Monolithic Mode-Locked Ring Lasers: Model and Characterization Multi-wafer Project Run

L. J. Orbe-Nava, A. Jiménez-Galindo, G. Carpintero del Barrio
Department of Electronics Technology
Universidad Carlos III de Madrid
Leganes, Madrid, Spain
lorbe@ing.uc3m.es, ajgalind@pa.uc3m.es

***Abstract*—We present a traveling wave numerical model for a 15 GHz monolithically integrated symmetrical mode-locked ring laser, for which the results have been compared against experimental data from devices fabricated within a JePPIX platform run. On both, experimental and numerical, we show the relation that exists between the losses in the saturable absorber and the resultant pulse width when the device operates in a stable modelocking regime. Simulation results show good agreement with experiments for a given set of bias conditions which allows us to analyze the saturable absorber model.**

Mode-locked lasers, optical pulse generation, semiconductor ring lasers.

I. Introduction

Semiconductor lasers are suitable light sources for high rate optical fibre communications as well as for signal processing systems due to a range of unique characteristics such as small size, high efficiency, low cost and integration potential. This integration potential can only be realized if the requirement of cleaved facets to realize the optical resonator of a laser diode is avoided. Semiconductor ring lasers possess the attractive characteristic that the optical resonator is implemented through a circular waveguide, having as an added advantage the precise control by lithography of the cavity length. Due to this interest, research on these devices has already demonstrated continuous-wave (CW) [1] and single-mode operation [2] two decades ago. Moreover, ring lasers have been shown to operate in two counter-propagating directions (clockwise, CW and the counter-clockwise, CCW) [3].

Ring laser structures have been also used to implement integrated mode-locked sources, where it was shown that the counter-propagating modes actually allow the device to operate in a colliding pulse mode-locked (CPM) regime [4]. Extremely high pulse repetition rates up to 860 GHz have been shown [5]. It is not usual to find such high repetition rates in integrated devices due to the lengths of the ring resonators, due to bending loss limits on the curve waveguide radius, and they were attributed to intracavity back reflections in the ring resonator. Thus, the development of suitable models for the description of the ring laser devices is required.

In the present analysis, we present a travelling-wave model description of a 15 GHz monolithically integrated symmetrical mode-locked semiconductor ring laser. This model allows the inclusion of active and passive sections, in order to describe devices produced within an active-passive InP-based integration technology such as it is offered within the Joint European Platform for Photonic Integration of InP-based Components and Circuits, JePPIX [6]. The devices were designed, fabricated and tested, and we compare the experimental results against the model.

II. Numerical Model of a Mode-Locked Semiconductor Ring Laser

For the ring laser description, we have chosen the forward-difference time-domain travelling wave (FDTD-TW) modelling technique [7], which allows describing laser structures where the longitudinal dimension needs to be taken into account [8], such as in distributed feedback lasers (DFB). In our case, the FDTD-TW description of the device naturally originates the two counter-propagating modes, and allows including in the description the back reflection effects within the cavity. The most common form of implementation of this model is through a Transfer-matrix technique in which the entire structure is divided into several elemental sections. This establishes a time-domain technique which also incorporates the multimode nature of each propagation direction on the ring as well as spectral mixing effects.

The simulated device structure, shown in Fig. 1, is a symmetrical mode-locked ring laser composed by two optical amplifiers of 200 µm length each (SOA1 and SOA2), separated by a 30 µm saturable absorber (SA) and a passive section of 4970 µm, with a total cavity length of 5400 µm (15GHz modal frequency spacing) as seen in Fig. 1. The model also includes a 50/50 Multi-Mode Interference Coupler (MMI). We have used for the models the laser parameters as in reference , with the additional consideration that the carrier lifetime in the saturable absorber depends of the applied reverse bias voltage [9], modeled through varying the loss coefficient α [10].

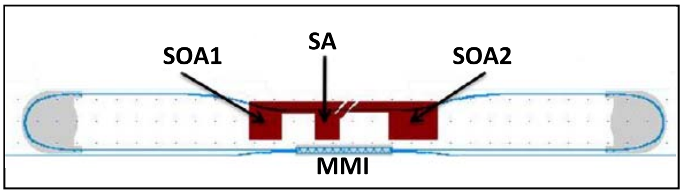

Figure 1. Simulated Semiconductor ring laser structure

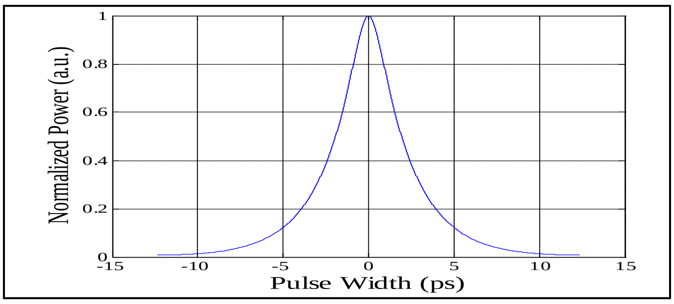

Figure 2. Spectral response of the numerical model

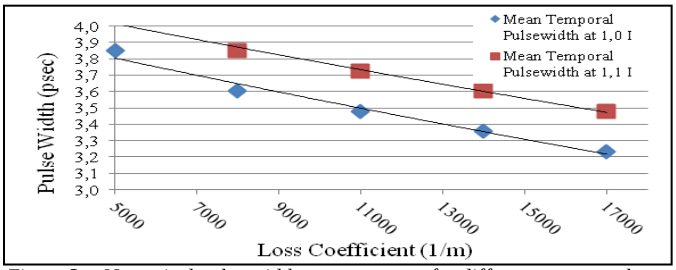

Figure 3. Numerical pulse width measurements for different current values. The inset shown the autocorrelation of the resulting pulses in the model for the conditions on Figure 2.

