Review Article

Katarzyna Ławniczuk*, Luc M. Augustin, Norbert Grote, Michael J. Wale, Meint K. Smit
and Kevin A. Williams

Open access to technology platforms for InP-based photonic integrated circuits

Abstract: Open access to generic technology platforms for photonic integrated circuit manufacturing enables low-cost development of application-specific photonic chips for novel or improved products. It brings photonic ICs within reach for many industrial users and research institutes, by moving toward a fabless business model. In the current status, InP-based open access manufacturing services are offered through multi-project wafer runs by Fraunhofer Heinrich Hertz Institut, SMART Photonics, and Oclaro. In this paper, we review state-of-the-art InP photonic integration technology platforms, present examples of complex InP photonic ICs developed in the generic technologies, and give a prospect for further development of these photonic integration platforms.

Keywords: generic foundry; InP; photonic IC; photonic integration technology.

DOI 10.1515/aot-2015-0012
Received January 18, 2015; accepted February 26, 2015; previously published online March 19, 2015

1 Introduction

Photonic integration and photonic integrated circuit (PIC) technologies are trendsetting technologies for the development of novel and improved photonic products in the application fields of telecommunication, fiber sensing, datacom, antenna systems, medical diagnostic, metrology, among others [1]. Conceptually, photonic ICs are very similar to electronic integrated circuits and combine multiple optical components on a single chip to form a single multifunctional photonic device. The use of fewer photonic chips inherently simplifies the whole assembly process, compared to discrete components, and enables radical miniaturization, cost reduction, and performance enhancement, as illustrated in Figure 1. Present-day photonic ICs can be realized using various technological platforms, the most common being indium phosphide (InP)-based platforms [3, 4], silicon (Si)-based platforms, silica-on-silicon (SiO_2/Si) [5], silicon-on-insulator (SOI) [6], silicon nitride (Si_3N_4) [7], and polymer-based technology [8]. Among these technologies, the most powerful materials for today's PIC development and fabrication are InP-based compounds, the only material platform of the above to support full monolithic integration. These have excellent optical properties (direct band gap that allows for light amplification, generation and detection, light guiding, and fast modulation), and they have a potential for future heterogeneous integration with CMOS electronic chips [9]. Open access services to technology platforms for photonic integrated circuits based on InP and siliconare typically organized by a broker that provides wafer space in multi-project wafer (MPW) runs [10, 11].

1.1 Generic technology in photonics

The complexity of today's photonic ICs includes hundreds to in excess of 1000 components integrated in a single chip [12–17]. This increase in complexity has proceeded

---

***Corresponding author: Katarzyna Ławniczuk,** COBRA Research Institute, Eindhoven University of Technology, Eindhoven, The Netherlands, e-mail: k.lawniczuk@tue.nl
Luc M. Augustin: COBRA Research Institute, Eindhoven University of Technology, Eindhoven, The Netherlands; and SMART Photonics, Eindhoven, The Netherlands
Norbert Grote: Fraunhofer Heinrich Hertz Institut, Berlin, Germany
Michael J. Wale: COBRA Research Institute, Eindhoven University of Technology, Eindhoven, The Netherlands; and Oclaro, Caswell, Northamptonshire, UK
Meint K. Smit and Kevin A. Williams: COBRA Research Institute, Eindhoven University of Technology, Eindhoven, The Netherlands

www.degruyter.com/aot

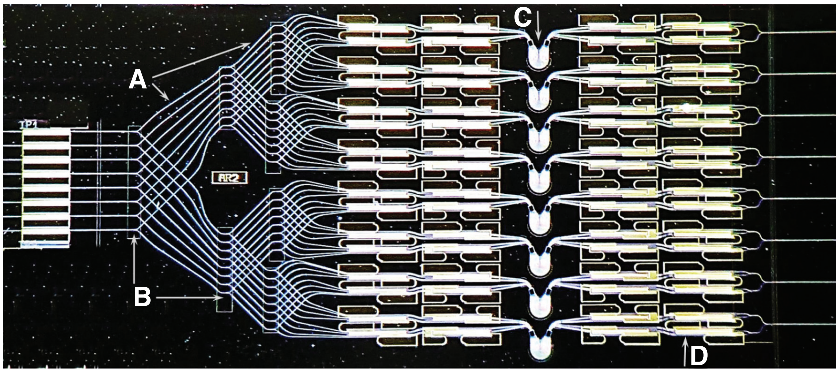

Figure 1: Complex InP photonic IC: 8×8×8λ cross-connect, integrating 136 semiconductor optical amplifier gates, 48 optical couplers, and eight router arrays with shuffle networks and on-chip fan-out and fan-in circuits. The chip from Stabile et al. [2] was fabricated at COBRA Research Institute and measures 14.6 mm×6.7 mm. The insets in the photograph indicate (A) waveguides, (B) MMI couplers, (C) AWG-demux array, (D) optical amplifier gate, as labeled in Figure 3.

over decades, following a trend similar to Moore's law in microelectronics, and has been driven by sustained technology and manufacturing process improvements. Despite this increase, the integrated photonic market is still not as dynamic as the electronics market. The reason for this is that until recently, each process technology has been individually optimized for a specific product or application. This led to a large fragmentation of the market and prevented the development of low-cost photonic integration processes. As a consequence, large investments in technology development have typically been required for new PICs, hampering the growth of new markets. A solution to this deadlock is the generic integration approach, which has been so successful in microelectronics and CMOS technology [18].

