Generic InP-Based Monolithic Photonic Integration Platforms

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***Abstract*—The capability of two InP-based, generic platforms for the fabrication of Photonic Integrated Circuits (PICs) is described. Examples of several different complex PICs, fabricated using industrial process facilities will be given.**

I. Introduction

In the photonic components arena photonic integration, both hybrid and monolithic, has regained enormous momentum since the past decade in order to cope with the steadily increasing demand for more and more complex devices (e.g. for phase-modulation transmission), lower-footprint, reduction of assembly effort and lower power consumption. So far, however, this field is characterized by a wide range of proprietary, application-specific integration technologies and, owing to the limited production volumes for each one, the entry cost for new users and products is often high. To mitigate this fragmentation, the introduction of standardized photonic integration technology relying on well defined building blocks is considered an attractive solution, eventually facilitating a generic foundry operation for photonic integrated circuits (PIC), including Multi-Project Wafer runs [1, 2]. In pursuit of such a revolutionary approach, which rendered silicon microelectronics so extremely successful, two major European projects, EuroPIC [3] and PARADIGM [4], have recently been launched. Across the two projects, a total of more than 20 partners are collaborating to join their complementary skills in design, software development, InP based epitaxy and processing technologies, characterization, packaging and, last but not least, applications. The present paper focuses on the InP integration platforms for which the "foundry" partners, Oclaro and Fraunhofer-HHI, are mainly responsible.

II. Platform capabilities

The InP platforms currently provided by these project partners are targeting C-band applications. HHI's platform uses a semi-insulating substrate to essentially enable high-speed receiver type PIC structures. Oclaro's PIC process, on the other hand, is being developed from the "transmitter side" relying on N^+-substrate technology. In PARADIGM both platforms will be mutually extended to incorporate transmitter and receiver functionalities, respectively. Table I provides an overview of (composite) buildings blocks currently available at each partner. All of the building blocks are described in a comprehensive Design Manual that has been compiled by the EuroPIC consortium and made available to EuroPIC users to generate their own PIC designs. The list of building blocks designed for C-band operation will be steadily extended, particularly through the PARADIGM project, where partner TU Eindhoven/COBRA will also be developing a platform for extended-wavelength (up to ~ 2 µm) applications.

TABLE I. OCLARO's AND HHI's CURRENT INP PLATFORMS

(Composite) building blocks	Oclaro	HHI
Substrate	N^+-InP	InP:Fe
Waveguide, ridge type, weak and strong guiding	X	X
Waveguide transition elements	X	X
Waveguide crossing	X	X
Isolation slots	X	X
Curved waveguides, S-bend	X	
Circular arc		X
Y-coupler		X
Waveguide spot-size converter	X "3 µm" spot	X "10 µm" spot
Phase shifter	X carrier injection	X thermo-optic
Electro-optic phase modulator	X reverse bias	
pin PD	X dc, low bandwidth (10 GHz)	X high bandwidth (40 GHz)
Balanced pin PD		X 40 GHz
MMI coupler	X 1x2, 2x2	X 1x2, 2x2, 1x4
SOA	X	
Tunable DBR grating	X	

Key element of HHI's receiver platform is a waveguide integrated pin photodiode that has already been under development and optimization for many years. The p-i-n structure is located on top of a semi-insulating waveguide comprised of a stack of quaternary and InP layers, which again are formed on an InP:Fe substrate to facilitate very high-speed operation. 40 GHz bandwidth is guaranteed. Three rib waveguides with different index contrasts are offered. Optical transitions between those waveguides are defined as separate building blocks. On the basis of such waveguides a variety of passive optical building blocks are available, such as Y-junctions, crossings, bends and also thermo-optic phase shifters. Furthermore, the waveguides can be designed with spot-size converters ("tapers") providing "10 µm" mode expansion for optimal fiber coupling. With regard to composite building blocks, the platform contains Multimode Interference (MMI) couplers as well as balanced PDs (40 GHz).

Oclaro's platform is based on the integration process developed over many years and used commercially for devices such as tunable laser-Mach Zehnder PICs employed in tunable XFP-format transceivers [6]. Again, it provides a generic monolithic integration process that supports integration of basic blocks and their application in a number of composite building blocks, as listed in Table I. A library-based, building-block approach allows complex optical sub systems to be designed and realized, including semiconductor laser- and modulator based PICs operating up to >10GHz or 10Gb/s.

