Optical shift register based on an optical flip-flop with a single active element

S. Zhang, Z. Li, Y. Liu, R. Geldenhuys, H. Ju, M.T. Hill, D. Lenstra, G.D. Khoe and H.J.S. Dorren
COBRA Research Institute, Eindhoven University of Technology,
P.O. Box 513, 5600 MB Eindhoven, The Netherlands (e-mail: s.zhang@tue.nl)
D. Lenstra is also with Vrije University, Amsterdam, The Netherlands

We present an optical shift register consisting of two optical flip-flop memories placed in series. Each flip-flop consists of a bi-stable ring laser. The shift register operates as follows. A strong clock pulse that clears each flip-flop is injected in the shift register to clear the second flip-flop. The output of the first flip-flop then sets the new state of the second flip-flop before it is cleared itself by the delayed clock pulse. Afterwards new information is written in the first flip-flop. The shift register was implemented using fiber pig-tailed components which made the cavities long. 20 KHz operation is experimentally demonstrated.

Introduction

Optical shift registers might become essential building blocks for future packet buffers and synchronizers [1, 2, 3]. In most cases, shift registers are realized out of coupled flip-flops. However, due to the lack of a stable all-optical flip-flop that is easy to cascade, alternative ways have developed to realize an optical shift register [4] by either using fiber buffers, Sagnac interferometers [1,2] or using self electro-optic effects [3].
In Ref. [5], we presented an optical flip-flop memory consisting of only one active element, which is easy to control and can be cascaded. We use this flip-flop as the basic building block of the shift register. We give proof of concept and show, using commercially available fiber pigtailed components that an operation speed of 20 KHz was realized. Photonic integration could drastically improve the performance of our set-up. To our knowledge, it is the first experimental result for the optical shift register based on optical flip-flop memory.

Principle and experiments

The basic building block of our shift register is the optical flip-flop memory that is shown in Figure 1a. The flip-flop memory is made out of a ring laser with two separate cavities sharing a bulk strained SOA as the laser gain medium. The two cavities were realized by using two 50/50 couplers. Each cavity contained a Fabry-Perot filter (FPF, 3dB bandwidth 0.20 nm) that acted as a wavelength selective element. A variable attenuator was placed in each ring to make the two cavities output equal power. The isolator was used to allow the light to propagate in only one direction. The central wavelength λ_1 of the FPF in the ring cavity 1 was 1550.92 nm while the central wavelength λ_2 in the ring cavity 2 was 1552.52 nm. In our experiments, the SOA was biased with the current of 250 mA (threshold current was 136 mA). Essential for bi-stability is the presence of lasing light that is fed back into the gain medium. It is shown in [5] that the feedback light makes the roundtrip conditions of the two ring cavities can not be satisfied simultaneously. It turned out that this system had only two stable states in which one of the two lasers can lase. This laser suppressed laser action in the other laser. Figure 1c shows an experimental result indicating that laser 1 was lasing and laser 2 was suppressed. Figure 1d shows the reverse situation in which laser 2 lased and laser 1 was suppressed. Switching between the two states can be realized by injecting external light, at the same central wavelength of the suppressed laser, through the port of 'In1'in Figure 1a. In our experiment, the threshold switching power was -15 dBm.

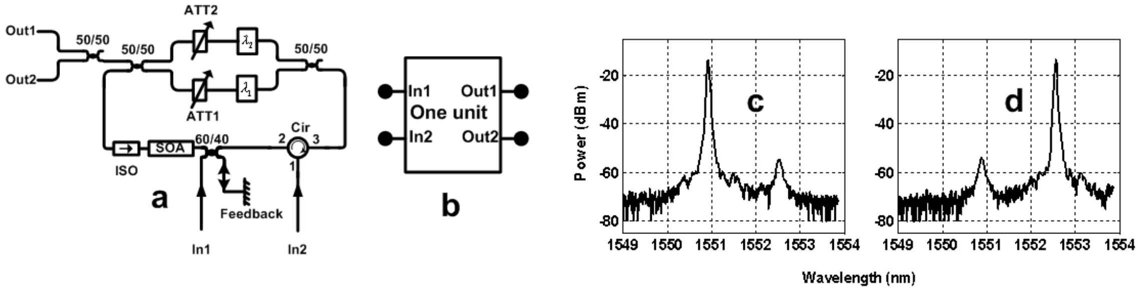

Figure 1 a: The flip-flop memory configuration. b; The icon of the flip-flop memory. c and d show the experimental results of two stable states. ISO: isolator, ATT: Attenuator