The generic approach for InP-based platforms was first introduced by the COBRA Research Institute [19] and later implemented in the foundries of Fraunhofer Heinrich Hertz Institut [20], SMART Photonics [21], and Oclaro [22]. It brought about a fundamental paradigm shift in integrated photonics and is changing the way in which many photonic chips are designed, fabricated, packaged, and tested. This change is based on a design method that allows the reuse of standardized and parameterized photonic building blocks (BBs) to form complex PICs using sophisticated design tools, powerful component libraries, and high-performance manufacturing and packaging technologies. The generic approach enables the design and fabrication of a variety of different photonic devices and circuits (for many applications) to be performed using the same technological processes, just as in Si electronics. The generic model in photonics, together with the use of multi-project wafer runs, provides cost-effective solutions, which can bring photonic devices within reach of many users, for whom the design and fabrication costs were previously too high. The generic foundry model also opens new market directions for companies specialized in PIC design, development and prototyping, based on a fabless business model [23].

1.2 Multi-project wafer run

Multi-project wafer (MPW) runs provide low-cost access to foundry processes and allow for a reduction of the development costs of photonic integrated circuits. The MPW runs in photonics are similar to the MPW runs in microelectronics, in that they make the total wafer area available to multiple designers, sharing space on the same wafer. Users of the MPW runs design their circuits following the design rules of the foundry using the building blocks provided by the foundry to build the whole circuit. The layout of the circuit is placed in individual cells within a single wafer, as illustrated in Figure 2. The foundry or a broker combines all designs on one wafer and runs a generic fabrication process without needing to know the design details. Fabricated devices are delivered to the users of the particular processing run. MPW users typically receive several copies of their device (in the order of 10).

Following a long period of research and development, three chip manufacturers, Oclaro, Fraunhofer Heinrich Hertz Institut, and SMART Photonics, a spinoff company of the COBRA Institute, began offering semi-commercial access to their InP-based processes in 2014. Open access is enabled by defining building blocks and creating a generic Process Design Kit for commercial processes as these had

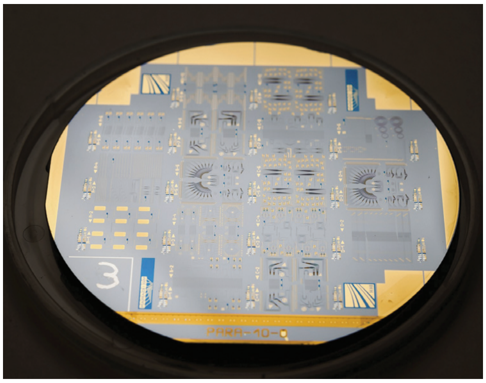

Figure 2: Example of a multi-project wafer with multiple designs, processed at the Fraunhofer HHI fab. Access was enabled via the JePPIX brokering service.

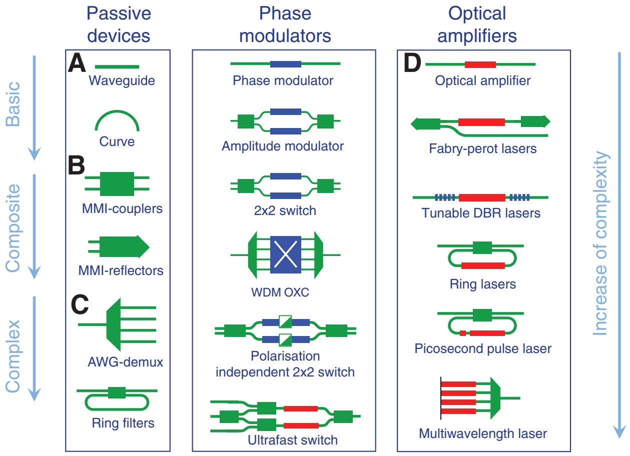

Figure 3: Building blocks concept allows increasing complexity of photonic circuits using basic (fixed and parameterized) photonic components and composite structures. Building blocks labeled as (A) waveguide, (B) MMI couplers, (C) AWG-demux, and (D) optical amplifier were used to form the photonic circuit shown in Figure 1.

been previously application specific. For example, in the case of Oclaro, the foundry process is similar to the one employed for commercial devices such as tunable laser-Mach-Zehnder PICs employed in Oclaro's tunable XFP format (10 Gbps Small Form Factor Pluggable) transceivers. In this case, the foundry platform takes a reliable and stable fabrication process, with high yield and reliability, proven in existing products. It also enables new application outside of telecom.

