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Wavelength Tunable Flip-Flop Operation of a Modulated Grating Y-branch Laser

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Abstract— **Wavelength tunable flip-flop operation is experimentally demonstrated in a single modulated grating Y-branch laser for the first time. The control pulses have energies of 0.16-0.34 pJ and the switching time is about 200 ps.**

Keywords- All-optical flip-flop; Wavelength bistability; MG-Y laser.

I. Introduction

All-optical flip-flops are key signal processing building blocks in order to implement optical memory and optical logic circuits that may be used to overcome the bandwidth bottleneck of electronics in some switching applications [1]. In particular, wavelength bistability is attractive in applications where optical wavelength selective components are subsequently used to selectively route signals depending on their wavelength, such as in some proposed packet switch architectures [2].

Being able to achieve wavelength bistability in typical laser structures conventionally used for telecommunication applications would represent a tremendous advantage in view of practical implementations. Huybrechts et al. demonstrated all-optical flip-flop operation using set and reset pulses on the same wavelength in a standard tunable distributed Bragg reflector (DBR) laser diode and predicted that the principle can be extended to other laser diodes with long cavities [3]. All-optical flip-flop in a DBR with two control pulses injection locking onto the side-mode was demonstrated and analysed [4, 5]. However, no wavelength flip-flop with wide wavelength-tunable capability has ever been reported in a single telecommunication laser device so far.

The modulated grating Y-branch (MG-Y) laser uses the Vernier effect to achieve wide wavelength tunability with two multi-peak reflectors [6], similarly to sampled grating DBR (SG-DBR) lasers. Compared to SG-DBR lasers, MG-Y lasers offer advantages in term of output power variation when tuned, since their design avoids the output light to pass through the reflectors where free carrier absorption happens. Therefore, they are more commonly used in real transmitters than 2 or 3-section DBR lasers.

In this paper, we experimentally demonstrate for the first time all-optical flip-flop operation on multiple wavelengths emitted by a single commercially available widely tunable laser. Wavelength bistability is reported for the first time in an MG-Y laser at three different wavelengths. More operation windows at different wavelengths are believed to be also bistable, making the MG-Y laser a promising widely tunable optical logic component with great potential for multi-wavelength switching applications. Furthermore, switching energies in the range of 0.16-0.34 pJ and a switching time of about 200 ps are achieved.

II. Static Characteristics of the Device

The MG-Y laser used in our experimental demonstration is a commercially available device manufactured by Syntune. Only common phase control is implemented since differential phase control is not necessary, as explained in [6]. Fig. 1 shows the structure of the MG-Y laser chip used in our experiment.

The chip is not packaged. Therefore a piece of tapered fibre was used to couple the laser output to a circulator to allow injection of the control pulses. The measured output power after the circulator was ~8 dBm. Taking into account the coupling and circulator losses, the output power of the MG-Y laser in normal configuration was estimated to about 11 dBm.

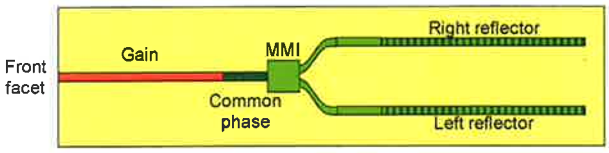

Figure 1. MG-Y laser structure.

The current injected to the gain section was set to 100 mA throughout this work. Changing the currents applied to the reflectors will change the lasing wavelength of the MG-Y laser. Under some reflector currents operating conditions, wavelength bistability could be obtained by varying the phase current, as shown in Fig. 2(a) for a lasing wavelength of about 1554 nm. The bistable window lies between 2 mA and 5.6 mA phase current, values at which the lasing wavelength jumped, as seen in Fig. 2(a) and (b). The lowest side-mode suppression ratio (>40 dB) was measured just before the laser toggled lasing state. In order to achieve flip-flop operation under optical control, a phase current of 3.6 mA is chosen. At this value the side-mode suppression ratio is ~50 dB.

When tuning to other wavelengths by applying currents to the reflectors, such static bistability may not always be obtained. Instead, unstable lasing was noticed where two competing modes were present, as shown in Fig. 2(c). The noisy spectra were due to the unstable lasing. However, by changing the gain current, static bistability could be obtained at other wavelengths. For instance, static bistability around ~1539 nm was achieved with a gain current of 130 mA and zero reflector current.

