA_4 is biased with 300 mA of current. The output power of PSW_1 at PBS versus the input power to the pigtail of SOA_1 (See Figure 1) is presented in Figure 2. It is shown that for such a PSW, it is sufficient to inject –2.2 dBm (0.6 mw) of light to suppress the PSW output. The spectral output of the all-optical memory at each state is presented in Figure 3. Figure 3a, 3b and 3c correspond to State 1, State 2 and State 3 respectively. It is shown that the contrast ratio between the each states of the memory is over 20 dB.

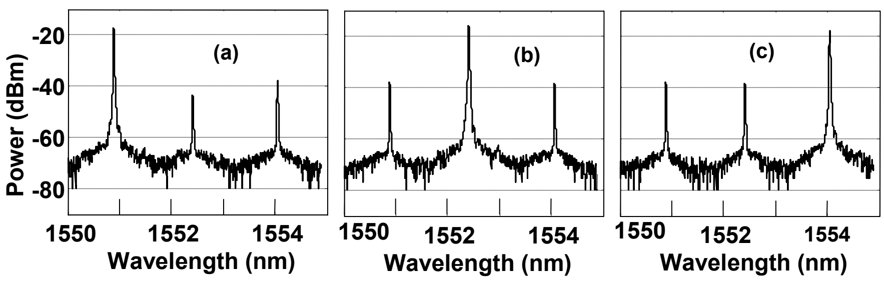

Figure 3. *Spectral output of the all-optical memory at each state.*

The dynamic operation of the memory is demonstrated by toggling the state of the memory by injecting a regular sequence of optical pulses into each of the set ports (see Figure 1). The injected pulses had a wavelength of 1557.36 nm and duration of 480 ns. The pulses to change the state of the memory were injected once every 2.8 μs, as shown

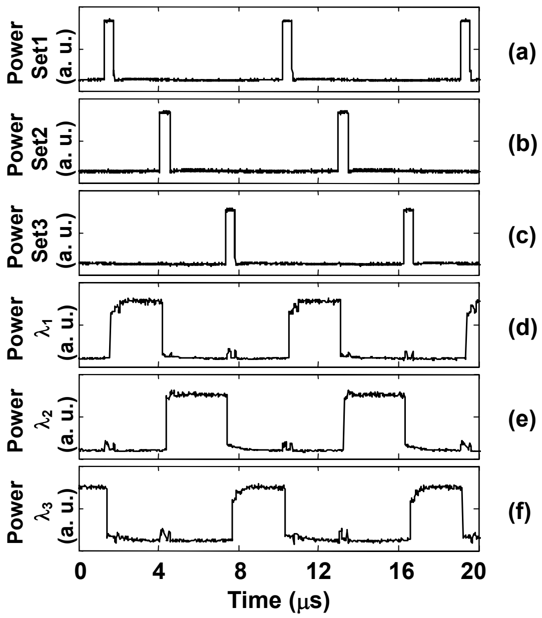

Figure 4. *Dynamic output of the memory showing switching between each states every 2.8 μs.*

in the upper panels of Figure 4 (Figure 4a, 4b and 4c). The optical peak power of pulses was 8 dBm at each input ports of the memory. Figures 4d, 4e and 4f show the oscilloscope traces of the optical output power of memory for each state. In Figure 4, regular toggling between the memory output states every 2.8 μs is visible. Furthermore, it can be observed that the memory's state is stable in the time between changing states.

Conclusion

A three-state all-optical memory based on three-coupled nonlinear polarization switches has been demonstrated. The state of the optical memory is determined by the wavelength of the memory's light output. In each state, only one wavelength is dominant. The contrast ratio between output states of the memory is over 20 dB and the optical switching power is around 8 dBm. In the experimental setup, approximately 40 meters of fiber is used between each SOAs, which implies that about at least 400 ns are required to change the states of the memory. However, integrated versions of the memory could reduce the distance between each SOAs to several millimeters, indicating the memory can reach a few GHz [3]. Finally, we remark that the concept of this three-state memory can be extended for an all-optical memory with a large number of states.

Acknowledgement

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