1.3 Building blocks in photonics

Generic photonic integrated circuits are developed using a set of elementary components called basic building blocks (BBB). This approach, similar to microelectronics, supports a small set of photonic building blocks that are sufficient to develop a broad class of photonic functions. These are (1) passive waveguides, (2) semiconductor optical amplifiers (SOAs), (3) phase modulators, (4) polarization converters, and photodiodes (5). The BBBs can also be used to implement more complex optical elements, called composite BBs (CBBs), as schematically shown in Figure 3. Passive waveguide structures can be used to form waveguide bends, s-bends, tapers, power splitters, and combiners (for example, in the form of multimode interference couplers, MMIs), mode filters and wavelength (de)multiplexers, such as arrayed waveguide gratings (AWGs). Optical amplifiers can be used in a variety of lasers, for example, Fabry-Pérot lasers, ring lasers, mode-locked lasers, or tunable lasers, as well as multiwavelength sources. Reverse biased short SOA sections can be also used as a saturable absorber. Phase modulators that control the phase of optical signals can be utilized in switches and modulators, such as those based on Mach-Zehnder or Michelson interferometers. Another important building block is the polarization converter. This component has been studied thoroughly [24–26], and it will become available soon. For high-performance photodetection, dedicated photodiode building blocks are used that rely on waveguide integrated photodiode structures [27].

2 State-of-the-art in InP photonic integration

Access to foundry services for InP-based photonic ICs for research purposes was started in 2007 by the COBRA Research Institute. These services included an active-passive integration platform and were organized in the framework of the EU-FP6 Network of Excellence ePIXnet [28]. Further improvement of the generic technology resulted in high-quality and versatile passive components, integrated lasers, optical amplifiers, modulators, and detectors. In 2009, the generic foundry model was introduced at COBRA's industrial partners Oclaro and Fraunhofer-HHI, and further explored and improved in the framework of two European projects, EuroPIC [29] and PARADIGM [30]. These projects resulted in the development of process design kits (PDK) and standardized packaging solutions for application-specific photonic ICs. Moreover, the platforms developed in these projects are now at the semi-commercial level and available via the open access services provided by JePPIX as broker [10]. An overview of these three platforms with photonic building blocks available for circuit development is presented in Table 1. The platform technology of COBRA was transferred to SMART Photonics, a spinoff company of the TU Eindhoven.

2.1 Open access to photonic integration platforms

Open access to the technology platforms of Fraunhofer-HHI, SMART Photonics, and Oclaro is organized via multi-project wafer runs and brokered by JePPIX. The foundries provide access to their manufacturing processes on a regular basic, typically two to three times per year. The available design sets for the MPW users include advanced photonic design kits (PDKs) with component libraries that contain accurate models of the building blocks in the foundry platforms, as well as the mask layout tools. Photonic PDKs are under development, and composite level building blocks, such as mode-lock lasers, DBR lasers, Mach-Zehnder modulators can be envisaged in the future. The process design kit is implemented in commercially distributed software with layout and simulation capabilities, including design rule checking (DRC) by PhoeniX Software [31], ASPIC™ of Filarete [32], and Photon Design [33]. The typical procedure for having a photonic IC fabricated with JePPIX is shown in Figure 4. A standard JePPIX user agreement is required to get access to platform design manuals and PDKs. The users reserve cells in MPW runs and design their circuit layouts. These pass the DRC before the mask-level description is transferred to the manufacturers. The fabrication processes take between 4 to 6 months.

For the JePPIX InP-based MPW runs, the entry costs are between 5000 € for an 8-mm^2 design in a simple process, scaling up to 40,000 € for a 36-mm^2 photonic ASIC in the most complex process. The roadmap for the generic InP technology targets 10 €/mm^2 for volumes of around 1000 chips with further reductions as volumes increase. These costs are very competitive, when compared to advanced silicon photonic MPW runs, while offering distinctly more functionality (on-chip integrated optical amplifiers and lasers). At the present price level, these costs are attractive for integrating complex subcircuits containing larger numbers of photonic components. This makes them much cheaper, more compact, and robust than their alternatives based on discrete components. As the entry costs are affordable for most small and medium-size companies and research institutes, rapid expansions in the application of PICs is expected, as well as an increase in applying photonic ICs in novel or improved products.

Table 1: Comparison of the most relevant features of the InP and silicon photonic MPW platforms, for 2014.

Broker	Process	Lasers	SOAs	TBR	Modulators/Phase shifters				Detectors			Prop. loss	MPW cost			
					L (mm)	V_p-P_p	Loss (dB)	B (GHz)	R(A/W)	B (GHz)	I_{dark} (nA)	dB/cm	Smallest chip	Price	MPW cost/mm^2	#Chips
JePPIX	Oclaro TxRx 10	Yes	Yes	Yes	1	3.5	<2	>10	0.8	10		2–3	2×6	€ 12 000	1000	8
JePPIX	HHI Rx 40				0.5	(25 mW)	<2	(kHz)	0.8	40	<10	1–2	3×6	€ 5500	300	8
JePPIX	SMART TxRx10	Yes	Yes		2	7	<2	10	0.8	10	<20	3–4	2×4.6	€ 4500	500	8
JePPIX	TriPleX (DS-500-170)				1–2	(500 mW)	<0.1	(kHz)				<0.5	16×16	€ 16 000[a]	63	4
ePIXfab	imec ISIPP25G				1.5	8.5	5	11	0.5	>50	<50	1.5–2.5	2.5×2.5	€ 10 000	1600	10
ePIXfab	CEA-LETI Full Platform				1–4.7	?	?	10	?	10	?	?	3.4×3.7	€ 21 750	1700	50
OPSiS[b]	OpSIS-IME OI50				3	9	5	30	0.7	>50	3300	1–2	2.5×2.5	€ 8000	1300	20

[a] Universities get 45% reduction on TriPleX MPWs, [b] OPSIS stopped brokering service in 2014.