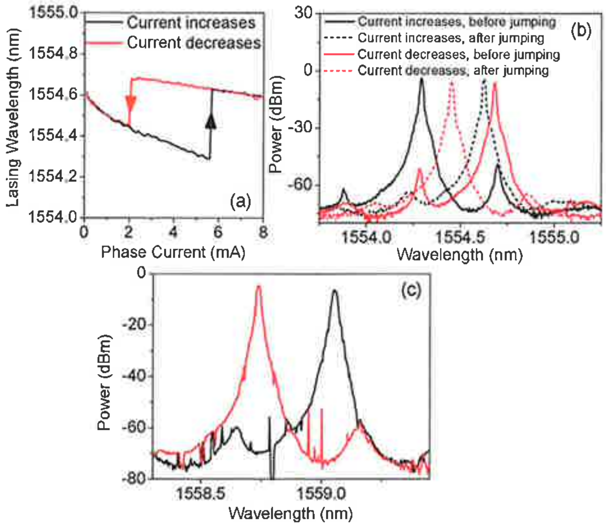

Figure 2. Static lasing characteristics of the MG-Y laser. (a) Lasing wavelength as a function of the phase current for the 1554 nm bistable window; (b) optical spectra of different lasing states in the 1554 nm bistable window; (c) lasing behaviour at 1559 nm.

III. Experimental Setup

The experimental setup for optically controlled wavelength flip-flop operation is shown in Fig. 3. Two tunable continuous wave (CW) sources were separately modulated by Mach-Zehnder modulators (MZM) driven by programmed 40 Gbit/s and 5 Gbit/s data patterns, so that a ~25 ps (control #1) and a ~200 ps (control #2) optical control pulses were generated every 12.8 ns. Both control signals were amplified by erbium-doped fibre amplifiers (EDFAs) and filtered by 1 nm band-pass filters (BPFs). The control pulses were combined and fed into the MG-Y laser via a circulator and their polarisation states were controlled (PC) individually to match the MG-Y laser. The laser output was filtered by a 0.3 nm thin-film filter and monitored on an oscilloscope following detection.

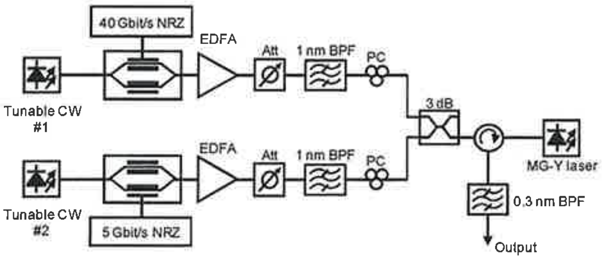

Figure 3. Experimental setup for wavelength flip-flop demonstration.

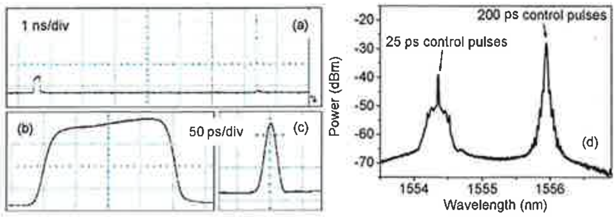

Figure 4. Control pulses: (a) both control pulses are present; (b) control #2 pulse; (c) control #1 pulse; (d) spectrum of the combined control signals.

The waveforms and spectra of the control pulses are shown in detail in Fig. 4. The time interval between adjacent control pulses #1 and #2 pulses was about 6-7 ns. The measured pulse widths were 22 ps and 202 ps for control #1 and control #2, respectively.

IV. Experimental Results

A. Dynamic flip-flop characteristics in the 1554 nm window

The MG-Y laser was operated with 100 mA gain current and 3.6 mA phase current in order to obtain dynamic bistable operation. Control #1 is placed at 1554.304 nm and has an average power of -16.9 dBm (corresponding to 0.26 pJ) while control #2 is at 1554.774 nm with -16.1 dBm average power (0.31 pJ). The flip-flop lasing is at the two wavelengths of 1554.37 nm and 1554.66 nm, as shown in Fig. 5(a) and (b). The switch-on and switch-off time at both wavelengths is about 200 ps. The measured output power under bistable operation is 5 dB lower than under normal operation, at about 6 dBm.

