Optical flip-flop based on a multiple cavity ring laser with feedback

S. Zhang, Y. Liu, D. Lenstra, M.T. Hill, H. Ju, 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, FEW, Division of Physics and Astronomy,

De Boelelaan 1081, 1081 HV, Amsterdam, The Netherlands

We present a novel concept for optical bi-stability that exists in a ring laser with two separate but coupled cavities that operate at different wavelength. We show that lasing light in each of the cavities can suppress lasing in the other cavity so that this configuration forms an optical bi-stable element. Essential in the operation is the presence of feedback of the lasing light. We show that this configuration can be optically set and reset, has a contrast ratio of over 40 dB and allows low optical power operation.

Introduction

All-optical flip-flops form a key component in all-optical packet switches [1]. Optical flip-flops can be realized by using a variety of techniques described in [2]. An optical flip-flop concept based on two coupled lasers was presented in [3]. Such a system forms a master-slave configuration which operates at low switching power. Also, the system can be all-optically set and reset. This flip-flop configuration turned out to be useful for telecommunications. Applications in optical packet switches and buffers are described in [4]. This flip-flop concept was developed further in [5,6] where flip-flop operation was demonstrated by employing Mach-Zehnder interferometers and nonlinear polarization switches in a master-slave configuration.

In order to employ optical flip-flops in a telecommunication system, the devices should allow high switching speed, have a sufficient contrast and operate at low power. The last requirement becomes especially important for photonic integration since it is essential to reduce the number of heat dissipating elements on an optical chip. In this paper, we present a novel concept for optical bi-stability. The configuration that we present contains only one active element but exhibits a contrast ratio and switching comparable to the system presented in [3].

In our work, the flip-flop configuration consists of a ring laser with two separate cavities. Each cavity operates at a different wavelength. Essential for obtaining bi-stability in such a system is the presence of feed back of light at the lasing wavelength. To our knowledge, we show for the first time that such a configuration forms an optical bi-stable element. Switching between the states can be realized by injection of external light at the wavelength of the cavity that is not lasing. We can obtain a contrast ratio higher than 40 dB between the states and flip-flop operation is realized by external light injection in low power.

Experimental setup and results

The experimental setup of the flip-flop is shown in Fig. 1. The flip-flop is made out of a ring laser with two separate ring cavities. A bulk semiconductor optical amplifier (SOA) acts as the laser gain medium. The two cavities are made by using two 50/50 couplers.

Each cavity contains a Fabry-Perot filter (bandwidth 0.2 nm) that acts as a wavelength dependent element. A variable attenuator is placed in each ring to control the optical power. Optical isolators are used to allow the light to propagate in only one direction [7]. Essential for flip-flop operation is the presence of lasing light that is fed back into the laser. In this particular configuration, the feedback light is implemented by using the feedback loop made of one 50/50 coupler.

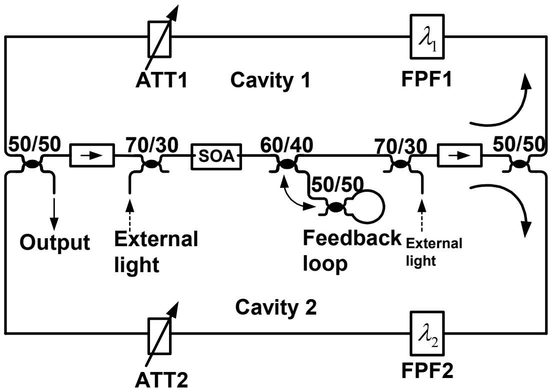

Figure 1. The experimental setup configuration.
SOA: Semiconductor optical amplifier
ISO: Isolator
FPF: Fabry-Perot Filter
ATT: Attenuator
FBG: Fiber-Bragg Grating

Figure 1

The central wavelength λ_1 of the Fabry-Perot filter in the ring cavity 1 is 1550.92 nm and the central wavelength λ_2 in the ring cavity 2 is 1552.52 nm. The attenuators in the ring cavity 1 and 2 are 0.5 dB and 0.82 dB, respectively. In our experiments, the SOA is biased with the current of 300 mA (threshold current is 172 mA).

In the first place, we investigate the bi-stability of the system by blocking one of the cavities, i.e. the cavity 2 and making the system lase in the other cavity, i.e. the cavity 1. Unblocking the cavity 2, does neither prevent the cavity 1 from lasing, nor develop lasing in cavity 2 itself. A similar situation takes place the other way around. This is illustrated in Fig. 2(1a and 1b) where the optical spectra are shown for both states after unblocking the cavity. The contrast ratio between the lasing and suppressed states is over 40 dB. Also, such a bi-stability can be obtained with the wavelength difference ranges from 0.1nm to 62.87 nm as shown in Fig. 2(2a and 2b). The lower-limit of the range is limited by the bandwidth of FPF whereas the upper-limit by the optical gain bandwidth of the SOA.

