Quantum-Dot spin-VCSEL based Reservoir Computing for Hénon Attractor Reconstruction

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Abstract. We introduce a Reservoir Computing setup where a QD VCSEL with optical spin injection and delayed optical feedback is used as reservoir. The proposed Reservoir Computing aims at ultrafast reconstruction of Hénon Attractor, benefiting from unique spin coupling between electrons and photons in spin-VCSELs leading to ultrafast dynamics. The speed achieved with QD spin-VCSEL based Reservoir Computing is 100 *GSa/s*, yielding a five-fold improvement compared to time series prediction processing speed of QW spin-VCSEL, while maintaining the error rate low.

Introduction

Spin-Vertical Cavity Surface Emitting Lasers (spin-VCSELs) for both gain materials, i.e. Quantum-Well (QW) and Quantum-Dot (QD), are undergoing increasing research effort for new paradigms in high-speed photon-enabled computing. Skontranis *et al.* have exploited two discrete wavebands and two polarization states of QD spin-VCSEL to enhance computational efficiency of signal equalization [1]. Harkhoe *et al.* have used polarization modulation in QW spin-VCSELs to improve the processing speed of a photonic Reservoir Computing (RC) for Santa Fe timeseries prediction task since the bandwidth in spin-VCSELs is only linked to the birefriengence of the cavity [2]. The present contribution provides a link between spin-VCSEL's ultrafast dynamics and inherent advantages carried by QD laser technonolgy. We perform another benchmark task to demonstrate the prediction of temporal signals. Hénon map has been established as a typical discrete-time dynamic system with chaotic behavior [3]. Our investigations reveal that information processing rate exceeds the one of QW spin-VCSEL [4].

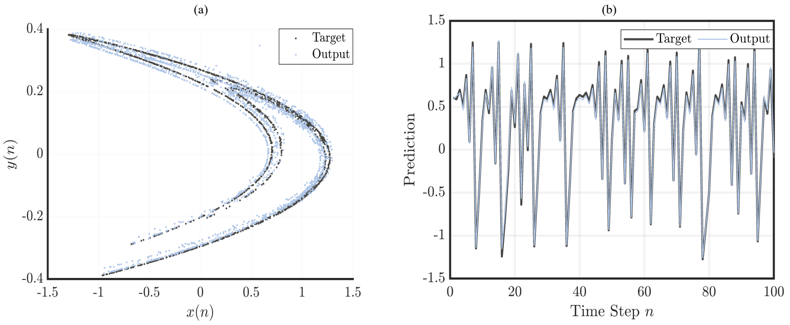

Figure 1: Performance illustration of (a) the Hénon Map reconstruction and (b) the time series prediction with $\alpha = 3$, $h = 1.1995$, $\eta = 3$, $\gamma_s = 200\ ns^{-1}$, $\gamma_p = 250\ ns^{-1}$, $\gamma_n = 1\ ns^{-1}$, $\gamma_0 = 400 ns^{-1}$, $\gamma_a = -1.6\ ns^{-1}$, feedback strength $k_f = 30\ ns^{-1}$ and feedback delay time τ = 10 ps.

Results and discussion

We simulate the laser using the generalized spin-flip model for QD spin-VCSEL as described in [5] with additional terms for optical feedback. The data is inserted using the optical spin injection and is defined as $P(t)$ = $I(t)M(t)$ during each time interval where $I(t)$ is the data to be trained/tested on and $M(t)$ is the mask. In our system we match feedback delay time τ_D to the mask length τ_M $(\tau_D = \tau_M = \tau)$, leading to $N = \tau/\theta$, with θ the node-separation. A smaller θ can be tailored due to ultrafast dynamics in spin-VCSELs, allowing to store more neurons in a shorter delay line. For this task 2000 points are adopted for training while 2000 for testing, and the gauge of evaluation is the Normalized Mean Square Error (NMSE). For this benchmark we typically want the NMSE to be lower than 0.1. The use of θ = 0.5 ps and τ = 10 ps can improve information processing rate up to 100 GSa/s for efficient Hénon attractor reconstruction (see Figure 1) with relatively low NMSE (NMSE=0.052). Notably, QD-spin-VCSELs allow high-speed RC and with the employment of more energy and polarization states can provide an exciting platform for use in future photonic neuromorphic systems.

References

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