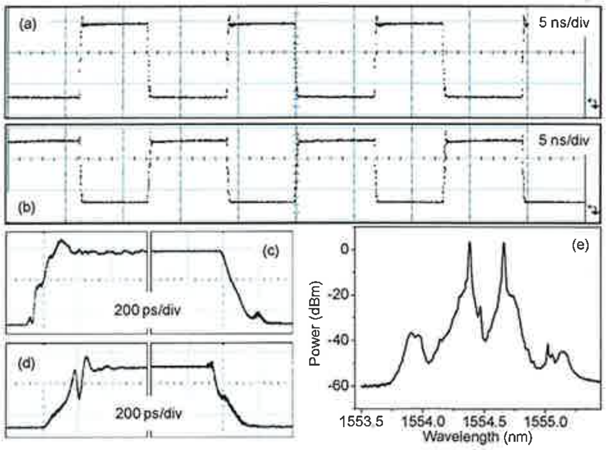

Figure 5. Wavelength flip-flop operation in the 1554 nm bistable window. (a) Bistable MG-Y output at 1554.37 nm; (b) output at 1554.66 nm; (c) switch-on/off feature at 1554.37 nm; (d) switch-on/off at 1554.66 nm, and (e) spectrum of the bistable output.

In order to understand further the effect of the control signal power level, the duration of control #1 was increased to 200 ps by adjusting the data pattern applied to the MZM, while keeping all other conditions identical. Bistability was still obtained when the peak power of the control #1 pulse remained the same. This suggests that the peak power of the controls was the important factor for the flip-flop operation of the MG-Y laser and that it may be possible to further decrease the control pulse energy by using short pulses.

It was also noticed that, when detuning control #1 by 40 pm to 1554.344 nm, the required control power rose to -12.9 dBm (0.66 pJ), with a more noisy output. This observation is in agreement with the effect reported in [5]. The bistability was still obtained in a 180 pm range (1554.214 nm~1554.394 nm). The detuning could not be increased further due to insufficient control pulse power.

We also checked the flip-flop operation following the same principle as described in [3]. When a high energy reset pulse (200 ps, 5.85 pJ) at an arbitrary wavelength (here 1556 nm) is injected to deplete the carriers, the laser will be set to the state with lower carrier density (lasing at 1554.66 nm). When a weak set pulse (25 ps, 0.39 pJ at 1554.344 nm) is injected, it will set the MG-Y laser to lase at 1554.39 nm. However, strong overshoots on the flip-flop output were observed at switch-on and switch-off due to the strong control pulse.

B. Wavelength-tunable flip-flop operation

Wavelength flip-flop operation was also obtained at 1559 nm and 1560 nm. The corresponding control pulse wavelengths and energies are listed in Table I, and the bistable operations in the two windows are shown in Fig. 6.

TABLE I. CONTROL PULSES FOR FLIP-FLOP AT 1559 NM AND 1560 NM.

MG-Y lasing output (nm)		**Control #1**		**Control #2**	
		Wave-length (nm)	***Pulse energy (pJ)***	***Wave-length (nm)***	***Pulse energy (pJ)***
1560.12	1560.42	1560.054	0.34	1560.506	0.16
1558.75	1559.04	1558.780	0.65	1559.146	0.54

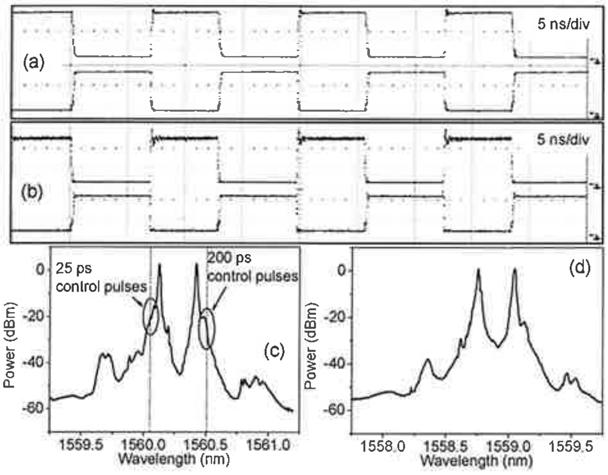

Figure 6. All-optical flip-flop operations at other wavelengths: (a) flip-flop in the 1560 nm window; (b) flip-flop in the 1559 nm window; (c) spectrum of the bistable output in the 1560 nm window and (d) spectrum of the bistable output in the 1559 nm window.