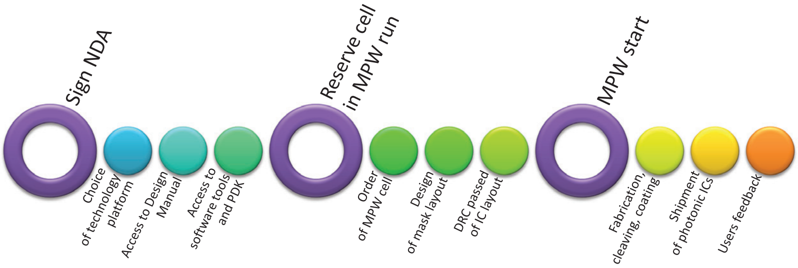

Figure 4: JePPIX brokering services offer access to design software and PDK, support in design of photonic ICs, and access to MPW runs of Fraunhofer HHI, SMART Photonics, and Oclaro.

2.2 Present capabilities of the InP photonic integration platforms

Users of the semi-commercial InP photonic integration platforms can presently choose between the high-speed 40 Gb/s receiver platform of Fraunhofer HHI, and the 10-Gbps transmitter-receiver platforms of SMART Photonics and Oclaro. All three platforms offer a variety of passive devices, including waveguide bends, MMI couplers and AWG (de)multiplexers. Waveguide propagation loss varies between 0.5 dB/cm for low contrast waveguides to 2 dB/cm for high contrast waveguides on Fraunhofer HHI's platform and up to 3 dB/cm for the deeply etched waveguides of SMART Photonics and Oclaro. The receiver platform of Fraunhofer HHI includes 40 GHz photodetectors and balanced PIN diodes with responsivity of ~0.7 A/W, and a dark current <10 nA. The platforms of SMART Photonics and Oclaro enable monolithic integration of amplifiers (SOAs) and various lasers on a single chip. The SOAs of SMART Photonics provide 60/cm gain and 20 mW output power, while Oclaro can deliver up to 50 mW. The electro-optical modulators support a 10-Gb/s modulation with a <5-V drive voltage for 2-mm-long phase modulators (SMART Photonics) and a 3.5-V modulation voltage for a phase modulator length of under 1 mm (Oclaro). Input/output spot-size converters (SSCs) are available on the Fraunhofer HHI (coupling loss of around 1.5 dB to a cleaved standard single mode fiber with a spot diameter of 10 μm) and the Oclaro platform (3 μm spot diameter with coupling loss to lensed fibers of 2 dB). Tunable Bragg gratings are offered on the Oclaro platform and support wavelength tuning of up to 9 nm. A summary of the current MPW semi-commercial platforms, for 2014, with available building blocks is given in Table 1.

When compared to other open access photonic integration platforms, in particular, silicon-based solutions [34, 35] and silicon nitride [36], the main advantage of the InP platforms is monolithic integration of SOAs and lasers. Moreover, the InP modulators have lower drive voltages and shorter lengths. The propagation loss of the silicon-based passive structures is 0.5 dB/cm [36] up to 2.5 dB/cm [35]. The bandwidth of the silicon photodetectors can reach 50 GHz, though the Fraunhofer HHI platform has currently 40-Gbps receivers with lower dark current and low-loss waveguides. The silicon ICs are typically processed on 6″–8″ wafers, while InP prototypes are developed on 2″–3″ wafer sizes. For a detailed discussion on scaling, yield, and reliability issues, we refer the reader to the JePPIX roadmap 2015 [23].

2.3 Application-specific photonic ICs

The InP generic integration platforms facilitate the development of versatile application-specific photonic ICs. The application range varies from telecom [37, 38], datacom [39, 40], and switching [41, 42] to medical [43], sensor [44], and THz devices [45]. Recent examples of photonic ICs developed for millimeter-wave wireless communication are reported in [46]. These devices were designed as a dual distributed feedback (DFB) wavelength source and an AWG-based laser for dual wavelength operation. A photonic IC developed for sensor application is shown in Figure 5 [15]. The chip is a spectrometer with integrated detectors, fabricated at Fraunhofer HHI. The device was developed to demultiplex 100 wavelength channels with a channel spacing of 1 nm, integrating 100 photodetectors and 11 cascaded arrayed waveguide gratings. Another example is a widely tunable laser with a tuning range of 60 nm and single-mode operation. This was developed on the SMART Photonics platform [48]. The device was designed using intracavity tunable asymmetric Mach-Zehnder interferometers that use voltage-controlled phase modulators (Figure 6). It was developed for optical gas sensing of several gas species. In Figure 7, a scalable low-energy high-speed optical switch is shown [42]. The switch integrates both Mach-Zehnder modulators and SOAs and does not require 50 Ω matching resistors,

