Compact micro ring lasers with fast frequency tuning using filtered optical feedback

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We investigate the wavelength tuning speed in semiconductor ring lasers with filtered optical feedback. The device consists of a micro ring laser and a feedback section which contains two arrayed waveguide gratings and four semiconductor optical amplifiers. The wavelength tuning and switching are controlled by changing the injected currents into the gates. We obtained a wavelength transition time of a few nano seconds together with a substantial delay time of several nano seconds in the switching event.

Introduction and Device description

Semiconductor ring lasers (SRLs) are promising candidates as key components in photonic integrated circuits. They do not require cleaved facets or gratings to form the cavity. Thus, they are currently the subject of many experimental and theoretical investigations, ranging from fundamental studies of their nonlinear dynamical behavior to multiple practical applications [1]. In particular, SRLs attract a lot of attention due to their directional bistability, providing the possibility of operation in either of the two counter-propagating directions. This bistability has been exploited for the realisation of optical switching and all-optical flip-flops [2].

Wavelength switchable compact lasers are highly desirable for applications such as optical routing and multiplexing /demultiplexing application. Recently on-chip filtered optical feedback (FOF) has been proposed to achieve integrated and fast switching lasers. FOF is an interesting approach to achieve tunable and multi-wavelength lasers [3] due to the fact that the tuning process in this approach will be done outside the main laser cavity. As a result there is no change in refractive index in the main ring laser cavity when the wavelength is tuned. In this approach, the temperature-induced wavelength drift due to changing tuning currents is very small and no special thermal control is needed. In [4], the FOF section is integrated with a Fabry Perot laser using deep etching to fabricate the distributed Bragg reflectors (DBRs) of the laser cavity, these mirrors increase the complexity of the device fabrication process and reduce the total output power of the device.

Previously, we have used FOF with semiconductor ring lasers (SRLs) to achieve tunable multi-wavelength emission [3, 5]. The ring geometry is easy to be integrated on-chip with other components. The mask layout of the ring laser with on-chip FOF is shown in Fig. 1 (a). In this work, we show that using FOF approach, it is possible to switch between two wavelengths in SRLs, where we show that there is a short transition time and non-negligible (longer) delay time in each switching event.

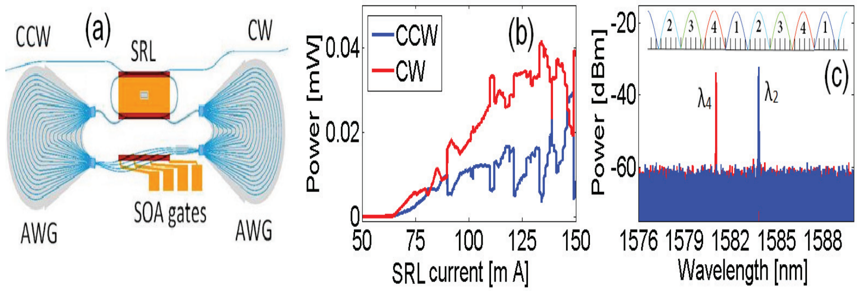

Figure 1: (a) Mask layout of the integrated semiconductor ring laser with filtered optical feedback. (b) P-I curve of the device. (c). Spectrum of the device's output in the CCW direction when pumping the SRL at 95 mA, gate 4 at 14.2 mA and gate 2 either at 3.55 mA (red) or at 38 mA (blue). A schematic representation of the AWG channels passbands is plotted at the top.

Experimental study

The device chip is mounted on a brass submount. The laser temperature is stabilized at 21°C using a 10 kΩ thermistor and a Peltier element. We use electrical probes to pump the SRL and the gates which are chosen to provide feedback. The SRL output in the CW and the CCW directions is collected using lensed fibers. We start our experiments by checking the P-I curve of the device, the device's threshold is 64.5 mA as can be seen in Fig. 1(b). Above the threshold the device output is bidirectional with slightly higher power in the CW direction than the power in the CCW direction. Next, we apply 95 mA on the SRL and we connect two of the gates to current sources. By changing the currents sent through these gates, we can tune the emission from one longitudinal mode (LM) to another LM. For example, if we pump gate 4 and gate 2 with currents of 14.2 mA and 3.55 mA, respectively, the device output will be a single LM at λ_4 = 1581.048 nm, which is positioned within the passband of gate 4' s channel. By increasing gate 2's current to 38 mA, wavelength switching is observed in the device output from λ_4 to λ_2 = 1583.790 nm, which corresponds to the passband of gate 2. Both wavelengths λ_4 and λ_2 in the CW direction are shown in Fig. 1(c). Similar switching behavior is observed in the CCW direction, so the wavelength switching in this device takes place in both directions whereas the switching between wavelengths in [6] can be achieved in only one direction. To measure the wavelength switching speed between λ_4 and λ_2, we use the setup which is shown in Fig. 2(a). A driving square wave signal (with period of 2.56 μs and the peak to peak voltage amplitude V_{pp} of 0.4 V) is applied to gate 4 using an arbitrary waveform generator (Tektronix-AWG 520), which is connected to the AC input of a bias-T, the DC input of the bias-T will be connected to a DC current source. The output of the bias-T is connected to the electrical probe which is connected to gate 4. A second current driver is used to bias gate 2 and a third one is used to bias the SRL. The device's output in the CW direction is amplified using an external semiconductor optical amplifier (Thorlabs LM14S2) to ensure accurate measurements of the switching time, and then filtered using a tunable optical bandpass filter (Santec OTF-320 with 3 dB bandpass width of 0.5 nm). Finally the time traces are recorded using a 2.4 GHz bandwidth detector connected to a 4 GHz bandwidth oscilloscope (Tektronix CSA7404). An Ando AQ6317B optical spectrum