We may notice that the control pulse energies in the 1559 nm window are higher than at 1560 nm. This is due to that fact that the control pulse wavelength was not placed to the optimum position and also the polarisation was not fully optimised. The flip-flop waveforms in Fig. 6(b) are therefore noisier than those in Fig. 6(a) because of higher injection.

Fig. 6(c) illustrates the positions of the injection wavelengths with respect to the lasing spectra. The dash lines indicate the central wavelengths of the optical controls. The asymmetries in the spectra of the MG-Y output are due to the presence of the control pulses, which could already be observed in Fig. 5(e). It has to be pointed out that the MG-Y lasing wavelengths are different from those of the injected control signals, which indicates that the injection was set on the side-mode, but the lasing was not locked to the injection. It can be understood that the side-mode injection enhanced the interaction between the main mode and the side mode in the MG-Y laser, which broke the lasing balance and hence the wavelength jumped.

V. CONCLUSION

We have experimentally demonstrated wavelength-tunable wavelength flip-flop operation in a single MG-Y laser. Even though the present demonstration was restricted to three wavelengths, more bistable regions are believed to be present in the MG-Y laser tuning range. The measured switching energy was in the range 0.16-0.34 pJ when the control pulse wavelength was set close to the lasing side-mode. The measured switching time was about 200 ps.

ACKNOWLEDGMENT

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Session 1.8 Optical processing (II)

14h00 - 14h30
Fr-S18-I12 : Recent Advances in SOA-based Optical Signal Processing
Speaker : Hiroyuki Uenohara - Tokyo Institute of Technology - Japan

14h30 - 14h45
Fr-S18-O21 : Wavelength Tunable Flip-Flop Operation of a Modulated Grating Y-branch Laser
Speaker : Yi An - Technical University of Denmark, Kgs. Lyngby - Danmark

14h45 - 15h00
Fr-S18-O22 : Colorless All Optical XOR Gate for BPSK Signals Based on Periodically Poled Lithium Niobate Waveguide
Speaker : Antonio Malacarne - National Laboratory of Photonic Networks - CNIT, Pisa - Italy

15h00 - 15h15
Fr-S18-O23
Speaker : All-optical 2x4 decoder using external cavity self- locked Fabry-Perot laser diode
Speaker : Bikash Nakarmi - KAIST, Daejeon - South Korea

15h15 - 15h30
Fr-S18-O24 : All-optical SR Latching Circuit with Simultaneous Inverted and Non-inverted Outputs Using Fabry-Perot Laser Diodes
Speaker : Hoai Tran Quoc - KAIST, Daejeon - South Korea

PROGRAMME AT A GLANCE

	September 11th	September 12th	September 13th				September 14th		
9:00 / 9:30 / 10:00		Plenary session	Session 1.3 Transmission Systems (I)	Session 2.3 Switching Techno.	Session 3.3 Optical Transport Net	Telecom & Energy Forum	Session 1.6 Wave. conv. and reg.	Session 2.6 Switching Systems	Sessi 3.6 High Capac Route
10:30			Coffee break				Coffee break		
11:00 / 11:30 / 12:00			Session 1.4 Transmission Systems (II)	Session 2.4 Switching Techno. & Ampl.	Session 3.4 Dynamic Networks	Telecom & Energy Forum	Session 1.7 Optical processing (I)	Session 2.7 Switching Systems and net	Sessi 3.7 Route and D/ cente
12:30 / 13:00 / 13:30		Lunch	Lunch				Lunch		
14:00 / 14:30	WKP 1 / WKP 2 / WKP 3	Session 2.1 / Session 3.1 / Symposium	Poster session			Telecom &	Session 1.8	Session 2.8	Sessi 3.8

15:00	Progress in Optical Routers and Buffers	What do we need to make an optical network robust against disasters?	Research directions for green networks	Session 1.1 Sources	Low Energy Functions	Network design					Energy Forum	Optical processing (II)	OADM-based systems	Nev Genera Netwo
15:30	**Coffee break**			**Coffee break**				**Coffee break**				**Closing**		
16:00	WKP 1	WKP 2	WKP 3	Session 1.2 Modulators	Session 2.2 Integrated devices	Session 3.2 Green Networking	Symposium	Session 1.5 OFDM, CDMA	Session 2.5 OPS Enablers	Session 3.5 Elastic Networks	Telecom & Energy Forum			
16:30														
17:00														
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18:00				**Welcome Reception at the City Hall**				**Gala dinner**						

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