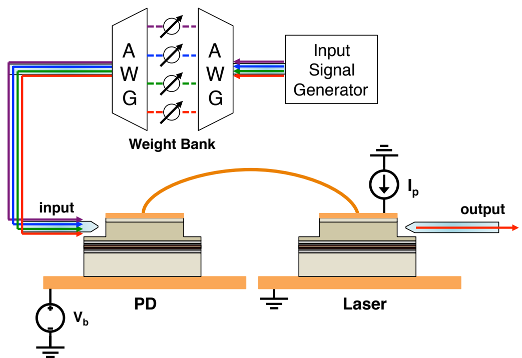
Demonstration of an O/E/O Receiverless Link in an Integrated Multi-Channel Laser Neuron

Mitchell A. Nahmias, Alexander N. Tait, Leonidas Tolias, Matthew P. Chang, Thomas Ferreira de Lima, Bhavin J. Shastri, Paul R. Prucnal

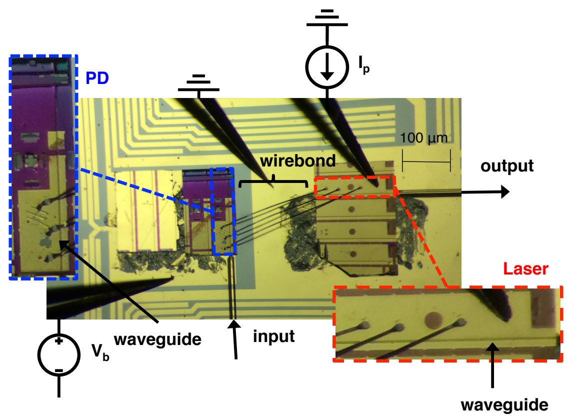
Department of Electrical Engineering, Princeton University, Princeton, NJ, 08544 USA

mnahmias@princeton.edu

Abstract: We present an integrated, multi-channel laser processor. It utilizes a novel photodetector-to-laser O/E/O receiverless link to receive multiple wavelength inputs. To our knowledge, this is the first laser neuron compatible with a wavelength-based networking scheme.



(a)

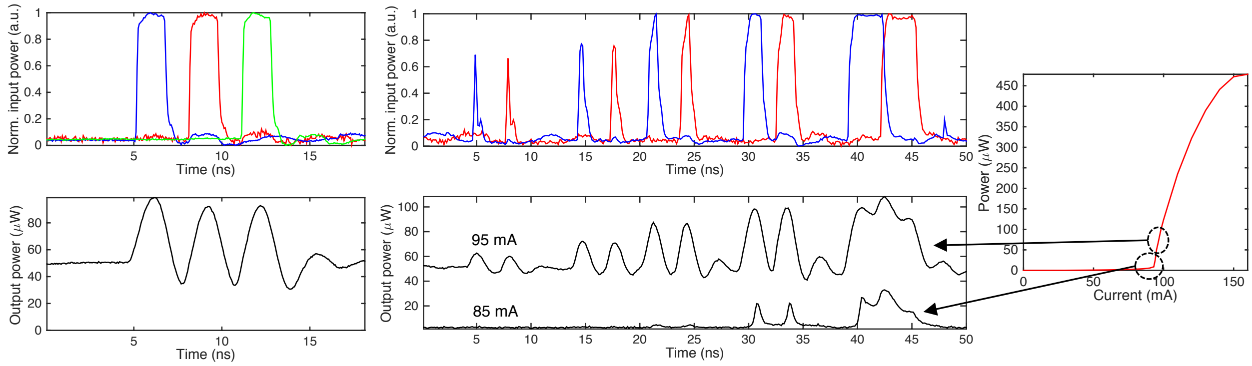


(b)

Fig. 1: (a) Experimental set-up. Input signals are summed in the PD, which drives a laser performing a nonlinear operation. Generated input signals experience different weights through a series of variable attenuators nested between two AWGs. The WDM signal travels into the PD, which current modulates the laser. (b) picture of fabricated device.

