Effect of Filtered Optical Feedback on The Dynamics of Semiconductor Ring Lasers

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We report on the dynamics of a semiconductor ring laser under the effect of filtered optical feedback. This feedback is realized on the laser chip and its strength can be controlled electrically. Due to the feedback, we observe anti-phase oscillations in the intensity of the clockwise and counterclockwise propagating modes. We investigate how the frequency of these oscillations depends on the feedback strength and how they can be suppressed.

Introduction and Device description

Semiconductor ring lasers (SRLs) have received increasing attention in recent years owing to their possible applications in photonic integrated circuits, as their cavities do not require cleaved facets or gratings. SRL are promising candidates for multiplexing / demultiplexing applications, tunable lasers [1], electrical and all-optical switching [2, 3] and optical memories [4]. The circular geometry of the cavity allows a SRL to operate in two possible directions, clockwise mode (CW) and counterclockwise mode (CCW). If the pump current is just above threshold, SRLs operate in a bidirectional regime where the SRLs emit in the two directions CW and CCW simultaneously. On the other hand if the pump current is sufficient high, SRLs emit only in one direction either the CW direction or the CCW direction (unidirectional regime). Sorel et al [5] reported on the bidirectional regime where the intensities of the two counterpropagating modes undergo alternate sinusoidal oscillations with frequency in the tens of megahertz range. These oscillations strongly depend on backscattering (dissipative and conservative backscattering) which affect the lasing operation close to threshold. More details about this alternate oscillating regime can be found in [5, 6].
Recently, filtered optical feedback (FOF) has been proposed as an approach to achieve tunable SRLs. An example of a device using this approach is shown in Fig. 1 (a). The filtered feedback control is done outside the ring laser cavity. Therefore, changes in the filtered feedback loop will have only a small effect on the main ring laser cavity. The quasi-static behavior of these devices has been investigated previously in [7]. In this work, we investigate the dynamics of the SRL under the effect the FOF.
The device's fabrication was done in the framework of JePPIX using InP wafer [8]. Both active and passive components have a p-doped InP top cladding and a p+-InGaAs contact layer, removed later from the passive areas to prevent additional propagation loss. All layers are grown using a three-step MOVPE butt-joint regrowth process, more details about the fabrication process can be found in [9]. The SRL output is coupled to the

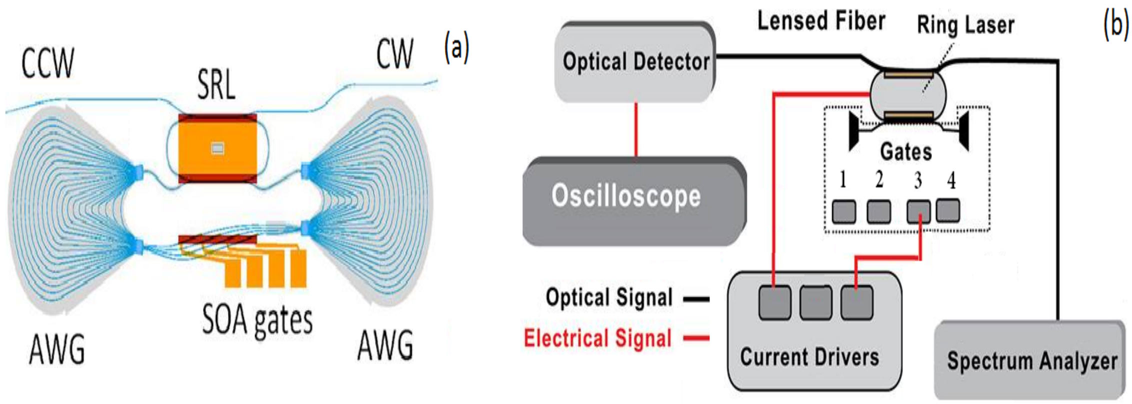

Figure 1: (a). Mask layout of the integrated ring laser with filtered optical feedback. (b). Lab setup.

arrayed waveguide grating (AWG) filters by a directional coupler. The AWG channel spacing is 1.336 nm and the free spectral range of the AWG is 5.65 nm, whereas the longitudinal mode (LM) spacing is 0.305 nm. Therefore, each AWG channel supports four LMs. Four semiconductor optical amplifiers (SOA) are located between the two AWGs in order to control the feedback strength. Each SOA gate can be independently pumped electrically. When a gate is biased, the feedback strength and phase of the LMs in the corresponding AWG channel changes. When a gate is not biased, or when it is reverse biased, light is absorbed and therefore there is no feedback.

