Wavelength selective electro-optic flip-flop

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Abstract

Operation of a novel wavelength selective electro-optic flip-flop is demonstrated. The flip-flop consists of an anti-reflection coated two-section semiconductor laser diode with optical feedback from two fiber Bragg gratings. Electrical set and reset signals cause the lasing output to toggle between two distinct lasing wavelengths with a mode suppression ratio of greater than -35 dBm.

To realize the full potential of Wavelength Division Multiplexing (WDM) it will be necessary to develop new components which serve to enhance the functionality of these systems to include electro-optic as well as all-optical switching and routing capability. Key components which must be created are optical switching and logic devices. An important missing element is the electro-optic equivalent of an electronic SR flip-flop. In this letter we present a novel hybrid electro-optic flip-flop which is able to toggle between two Bragg grating (BG) defined lasing wavelengths by application of electrical set and reset signals.

Figure 1 shows a schematic diagram of the experimental arrangement. The laser diode used for these experiments is a 500 μm long InGaAs / InP buried heterostructure four quantum well device with an integrated saturable absorber. Details of the diode structure and fabrication are given in Ref. 1. The series resistance between the 12 μm long saturable absorber and the laser gain section is 500 Ω . The as-cleaved device lases at wavelength λ = 1548 nm with a threshold current of 20 mA. The threshold current of the laser after anti-reflection (AR) coating one mirror facet is greater than 100 mA. As illustrated in Fig. 1(a), optical feedback is provided by coupling emission from the AR coated facet into a single-mode fiber (SMF) in which is embedded a dual reflection peaked BG. The 10.5 mm long BG has peaks in reflectivity of greater than 90% centered at wavelengths λ_1 = 1519.03 nm and λ_2 = 1519.91 nm with a -3 dB full-width optical bandwidth of 0.13 nm (16.9 GHz) and 0.12 nm (15.6 GHz) respectively. The measured photon-cavity resonance frequency is 14.7 GHz corresponding to a photon cavity round-trip time of 71 ps.

Figure 2 shows results of measuring the output light intensity versus gain-section current (L-I_{gain}) characteristic of the device for saturable absorber voltage, V_{sat} = 0.9 V. When I_{gain} = 50 mA and V_{sat} = 0.9 V, lasing occurs at wavelength λ_1 at operating point 1 and at wavelength λ_2 at point 2 on the L-I_{gain} curve. The optical spectrum at operating points 1 and 2 is shown as insets to Fig. 2.

The center wavelengths of the BGs are $\Delta\lambda_{BG}$ = 0.89 nm apart. Since cavity modes of the AR coated semiconductor laser are spaced $\Delta\lambda_{cav}$ = 0.59 nm apart, $\Delta\lambda_{BG} = 1.5\ \Delta\lambda_{cav}$. Hence, coupled cavity effects should select one of the BG defined wavelengths as the lasing wavelength [2]. Along the L-I_{gain} curve from I_{gain} = 40 mA to 55 mA the laser emits at λ_1 at a relatively lower carrier density, n, in the laser gain medium. At a relatively larger value of n, coupled cavity effects select lasing wavelength λ_2. The hysteresis in the L-I_{gain} characteristic due to coupled cavity effects may be exploited to build an electro-optic SR flip-flop.

The optical output of the laser is stable at both operating points 1 and 2 on the L-I_{gain} shown in Fig. 2. Fig. 3 shows the device acting as an electro-optic SR flip-flop. The light output of the device is measured after passing through a monochromator using a detector with a -3 dB bandwidth of 2 GHz. When the laser is operating at point 1 and lasing at wavelength λ_1, a 9 mA 'set' electrical pulse applied to the laser for 20 ns switches the laser operating point to 2 and lasing occurs at wavelength λ_2. The laser continues to operate at point 2 with lasing at λ_2 until a 20 ns -9 mA 'reset' electrical pulse switches the operating point to 1 with lasing at λ_1. Our measurements indicate that the temporal response to set and reset signals can be as short as 2 ns. The optical emission at wavelength λ_2 serves as Q output of the flip-flop while emission at wavelength λ_1 serves as the $\overline{Q}$ output. The measured optical mode suppression ratio between the two lasing states is greater than -35 dB.

