The Demonstration of Photorefractive Synaptic Connections for an Integrated Photonic Crossbar Array

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For the past decade, the progress in artificial intelligence (AI) has been requiring an exponential size increase of artificial neural networks (ANN), at a rate close to 10 times that of Moore's law [1]. Consequently, the signal processing in ANNs is fueling a compute demand that is unsustainable for general-purpose computers, both in terms of energy and hardware requirements [1,2].

The analog crossbar array is an application-specific accelerator for matrix-vector multiplications (MVM), and can compute the synaptic signal transfer between fully-connected layers in ANNs [3,4]. The signal propagation between densely connected layers generates a multiply-accumulate (MAC) workload that scales quadratically with network width. Interestingly, the analog crossbar array can perform it with linear scaling on power and latency.

We have proposed a programmable integrated photonic crossbar array architecture [3,5], based on the photorefractive effect [6], and super-imposed refractive index gratings that act as Bragg-mirrors. This architecture is of interest, since it supports all matrix operations for ANN backpropagation training.

Previously, we reported on the fabrication of photorefractive thin-film GaAs substrates, and the realization of photonic integrated circuits (PIC) therein [3]. Now, we report on the successful writing of a photorefractive synaptic connection in our prototype crossbar processor (Fig. 1).

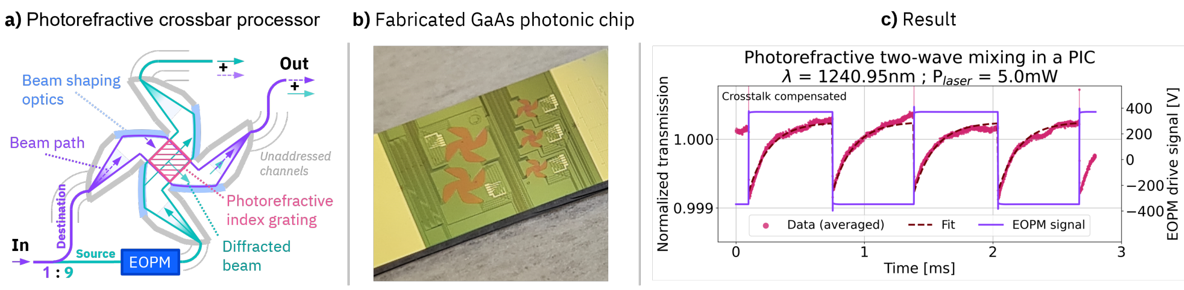

Fig. 1 The experimental demonstration of a photorefractive synaptic connection in a photonic integrated circuit by two-wave mixing [6]. **a)** A schematic of the prototype crossbar circuit. **b)** The fabricated circuit in photorefractive GaAs waveguides. **c)** The periodic writing of a synaptic connection between the destination and source channel.

Fig. 1 **c)** illustrates the analog writing of a synaptic connection between two optical signals, achieved by their interference in a photorefractive integrated optic structure. The moment that the source beam is π phase-shifted by the electro-optic phase modulator (EOPM) (purple), the diffracted signal interferes destructively with the measured destination beam (red), until the photorefractive index grating is rewritten by an exponential saturation process [3].

In conclusion, to our knowledge this work constitutes the first demonstration of the photorefractive optical effect in a PIC for neuromorphic computing. Thereby, we validated the basic operational principle of our photorefractive crossbar array design. To extend this work into a fully functional crossbar array, programmable I/O circuits need to be added to the prototype design, so that multiple I/O waveguides can addressed in parallel and individually (Fig. 1 **a)**) [3]. Future work includes: the design optimization for attenuated crosstalk, the fabrication of a programmable multi-coefficient crossbar array device, and the demonstration of all the relevant signal processing.

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