Simulation of switching between stable unidirectional states in semiconductor ring lasers

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Semiconductor ring lasers (SRLs) are interesting devices for their applications in photonic integrated circuits. For example, bi-stable unidirectional regimes [1] in monolithic SRLs open the possibility to use these lasers in systems for all-optical switching, gating, wavelength conversion and optical memories [2].

To model a spatial-temporal dynamics of the clockwise (CW) and counter-clockwise (CCW) propagating slowly varying optical fields and the carrier density in SRLs we use the Traveling Wave (TW) approach. This partial differential equation model allows simulating ring structures consisting from differently driven sections, considering longitudinal distributions of the carriers and of the optical fields, which can be also expressed as a superposition of the multiple longitudinal optical modes. Moreover, the TW modeling can take into account optical injections, localized reflections and, therefore, delayed feedbacks of the optical fields [3].

We consider an all-active ring laser schematically depicted in Fig.1A. It is known [1] that the dominance of the cross-gain saturation over the self-saturation in such SRL yields a bi-stable unidirectional regime, where the field intensity is concentrated in the CW or CCW propagating field. The switching between these states can be realized by optically injected short pulses [3], see Fig. 1B,C. In this paper we simulate different SRLs and estimate the duration, the wavelength and the intensity of the optical pulses needed to realize such transitions.

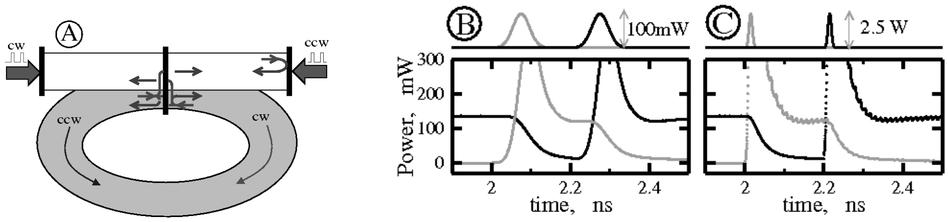

Fig. 1 A: Scheme of an all-active SRL with indication of optical injections (thick arrows), some possible field reflections and transmissions at the coupler and at the edges of the waveguide, and directions of the CW and CCW propagating fields (thin arrows). B, C: time traces of emitted CW (grey) and CCW (black) field intensities. Top of the diagrams: a pair of consequently injected 50ps (B) and 10ps (C) long resonant CW (grey) and CCW (black) pulses implying these transitions.

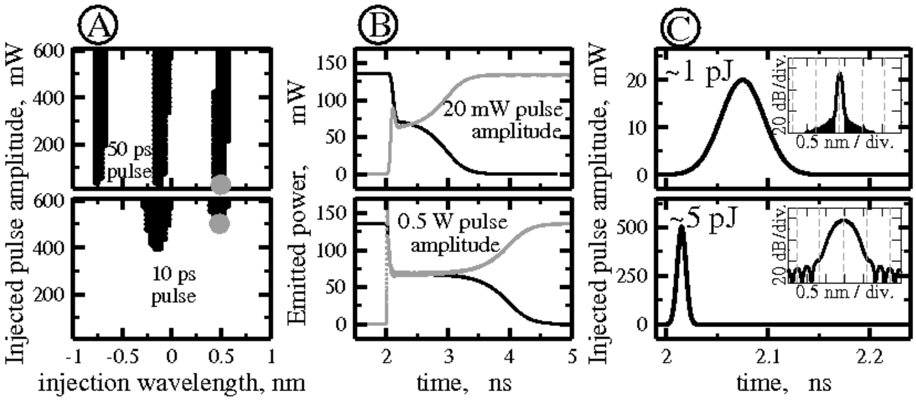

Fig. 2. Upper and lower rows represent a study of 50ps and 10ps long injected optical pulses, respectively. A: black areas show wavelengths and amplitudes of the injected pulses realizing the switching between two states. B: time traces during the state switching. C: resonant injected CW pulses corresponding to the grey dots in panel A and implying the switching between two states shown in panel B. Inserts: optical spectra of these pulses. Dotted lines: SRL resonances.

Some aspects of our study are summarized in Fig. 2. Panel A gives characteristics of the injection pulse required for the state switching. Panel B shows a relatively slow two state switching by different injected resonance optical pulses having just sufficient energy to realize these transitions. To make the switching faster one should apply more intensive injected pulses (cf. to Fig. 1B,C, where 5 times stronger pulses were applied). Spectral characteristics of the injected pulses in panel C give a reasonable explanation of the larger required 10ps long pulse energy: only some finite resonance part of the pulse spectra is used to realize the switching.

References

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