Selecting a bias level in which mode locking is observed, with I = 1.1I and α = 5000 m^{-1}, where I represents the initial current in which mode-locking is obtained, the simulation results show optical pulses in the output. Fig. 2 shows the result of autocorrelating the numerical output for one such pulse, obtaining a pulse width of 4.034 psec, which adjusts to a Lorentzian profile and a temporal pulse width of 2.06 psec. In the optical spectrum we find modes spaced by 0.125 nm, providing the expected repetition rate of 15 GHz. From the autocorrelation data, we are able to investigate the dependence of their pulse width against the reverse bias voltage (i.e. the loss coefficient α), much in the same way as in the experiment. Fig. 3 shows the pulsewidth decreasing exponential trend when the loss coefficient in the saturable absorber is increased, equivalent to an increase on the reverse bias of the saturable absorber.

III. Device Characterization

An optical chip was fabricated within the JePPIX platform following the ring structure on Fig. 1, with 7º angled output waveguides to avoid reflections. When the two gain sections are short-circuited, we have measured the optical output from the counter-clockwise direction. The optical pulses were measured on an APE Pulse-Check optical. Fig. 4 shows the experimentally observed autocorrelation for the bias conditions I = 110 mA and V_{SA} = -2.6 V, offering a Gaussian profile for the measured autocorrelation and a temporal pulse width of 2.50 psec. For two different bias levels, 105 and 110 mA, we have measured the pulse width dependence on the reverse voltage on the absorber averaging three consecutive measurements at each voltage level. The experimental results offer a decreasing trend, as seen in Fig 5, which agrees with the numerical result for the highest values of the reverse bias.

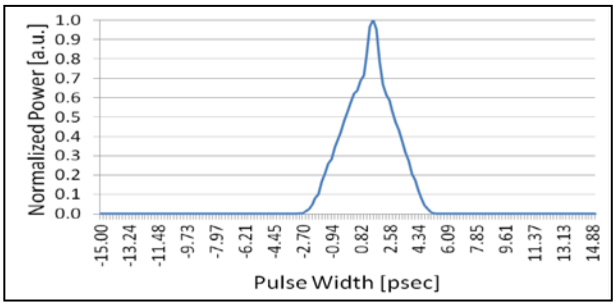

Figure 4. Experimental autocorrelation trace.

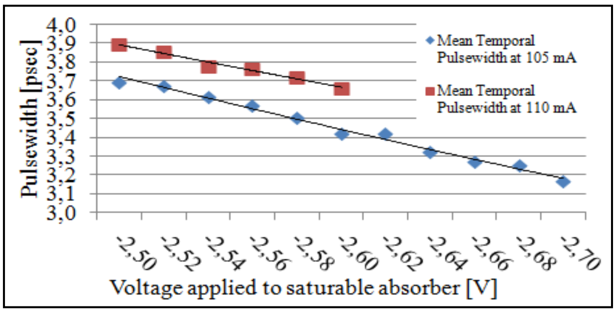

Figure 5. Experimental pulse width measurements for the ring laser's CCW output for two different current values.

However, the limited range of reverse bias over which we achieved mode locking requires further investigation.

References

[1] Krauss, T., P.J.R. Laybourn, and J. Roberts, *CW operation of semiconductor ring lasers.* Electronics Letters, 1990. **26**(25): p. 2095-2097.

[2] Hohimer, J.P., et al., *Single-frequency continuous-wave operation of ring resonator diode lasers.* Applied Physics Letters, 1991. **59**(26): p. 3360-3362.

[3] de Dios, C., *Generación de Pulsos Cortos mediante Diodos Láser Gain Switching. Estudio de Técnicas de Compresión Experimental basadas en Lazos Ópticos no Lineales NOLM*, in *Electronic Technology*. 2010, Universidad Carlos III de Madrid: Madrid. p. 261.

[4] Hansen, P.B., et al., *A 1.54 µm monolithic semiconductor ring laser: CW and mode-locked operation.* Photonics Technology Letters, IEEE, 1992. **4**(5): p. 411-413.

[5] T. Shimizu, I. Ogura and H. Yokoyama, "*860 GHz rate asymmetric colliding pulse modelocked diode lasers*," Electronics Letters, vol. 33, no. 22, pp. 1868-1869, 1997.

[6] *Joint European Platform for Photonic Integration of InP-based Components and Circuits* [Online] http://www.jeppix.eu

[7] Orbe-Nava L.J., Guzmán-Martínez R.C. and Carpintero-de-Barrio G., Traveling wave model of a twin ridge semiconductor laser, Proceedings of the 2010 Annual Symposium of the IEEE Photonics Benelux Chapter, pp. 281-284, 2010.

[8] Orbe-Nava L.J., Guzmán-Martínez R.C. and Carpintero-del-Barrio G., *Modelo de propagación de un láser semiconductor en anillo*, in *Simposio Anual de la Unión Científica Internacional de Radio 2011*, Leganés, Madrid. p. 53.

[9] Bente. E., Barbarin Y., Heck M. and Smit M., *Modeling of integrated extended cavity InP/InGaAsP semiconductor modelocked ring lasers.* Opt. Quant Electron. 2008. Vol. 40: p.131-148.

[10] Tsang C.F., Marcenac D.D., Carroll J.E., Zhang L.M., Comparison between power matrix model and time domain model in modelling large signal responses of DFB lasers, IEE Proceedings-Optoelectronics, vol. 141, pp. 89-96, 1994.