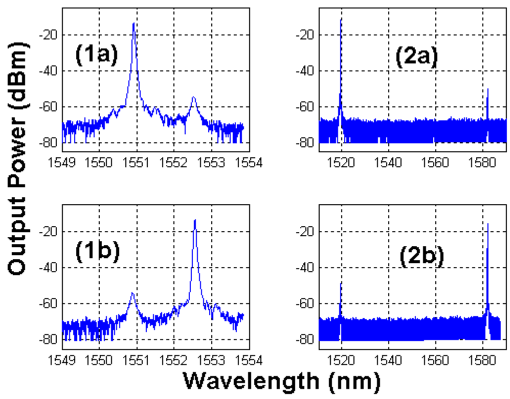

Figure 2. Spectral output at each bi-stable state. Fig. 2 (1a and 1b) represents the bistability between the two wavelength of 1550.92nm and 1552.52nm

Fig. 2(2a and 2b) represents that of 1519.34nm and 1582.21nm

Figure 2

There are two methods to realize the flip-flop operation. The first one is to inject external light in the opposite direction of the lasing light. The switching from the dominant state of λ_1 to that of λ_2 by injecting light at λ_2 is shown by the solid line in

Fig. 3a. The switching power is -8.92 dBm, when corrected for the splitter loss (70 %) of the coupler. After the switching happens, the system keeps the dominant state of λ_2 in spite of the removal of the external light. The second method is to inject external light in the same direction of the lasing light. The solid line in Fig. 3b shows the switching.

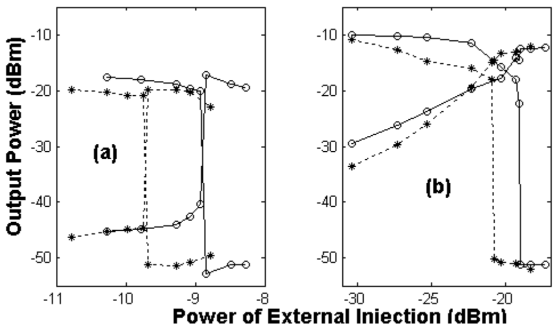

Figure 3. The switching from the state of λ_1 (1550.92 nm) to that of λ_2 (1552.52 nm) by injecting external light at 1552.52 nm.
Fig. 3(a) and (b) represent external light injected in the opposite and same directions as the lasing light, respectively. The solid and dashed lines represent (ATT1=0.5 dB, ATT2=0.82 dB), and (ATT1=1.0 dB, ATT2=1.32 dB), respectively.

Figure 3

The switching procedures of both methods are similar to each other except two aspects. Firstly, the switching power of the second method is much lower (-19.1 dBm) than that of the first method (-8.92 dBm), because the injected light is amplified by the SOA. Secondly, the output power of λ_2 changes sharply with the external injected light power in Fig. 3a, while almost linearly in Fig. 3b. This is because the output light includes the amplified external light injected in the lasing light direction.
When the attenuation of both cavities increases by 0.5 dB, the corresponding switching power reduces down to –9.75 dBm and –20.8 dBm as shown by the dashed lines in Fig. 3a and Fig. 3b, respectively.
It is the same for the reverse operation from the dominant state of λ_2 to that of λ_1 with injecting external light at λ_1.

Conclusion

It is demonstrated that two coupled ring lasers sharing one SOA with optical feedback realize optical flip-flop operation. Over 40 dB contrast ratio is achieved between both states. The flip-flop operates by external light injected in the same or opposite direction of the lasing light in reasonable low power. The system is polarization-independent and operates via wavelength difference only limited by the bandwidth of FPF and SOA. This configuration can be extended to create multi-state flip-flop by using multi-wavelength ring lasers coupled with one SOA.

Acknowledgements

This work was supported by The Netherlands Organization for Scientific Research (NWO), the Technology Foundation STW and the Ministry of Economic Affair through respectively the NRC Photonics grant, the Innovational Research Incentives Scheme program and grant ETC.5579

References

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

[2] H. Kawaguchi, Bistabilities and Nonlinearities in Laser Diodes, London: Artech House, 1994

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

[4] H.J.S. Dorren, M.T. Hill, Y. liu, N. Calabretta, A. Srivatsa, F.M. Huijskens, H. de Waardt and G.D. Khoe, “Optical packet switching and buffering by using all-optical signal processing methods”, Journal of Lightwave Technology, Vol. 21, pp. 2-12, 2003

[5] M.T. Hill, H. de Waardt, G.D. Khoe and H.J.S. Dorren, “Fast optical flip-flop by use of Mach-Zehnder interferometers”, Microwave and Optical Technology letters, Vol. 31, pp. 411-415, 2001

[6] Y. Liu, M.T. Hill, H. de Waardt, G.D. Khoe, D. Lenstra and H.J.S. Dorren. “All-optical flip-flop memory based on two coupled polarization switches”, Electonics Letters, Vol. 38, pp. 904-906, 2002

[7] M.T. Hill, E.E.E. Frietman, H. de Waardt, G.D. Khoe and H.J.S. Dorren, “All fiber-optic neural network using coupled SOA based ring lasers”, IEEE Transactions on Neural Networks, Vol. 13, pp. 1504-1513, 2002