Experimental study

Experimentally the device chip is mounted on a brass submount. The laser temperature is stabilized at 21°C using a 10 k Ω thermistor and a Peltier element. Two electrical probes are used in the experiments: one of them is used to bias the SRL while the other is used to pump one of the gates. The light in the CW and CCW directions is collected using two lensed fibers. We check the optical spectra in the CW direction using an optical spectrum analyzer (Ando AQ6317B), while we observe the time traces in the CCW direction using a 2.4 GHz bandwidth detector connected to a 4 GHz bandwidth oscilloscope (Tektronix CSA7404). The lab set up can be seen in Fig.1 (b).

The device has a threshold value of 65 mA, we choose to pump the SRL at 85 mA. At this pumping current, the device output is multi-mode, while the time traces of the device's output in both CW and CCW directions are stable. Next, we show the effect of FOF on the dynamical behavior of the device by investigating the change of the dynamics when we change the pumping current on one of the gates (in this work we pump gate 3).

When the current of gate 3 is less than 10 mA, the device output is multi-mode as the strength of FOF is not sufficient to force the device to lase at a single mode (SM). When the current of gate 3 is increased from 10 mA to 26 mA, the device output is SM with wavelength $\lambda = 1582.2$ nm, which corresponds to the wavelength passband of gate 3 [9]. The time traces of the device's output for both CW and CCW directions are stable. By increasing the pumping current in gate 3 from 26 mA to 70 mA, the optical spectrum analyzer shows that the device output is SM with a wavelength of $\lambda = 1581.716$ nm, as can be seen in Fig. 2 (a). This wavelength still corresponds to the wavelength passband

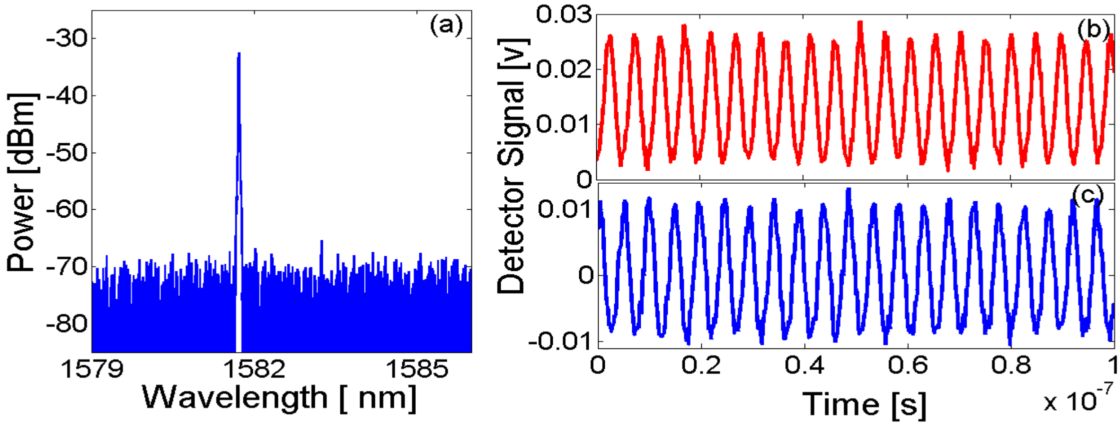

Figure 2: While pumping the SRL at 85 mA, gate 3 at 46.7 mA. (a). Optical spectrum in the CW direction. (b). Time trace of the device output in the CW. (c). Time trace of the device output in the CCW.

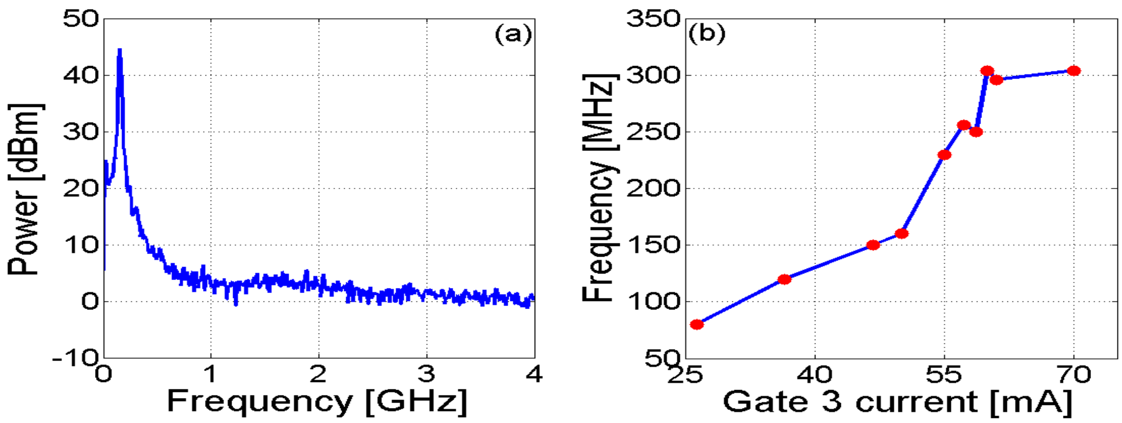

Figure 3: (a). Electrical spectrum in the CW direction. (b). Frequency of the oscillations as function of gate 3's current while SRL current is fixed at 85 mA.