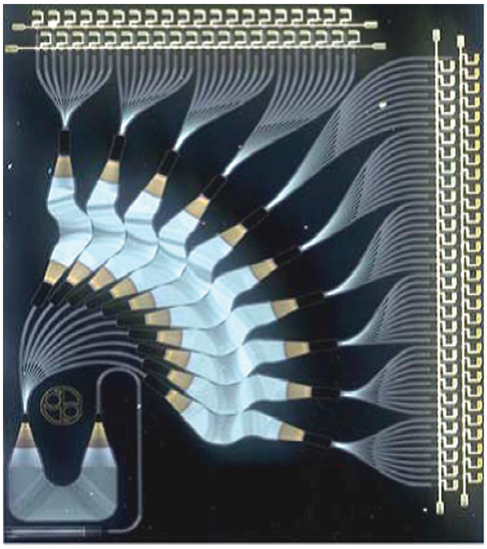

Figure 5: Photonic IC that integrates more than 100 components (photodetectors, multiplexers, and routing waveguides) to create a sensor readout [15]. The chip was developed by BRIGHT Photonics [47] and fabricated at Fraunhofer HHI. The size of the device is 6 mm×7.4 mm.

allowing electrical power consumption reductions. The device was fabricated at the Oclaro technology platform. An example of a picosecond pulse laser IC is presented in Figure 8. This chip is a mode-locked extended cavity laser with a repetition rate of 2.5 GHz [49]. The device includes intracavity phase modulator, semiconductor optical amplifiers, and a saturable absorber.

Up until now, more than 250 application-specific photonic ICs have been fabricated in MPW runs on the foundry platforms of COBRA Research Institute, SMART Photonics, Fraunhofer HHI, and Oclaro.

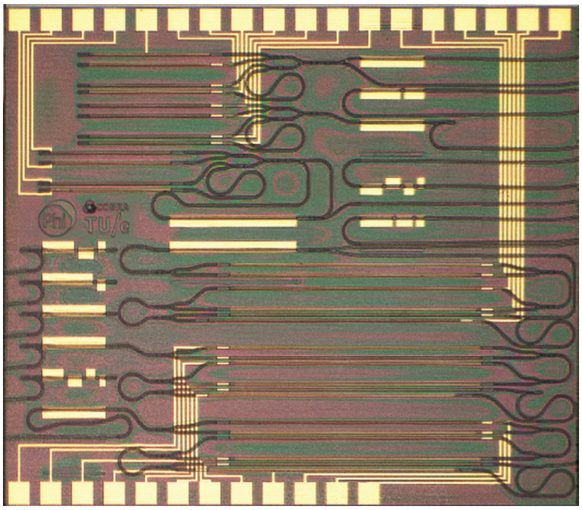

Figure 6: Photonic IC with a number of tunable lasers fabricated at the SMART Photonics platform [48]. The size of the chip is 4 mm×4.6 mm.

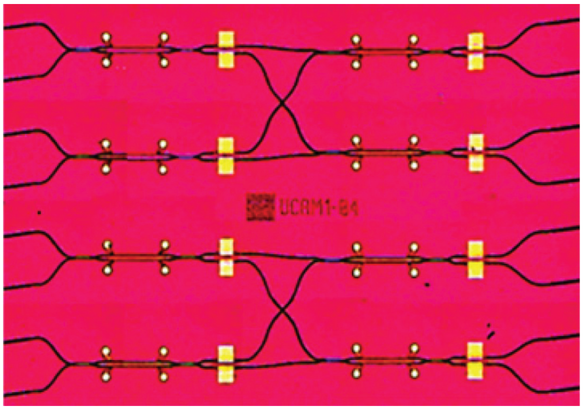

Figure 7: Optical switch fabricated at the Oclaro platform. The photograph shows a chip containing 2×2 switch elements, courtesy of A. Wonfor from University of Cambridge [42].

3 Technology development and prospect

Further technology development is focused on the improvement of the InP photonic IC platforms, in particular, for reaching a higher speed of the modulators and detectors, lowering the optical loss of the passive components, and introducing new functionality into the platforms.

The Fraunhofer HHI platform is currently being extended to additionally integrate transmitter functionalities by incorporating SOAs, distributed feedback lasers,

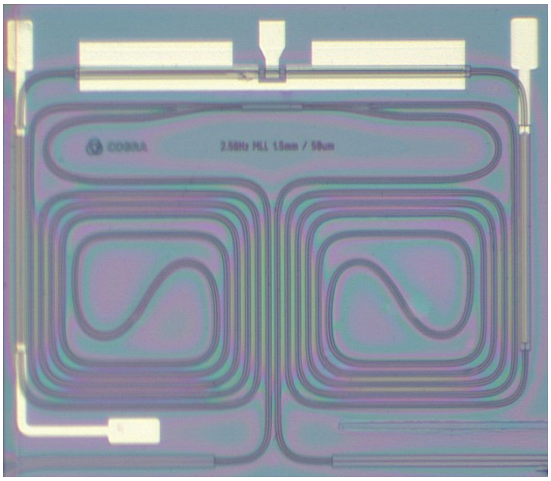

Figure 8: A 2.5-GHz ring mode-locked laser for optical frequency comb generation. The chip measures 2.3 mm×1.75 mm and was fabricated by SMART Photonics in a multi-project wafer run [49].

