DE GRUYTER Adv. Opt. Techn. 2015; 4(2): 179–188

Review Article

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Lasers in InP generic photonic integration technology platforms

Abstract: A review is given of a number of lasers in a form of photonic integrated circuits realized on InP substrate using a generic integration approach. The potential of these photonic circuits lies in their compactness, low power consumption, and significant reduction of fabrication cost by realization in generic foundry runs. Generic integration platforms offer the possibility of realizing functionally advanced photonic circuits using combinations of just a few standardized and parameterized building blocks. This vibrant field opens new doors to innovative product development for SMEs as well as curiosity-driven research.

Keywords: lasers and laser optics; photonic integrated circuits; semiconductor lasers.

OCIS codes: 140.0140; 140.5960; 250.5300.

DOI 10.1515/aot-2015-0014
Received January 22, 2015; accepted February 27, 2015

1 Introduction

Indium phosphide (InP)-based photonic integration technology platforms offer an excellent facility for development and fabrication of complex yet compact optical circuits for a variety of applications ranging from innovative product development for small and medium-sized enterprises (SMEs; see Table 2 in the appendix for a list of acronyms used in this paper) to curiosity-driven research. These platforms provide technologies that enable on-chip means for manipulation of light, allowing for its generation, amplification, propagation, modulation, and detection. In a generic photonic integration concept, these functionalities are implemented as a set of standardized and well-characterized building blocks (BB). These can be combined into a variety of photonic integrated circuits (PICs) of large (topological) complexity. In this way, adequate application-oriented functionality can be offered to the customer [1]. Moreover, access to such generic photonic integration platforms at relatively low cost is provided by foundries via multiproject wafer (MPW) runs in which different PIC designs from independent users are combined on a single wafer and follow the same fabrication process, therefore, sharing the processing costs. Such approach enables the development and fabrication of affordable user-specific PICs for a broad range of research and commercial applications [1].

In a generic photonic integration process, the availability of building blocks is essential. These are components with a dedicated functionality that can be fabricated with the materials composite provided in the technology platform offered by a particular foundry. By an analogy to the fundamental building blocks in microelectronics, given by electrical connectors (wires), resistors, capacitors, and transistors, the basic building blocks in photonic integration are passive waveguides, optical phase modulators, polarization rotators (convertors), and optical amplifiers. In Figure 1A, an example of vertical cross sections of basic BBs developed in COBRA Research Institute is schematically presented.

The particular set of BBs available indifferent technology platforms depend on the particular foundry. Additional composite BBs extending the range of basic functionalities are also available, e.g., multimode interference couplers (MMI) for splitting and/or combining of the light, arrayed waveguide gratings (AWG) for wavelength multiplexing and demultiplexing, on-chip reflectors, photodetectors, saturable absorbers, etc. Symbolic representation of basic and a few commonly used composite building blocks are shown in Figure 1B. Furthermore, a certain functionality can be implemented by various means depending on the particular technology platform. For example, the on-chip reflector, which is a crucial BB for realizing linear laser

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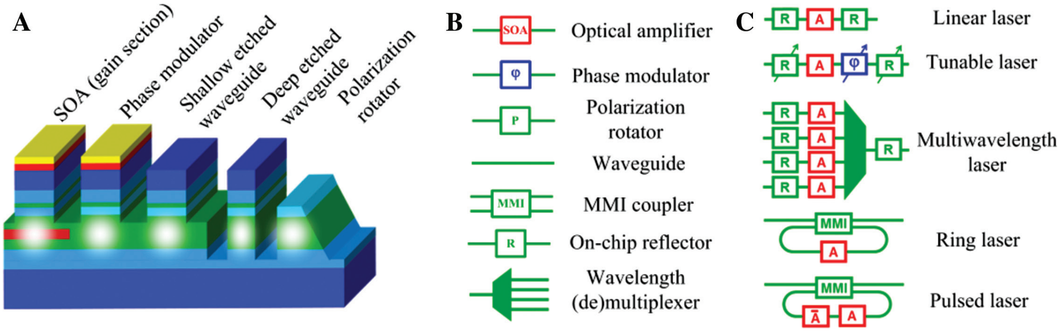


Figure 1: (A) Cross sections of basic building blocks available in the InP-based active-passive generic integration platform developed in COBRA Research Institute (from [1]). (B) Symbolic representation of four basic and three composite building blocks (after [1]). (C) Examples of lasers of various topologies as PICs.

structures that do not depend on the chip facet reflections, can be realized in various forms. It could be a multimode interference reflector (MIR), but it could also be based on a strong or weak grating implemented on the waveguide, in which case, it is a form of distributed Bragg (DBR) or distributed feedback (DFB) reflector, respectively. Using a combination of BBs based on active and passive layer stacks, one can build different types of lasers having either linear/Fabry-Pérot (FP) or ring geometries, operating in single frequency/continuous wave or pulsed regime, etc. A few possible laser configuration topologies are shown in Figure 1C.

A number of application-specific photonic-integrated circuits (ASPIC) were already successfully realized using InP-based photonic integration platforms via access to MPW runs. Such technologies have been developed and services are offered by a few European foundries: OCLARO [2], Fraunhofer Heinrich Hertz Institute (HHI) [3], and COBRA Research Institute of which foundry services are currently provided by SMART Photonics [4].