A scalable neural network typically requires that processors can receive a significant number (i.e. 100s) of distinguishable signals simultaneously. Because of the topological constraints of integrated chips, typical electronic implementations utilize a packet routing-based multiplexing strategy [1, 2]. This, however, requires that the speed of the underlying devices is much faster than the processing speed of the neural network. At very high neural network speeds (i.e. above $\sim$10 MHz [3]), electronic implementations can no longer support high signal bandwidths and large interconnect densities simultaneously. To address this problem, optics may provide a solution. Compared to electronic signals, optical signals have a greater bandwidth-density per wire and display lower crosstalk between multiplexed channels. In this regard, an optical networking called broadcast-and-weight was recently proposed [4] that uses wavelength division multiplexing (WDM) to take advantage of the enormous bandwidth of optical waveguides. Potentially hundreds of photonic units could form networks with one another through a single waveguide with all-to-all connectivity.

In this paper, we experimentally demonstrate a neuron model that is compatible with this networking strategy at bandwidths beyond what is possible in electronics. We utilize a photodetector (PD) direct driving approach, in which a PD receives optical inputs and drives an adjacent laser with its current output. This configuration has been recently shown in a fiber prototype [5], and simulated in a full device model [6]. By assigning each input a unique wavelength, signals can be multiplexed incoherently onto a single waveguide and summed together electronically in a receiving photodetector. A spectral filter modulates the amplitude of each signal, allowing for network reconfigurability. Multiple signals at different wavelengths are incident on a photodetector, which drives an laser with a current signal across a wire-bonded junction. The laser's L-I curve is used as a simple sigmoidal nonlinear function. Bringing neural networks to large signal bandwidths could open up new application domains, including the processing of radio frequency carrier waves (i.e. for blind source separation or RF fingerprinting).



(a) (b)

Fig. 2: (a) Demonstration of multi-channel summation. (Top) Normalized temporal pulse profiles of three independent wavelength channels traveling into the photodetector. (Bottom) The resulting output of the laser when biased at 95 mA. (b) Demonstration of summation and thresholding. (Top) Inputs to the device, which includes two wavelength channels. (Bottom) Output of laser biased below and above the lasing threshold. (Right) Corresponding areas of the L-I curve used by the laser during operation.

Active devices were fabricated in-house using a standard AlGaInAs multi-quantum well epitaxial structure on indium phosphide, designed to operate in the optical C-band. They were then cleaved and separately mounted on a silicon-based submount. Two fiber tapers were aligned to the PD and the laser (Figure 1b). The input was generated using a configuration similar to [7]. The resulting optical output was then measured with a sampling scope. A simple schematic of the experimental set-up is shown in Figure 1a. As shown in Figure 2a, our composite device can receive and react to signals along from three different wavelengths. The output of the laser is a simple (bandwidth-limited) sum of inputs. The fan-in per processor could be scaled to much larger numbers simply by adding more wavelength channels, as long as they are within the spectral responsitivity profile of the photodetector.

A simple neuron model includes two primary functions: a weighted sum of input signals, and a nonlinear operation. As shown in Figure 2b, this device can apply both operations, including a nonlinear operation akin to a neural perceptron model (i.e. a sigmoid). As shown, all pulses are passed through if the laser is pumped above threshold (95 mA), but if the laser is pumped just below threshold (85 mA), lower amplitude signals are suppressed. In addition, pulse collisions between channels ($\sim$43 ns) results in a larger summed output. Since the L-I curve includes both zero and one-level saturation regions, networks of such devices emulate a well-known sigmoidal neuron model. Further optimizations could lead to this configuration performing at state-of-the-art levels (i.e. $\sim$10 GHz). The device could also be fabricated monolithically through top-side grounding pads as investigated in [6].

In conclusion, we have fabricated a composite device structure that can be used as a network node in a high bandwidth neural processor. Our device successfully demonstrates several important properties necessary for network integration and processing, including nonlinear thresholding and the summation of many distinguishable input signals (i.e. fan-in). Although the bandwidth of the device is currently $\sim$250 MHz, it can easily be extended to $\sim$10 GHz with further optimizations [6] and it currently far exceeds the speeds of electronic implementations [3]. Future improvements may include monothilic integration of the PD-laser system, an increased operating bandwidth through device geometry optimization, more complex laser dynamics (i.e. spiking dynamics [8]), and larger network interconnectivity.

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