The speed of operation of the electro-optic SR flip-flop is limited to the 100 MHz range due to the turn-on delay as well as switching timing jitter. Preliminary experiments indicate that the turn-on delay as well as timing jitter switching to wavelength λ_1 (λ_2) can be reduced by either continuously injecting photons into the laser at the wavelength λ_1 (λ_2) or by switching between the states using an *optical* pulse at λ_1 (λ_2).

In conclusion, we have demonstrated operation of a novel electro-optic flip-flop. The device makes use of a semiconductor laser diode in an external cavity with optical feedback from BGs embedded in a SMF. The measured transient dynamics indicate that this preliminary version of the electro-optic flip-flop is capable of operating in the 100 MHz frequency range. Further work will explore methods to increase the speed of operation of this device.

Acknowledgment:

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References

[1] Berthold, K., Levi, A. F. J., Tanbun-Ek, T., and Logan, R. A.: ‘Wavelength switching in InGaAs/InP quantum well lasers,’ Appl. Phys. Lett., 1990, **56** (2), pp. 122-124.

[2] Kanjamala, A. P., and Levi, A. F. J.: ‘Wavelength switching in multi-cavity lasers,’ Appl. Phys. Lett., 1997, **71** (3), pp. 300-302.

Figure captions

Figure 1. Schematic diagram of the experimental arrangement. The laser diode used for these experiments is a 500 µm long InGaAs / InP buried heterostructure four quantum well device with an integrated saturable absorber. Optical feedback is provided by coupling emission from the AR coated facet into a SMF in which is embedded a dual reflection peaked BG. The 10.5 mm long BG has peaks in reflectivity of greater than 90% which are centered at wavelengths λ_1 = 1519.03 nm and λ_2 = 1519.91 nm with a -3 dB full-width optical bandwidth of 0.13 nm and 0.12 nm respectively. The coupling efficiency between emission from the laser and the lensed SMF is 0.4.

Figure 2. Measured L-I_{gain} characteristic of the laser in an external cavity for saturable absorber voltage V_{sat} = 0.9 V. The optical spectrum of the light output at operating points 1 and 2 are shown as insets.

Figure 3. **(a)** Measured temporal reponse of the device acting as an electro-optical SR flip-flop. The laser is biased at I_{gain} = 50 mA with the absorber bias V_{sat} = 0.9 V. A 9 mA positive going electrical pulse applied to the device sets the lasing wavelength to λ_2. The device stays in that state until a -9 mA electrical pulse resets the device to lase at λ_1. **(b)** Truth table of a conventional electrical SR flip-flop and the electro-optical SR flip-flop. The positive (negative) going pulse mimics S = 1, R =0, input (S = 0, R =1). The S = 0, R = 0 input is equivalent to having no electrical pulse input to the electro-optical SR flip-flop.

