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***Citation for published version (APA):***

Smit, M. K., Baets, R. G. F., & Wale, M. J. (2009). InP-based photonic integration : learning from CMOS. In *Proceedings of the 35th European Conference on Optical Communication (ECOC 2009) 20 - 24 September 2009, Vienna* (pp. 1.7.3-1/2). Institute of Electrical and Electronics Engineers.

***Document status and date:***

Published: 01/01/2009

***Document Version:***

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

***Please check the document version of this publication:***

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

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# InP-based Photonic Integration: Learning from CMOS

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**Abstract** *In the last decades the complexity of InP-based Photonic Integrated Circuits has increased by almost two orders. In this paper past and future developments in Photonic Integration will be discussed.*

## Introduction

The markers in Figure 1 show the complexity development of InP chips reported in the literature, measured as the number of components integrated on a single chip<sup>1,2</sup>. Up till now, 2009, they show a clear exponential trend, similar to Moore's law in electronics, which suggests that Photonics is following the same process-driven development path as microelectronics. There is an important difference, however: micro-electronic ICs in the Moore-chart are commercially applied devices, whereas most of the complex Photonic ICs are research devices which ended with a paper but did not make it to the market. The only truly complex chip which is currently applied in a commercial product is the WDM transmitter chip (10x10 Gb/s) of the US company Infinera<sup>3</sup>, used in a 100 Gb/s WDM system.

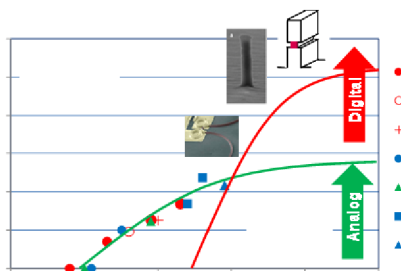


Fig. 1: Complexity increase of Photonic ICs for WDM

## What Went Wrong?

It is an interesting question why so few of the advanced PICs reported in the literature have made it to the market, despite the fact that in the last two decades there has been substantial investment in the development of integration technologies in national and international projects in Europe, America and the Far East.

The problem with current project funding models is that they tie the technology development closely to an application: you get no money without a clear and challenging application. In order to meet the challenging specifications the technology has to be fully optimized for that application and, as a result, we have almost as many technologies as applications. Owing to this huge fragmentation, the market for these application-specific technologies is usually too small to justify their further development into an

industrial volume manufacturing process that would really lead to low chip costs. This is quite different from the situation in micro-electronics where a huge market is served by a relatively small set of integration technologies (most of them CMOS technologies).

## The Solution: Generic Integration Technology

The solution to this problem seems obvious: introduce the same methodology to photonics that allowed microelectronics to change the world. In micro-electronics a broad range of functionalities is realised from a rather small set of basic building blocks, like transistors, diodes, resistors, capacitors and interconnection tracks. By connecting these building blocks in different numbers and topologies we can realize a huge variety of circuits and systems, with complexities ranging from a few hundred to over a billion transistors.

In photonics we can actually do the same. On inspection of the functionality of a variety of optical circuits we see that most of them consist of a rather small set of components: lasers, optical amplifiers, modulators, detectors and passive components like couplers, filters and (de)multiplexers. By proper design these components can be reduced to an even smaller set of basic building blocks. In a generic integration technology that supports integration of the basic building blocks we can realize a wide variety of functionalities.

Today several companies have integration processes that are suitable as a starting point for development of a truly generic integration process. What is missing is the organizational and software infrastructure to provide easy and low-cost access.

## A Generic Photonic Foundry Model

A number of clean room owning companies presently offer photonic foundry service. They have opened their fabs to the development of photonic components tailored to customer needs, thus making it possible for customers to develop PICs without the need to own a fab by themselves (fabless operation). This leads to a significant cost reduction. The entry costs remain relatively high, however, because of the process development that is needed to tailor the fabrication process to the specific customer application and the subsequent qualification required to prove that the device is fit for purpose and reliable in operation.

Although these companies are usually called just “foundries” we will call them “custom foundries” in order to distinguish them from “generic foundries”: Generic foundries do not simply offer clean room access for custom process development, but access to a stable and well defined generic integration process, with a software design kit providing accurate models for the building blocks, component libraries and powerful simulation engines, which make it possible to obtain a working PIC in a very small number of design and fabrication cycles. This approach leads to a dramatic reduction of the cost of both PIC R&D and manufacturing, as compared to the custom foundry approach, similar to what happened with CMOS in micro-electronics.

Generic photonic foundries do not exist today, but first steps to establish them have been taken. Within the European FP6 Network of Excellence ePIXnet ([www.epixnet.org](http://www.epixnet.org)), in which a large number of universities, companies and research institutes active in the field of photonic integration have been cooperating, a number of important steps have been taken towards the introduction of a foundry approach for three major photonic integration technologies:

- InP-based integration technology, which supports the highest degree of functionality, including compact lasers and amplifiers.
- Silicon Photonics technology, which cannot presently offer lasers or optical amplifiers (except by hybrid approaches such as bonding of InP epitaxial thin films on silicon) but can achieve high performance, good process control and low cost in a wide range of functions through its compatibility with mature CMOS technology.
- Dielectric waveguide technology, which offers low-loss and high-quality passive optical functions and some thermo-optic active functions, through the whole wavelength range from visible to infrared.

Presently a number of research activities and projects based on this approach are running, and we expect the industrial impact of these initiatives to become visible in the coming years.

#### **The Next Step: Digital Photonics**

Once generic integration technologies are introduced in photonics we expect a development similar to what happened in micro-electronics: a dramatic reduction of the cost of R&D and chip manufacturing and a correspondingly expanding application market, both in volume and diversity. Applications will follow in many

fields where PICs are presently too expensive, such as sensors, health care, interconnect, metrology etc.

We do not expect, however, that the complexity supported by the generic processes as described above will exceed a component count of 1000 for a number of reasons. In passive devices the complexity will be restricted due to unavoidable component losses which restrict the total number of components that can be cascaded. But in active PICs SOAs and lasers typically have a power dissipation of several 100 mW. So their number is restricted to several tens up to a maximum of a few hundreds, because of heat sinking limitations. Secondly, although today's PICs often carry digitally modulated signals, the basic building blocks and the circuits built from them essentially operate in an analog mode, which means that on passing a number of components the signal will accumulate noise and distortion and need to be regenerated. Regenerators can be integrated too, but they consume space and power.

This is quite similar to the development path in microelectronic ICs, where analog circuits usually do not contain more than a few hundred transistors per circuit block. The breakthrough to VLSI did not occur in analog electronics but in digital electronics, where signal regeneration inherently occurs after each processing step, so that operations can be concatenated endlessly.

For Photonic integration to move towards LSI or VLSI circuit complexity a change from analog to digital signal processing will be necessary too. Digital Photonics has been receiving increasing interest in the recent years. In particular, digital photonics based on coupled micro or nanolasers is a promising candidate for integrating large numbers of digital circuits. The recent breakthrough in plasmonic lasers<sup>4</sup>, which are no larger than modern transistors and can operate with low switching energies at very high switching speeds, holds the promise that digital photonic circuits with more than 100,000 lasers operating at THz clock rate will become reality. Such circuits might avoid a lot of power-hungry electro-optical conversions in high speed internet routers. And they may lead to a complexity increase for Photonic ICs of three orders of magnitude.

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