Nonlinear Dynamics in Semiconductor Ring Lasers
Towards the integrated optical neuron

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Semiconductor ring lasers distinguish themselves from other semiconductor lasers by their circular waveguide cavity. This enables them to lase in two counterpropagating directions and to function as all-optical memories, storing a bit of information in the propagation direction of the light. They are very suitable for monolithic integration, since they do not require any cleaved facets. Their small footprint (the area they occupy on chip) and their low power consumption are ideal characteristics for optical interconnects, which are needed to tackle the demanding communication requirements between a future computer chip and its RAM memory. Their bistable character moreover enables semiconductor ring lasers to be deployed as ultrafast optical memories, buffers and to realize complex nonlinear networks.

Recent investigations have shown that semiconductor ring lasers are also able to mimic behavior that is typical for nerve cells, i.e., excitability. They are able to generate large pulses as a response to a small trigger pulse that is larger than a certain threshold. This excitable regime exists when the coupling between the counterpropagating modes is made asymmetric. This opens up perspectives for fully integrated all-optical neural networks, which are attractive because of the high degree of parallelism, and the large optical bandwidth allowing for very fast processing. These artificial neural networks may be used to perform tasks that are very difficult for ordinary computers such as, e.g., speech recognition.

In this thesis, we work towards the goal of realizing such an optical neural network using semiconductor ring lasers as building blocks. The thesis starts with a brief overview of the physical principles underlying (semiconductor) lasers, and a review of semiconductor ring lasers in particular. The dynamics describing the excitability are reviewed, and the properties of noise-excited pulses are investigated. It is shown that instead of noise, externally injected optical pulses can serve as a deterministic trigger mechanism. It is also shown that two coupled excitable SRLs are able to excite pulses in each other, realizing a first step towards an optical neural network. We propose a chip design realizing a fully integrated optical excitable unit that has no need for any external measures to induce the excitability, as was required in its first demonstration. In order to further investigate the influence of coupling on the behavior of individual laser units, we study a semiconductor ring laser subjected to optical injection (a continuous external forcing). Subsequently, we study the dynamical behavior of two coupled semiconductor ring lasers, both theoretically and experimentally.