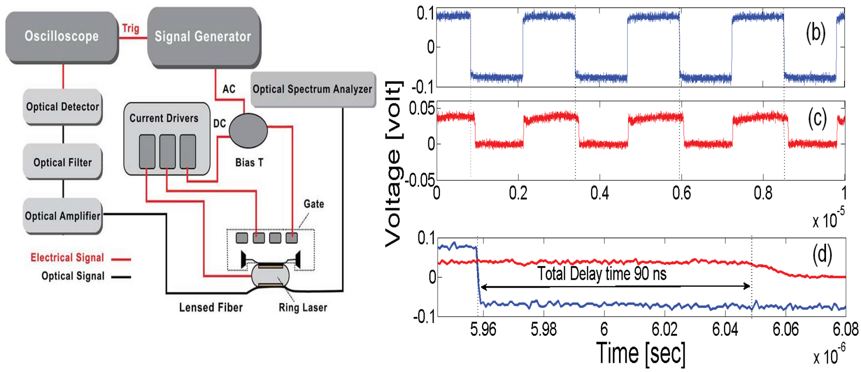

Figure 2: (a) Schematic of the lab setup. (b) Trigger signal from arbitrary waveform generator to the oscilloscope. (c) Device output signal when the tunable bandpass filter is centered at λ_4. (d) Zoom in of a single switching event.

analyzer is connected to the CCW direction to measure the optical spectra.
We show the driving square wave signal which is applied to gate 4 in Fig. 2(b). The signal at the device output in the CW direction (while the central frequency of the tunable filter is centered at λ_4) is shown in Fig. 2(c), which clearly shows that the wavelength switches with the same periodicity as the reference signal. When the signal send to gate 4 (see Fig. 2(b)) is high, the device output at λ_4 (see Fig. 2(c)) is on. When the signal send to gate 4 is switched to a low value, the device output at λ_4 switches off. Repeating these measurements, but with the tunable filter centered at λ_2 (not shown), shows that λ_2 is switched completely off when λ_4 is switched on. In order to estimate the wavelength switching speed, we assume that a switch is completed once the mode power reaches 90% of the final power, so we define the transition time as the time which is measured between 10% to 90% of the final power.
The results show a transition time of 4-7 ns. However, next to the transition time, there is also a non-negligible delay (90 ns) between the trigger signal from the arbitrary waveform generator and the start of the switching transition as can be seen in Fig. 2(d). This delay time is not constant, but varies from one switching event to another. To measure the real delay time we have to take into account that, there is a time of flight difference between the trigger signal and the signal reaching the optical detector. This time depends on our lab set up and it is 50 ns in our measurements. We also considered the RC time constant of the on-chip SOA gates which was measured to be around 10 ns. Remark that this time can be reduced in the future devices by optimizing the SOA dimensions for high speed operation. In order to have a more detailed analysis about this delay time, we show in Fig. 3 a histogram of the delay time for 143 switching events after subtracting both the RC time and the time of flight difference. This figure shows a quasi-Gaussian distribution in the delay with an average of 31.7 ns and standard deviation of 4 ns. A detailed numerical study based on rate equations model of the wavelength switching speed in SRLs using FOF will be presented at the conference.

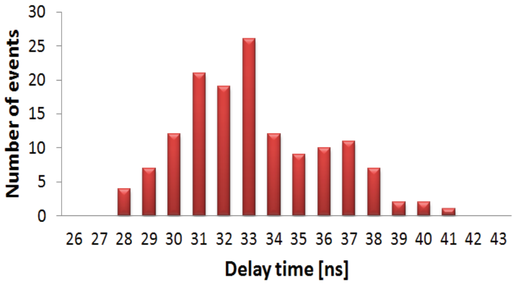

Figure 3: Histogram of the wavelength switching' s delay time using $V_{pp} = 0.5$ V .

Conclusions

We proposed an approach to achieve wavelength switching based on semiconductor ring laser with FOF. We have shown that mode switching is obtained by changing currents injected in the SOA gates that control the amount of FOF. We measured the switching speed using a square wave signal. The results show that the LMs transition time is between 4-7 ns, and the delay time is between 28-40 ns. The tunability and the high switching speed make the device interesting for all optical packet switching applications. More details about this work can be found in [6].

Acknowledgment

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