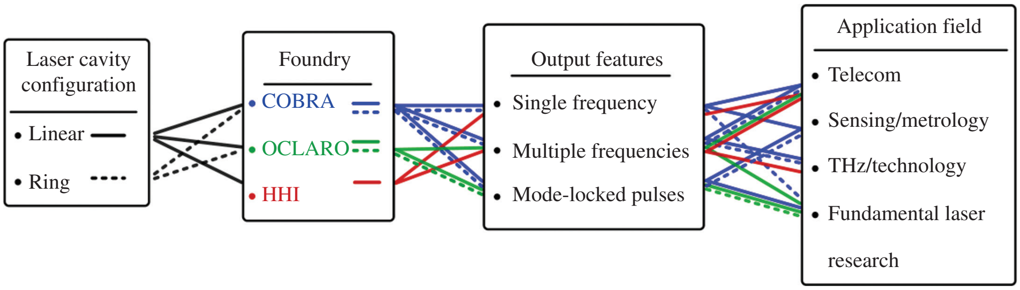
In this review, we focus on several laser designs realized in a form of PIC since 2010. All devices were designed following the generic integration approach and fabricated using a monolithic integration scheme on an InP substrate in one of the foundries mentioned above [1]. For the sake of this review, these systems can be categorized on the basis of criteria such as cavity geometry, foundry where the chip was fabricated, type of the output signal, and application field as shown in Table 1.

2 Linear lasers

2.1 Single-frequency lasers with weak filtered feedback

Several single-frequency, continuous-wave (CW) lasers showing relatively small linewidths (~1 MHz) have recently been fabricated in generic platform technology. Some devices make use of filtered-feedback delay effects for the longitudinal mode selection. An example of such a laser, developed and designed by J. Zhao et al. in 2012 [5] and fabricated by OCLARO foundry, makes use of weak filtered optical feedback into a Fabry-Pérot (FP) type of laser. In fact, by employing four different channels of a single AWG, four identical FP lasers operating at different wavelengths are combined on a single chip, as shown in Figure 2. The AWG in the external feedback path enables the wavelength

Table 1: The PIC-based laser systems reviewed in this paper and categorized with respect to their geometry, foundry, type of the output signal, and application field. Solid lines refer to linear, dashed lines to ring lasers, colors refer to the foundries as indicated.



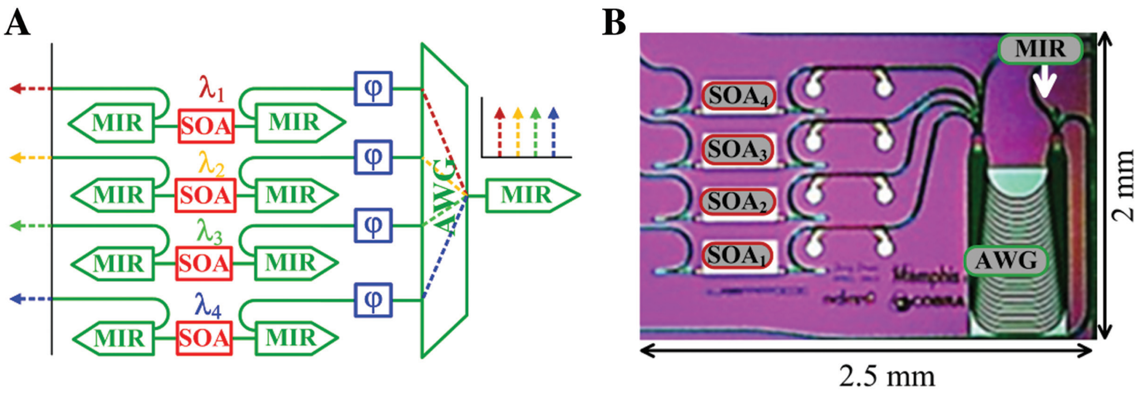


Figure 2: (A) Schematic diagram of filtered-feedback multiwavelength laser including: semiconductor optical amplifiers (SOA), on-chip multimode interference-based reflectors (MIR) and phase modulators (φ). (B) Microscope photograph of the fabricated filtered-feedback multiwavelength laser circuit, with dimensions 2.5×2 mm; the light output is from the left side of the chip. Figures after [6].

filtering, and the phase shifter section in each channel allows to control the phase of the feedback signal.

The role of the filtered feedback in this device is to lower the effective roundtrip loss of each laser with wavelength in one channel of the AWG such that one particular mode hits the threshold condition first and when started lasing, suppresses all other longitudinal modes in the same wavelength channel by holding their gain below lasing threshold value. This is already achieved for a feedback level as low as 1% in power. The individual phase shifters are needed to control the absolute external feedback phase φ with accurate precision within a 2π interval, which was proven to be essential for stable narrow-linewidth (150 kHz) operation [6]. In fact, under the above conditions of weak feedback, φ regions of stability form isolated subsets on the 2π interval with stability boundaries corresponding to the generation of feedback-induced sustained relaxation oscillations [6].

These detrimental effects inspired D'Agostino et al. [7] to design and fabricate a FP-type DBR laser with weak optical feedback monolithically integrated on one single chip, which could be operated under the condition of resonant relaxation oscillations (RO), i.e., the external roundtrip time is a multiple of the RO period. It had been predicted that under such conditions one, two, or more stable regions of injection current exist where the RO stays damped, as in a solitary laser [8]. The laser was fabricated within an MPW run provided by OCLARO via the Paradigm project [9]. The device makes use of basic BBs available in this foundry, to match the schematic presented in Figure 3A, and the corresponding chip is shown in Figure 3B.