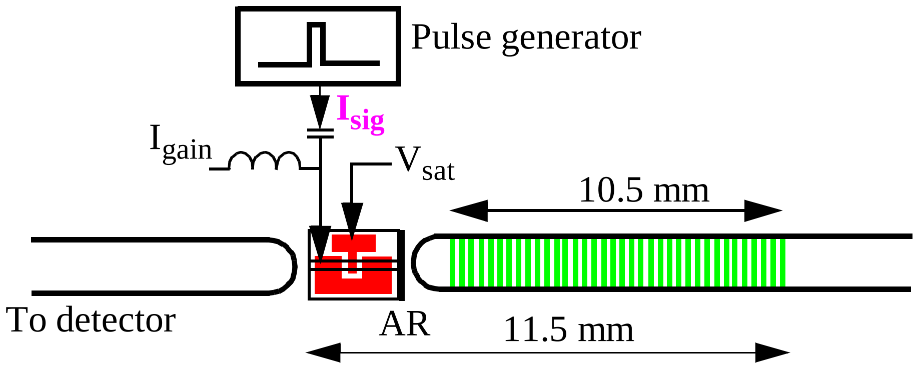
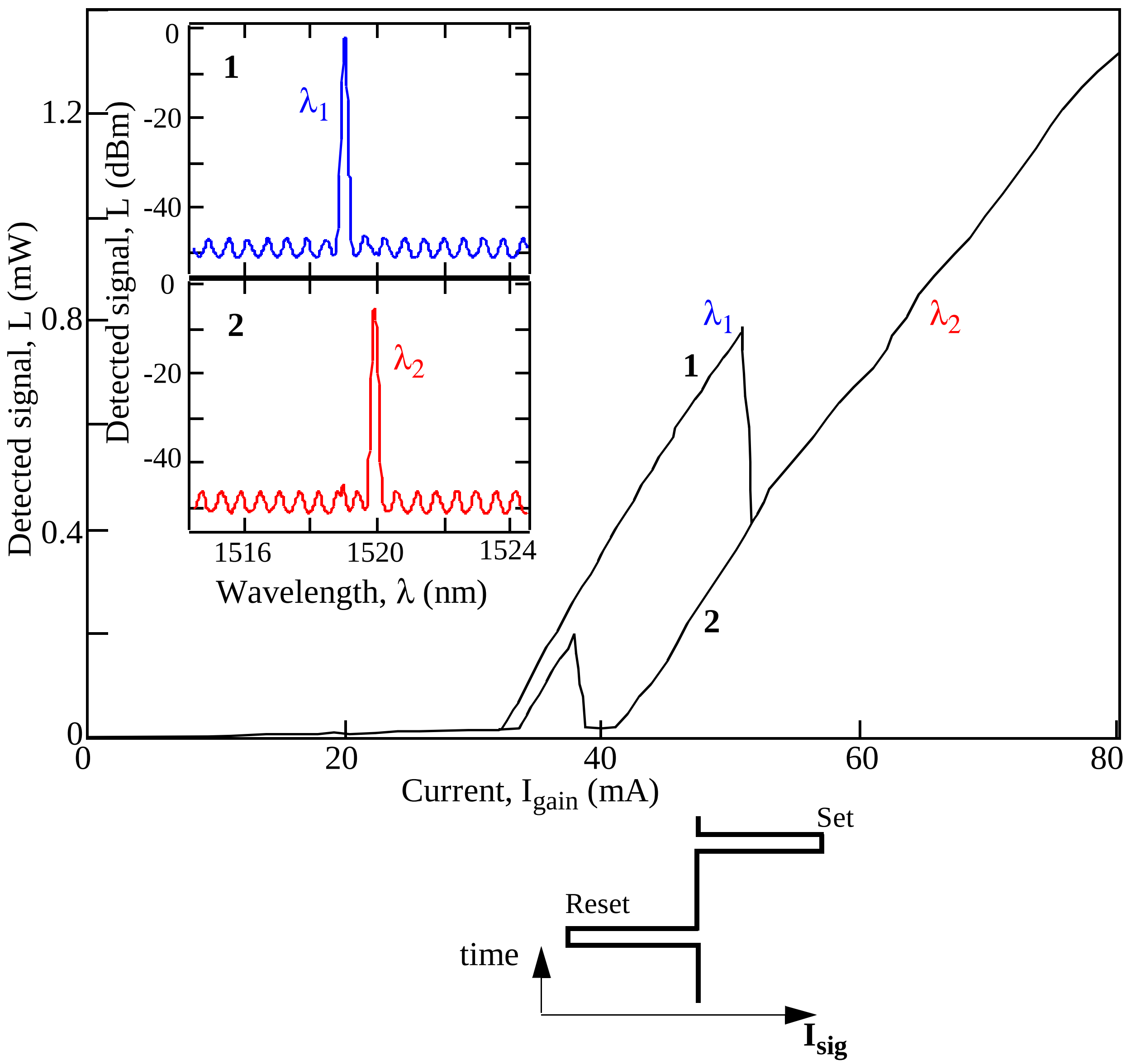