and electro-absorption modulators (EAMs) in the current receiver platform. The platform will support a 25-Gbps modulation, which can be obtained either by direct modulation of DFB lasers or by using EAMs. Further development will be focused on providing polarization handling capabilities. The SMART Photonics platform will aim at lowering the waveguide propagation loss (below 1 dB/cm) and support smaller device features (down to 100 nm). This will be done by introducing a 193-nm ArF lithography scanner into the technology process. Further in prospect, the platform will add spot size converters and enhance the data rate of modulators and photodetectors. Both the Fraunhofer HHI and the SMART Photonics platform aim to extend their platform capabilities by adding polarization handling components. Current developments on the Oclaro platform, conducted within the PARADIGM project [30], are focusing on transmitter-receiver functionality at data rates up to 40 Gb/s, lowering the driving voltage of the modulators and enhancing responsivity of the photodetectors, all on semi-insulating (SI) InP substrates, offering high electrical isolation and low parasitics.

A comparison of the InP and silicon photonic MPW platform capabilities, for 2014, is given in Table 1. Most of the MPW platforms are in the course of improvement of their specification and capabilities. The yield and reliability for InP photonics are established for high-performance telecom products. We believe pricing will scale with market size in just the same way as it does for all other semiconductor wafer-based technologies.

On-chip integration of InP photonics and CMOS electronic functionalities is an important research theme at the COBRA Institute. The integration of high-speed electronics with fully functional photonic ICs will have a great impact on performance and module costs.

4 Summary

The InP-based foundry platforms of Oclaro, Fraunhofer HHI, and SMART Photonics have unrivalled functionality and are competitively priced for multi-project-wafer prototyping. Open access to these generic integration foundries enables development of novel photonic ASICs. As a result of the generic concept, it became possible to separate the design from the technology. By reusing the foundry-approved photonic building blocks, the design time and number of design (and fab) cycles needed to achieve a required performance of the prototype photonic IC device is significantly reduced. Access to the InP technology platforms is brokered by JePPIX.

Acknowledgments: The authors would like to acknowledge the project partners from the EU program EuroPIC (grant agreement no. NMP 228839) [29], EU Programme PARADIGM (grant agreement no. NMP 257210) [30], and from the Dutch projects: NRC Photonics, MEMPHIS [50], IOP Photonic Devices [51], and STW GTIP [52].

References

[1] M. Smit, X. Leijtens, H. Ambrosius, E. Bente, J. van der Tol, et al., Semicond. Sci. Technol. 29, 083001 (41pp), (2014).

[2] R. Stabile, A. Rohit and K. A. Williams, J. Lightwave Technol., 32 201–207 (2014).

[3] R. Nagarajan, M. Kato, J. Pleumeekers, P. Evans, S. Corzine, et al., IEEE J. Sel. Topics Quantum Electron. 16 1113–1125 (2010).

[4] M. Smit, R. Baets and M. Wale, in 'Proc. 35th European Conference on Optical Communication', Vienna, Austria, (2009) pp. 1.7.3–1/2.

[5] L. Wosinski, in 'Proc. 6th International Conference on Transparent Optical Networks', (2004) pp. 274–279.

[6] W. Bogaerts, P. Dumon, D. van Thourhout, D. Taillaert, P. Jaenen, et al., IEEE J. Sel. Topics Quantum Electron. 12, 1394–1401 (2006).

[7] B. Jalali, Phys. Stat. Sol. (a), 205 213–224 (2008).

[8] Z. Zhang, N. Mettbach, C. Zawadzki, J. Wang, D. Schmidt, et al., IET Optoelectronics 5, 226–232 (2011).

[9] J. van der Tol, R. Zhang, J. Pello, F. Bordas, G. Roelkens, et al., IET Optoelectronics 5, 218–225 (2011).

[10] JePPIX: Joint European Platform for Photonic Integrated Components and Circuits, http://www.jeppix.eu.

[11] ePIXfab, the Silicon photonics platform, http://www.epixfab.eu.

[12] R. Nagarajan, C. H. Joyner, R. P. Schneider, J. S. Bostak, T. Butrie, et al., IEEE J. Sel. Top. Quant. Electron. 11, 50–65 (2005).

[13] S. C. Nicholes, M. L. Masanovic, B. Jevremovic, E. Lively, L. A. Coldren, et al., in 'Proc. Opt. Fibre Com. Postdeadline Paper', (2009), pp. PDPB1.

[14] F. M. Soares, J. H. Baek, N. K. Fontaine, X. Zhou, Y. Wang, et al., in 'Proc. Opt. Fibre Com.', (2010), pp. OThS1.

[15] R. Stabile, A. Albores-Mejia and K. A. Williams, Opt. Lett., 37 4666–4668 (2012).

[16] M. Baier, R. Broeke, F. Soares, M. Gruner, A. Seeger, et al., in 'Proc. 40th European Conference on Optical Communication', (2014), pp. We.2.4.5.

[17] J. Summers, T. Vallaitis, P. Evans, M. Ziari, P. Studenkov, et al., in Proc. ECOC 2014, Cannes, France, 21–25 Sept. 2014, DOI:10.1109/ECOC.2014.6963890.