The device is an example of the generic photonic integration approach for fundamental laser research. It allows to experimentally demonstrate a laser with a weak optical feedback and shows broad regions of operation without RO-induced instabilities where the side-mode

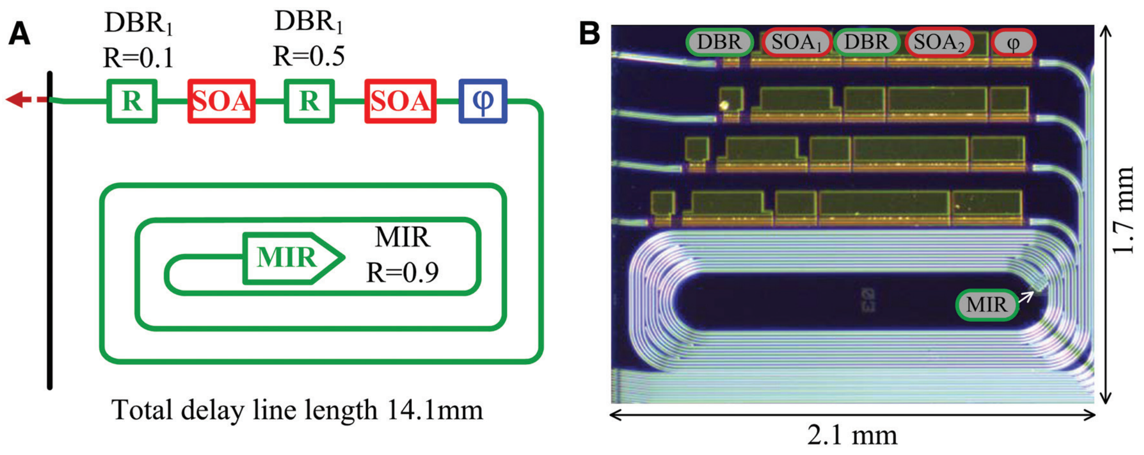


Figure 3: (A) Schematic of one integrated DBR laser with feedback delay line. (B) Microscope photograph of realized chip, including four test structures. Figures after [7].

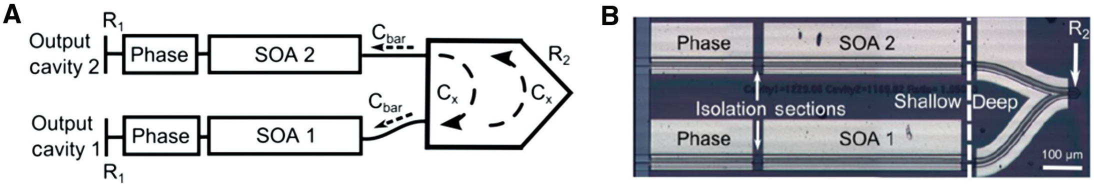


Figure 4: (A) Schematic of fabricated laser, with two-port multimode interference reflector. C_x, and C_{bar} denote the complex amplitude coupling coefficients between the cavities. (B) Microscope image of the fabricated device. R_2 is the coupling mirror. The dashed line indicates the transition between the shallowly and deeply etched areas. Figures from [10].

suppression ratio (SMSR) is above 40 dB irrespective of the feedback phase [7].

2.2 Integrated, tunable coupled cavity laser

A new type of a monolithically integrated coupled-cavity laser (CCL) was designed and realized by D’Agostino et al. [10] in 2014. A crucial requirement for operation of a CCL is that the coupling phase should be kept fixed at an integer multiple of π [11], which actually restricted the applicability of this type of lasers severely during the past three decades. With the use of a two-port reflector derived from a 3×3 multimode interference coupler and designed by D’Agostino et al. [12], the two lasers are coupled in such a way that the coupling phase condition is fulfilled for certain wavelengths and results in robust, stable, and tunable single-wavelength operation. The laser cavity layout and a micrograph of the device fabricated in OCLARO are shown in Figure 4. The tuning range of 6.5 nm, SMSR up to 40 dB, and ~1 MHz linewidth makes this compact laser (1.1×0.4 mm) an attractive alternative to grating-based lasers.

2.3 DFB lasers in photonic integrated circuits

A series of different devices for different functionalities and applications were realized in the Fraunhofer Institute for Telecommunications at HHI and are all based on DFB single-wavelength lasers monolithically integrated with an electroabsorption modulator, MMI couplers, detectors in an InP generic platform, or with polymer AWGs in a hybrid InP/polymer generic technology platform.

2.3.1 DFB lasers with vertical outcoupling

One device developed by Moehrle et al. [13] is a horizontal-cavity surface-emitting (HCSEL) (through a 45° turning mirror) DFB laser with integrated monitor for laser power control, operating at 1490 nm with ultralow threshold currents around 5 mA, i.e., comparable to VCSELs, and with superior output power performance of 5 mW. The concept of the device is shown in Figure 5A and a microscope image of realized PIC chip in Figure 5B.

2.3.2 Lasers integrated in transmission modules

Laser chips for transmission systems for long and extended reach, operating near 1300 nm, were reported by Klein et al. [14] and Troppenz et al. [15]. Here, the monolithic chip has a DFB section and an electroabsorption modulation (EAM) section with identical waveguide core.

