Programmable Photonic Circuits: a flexible way of manipulating light on chips

Wim Bogaerts, Abdul Rahim, Xiangfeng Chen, Lukas Van Iseghem, Hong Deng, Mi Wang, Iman Zand, Antonio Ribeiro, Alejandro Diaz Tormo, Umar Khan

Ghent University - IMEC, Department of Information Technology, Photonics Research Group
Center of Nano- and Biophotonics, Ghent University, Ghent, Belgium.
Wim Bogaerts@ugent.be

Abstract: Programmable Photonic integrated circuits are optical chips where the flow of light is configured through electronics. This provides a flexible way to explore new photonic functions, and a lower threshold for deployment in new applications.

1. Introduction

Photonic Integrated Circuits (PIC) are slowly growing beyond the field of telecommunication and datacommunication that has pushed most technological developments over the past decades. On a PIC, optical functional building blocks are connected together with waveguides. Most PICs today are developed as an application-specific circuits (ASPIC), which is one of the reasons that the adoption of these optical chips is quite limited today, even when the technology has proven to be very useful for diverse applications, such as sensing, spectroscopy, and microwave processing, and the benefits of on-chip integration are similar as those of integrated electronics, in terms of cost, form factor, complexity, energy consumption and increased functionality. But then, like in electronics, it can easily take a year to design and prototype a new PIC [1]. Enter a new class of photonic circuits: programmable PICs [**?**, 2, 3]. These are essentially photonic circuits where the flow of light can be controlled after fabrication, using electronics and software. Such programmable PICs have a more generic architecture for connecting the functional blocks, using a waveguide mesh of 2×2 tunable beam couplers and optical phase shifters. For that reason, they are often compared to electronic *field programmable gate arrays* (FPGA) [4], because they make it possible to prototype new functions without the need for a custom chip fabrication.

2. Programmable PIC technology

By making a PIC programmable, we need to introduce additional building blocks in the path of the light. As a result, we can expect a programmable PIC to be larger than an ASPIC, with a higher optical insertion loss. That means the PIC technology should be of high quality, and the basic building blocks should be well engineered and have a low power consumption. Today, the PIC technology with highest integration density is silicon photonics [5], with submicrometer waveguides that can be stacked a few micrometer apart. Waveguide losses in this technology are steadily improving, to less than 1dB/cm. Tunable elements are a somewhat weak point, with thermo-optic phase shifters still the technology of choice. These can be quite efficient in silicon [6], but they still require a constant power consumption and they suffer from thermal crosstalk [7]. More efficient actuator technologies, such as MEMS [8] or Liquid Crystals [9] are rapidly gaining maturity but are still not widely available.

The technology stack of programmable PICS is more than just the photonic chip. To make programmable photonics really programmable, it needs to be interfaced with control driver circuits that control the actuators and read out the optical power from the on-chip monitor detectors.When combined with high-speed modulators and (balanced) photodetectors, it also becomes possible to convert microwave signals to the optical domain and back, and process them on the programmable chip [10]. This handling of RF signals obviously requires specialized packages, which also need to take care of the optical fiber interfaces, thermal stabilization, and the many connections between the photonic chip and the control electronics. And to make this combination really useful to developers, it requires software layers to program new functionality onto the chip.

3. Access model for programmable PICs

Because they are generic and programmable, programmable PICs can change the way PICs are used in the development of new applications and products. This can be compared with programmable electronics: the widespread availability of programmable electronics (FPGAs, microprocessors, digital signal processors, ...) makes it possible to implement new functions in a matter of days, without the need to fabricate custom silicon. This speeds up

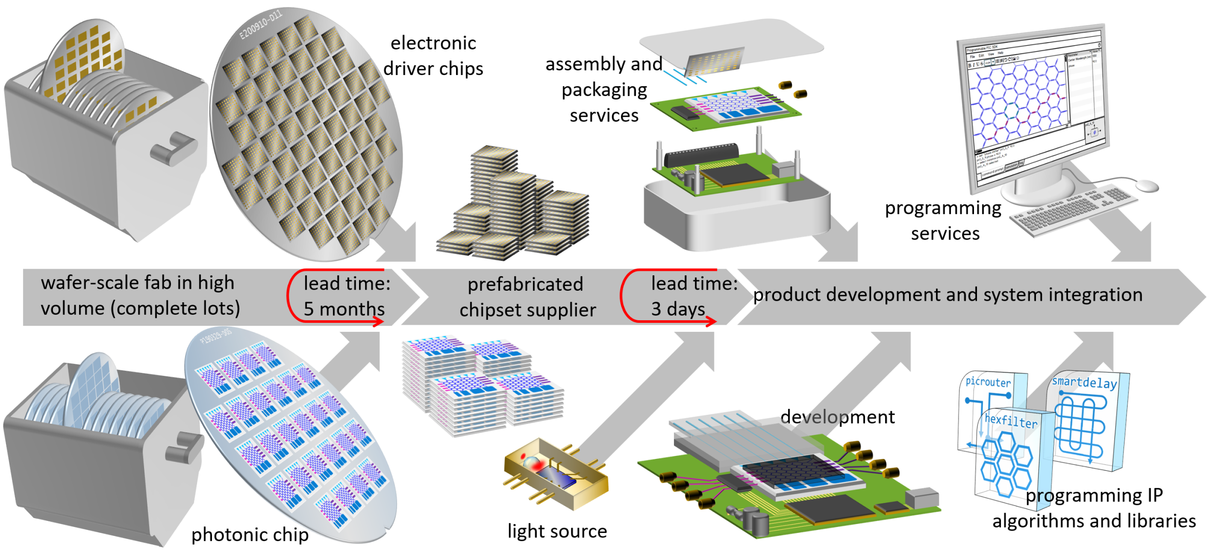

Fig. 1. supply chain for programmable PICs. While they are more complex than ASPICs, their flexibility makes it possible to use these PICs off-the-shelf, dramatically shortening the lead time [**?**]

prototyping and even product development, and only if it is needed for reasons of cost or performance, a dedicated chip is designed and fabricated. Programmable PICs can do the same for photonics, opening up the manipulation of coherent light to a diverse range of applications. And only if a market value has been confirmed, a dedicated ASPIC needs to be made.

Beyond telecommunication, there are many fields where programmable PICs could be useful [**?**, 2]. They can be used as generic transceiver modules in access networks, or programmed as fiber switches. Depending on the type of waveguide mesh, they can be programmed as a wavelength filter, and thus function as a spectrometer of a readout circuit for other optical sensors, such as fiber Bragg gratings. Such filters can also be used to process microwave signals modulated on an optical carrier [10].

Overall, we expect that, as the technology for programmable PICs is maturing, to see different versions of such PICs appearing in the market, with different architectures and different levels of programmability. When drawing the comparison with electronics, the success of the basic concept of programmable PICs seems inevitable, but it is as yet unclear what the landscape will look like 5 years from now.

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