[18] M. Smit, X. Leijtens, E. Bente, J. van der Tol, H. Ambrosius, et al., IET Optoelectronics 5, 187–194 (2011).

[19] Eindhoven University of Technology – COBRA Research Institute, Eindhoven, The Netherlands, www.tue.nl/cobra.

[20] Fraunhofer Heinrich Hertz Institut, Berlin, Germany, http://www.hhi.fraunhofer.de.

[21] SMART Photonics, http://smartphotonics.nl.

[22] Oclaro Technol. Ltd., Caswell, United Kingdom, http://www.oclaro.com.

[23] M. Smit. K. Williams, K. Lawniczuk, D. Robbins, M. Wale, et al., JePPIX Roadmap 2015, http://jeppix.eu/document_store/JePPIXRoadmap2015.pdf.

[24] D. O. Dzibrou, J. J. G. M. van der Tol and M. K. Smit, Opt. Lett. 38, 1061–1063 (2013).

[25] D. O. Dzibrou, J. J. G. M. van der Tol and M. K. Smit, Opt. Lett. 38, 3482–3484 (2013).

[26] L. M. Augustin, J. J. G. M. van der Tol, E. J. Geluk, and M. K. Smit, IEEE Photon. Technol. Lett. 19, 1673–1675 (2007).

[27] H. G. Bach, A. Beling, G. G. Mekonnen, R. Kunkel, D. Schmidt, et al., IEEE J. Select. Topics Quantum Electron. 10, 668–672 (2004).

[28] The FP6 Network of Excellence ePIXnet www.epixnet.org.

[29] EU-FP7 NMP SME project EuroPIC www.europic.jeppix.eu.

[30] EU-FP7 IST Integrating Project Paradigm www.paradigm.jeppix.eu.

[31] PhoeniX Software, Enschede, the Netherlands www.phoenixbv.com.

[32] Aspic Filarete, Milano, Italy, www.aspicdesign.com.

[33] Photon Design, Oxford, United Kingdom, www.photond.com.

[34] LETI Full Platform, http://www.epixfab.eu/technologies/full-platformleti.

[35] IMEC ISIPP25G, http://www.epixfab.eu/technologies/isipp25g.

[36] TriPleX technology, http://lionixbv.nl/triplexmpw.html.

[37] K. Lawniczuk, C. Kazmierski, J. Provost, M. J. Wale, R. Piramidowicz, et al., IEEE Photon. Technol. Lett. 25, 352–354 (2013).

[38] J. Zhao, K. Dijkstra, M. J. Wale, P. Maat, M. K. Smit, et al., in 'Proc. 16th European Conf. of Integrated Optic and Technical Exhibition' (2012).

[39] F. Bontempi, S. Pinna, N. Andriolli, A. Bogoni, X. Leijtens, et al., IEEE J. Quantum Electron. 48, 1453–1461 (2012).

[40] S. Stopinski, M. Malinowski, R. Piramidowicz, M. K. Smit, X. J. M. Leijtens, in 'Proc. Optical Fiber Conf.', (2013), pp. OW4J.7.

[41] A. Rohit, J. Bolk, X. J. M. Leijtens and K. A. Williams, J. Lightwave Technol. 30, 2913 (2012).

[42] Q. Cheng, A. Wonfor, R. V. Penty and I. H. White, J. Lightwave. Technol. 31, 3077–3084 (2013).

[43] S. Tahvili, S. Latkowski, B. Smalbrugge, X. J. M. Leijtens, P. J. Williams, et al., IEEE Photonics Technol. Lett., 25, 450–453 (2013).

[44] R. F. Klein Breteler, J. J. G. M.van der Tol, M. Felicetti, G. D. J. Sasbrink and M. K. Smit, Opt. Eng. 50, 071111 (2011).

[45] F. M. Soares, J. Kreissl, M. Theurer, E. Bitincka, T. Goebel, et al., in 'Proc. 25th Intern. Conf. on InP and Related Materials', (2013) pp. TuD4-4.

[46] G. Carpintero, K. Balakier, Z. Yang, R. C. Guzmán, A. Corradi, et al., J. Lightwave Technol. 32, 3495–3501 (2014).

[47] BRIGHT Photonics BV, http://brightphotonics.eu/.

[48] E. Bente, S. Latkowski, T. de Vries, M. Smit, in 'Proc. 16th Intern. Conf. Transparent Optical Networks', (2014) p. Mo.D2.4-1/4.

[49] S. Latkowski, V. Moskalenko, S. Tahvili, L. Augustin, M. Smit, et al., Opt. Lett. 40, 77–80 (2015).

[50] Dutch Smartmix project MEMPHIS (Merging Electronics and Micro&Nano-Photonics in Integrated Systems) www.smartmix-memphis.nl/.

[51] Dutch IOP Photonic Devices www.agentschapnl.nl/subsidies-regelingen/iops/iop-photonic-devices.

[52] STW (Dutch Technology Foundation) Perspective Program 2010: Generic Technologies for Integrated Photonics (GTIP).