De Felipe et al. [16] realized 40-channel optical line terminals with 100-GHz channel spacing based on a hybrid InP/polymer integration platform at HHI. The transmitter

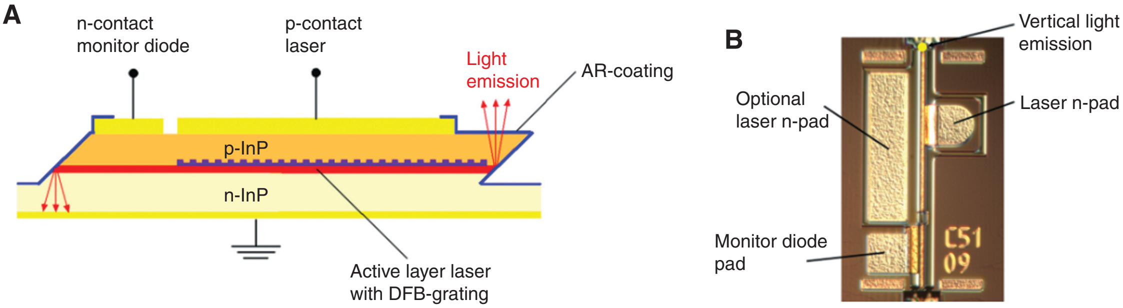


Figure 5: (A) Schematic cross-sectional view of developed HCSEL structure. (B) Microscopic image of a processed HCSEL device with integrated monitor diode. Figures from [13].

and receiver components consist of polymer AWGs integrated with InP-based multiwavelength lasers arrays and planar photodetectors, respectively. This device illustrates that technology platforms based on different materials can successfully be mixed.

2.3.3 Integrated circuit for THz generation

Generation of continuous-wave THz radiation is the central application of the PIC (see Figure 6) developed by Theurer et al. [17]. By comprising two lasers and an optical phase modulator on a single chip, the full control of the THz beat signal is enabled via a unique bidirectional operation technique. Integrated heaters allow for continuous tuning of the THz frequency over 570 GHz.

Applied to a coherent CW THz photomixing system operated at 1.5 μm optical wavelength, a signal-to-noise ratio of 44 dB at 1.25THz is obtained, which is identical to the performance of a standard system based on discrete components.

2.4 Multiwavelength and multimode lasers

2.4.1 Multiwavelength transmitter with array of DBR lasers

Arrays of up to eight DBR lasers, integrated with electro-optical Mach-Zehnder modulators and an AWG for application in optical access networks, were reported by Lawniczuk et al. [18] (see Figure 7). Successful operation of this functionally advanced photonic multiwavelength transmitter circuit with four and eight channels and modulators has been achieved. The devices fabricated using OCLARO platform offer a modulation data rate up to 12.5 Gbps per transmission channel with an output power up to 4 dBm in fiber. This was the first multiwavelength transmitter of this kind, realized on a generic platform. It was designed for application in the next-generation flexible passive optical access networks and Fiber-to-the-Home (FTTH) systems to operate as a key source localized in the central office of the network. The device was designed to simultaneously produce both continuous CW pilot tones that will act as a carrier for the upstream data and modulated downstream data.

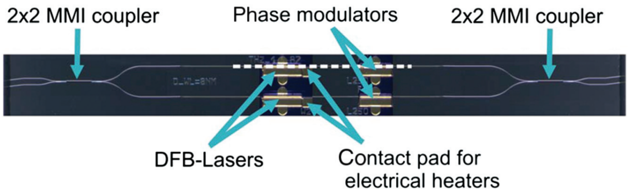


Figure 6: Micrograph of the fabricated PIC. Figure after [17].

2.4.2 Lasers for curiosity-driven research

An example of an academic research curiosity-driven application is the AWG-based laser with single-contact double-waveguide SOAs together with a common booster amplifier SOA monolithically integrated in one PIC (Figure 8), designed by Lawniczuk et al. [20] and manufactured in OCLARO services. With this device, four-wave mixing in the booster amplifier was demonstrated and experimentally characterized for various wavelength shifts ranging from 1 nm (within one FSR) to 15 nm (between two FSRs), for both up and down conversion [19].

Another example of using generic photonic integration technology for fundamental laser research is the device developed by Moskalenko et al. [21]. This device, schematically presented in Figure 9, allows for a study of passive mode locking in a linear FP type of structure and was fabricated within a MPW run available through

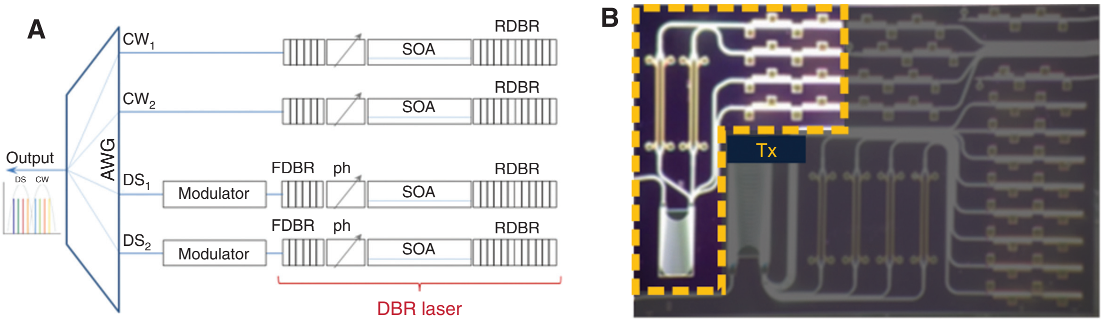


Figure 7: (A) Schematic diagram of multiwavelength transmitter. (B) Photograph of a 4×6 mm circuit with the photonic multiwavelength transmitter implemented within the area enclosed by the yellow dashed line. Figures after [18].