III. PIC IMPLEMENTATIONS

A broad range of PICs have been designed covering both optical communication and sensors applications. Respective chips were fabricated on 3-inch wafers utilizing the aforementioned generic building blocks and a Multi-Project Wafer (MPW) run approach.

Figure 1 displays a chip that was made on HHI's platform and which is to form the core of a read-out unit for Fiber-Bragg-Grating (FBG) sensors. It incorporates an AWG, an array of 4 Mach-Zehnder Interferometer delay line structures and a 5-array waveguide-integrated balanced photodetectors (BPD). Figure 2 shows a detector chip for the demodulation of 28 Gbaud quadrature phase-shift keying (QPSK) signals. It is comprised of a 2x4 MMI 90° hybrid with tapered input waveguides and two balanced PD pairs [5]. Though not specifically developed in EuroPIC the same fabrication process was used for this PIC which is already exploited in commercial products proving the relative maturity of the technology.

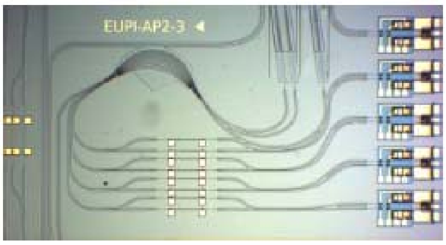

Figure 1. FBG read-out chip (HHI platform; proposal/design: FiberSensing/Bright Photonics)

Figure 2. 28GBaud QPSK receiver chip (HHI)

Two representative PICs made on the Oclaro N+-platform are shown in Figure 3, illustrating how a common foundry process may serve completely different applications. An AWG-based optical pulse shaper for bio-imaging (Fig. 3 left) comprises passive waveguide elements integrated with electro-optical phase modulators and Semiconductor Optical Amplifiers (SOAs). Fig. 3 (right) shows a multi-wavelength transmitter for application in a Fibre-to-the-Home (FTTH) network. It integrates eight Distributed Bragg Reflector (DBR) lasers with four Mach-Zehnder modulators. The light from eight channels is multiplexed and coupled to a single output channel by an AWG. The transmitter exhibits a wide open eye with extinction ratio >24 dB at 12.5 Gb/s after transmission through 20 km of fibre.

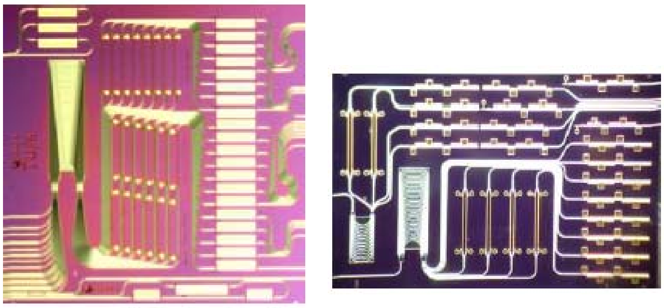

Figure 3. Pulse shaper for a bio-imaging microscope (left), and hybrid TDM-WDM transmitter PIC (right). Designs: TU Eindhoven, PIC fabrication: Oclaro

IV. CONCLUSIONS AND ACKNOWLEDGEMENTS

Funded by the European Commission a joint development is being undertaken to establish generic foundry services for the fabrication of InP based application-specific PICs in Europe. MPW runs were successfully conducted at Oclaro and Fraunhofer-HHI demonstrating the viability of this approach.

Funding from the European Community's 7th Framework Programme FP7/2007-2013 under grant agreement NMP 228839 (EuroPIC) and ICT 257210 (PARADIGM) is gratefully acknowledged.

[1] JePPIX Roadmap 2012: The road to a multi-billion Euro market in InP-based Integrated Photonics (to be found e.g. via [3], [4])

[2] M. Smit et al., "A Generic Foundry Model for InP-based Photonic ICs", OFC 2012 (Los Angeles, March 2012), category 8, invited paper (to be published)

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[4] http://paradigm.jeppix.eu

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[6] A. Carter, "Unlocking the value of fab ownership", Compound Semiconductor, **16** (1), February 2010, pp. 34-37.