Katarzyna Ławniczuk
COBRA Research Institute, Eindhoven
University of Technology, Eindhoven,
The Netherlands
k.lawniczuk@tue.nl

Katarzyna Ławniczuk was awarded a joint PhD degree from Eindhoven University of Technology, The Netherlands, and Warsaw University of Technology, Poland, in 2014. Her research focused on indium phosphide-based multiwavelength lasers and photonic integrated transmitters for application in optical access networks and fast interconnects. During the PhD studies, she was awarded for her work at international conferences, and in 2012, she received the Dutch Netelcom Award for the most innovative scientific contribution of a PhD student to the field of communication technology. Katarzyna has been the coordinator of JePPIX at the Photonic Integration Group at Eindhoven University of Technology since 2013.

Luc M. Augustin
COBRA Research Institute, Eindhoven
University of Technology, Eindhoven,
the Netherlands
SMART Photonics, Eindhoven,
The Netherlands

Luc Augustin received the MSc and PhD degrees in Electrical Engineering from Eindhoven University of Technology, The Netherlands. Luc has worked in the industry at Cedova, Philips Photonics Lab, stepped to the Photovoltaics industry and went to Solland Solar. Currently, he is working at SMART Photonics as CTO and partly at Eindhoven University as project manager. His expertise is in simulation and design of InP-based photonic integrated circuits, fabrication of III–V photonics components and integrated circuits and characterization of semiconductor-based photonic components.

Norbert Grote
Fraunhofer Heinrich Hertz Institut, Berlin,
Germany

Norbert Grote earned the Diploma and PhD degree in Physics from Aachen Technical University, Germany, in 1974 and 1977, respectively. In 1981, he joined the Heinrich-Hertz Institut für Nachrichtentechnik GmbH to help build up the newly established Integrated Optics Department, which later became the Photonics Components Department when the HHI became a member of the Fraunhofer Society in 2003. Since then, he is the Deputy head of the Photonic Components Department at Fraunhofer HHI. He is supervising different R&D groups focusing on InP materials technology, laser devices, and monolithic and hybrid integration technology, in the latter case using a PLC polymer platform. Over the years, he has extensively been involved in the initiation and coordination of photonics-related national R&D programs/projects in the public domain and of collaborative projects with companies. He has been engaged in several EU-funded projects, including MEPHISTO, EuroPIC, and PARADIGM projects. In 2011, he chaired the 22nd IPRM conference.

Michael J. Wale
COBRA Research Institute, Eindhoven
University of Technology, Eindhoven,
The Netherlands
Oclaro, Caswell, Northamptonshire, UK

Michael Wale is the Director of Active Products Research at Oclaro, a major supplier of photonic components for the global optical communications market, based at Caswell, Northamptonshire, UK. Mike received his BA, MA, and DPhil degrees in Physics from the University of Oxford. Since moving into industry in the early 1980s, he has been involved in many different aspects of research, development, and manufacturing of photonic devices and systems, with particular emphasis on photonic-integrated circuit technology. Alongside his role at Oclaro, where he has responsibility for strategic technology activities, he is a Professor of Photonic Integration/Industrial Aspects at Eindhoven University of Technology, The Netherlands, and an Honorary Professor at the University of Nottingham in the UK. Prof. Wale is a member of the Executive Board of the European Technology Platform, Photonics21, and chairman of its Working Group on Design and Manufacturing of Optical Components and Systems.

Meint K. Smit
COBRA Research Institute, Eindhoven
University of Technology, Eindhoven,
The Netherlands

Meint K. Smit graduated in Electrical Engineering at the Delft University of Technology in 1974, and received his PhD in 1991, both with honors. In 1974, he started work on radar and radar remote sensing. He joined the Delft University of Technology in 1976. He switched to optical communications in 1981, research field: Integrated Optics. He became the leader of the Photonic Integrated Circuits group of the Delft University in 1994. He is the inventor of the Arrayed Waveguide Grating for which he received a LEOS Technical Achievement award in 1997. He was appointed as professor in 1998. In that year, his group, together with the groups of Prof. Wolter and Prof. Khoe (COBRA, TU Eindhoven), received a research grant of 40 M€ for establishing a National Research Center on Photonics. In 2002, he moved with his group to the Technical University of Eindhoven, where he was a leader of the Opto-Electronic Devices group at the COBRA Research Institute until 2014. In 2002, he was appointed LEOS Fellow for contributions in the field of Opto-Electronic Integration.

Kevin A. Williams
COBRA Research Institute, Eindhoven
University of Technology, Eindhoven,
The Netherlands

Kevin Williams graduated in Electronic Engineering from the University of Sheffield and received his Ph.D. from the School of Physics at the University of Bath in 1995. He subsequently moved to the University of Bristol where he was awarded a Royal Society university research fellowship to study high-speed and high-power semiconductor lasers. In 2001, he moved to the University of Cambridge where he was also appointed a Fellow and lecturer at Churchill College Cambridge. In 2006, Kevin moved to the Technical University Eindhoven to take up an EC Marie Curie Chair award. In 2011, he received a Vici award from the Dutch NWO to perform research into large-scale high-performance photonic integrated circuits. He is presently leading the Photonic Integration group at the COBRA Research Institute.