External light can be simultaneously injected in the flip-flop through port 'In1' and 'In2', respectively. The light injected through port 'In1' has an optical power smaller than the threshold and its wavelength is equal to one of the lasing wavelength of the flip-flop. Light injected through port 'In2' has an optical power much larger than the threshold level, and its wavelength is not equal to any of the flip-flop lasing different wavelengths, and thus deeply saturates the SOA to suppress both lasers. This means that the memory is cleared. After clearing the flip-flop (and that the light injected through port 'In2' has been removed), the light injected through port 'In1' sets the new state of the memory. As a result, the laser with the wavelength of the external light will lase [5]. The flip-flop memory has two output ports:'Out1' and 'Out2. Port 'Out1' is used to cascade the flip-flop with the next flip-flop and 'Out2' is used to monitor the output state. In the following we indicate a single flip-flop as shown in Figure 1b

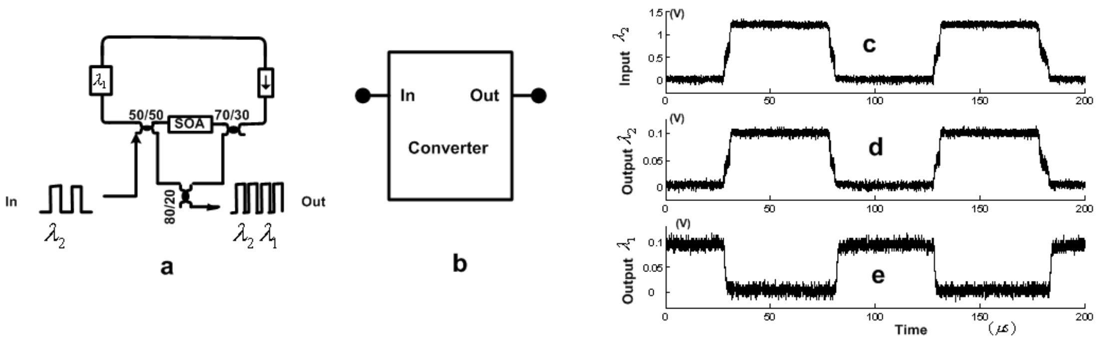

Figure 2 a: The converter configuration. b: The icon of the converter. c: the signal injected into converter at wavelength of λ2 (1552.52 nm). d and e are the signal out of the converter at wavelength of λ2 and λ1 (1550.92 nm), respectively.

Normally, the binary information is characterized by the intensity of the signal, but the state of the flip-flop discussed above is characterized by the wavelength of the output light. Therefore, the information encoded on an intensity modulated binary input signal needs to be transformed into wavelength encoding. This function is preformed by the converter shown in Figure 2a. The converter is a unidirectional ring laser operating at a central wavelength of λ1. Figure 2c shows the external signal at wavelength of λ2 that was injected into the laser cavity.

The converter outputs light with a wavelength that depends on whether a binary '1' or a binary '0' is injected. If the injected signal consists of a binary '1', the injected light saturates the SOA and suppresses laser action. Thus the converter outputs amplified light with a wavelength equal to the input wavelength, i.e. λ2. However, if the injected signal is a binary '0', the converter outputs light at the lasing wavelength, i.e. λ1. Figure 2d and 2e shows experimental results of the output of the converter. In the following, we indicate the converter as shown in Figure 2b.

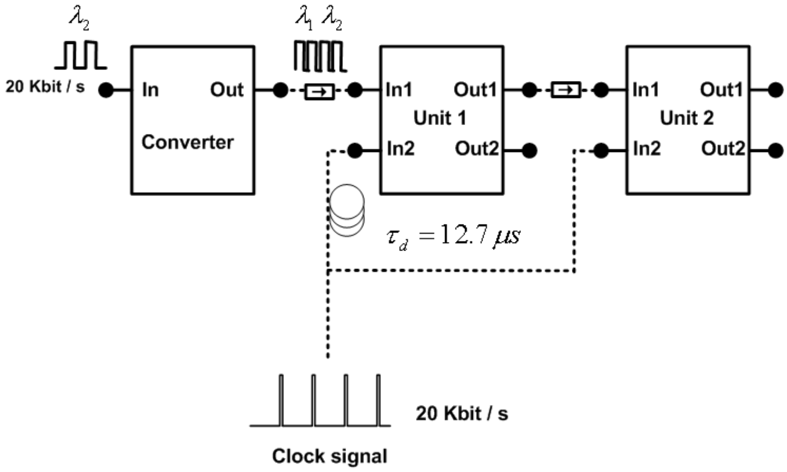

Figure 3 the schematic configuration of optical shift register

Figure 3 shows a schematic of the optical shift register, which combines a converter and two identical flip-flop memories that are placed in a series. The clock signal was at a wavelength of 1559.3 nm and had a modulation frequency of 20 KHz. The 3-dB pulse width of each clock pulse was 4 μs. An input signal at wavelength of λ2 was generated from a pattern generator and operated at the same frequency as the clock. This signal was synchronized with the clock signal.

