Towards fabless photonic integration

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***Abstract*—In this paper, the current state for generic photonic integration is reviewed from a fabless user perspective.**

I. Brief historical perspective

Generic integration for photonics is part of a vertical specialisation through the industry value chain. Restructuring results in different stages being controlled by different firms, compared to vertical integration within the boundaries of individual firms. This was the case for the US semiconductor industry, described in [1]. Large corporations as AT&T and IBM designed and manufactured both their components, and the main equipment and processes required to manufacture them in house. Specialisation in two parts of the food chain, design and manufacturing, lead to manufacture specialists and fabless design firms. For photonic integration, the seed for generic integration appears in 2007 [2], although some work by HHI early in 2000 already contains the spirit of generic photonic circuits [3]. Subsequent technical and organisational developments lead to the current generic foundry processes.

II. Current state of the art

The current state of the art for foundries offering generic photonic integration fab services is summarised in Fig. 1. *Operationally* the foundries can be described as follows. Some foundries are publicly funded research institutions (IMEC [4], CEA-LETI [4], IME [5], HHI [6], COBRA [6] and IMB-CNM [7]), whereas other are privately/publicly held companies (AMO [8], Luxtera [9], Oclaro [6], LioniX [10]). Most of them are located in Europe, except IME (Singapore) and Luxtera (USA). A significant difference exists also on the current state of access to the foundries. Silicon is well settled and access already open. However, access to InP generic technology is yet being developed in research projects which offer brokerage for accessing, but a clear roadmap exists [11]. In most of the cases access is through a Multi-Project Wafer (MPW) run, where the space of a wafer is shared amongst different designers by dividing it into reticules. However, some of the foundries do only perform dedicated runs (AMO, IME and IMB-CNM). Formalisation of the access is done either directly with the foundry, or through a brokering organisation, as ePIXfab, JePPIX and OpSIS. The track record on MPW wafer runs is hold by IMEC/CEA-LETI through their broker service ePIXfab, that at the end of 2012 will account for nearly 30 runs in total since 2007. On the InP side, COBRA has issued 1 MPW run per year since 2007, hence at the fall of 2012 a total of 7 will have been completed. LioniX has recently finished its first MPW on TripleX$^{\text{TM}}$ technology.

The photonic integration *technologies* offered can be considered mature and well developed in terms of photonic performance. The colour matrix in Fig. 1 shows the available photonic building blocks within each platform. The most remarkable technical aspects for each technology are now highlighted. For SOI, the trend during 2011 was the inclusion of ring modulators and photodetectors. This is currently being offered, or planned to be in the very short term, by all the SOI platforms. The combination with CMOS electronics is a feature offered to date exclusively through OpSIS using Luxtera technology. For InP, the use of Oclaro's industrial fab (traditionally an InP component manufacturer using a vertical model) to produce generic PICs was certainly a milestone, whereas HHI is the sole generic InP foundry offering a high speed (balanced) photo-detector, that can be combined with other passives. Silicon Nitride generic technology is mature but a bit unexplored, owing to its very recent jump into the generic foundry arena. Fig. 2 shows some examples of designs and PICs authored by Universitat Politècnica de València (UPV) and VLC Photonics S.L., a fabless design house that operates with generic technologies.

Tools for designers, Photonic Design Kits (PDK), are available in most of the platforms. PDK's allow to perform in a seamlessly integrated software environment both the photonic simulation and the mask layout, incorporating photonic process information from the foundries. Whereas PhoeniX Software is becoming the de facto standard in Europe, others as Luxtera have proprietary libraries embedded into EDA software as Cadence. The foundries not having PDK's communicate at a GDS level.

Back-end processes as packaging are one of several open issues, already identified and being addressed by some of the foundry players. The development of generic packages that can be reused amongst very different PIC designs, minimising non-recursive engineering costs, is already in place for InP Oclaro and HHI, whereas it will be developed for SOI by IMEC in the midterm.

III. What's next?

Europe was certainly the cradle of generic photonic integration, both for Silicon and InP photonics. Recently in 2011, US is following the trend with OpSIS and Luxtera for Silicon. While semiconductor industry already *offshored* its production to Asia [12], it is still unclear whether US and EU photonic industry will do as well in the near future. To the date, OpSIS first MPW run was already done at IME in Singapore.