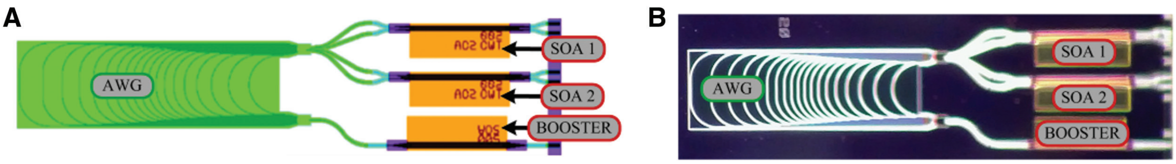


Figure 8: (A) Mask layout of 0.65 mm×2.75 mm four-channel AWG-based laser. This device has two SOAs: SOA1 and SOA2, each of which has two parallel waveguides connected to different ports (channels) of the AWG. Four different wavelengths can be generated using just two SOAs. Note that the booster amplifier is inside the FP cavity formed between the cleaved facet. (B) Fabricated device. Figures after [19].

Figure 9: Sketch of linear passive mode-locked laser. Multimode interference reflectors (MIRs) with 50 and 100% reflection were used as mirrors. Three active sections (gray) were positioned in the way that colliding and anticolliding designs were realized. Figure from [21].

the OCLARO foundry service. It consists of two multimode interference reflectors, two saturable absorbers, and one SOA. With such configuration, the influence of the position of the saturable absorber with respect to the output mirror can be investigated. The experimental results seem to confirm the theoretical prediction presented in [22].

2.4.3 Integrated lasers for mm wave transmitters

A particularly interesting application of a multiwavelength laser is for generation of mm continuous waves with stable and narrow linewidth. In sec. 2.3.3., we have seen already one other example of this. Millimeter wave frequency bands are of interest for broadband wireless communication systems because they can provide short-range communications with data rates above 1 Gb/s. For this purpose, a dual-wave semiconductor laser in which an AWG is used as intracavity filter to allow lasing on two wavelengths in a common booster amplifier (see Figure 10A) was developed by Corradi et al. [23] and Carpintero et al. [24]. The AWG in these devices can be designed to provide prescribed channel spacing, specifically within the 71–76 GHz, 81–86 GHz, and 92–95 GHz frequency bands. These bands are said to be of special interest to develop a point-to-point broadband fixed wireless system. The heterodyning of the two laser modes produces a beat note at the frequency corresponding to the AWG-channel spacing. Corradi et al. [23] designed and fabricated using COBRA integration technology the laser so as to produce a mm-wave that can be tuned around 70 GHz and realized both in a linear and in a ring laser configuration. A microscope photograph of a fabricated chip can be seen in Figure 10B.

Carpintero et al. [24] report on the first demonstration of the generation of a 95-GHz signal by optical heterodyning of two modes, each from a different channel of the AWG. As the two laser channels share the same booster amplifier within the FP configuration, the noise processes responsible for broadening of the laser lines are highly correlated so that the linewidth of the mm wave is not much larger than the largest linewidth of the originating laser modes, and its frequency is reported very stable.

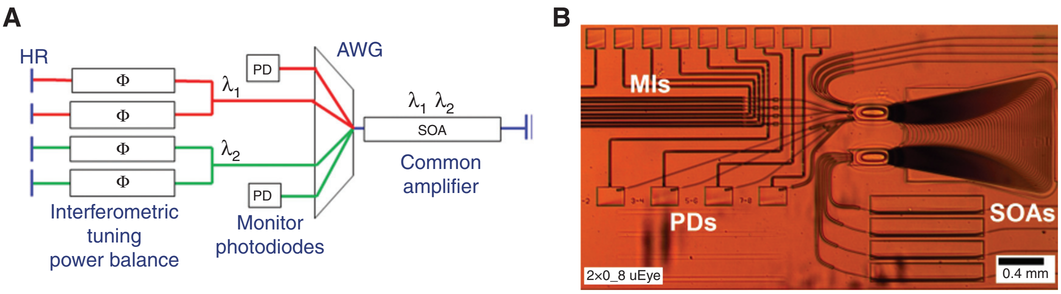


Figure 10: (A) Schematic of the linear AWG-based laser. (B) Picture of a fabricated chip with the linear dual-wavelength AWG laser. Figures after [23].

3 Ring lasers

3.1 Widely tunable lasers for optical coherence tomography at 1.7 μm

The paper by Tilma et al. [25] demonstrates that the active-passive integration technology developed in COBRA Research Institute, designed for the 1550-nm telecom wavelength region can also be used in the 1600- to 1800-nm region. This wavelength range is required for optical coherence tomography (OCT) in medical applications. There are several additional requirements for this application, i.e., a large tuning bandwidth (~100 nm), linewidth <0.07 nm, scan rate >20 kHz, and output power ~1 mW. The performance of their device, realized by using quantum dots (QD) for the active core, approaches or satisfies most of the requirements. It certainly means a crucial step toward the realization of the desired, i.e., monolithically integrated, affordable, low-power, and widely tunable laser for OCT applications.