of gate 3. In this current range for gate 3, we observe anti-phase oscillations between the time traces of the CW and CCW directions. An example of these anti-phase oscillations, as they appeared when gate 3 is pumped at 46.7 mA, is shown in Fig. 2 (b,c). The frequency of the oscillations is measured by an electrical spectrum analyzer (Anritsu MS2667C) and is 150 MHz as can be seen in the time trace in Fig. 3 (a) .
To further study the effect of the FOF on the frequency of the anti-phase oscillations, we measured the frequency of the oscillations as function of the current of gate 3. As the injected current in gate 3 increases from 22 mA to 70 mA, the frequency of the oscillations increases from 144 MHz to 304 MHz, as can be seen in Fig. 3 (b). By increasing the current of gate 3 from 71 mA to 80 mA, the device output remains SM at $\lambda = 1581.720$ nm, while the time traces of the device's output is stable in both the CW and CCW directions. Similar results have been obtained using the other gates. However, the feedback strength needs to be carefully adjusted if we want to suppress these oscillations.

Conclusions

We investigate the dynamics of SRL under the effect of FOF. Our results show that for a specific range of the feedback strength, anti-phase oscillations can be induced in the CW and CCW directions. These oscillations could not be seen in the same SRL without the feedback. We show how the frequency of these oscillations change under the effect of FOF. A theoretical and numerical study is under development in order to determine the bifurcation mechanism leading to the anti-phase oscillations.

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References

[1] M. Khoder, G. Verschaffelt, R. M. Nguimdo, J. Bolk, X. J. M. Leijtens, and J. Danckaert, ”Digitally tunable dual wavelength emission from semiconductor ring lasers with filtered optical feedback”, Laser Phys. Lett, vol. 10, 075804, Jun, 2013.

[2] G. Yuan and S. Yu, ”Bistability and Switching Properties of Semiconductor Ring Lasers With External Optical Injection,” IEEE J. Quantum Electron., vol. 44, no. 1, pp. 41–48, Jan. 2008.

[3] M. Khoder, R. M. Nguimdo, J. Bolk, X. J. M. Leijtens, J. Danckaert, and G. Verschaffelt, ”Wavelength Switching Speed in Semiconductor Ring Lasers With On-Chip Filtered Optical Feedback,” IEEE Photon. Technol. Lett., vol. 26, no. 5, pp. 520–523, Mar. 2014.

[4] M. T. Hill, H. J. S. Dorren, T. de Vries, X. J. M. Leijtens, J. H. den Besten, B. Smalbrugge, Y. S. Oei, H. Binsma, G. D. Khoe, and M. K. Smit, ”A fast low-power optical memory based on coupled micro-ring lasers,” Nature., vol. 432, pp. 206–209, Nov. 2004.

[5] M. Sorel, G. Giuliani, A. Scirè, R. Miglierina, J. P. R. Laybourn, and S. Donati, ”Operating regimes of GaAs-AlGaAs semiconductor ring lasers: experiment and model,” IEEE J. Quantum Electron., vol. 39, no. 10, pp. 1187–1195, Oct. 2003.

[6] M. Sorel, J. P. R. Laybourn, A. Scirè, S. Balle, G. Giuliani,R. Miglierina, J. P. R. Laybourn, and S. Donati, ”Alternate oscillations in semiconductor ring lasers,” Opt. Lett., vol. 27, no. 10, pp. 1992–1994, Oct. 2002.

[7] M. Khoder, G. Verschaffelt, R. M. Nguimdo, J. Bolk, X. J. M. Leijtens, and J. Danckaert, ”Controlled multiwavelength emission using semiconductor ring lasers with on-chip filtered optical feedback,” Optics. Lett., vol. 38, no. 10, pp. 2608-2610, Jul. 2013.

[8] X. J. M. Leijtens,” JePPIX : the platform for Indium Phosphide–based photonics,” IET Optoelectron., vol. 5, no. 5, pp. 202–206, Oct. 2011.

[9] I. V. Ermakov, S. Beri, M. Ashour, J. Danckaert, B. Docter, J. Bolk, X. J. M. Leijtens, and G. Verschaffelt, ”Semiconductor ring laser with on-chip filtered optical feedback for discrete wavelength tuning”, IEEE J. Quantum Electron, vol. 48, pp. 129–136, Jan, 2012.