Semiconductor lasers with delayed optical feedback for reservoir computing: short external cavities and multi-mode lasers

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The concept of reservoir computing (RC), a paradigm within neuromorphic computing, offers a framework to exploit the transient dynamics within a recurrent neural network for performing useful computation. It has been demonstrated to have state-of-the-art performance for a range of tasks that are notoriously hard to solve by algorithmic approaches, e.g., speech and pattern recognition and nonlinear control. RC rekindled neuromorphic computing activities in photonics [1]. Today, multiple photonic RC systems show great promise for providing a practical yet powerful hardware substrate for neuromorphic computing. Not all reservoirs are neural networks, i.e. based on discrete nonlinear optical nodes (neurons). Any high dimensional nonlinear dynamical system can be exploited for RC. The concept of delay line-based RC, using only a single nonlinear node with delayed feedback, was introduced some years ago by Appeltant *et al.* [2] as a means of minimizing the expected hardware complexity in photonic systems. The first working prototype was developed in electronics in 2011 by Appeltant *et al.* [2], and several performant optical systems followed quickly after that [1], one of which based on a semiconductor laser with external optical feedback [3].

Delay-based reservoir computing offers a simple technological route to implement photonic neuromorphic computation. From a nonlinear dynamical systems viewpoint, the systems used are also interesting as they combine delayed optical feedback with injection of high bandwidth optical signals. Its operation boils down to a time-multiplexing with the delay limiting the resulting processing speed. We focus on external cavities which are far shorter than what has been realized before in experiment. Specifically, we will experimentally show computational performance results on a semiconductor laser with a fully integrated feedback section of 10 cm. The design is based on a DBR laser with a spiral delay waveguide. The delay is sufficiently long to drive the laser into a chaotic regime due to the feedback. Reducing the delay line means a decrease in state diversity. To compensate the expected decrease in performance, we aim to increase the dynamical complexity of the semiconductor laser. As one possible route to take, we will show numerically that multi longitudinal mode lasers with delayed optical feedback are promising reservoir computing substrates.

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