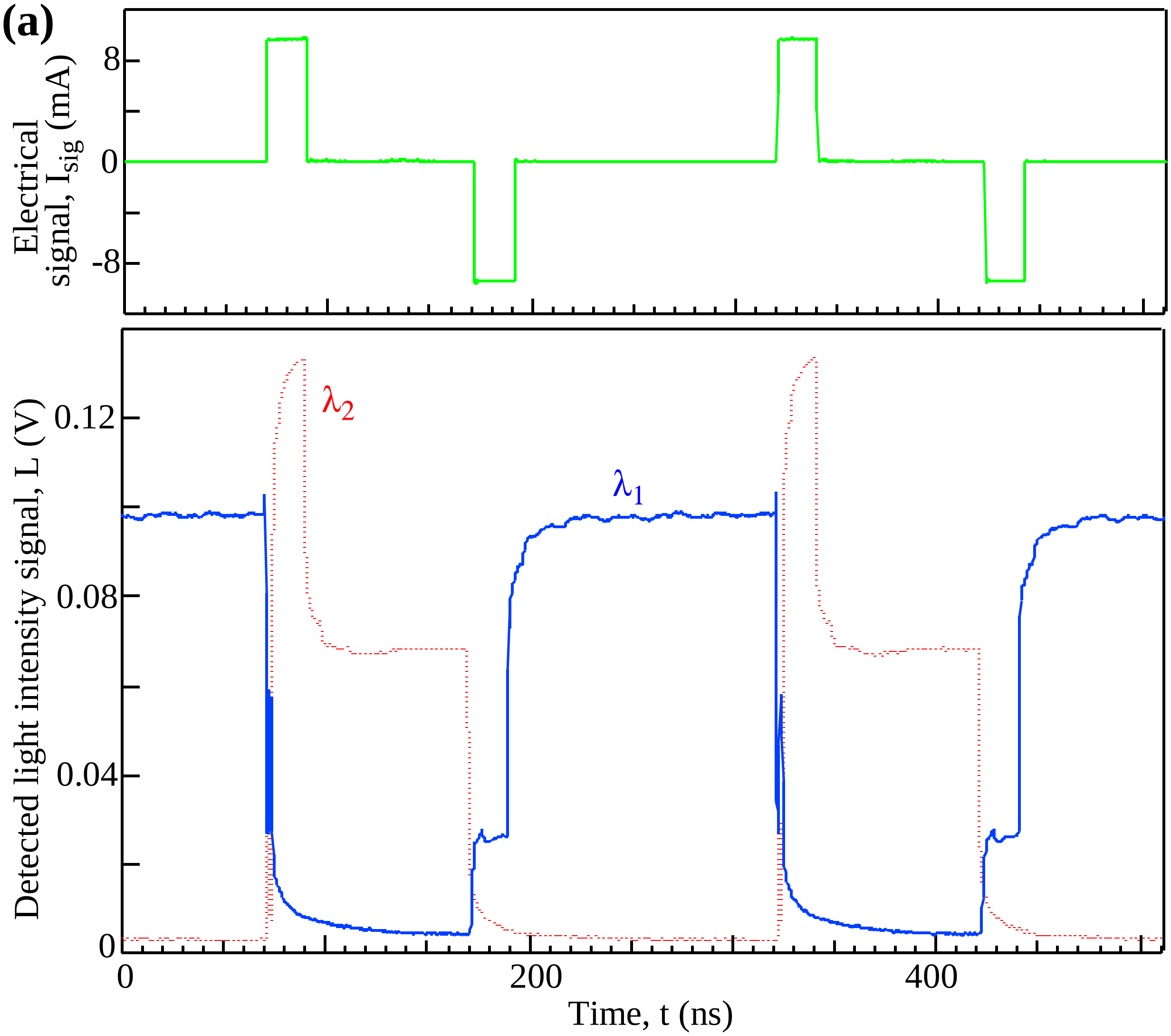
Figure 1.



Detected signal, L (mW)
0
0.4
0.8
1.2
0
20
40
60
80
Current, I_{gain} (mA)
λ_1
1
λ_2
2
Detected signal, L (dBm)
0
-20
-40
1516
1520
1524
Wavelength, λ (nm)
Set
Reset
time
I_{sig}

Figure 2.

(a)



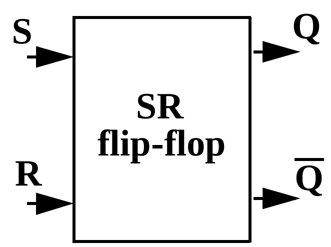
(b)

Truth table of electronic SR flip-flop

Inputs		Output	
S	**R**	**Q**	$\mathbf{\overline{Q}}$
0	1	0	1
1	0	1	0
0	0	Q	$\overline{Q}$
1	1	undefined	

Truth table of electro-optic flip-flop

Inputs		Output	
S	**R**	λ_2	λ_1
0	1	0	1
1	0	1	0
0	0	λ_2	λ_1
1	1	undefined	



Positive going pulse is S = 1, R = 0.

Negative going pulse is S = 0, R = 1.

Figure 3.