3.2 Discretely tunable ring laser for research

The tunable semiconductor ring laser, reported in Khoder et al. [26], fabricated within one of the MPW provided by COBRA, contains integrated filtered-optical-feedback sections and was tailor-made for the experimental characterization of the speed of wavelength tuning. The feedback is realized by employing two arrayed-waveguide gratings in order to split and then recombine light into different wavelength channels. All components of this ring laser system are monolithically integrated on a single chip (Figure 11), and this defines an excellent highly affordable tool for experimental research.

The wavelength tuning and switching is controlled by changing the currents injected in semiconductor optical amplifiers in the feedback section. A wavelength switching speed of a few nanoseconds was achieved.

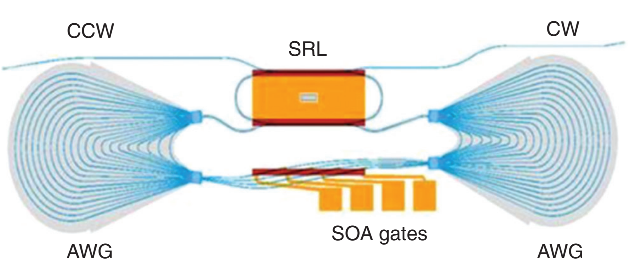


Figure 11: Mask layout of the tunable semiconductor ring laser. Figure after [26].

3.3 Widely tunable laser for trace gas detection

The ring laser developed by Latkowski et al. [27] was designed as a PIC to allow for continuous (grid-less) tuning over a wide range of wavelengths (>40 nm/5 THz) and precise and fast scanning around particular frequencies corresponding to absorption profiles of a gas of interest (in the order of a few GHz). Devices have been realized in a MPW runs offered within the COBRA/SMART platform. The lasers operate initially in the 1.5-μm wavelength range to demonstrate their capabilities. Characterizations of the fabricated PICs show that single-mode (longitudinal) operation and a tuning range in excess of 60 nm can be achieved [28, 29]. This performance is achieved using intracavity tunable asymmetric Mach-Zehnder interferometers (AMZI) that use voltage-controlled phase electrorefractive modulators (ERM) providing the wavelength discrimination mechanism. A schematic representation of the extended cavity laser with the intracavity filter based on a sequence of three AMZIs and a photograph of the fabricated chip are shown in Figure 12. This device was also fabricated as a linear Fabry-Pérot type laser: in this case, the end mirrors of the cavity were realized by MMI reflector building blocks, and with the various filter arrangements: cascaded and folded (Michelson configuration) as proposed in [27]. The designs are transferable to an integration platform operating at wavelengths around 2 μm, which is currently under development in the COBRA Research Institute.

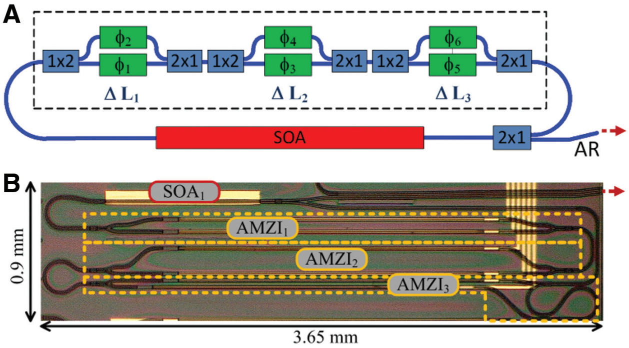


Figure 12: (A) Schematic representation of the extended cavity ring laser with a AMZI-based intracavity wavelength selection filter. The ring cavity consists of a three-stage wavelength filter (dashed box), SOA, and 2×1 MMI coupler used for coupling out the optical signal. All components are connected with passive waveguides (in blue); figure after [29]. (B) A photograph of the laser chip.

3.4 Coherent optical comb source

The chip designed by Moskalenko et al. [30] was fabricated within a MPW run at COBRA through the Jeppix services [31]. The 4-mm long laser cavity (Figure 13) includes two 345-µm-long SOA sections and a 30-µm saturable absorber section, which are separated by two 15-µm isolation sections, an MMI coupler and passive waveguides. The MMI and the bends at both sides of the ring are deeply etched waveguides, all other sections are shallow ridge waveguides. In order to provide carriers for both SOA sections using a single bias current source, the contacts of the two SOA sections share a single metal electrode. An MMI coupler allows for 3-dB outcoupling in both directions and enables equal power distribution among the two counterpropagating pulses. The relative position of the SOAs and saturable absorber (SA) was designed such that both pulses will experience the same amplification and meet in the SA. In order to minimize possible backreflections coming from the edges of the chip, the output waveguides were positioned at 7° with respect to the cleaved and antireflection (AR)-coated facets. The intracavity reflections were reduced by using angled active-passive interfaces, adiabatic bends, an optimized MMI structure, and deep-to-shallow waveguide transitions. With this passively mode-locked ring laser, an optical coherent comb, with a record-wide 3-dB bandwidth of 11.5 nm, and a subpicosecond pulse generation at 20 GHz repetition rate were demonstrated from a quantum well-based device.

