Study of the C-band dynamical response of an injection locked LA-EEL for fully integrated telecommunication data processing

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Summary. We implement a fully parallel photonic reservoir in a semiconductor laser operating at telecommunication wavelengths. With this, we process signals with bandwidths exceeding 20 GHz in real time, targeting telecom applications. Spatially projected and imaged on a digital micromirror device, our concept provides passive readout weights that can be programmed with standard software libraries.

In the context of developing new architectures for Neural Networks (NNs) in Photonics, optical reservoir computing is a suitable candidate to fully integrate such systems. At the same time, telecommunication digital signal processing (DSP) algorithms are exceedingly challenged by the operation rate of optical transmission lines. Several NNs to further improve DSP performance, have been developed on top of existing optical signal receiver for modulation format and bit rate identifications (MFI) [1] as well as signal reconditioning, showing that machine learning is able to tackle such task. However, these systems suffer from high computational loads and consume an excess of 50 W for long haul communications. In contrast, neuromorphic analog photonic approaches propose fully parallel photonic architectures using optical data injection. They are capable to process information up to signal bandwidth of 20GHz using a learning-based approach [2] ultimately achieving the full migration of DSP to the analog domain [3]. Integrating operations like MFI, data recovery, channel equalization, and optical header recognition [3], would allow to reduce energy consumption as well as the number of data processing operations and suppress the need to transduce signals between electronics and optics [4].

Semiconductor lasers (SLs) can provide highly nonlinear dynamics as well as several hundred degrees of freedom, exploitable for nonlinear information transformations, thus a hardware platform for computing [5]. A common challenge is to fully integrate photonic reservoirs including adjustable hardware output weights. This is tackled here using a digital micromirror device, which allows to spatially select spectral components of the signal, providing tuneable Boolean output weights. A schematic of the experiment is shown in Fig1(a).

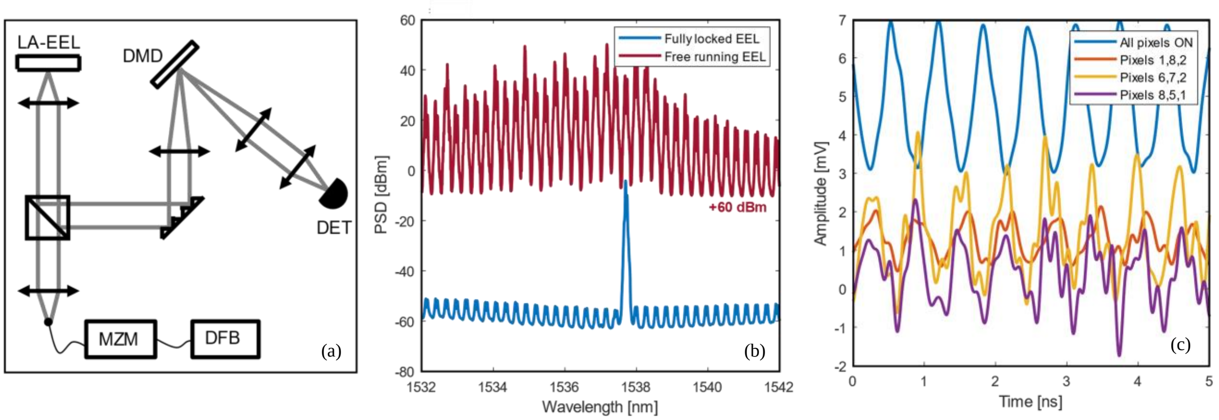

Fig. 1 – (a) Schematic of the experimental setup (b) Spectral response in both fully-locked and free running regimes, for clarity a 60dB offset is added to the free running signal. (c) Spatially selected responses for four exemplary DMD output weight configurations, and the full DMD mirrors on. For all cases the input modulated signal is sinusoidal of frequency 2GHz, and the different configurations show the response diversity in the different dimensions of the LA-EEL photonic reservoir.

A commercially available Large Area Edge Emitting Laser (LA-EEL) at telecommunication wavelength, whose spectrum is shown in Fig 1(b), when operated under normal conditions is highly multimode, both along its transversal and longitudinal directions. We show that such SL device can be locked to a single mode state by an external distributed feedback laser, as depicted in Fig 1(c). Such injection locking is the prerequisite for injecting information into a semiconductor laser and to use its nonlinear transient response to embed a photonic NN in its state space. Modulating the DFB signal using a Mach–Zehnder Modulator (MZM) provides the means to encode at ultra-high rates the injected signal, i.e., the to be processed information, which is nonlinearly transformed along the different spatial and spectral dimensions of the LA-EEL, see Fig. 1(c). We therefore leverage, both the spectral and spatial degrees of freedom to implement the real photonic neurons. Transversal modes are directly accessible by imaging the optical signal and its longitudinal components are projected from the spectral domain to the spatial domain using a blaze grating. This distribution is then imaged on a digital micromirror device (DMD) which acts as the network output weights. The resulting signal is retrieved with a high bandwidth photodiode, then analysed. In Fig 1(c) we show the signal for some exemplary readout weight configurations loaded onto the DMD. As a next step, we will optimize the readout weights in order to, first, demonstrate specific nonlinear transformations of the input data, to determine the system's fully implemented memory capacity, and then to finally inject corrupted telecommunication signals and to train the LA-EEL RC to recondition the original signal.

We successfully injection locked the LA-EEL with a modulated input signal at 2GHz. We dynamically read our reservoir specific neural responses using hyper-spectral imaging of the signal on the DMD, to implement programmable weights of our fully parallel high bandwidth photonic reservoir. This is the proof-of-concept of using such commercial and high-performance lasers for real time processing of ultra-fast signals in the telecommunication signal domain. Our experiments therefore open a wide range of future applications in this commercially relevant field, making a compelling case for neuromorphic photonics in a commercially relevant setting.

References

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