The input signal was firstly was transformed by the converter, to distinguish the '0' and '1' levels by different wavelength. The converter output was injected in port In1 of the first flip-flop (Unit 1). The output 'Out1' of the first flip-flop was injected into the second flip-flop (Unit 2) via port 'In1'. Since the power of the light that was injected in each flip-flop was lower than the threshold, all flip-flops kept their initial states until they were cleared by a strong clock signal. The clock signal was spitted into two parts. One part was directly injected into port 'In2' of the second flip-flop (Unit 2) to clear this memory. The clock pulse was timed such that after 4 μs (the duration of the clock pulse), the output of the first flip-flop (Unit 1) set the new state of Unit 2. The other part of the clock signal was delayed for 12.7 μs to clear the state of Unit 1, after the output of Unit 1 had shifted to Unit 2. The output of the converter set the new state of Unit 1 after the delayed clock pulse was removed. All the operations took place within one clock cycle.

Figure 4 shows how the information format of. a 01010011 was shifted. The clock signal is shown in Figure 4a. The output signals of the converter, Unit 1 and Unit 2 were filtered by a band-pass filter with central wavelength λ2 and are shown in Figure 4b, 4c and 4d, respectively (Note that a '0' state in Figure 4c and 4d means that the corresponding flip-flop was in the state that the lasing wavelength was λ1 as shown in

Figure 1c). It is clearly shown that when the clock pulses were removed, the state of Unit 1 set the new state of Unit 2. After $12.7\mu s$, the output of the converter set the new state of Unit 1. This means that the system showed a 'shift' function.

A shift register should not only shift information but also store the state in absence of clock pulses. This is shown in Figure 5, where the input signal was a repeating '01' signal. The clock signal was a repetitive signal with '00000111111' encoding. It is shown in Figure 5 that Unit 1 and Unit 2 stored the states if no clock pulses were present, and that the state was shifted if a clock signal was presented.

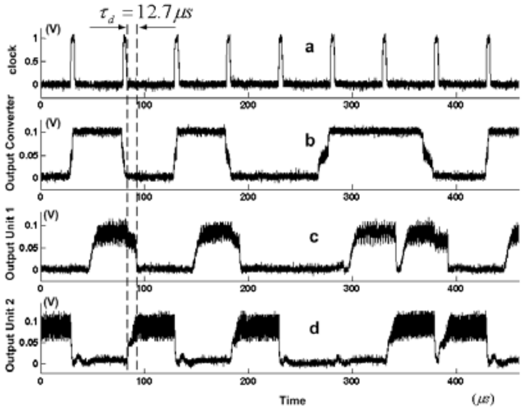

Figure 4 experimental results of shifting the format of 01010011. a: the 20 KHz clock signal. b, c and d shows the output of the converter, Unit 1 and Unit 2 that were filtered by the filter with the center wavelength of λ2 (1552.92 nm), respectively.

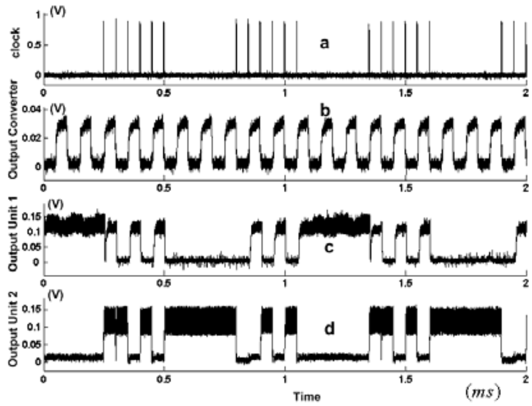

Figure 5 experimental results when the clock format is 1111110000. a: the 20 KHz clock signal. b, c and d shows the output of the converter, Unit 1 and Unit 2 that were filtered by the filter with the center wavelength of λ2 (1552.92 nm), respectively.

Conclusion

We demonstrated an all-optical shift register based on optical flip-flop memory presented in [5] at a speed of 20 KHz. The operation speed is limited by the switching speed of the flip-flop memory which is proportional with the cavity length of the flip-flop. In our setup, the cavity was made up by fiber pigtail component and thus had an about 10 meter long cavity. Photonic integration would increase the operation speed.

Acknowledgements

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