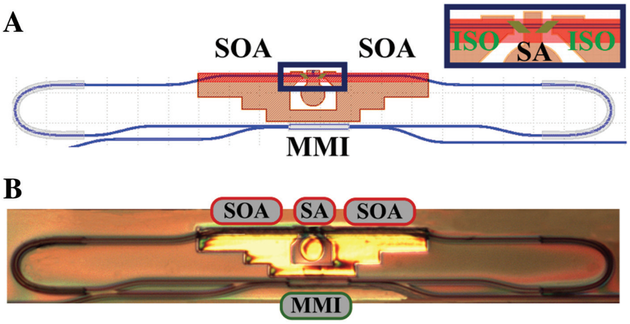


Figure 13: (A) Mask layout of a symmetrical ring mode-locked laser(ISO – two electrical isolation sections). The total length of the cavity is 4 mm. Figure after [30]. (B) A microscope photograph of fabricated chip showing three copies of such device.

3.5 Low repetition rate mode-locked laser for gas sensing

A passively mode-locked extended cavity quantum well ring laser operating at 1.58 µm with a repetition rate of 2.5 GHz in the form of a PIC has been designed by Latkowski et al. [32] and fabricated by SMART Photonics [4]. This laser was developed for use as a comb source in a gas-sensing system based on dual-comb Fourier-transform spectrometer. The photonic integrated laser circuit operates at 1.58 µm. Its 33-mm-long cavity contains gain, saturable absorption, and passive waveguide sections as well as electrorefractive modulator sections to enable fine tuning of the spectral position of the lasing modes. Device layout and fabricated chip are presented in Figure 14. Passive and hybrid mode-locked operation, along with the wavelength tuning of the laser modes, are experimentally demonstrated. In the passive mode-locking regime, an RF beat signal produced on a fast photodiode at the fundamental round-trip frequency of 2.5 GHz with a full width at half maximum (3 dB) bandwidth of 6.1 kHz is produced on a fast photo diode. This beat signal linewidth exceeds state-of-the-art values, which have been reported up to date from devices of similar geometries and realized in similar material systems.

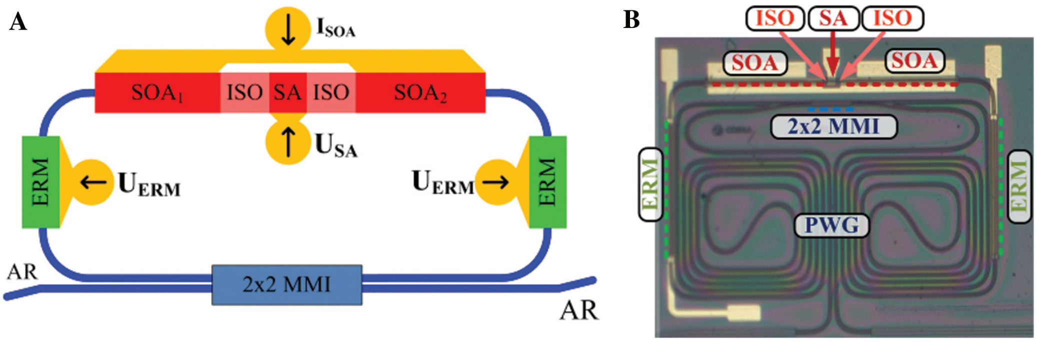


Figure 14: (A) Schematic diagram of a ring mode-locked laser: MMI sections and passive waveguides (PWG) in blue. (B) Microscope image of the fabricated device with and area of 4 mm² (2.3 mm×1.75 mm). Figures after [32].

4 Summary

Generic InP-based photonic integration technology allows tailor-made, customer-demanded photonic devices integrated on a single chip at affordable costs by wafer sharing. To illustrate and advocate the strength of such infrastructural collaborative facility, we have given an overview of selected photonic integrated circuits in which lasers play prominent parts and which were fabricated over the last few years in one of the three major European foundries offering access to generic photonic integration technology, i.e., OCLARO (Caswell, UK), the Fraunhofer Heinrich Hertz Institute (Berlin, Germany), and COBRA/SMART (Eindhoven, The Netherlands). The devices presented demonstrate a performance comparable or even better than achievable with lasers fabricated using conventional dedicated processes, proving the maturity of generic photonic integration technologies. Furthermore, the discussed photonic integrated circuits were developed for a variety of user-driven applications, demonstrating the promising potential of the widespread use of InP-based generic photonic integration platforms.

Appendix

Table 2: List of acronyms.

AMZI	Asymmetric Mach-Zehnder interferometer
AR	Antireflection
ASPIC	Application-specific photonic integrated circuit
AWG	Arrayed wave guide
BB	Building block
CCL	Coupled-cavity laser
CW	Continuous wave
DBR	Distributed Bragg reflector
DFB	Distributed feedback
EAM	Electroabsorption modulation
ERM	Electrorefractive modulator
FP	Fabry-Pérot
FSR	Free spectral range
FTTH	Fiber to the home
HHI	Heinrich Hertz institute
HCSEL	Horizontal-cavity surface-emitting laser
ISO	Isolator
MMI	Multimode interference
MPW	Multiproject wafer
OCT	Optical coherence tomography
PIC	Photonic integrated circuit
QD	Quantum dot
R	Reflector
RO	Relaxation oscillation
SA	Saturable absorber
SME	Small- and medium-sized enterprise
SMSR	Side-mode suppression ratio
SOA	Semiconductor optical amplifier
VCSEL	Vertical-cavity surface-emitting laser

References

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

[2] “OCLARO-Photonic Integration.” [Online]. Available: http://www.oclaro.com/technology/photonic-integration/.

[3] “Fraunhofer HHI.” [Online]. Available: http://www.hhi.fraunhofer.de/.