Foundry	IMEC	CEA-LETI	AMO	IME	LUXTERA	HHI	Oclaro	COBRA	LioniX	IMB-CNM
Technology	SOI	SOI	SOI	SOI	SOI	InP	InP	InP	SiNx	SiNx
Location	BEL	FRA	GER	SGP	USA	GER	UK	NL	NL	ESP
Access	MPW	MPW	Dedicated	Dedicated	MPW	MPW	MPW	MPW	MPW	Dedicated
Open	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Broker	ePIXfab	ePIXfab	No	No	OpSIS	No	FP7 Project	JePPIX	No	No
Cost per	Area	Area	Project	Project	Area	Area	Area	Area	Area	Project
SHWVG	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
DEWVG	Green	Green	Green	Green	Green	Green	Green	Green	Grey	Green
WVGX	Grey	Grey	Grey	Green	Grey	Green	Green	Grey	Grey	Grey
Y-B	Green	Green	Grey	Green	Green	Green	Grey	Grey	Green	Green
DC	Green	Green	Grey	Green	Green	Grey	Grey	Grey	Green	Green
MMI	Green	Green	Grey	Green	Grey	Green	Green	Green	Grey	Green
SPGC	Green	Green	Green	Green	Green	Grey	Grey	Grey	Grey	Grey
PSGC	Green	Grey	Grey	Green	Green	Grey	Grey	Grey	Grey	Grey
SSC	Green	Grey	Grey	Green	Green	Green	Green	Green	Green	Green
EOM	Grey	Grey	Grey	Grey	Grey	Grey	Green	Green	Grey	Grey
TOM	Orange (0.5)	Green	Grey	Green	Green	Green	Green	Green	Green	Grey
CIM	Orange (0.5)	Green	Grey	Green	Green	Grey	Grey	Grey	Grey	Grey
RR	Green	Green	Grey	Green	Green	Grey	Grey	Grey	Green	Grey
AWG	Green	Grey	Grey	Green	Grey	Grey	Green	Green	Grey	Grey
DBR	Grey	Grey	Grey	Green	Grey	Grey	Green	Grey	Grey	Grey
SOA	Grey	Grey	Grey	Grey	Grey	Grey	Green	Green	Grey	Grey
PD	Orange (0.5)	Green	Grey	Green	Green	Green	Green	Grey	Grey	Grey
BPD	Grey	Grey	Grey	Grey	Grey	Green	Grey	Grey	Grey	Grey
PKG	Orange (0.5)	Grey	Grey	Grey	Grey	Green	Green	Grey	Grey	Grey
SW	Green	Grey	Grey	Green	Green	Green	Green	Green	Green	Grey
ELECT	Grey	Grey	Grey	Grey	Green	Grey	Grey	Grey	Grey	Grey

Fig. 1: State of the art in generic foundry processes. (Colour code: Green=Available, Grey=Not Available, Orange=In progress. Abbreviations: SHWVG Shallow waveguide, DEWVG Deeply etched waveguide, WVGX Waveguide crossing, Y-B Y-branch, DC Directional coupler, MMI Multi-Mode Interference coupler, SPGC Single Polarisation Grating Coupler, PSGC Polarisation Splitting GC, SSC Spot-Size Converter, EOM Electro-Optic Modulator, TOM Thermo-Optic Modulator, CIM Carrier-Injection Modulator, RR Ring Resonator, AWG Arrayed Waveguide Grating, DBR Distributed Bragg Reflector, SOA Semiconductor Optical Amplifier, PD Photo-Detector, BPD Balanced PD, PKG Packaging, SW Software, ELECT Electronics).

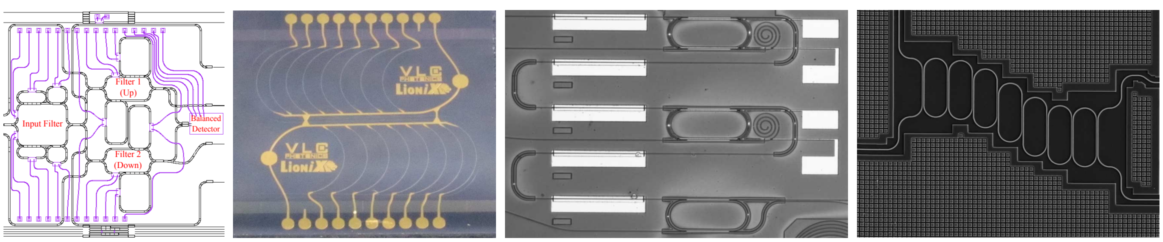

Fig. 2: Designs and PICs produced using generic foundry processes. Starting at the top line, from left to right: a) Microwave Photonics discriminator, FP7 NMP-EuroPIC with HHI InP technology, design by UPV; b) Tap and delay chip in LioniX MPW run#1 TripleX^{TM} technology, design by VLC Photonics S.L.; c) Microwave photonics phase shifter in JePPIX MPW run#3, COBRA InP technology, design by UPV; and d) apodised CROW filter in IMEC MPW run#6 SOI technology, design by UPV.

Currently there is no known initiative to establish an *InP generic foundry* in the US, whereas EU InP generic foundries will be established commercially in approximately 5 years [11]. We might also see a step forward in the short term by other US InP companies, as OpSIS/Luxtera did for Silicon.

The photonic design and prototyping *fabless firm ecosystem*, fostered by generic technologies, started to develop in Europe by 2009. Nowadays, it is made up of half a dozen of SMEs, at a rate of 1-2 companies started-up per year. This number might keep growing in the short term. Conversely in the US, start-ups have a strong linkage to a foundry/technology. US fabless PIC companies based upon generic integration might appear in the short term.

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