[4] “SMART Photonics.” [Online]. Available: http://www.smartphotonics.nl/.

[5] J. Zhao, P. J. Williams, M. K. Smit and X. Leijtens, in ‘Optical Fiber Communication Conference’, 2012, p. OW1G.5.

[6] J. Zhao, D. Lenstra, R. Santos, M. J. Wale, M. K. Smit, et al., Opt. Express 20, B270–B278 (2012).

[7] D. D’Agostino, D. Lenstra, H. Ambrosius and M. Smit, ‘Monolithically integrated laser with weak optical feedback demonstrating suppressed relaxation-oscillation dynamics’, presented at the The Optical Fiber Communication Conference and Exposition (OFC), 2015, W2A.21.

[8] D. Lenstra, IEEE Photonics Technol. Lett. 25, 591–593 (2013).

[9] “PARADIGM.” [Online]. Available: http://www.paradigm.jeppix.eu/.

[10] D. D’Agostino, D. Lenstra, H. Ambrosius and M. Smit, Opt. Lett. 40, 653–656 (2015).

[11] L. A. Coldren and T. L. Koch, IEEE J. Quantum Electron. 20, 659–670 (1984).

[12] D. D’Agostino, D. Lenstra, H. Ambrosius and M. Smit, in ‘Advanced Photonics for Communications’, 2014, p. IW1A.1.

[13] M. Moehrle, J. Kreissl, W.-D. Molzow, G. Przyrembel, C. Wagner, et al., in ‘2010 International Conference on Indium Phosphide Related Materials (IPRM)’, 2010, pp. 1–4.

[14] H. Klein, C. Bornholdt, G. Przyrembel, A. Sigmund, W.-D. Molzow, et al., in ‘39th European Conference and Exhibition on Optical Communication (ECOC 2013)’, 2013, pp. 1–3.

[15] U. Troppenz, M. Narodovitch, C. Kottke, G. Przyrembel, W.-D. Molzow, et al., in ‘26th International Conference on Indium Phosphide and Related Materials (IPRM)’, 2014, pp. 1–2.

[16] D. de Felipe, C. Zawadzki, Z. Zhang, A. Maese, M. Wenzel, et al., in ‘39th European Conference and Exhibition on Optical Communication (ECOC 2013)’, 2013, pp. 1–3.

[17] M. Theurer, T. Göbel, D. Stanze, U. Troppenz, F. Soares, et al., Opt. Lett. 38, 3724 (2013).

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

[19] K. Lawniczuk, D. Lenstra, M. Yousefi, X. Leijtens, M. Wale, et al., in ‘Proceedings of the 19th Annual Symposium of the IEEE Photonics Society Benelux Chapter’, (Enschede, The Netherlands, 2014).

[20] K. Lawniczuk, M. Wale, P. Szczepanski, R. Piramidowicz, M. Smit, et al., in ‘Proceedings of the 18th Annual Symposium of the IEEE Photonics Society Benelux Chapter’, (Eindhoven, The Netherlands, 2013).

[21] V. Moskalenko, V. Anand, M. Smit, K. Williams and E. Bente, in ‘Proceedings of the 19th Annual Symposium of the IEEE Photonics Society Benelux Chapter’, (Enschede, The Netherlands, 2014).

[22] J. Javaloyes and S. Balle, Opt. Lett. 36, 4407–4409 (2011).

[23] A. Corradi, G. Carpintero, B. Tilma, M. Smit and E. Bente, “Integrated dual-wavelength semiconductor laser systems for millimeter wave generation. Proceedings of the 23rd International Semiconductor Laser Conference (ISLC), 7–10 October 2012, San Diego, California, (pp. 34–35). Piscataway: IEEE Service Center.
[24] G. Carpintero, E. Rouvalis, K. Lawniczuk, M. Fice, C. C. Renaud, et al., Opt. Lett. 37, 3657–3659 (2012).
[25] B. W. Tilma, Y. Jiao, J. Kotani, B. Smalbrugge, H. P. M. M. Ambrosius, et al., IEEE J. Quantum Electron. 48, 87–98 (2012).
[26] M. Khoder, R. M. Nguimdo, X. Leijtens, J. Bolk, J. Danckaert, et al., IEEE Photonics Technol. Lett. 26, 520–523 (2014).
[27] S. Latkowski, M. Smit and E. A. J. M. Bente, in ‘Proceedings of the 17th Annual Symposium of the IEEE Photonics Society Benelux Chapter’, (Mons, Belgium, 2012).
[28] S. Latkowski, T. de Vries, L. Augustin, S. Meint and E. Bente, in ‘Proceedings of the 18th Annual Symposium of the IEEE Photonics Benelux Chapter’, (Eindhoven, Netherlands, 2013) pp. 97–100.
[29] E. Bente, S. Latkowski, T. de Vries and M. Smit, in ‘2014 16th International Conference on Transparent Optical Networks (ICTON)’, 2014, pp. 1–4.
[30] V. Moskalenko, S. Latkowski, S. Tahvili, T. de Vries, M. Smit, et al., Opt. Express 22, 28865–28874 (2014).
[31] “Joint European Platform for InP-based Photonic Integrated Components and Circuits.” [Online]. Available: http://www.jeppix.eu/.
[32] S. Latkowski, V. Moskalenko, S. Tahvili, L. Augustin, M. Smit, et al., Opt. Lett. 40, 77–80 (2015).

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