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Widely tunable laser source for trace gas detection fabricated within long-wavelength multi-project wafer run using InP based active-passive integration technology

S. Latkowski,[1] D. D'Agostino,[1] P.J. van Veldhoven,[1] H. Rabbani-Haghighi[1]
B. Docter,[2] P. Thijs,[1] H. Ambrosius,[1] M. Smit,[1] K. Williams[1] and E.A.J.M. Bente[1]

1) COBRA Research Institute, Eindhoven University of Technology
De Zaale, 5612 AJ, Eindhoven, The Netherlands
2) EFFECT Photonics B.V.
Torenallee 20, Eindhoven, The Netherlands

s.latkowski@tue.nl

A widely tunable laser source realized as an InP based monolithic photonic integrated circuit operating at wavelengths around 2 µm will be presented. The chip was fabricated within a multi-project wafer run using a long-wavelength active-passive integration scheme developed in COBRA research institute. The laser features a tunable nested asymmetric Mach-Zehnder interferometer filter for selection of the operating wavelength. The PIC operates at room temperature with the optical output centered at the wavelength of 2027 nm. The tuning range spans over 31 nm with the side mode suppression ratios better than 30 dB.

Introduction

The generic photonic integration technology platforms give application oriented specialists an access means of affordable design and fabrication processes of application specific photonic integrated circuits (ASPIC) [1]. The range of accessible wavelengths define the scope of potential applications. Most of the available technology platforms provide their functionalities at wavelengths around 1.55µm, covering the telecom C-band. Extended wavelength range of such technology platform has been demonstrated up to 1.75µm [2]. An access to wider range of spectral bands covered by such integration technologies, makes them an attractive for a wider field of applications. Gas sensing applications would benefit should the mid-infrared wavelengths at around 2µm become accessible. This is due to the presence of stronger absorption profiles of several gas species for example: acetone, ammonia, carbon dioxide, formaldehyde, diethylamine, ethylamine, methylamine. Generation and amplification of light at such wavelengths has been demonstrated with use of indium phosphide (InP) based strained quantum wells [3] and also quantum cascade based systems [4]. Development towards implementation of such functionality into the COBRA active–passive integration technology platform was undertaken based the InGaAs trained quantum wells [5].

In this work we demonstrate an extended ring cavity laser realized as a monolithic, InP photonic integrated circuit (PIC) operating at wavelengths range around 2027 nm. The PIC is designed and realized using a long wavelength generic integration technology developed at the COBRA research institute. Following the generic integration approach the laser cavity is designed using a predefined set of basic building blocks (BB) [1], [6]. The wavelength tuning mechanism is based on nested asymmetric Mach-Zehnder interferometers (AMZI) intra-cavity filter which uses electro-refractive modulators (ERM) [7]. The intracavity filter assures is single-mode output from the laser and in combination with the gain bandwidth of the strained quantum well based layer-stack [5] enables a tuning range of 31 nm.

Monolithic photonic integrated circuit

The ring laser cavity has an average physical length of 9 mm and was designed in the form of a photonics integrated circuit as shown in Fig. 1(a). The laser cavity consists of several basic building blocks connected with deeply etched passive waveguides. The optical gain is provided by a 4 mm long semiconductor optical amplifier (SOA). The wavelength tunable filter inside the laser cavity is based on asymmetric Mach-Zehnder interferometers (AMZI) in a nested configuration. Each of the AMZI stages is formed by passive waveguides and multimode interference couplers (2x2, 1x2, MMI) with 2 mm long ERM sections added in each branch in order to enable its tuning. Two inner AMZI stages of the filter have photodiodes (PD) added on both sides of each stage for on-chip monitoring and calibration functionalities. The ring cavity is closed with passive waveguides and the signals are coupled out from the laser cavity with two 1x2 MMI elements. The light is routed to the output ports which are angled with respect to the cleaved edges of the chip to reduce reflections. The resulting mask layout for one device occupies an area of 3.4 mm^2 as is shown in Fig. 1(b). The chip was designed following the generic integration approach using the COBRA long wavelength

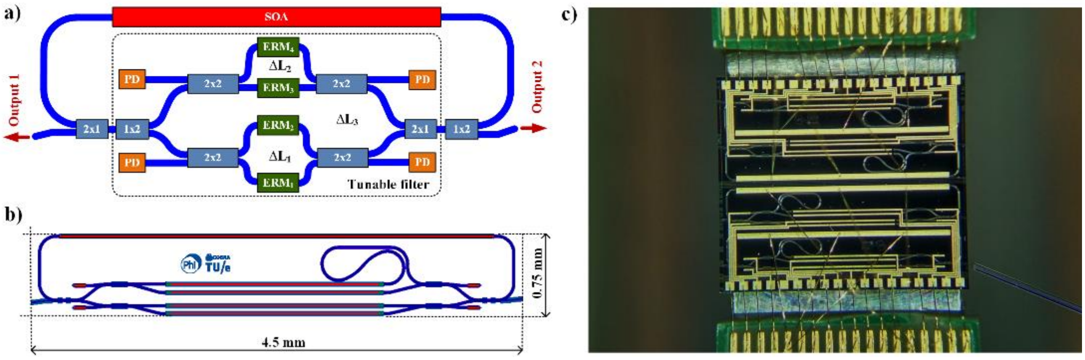

Fig. 1. (a) Schematic diagram of the photonic integrated circuit (PIC) based tunable ring laser featuring an intracavity tunable wavelength filter based on nested asymmetric Mach-Zehnder interferometers indicated with a dashed box. The PIC consists of several basic building blocks connected with passive waveguides (in blue): a semiconductor optical amplifier (SOA), multimode interference couplers (1x2, 2x2 MMI), electro-refractive modulators (ERM) and photodiodes (PD). The light is coupled out from the laser cavity with two MMI elements and using passive waveguides routed to the output ports which have angled with respect to the cleaved edges of the chip. (b) Mask layout of the laser caity with total area of 3.4 mm^2. (c) A microscope picture of a full long wavelength MPW cell of 20 mm^2 including four individual tunable extended ring cavity lasers.

extension of COBRA active-passive technology [1] and fabricated within a multi-project wafer (MPW) run at NanoLab@TU/e cleanroom [8]. The microscope photograph of the fabricated and wire-bonded chip is presented in the Fig. 2(c). The MPW cell of 4.2 x 4.7mm includes four individual extended cavity ring laser.

Experimental results

The fabricated chip is mounted on an aluminum block and all electrical contacts are wire bonded to a signal distribution printed circuit board (PCB) as can be seen in Fig. 1(c). The sub-mount is temperature stabilized with a passive water cooling system at 18°C. Optical signals are collected with an antireflection coated lensed fiber and fed with a standard single mode fiber and via an optical isolator to the measurement equipment. An extended wavelength range InGaAs amplified photodiode (Thorlabs PDA-10D) was used to record the total optical output power coupled into the fiber as a function of bias current injected into the SOA section. The LVI characteristics are presented in the Fig. 2(a). The lasing threshold is at 360 mA (J_{SOA} = 3.54 kA/cm^2). A Yokogawa AQ6375 optical spectrum analyzer with a 0.05 nm resolution was used to record the optical spectra for three several sets of reverse bias voltages applied to the ERM sections are shown in Fig. 2(b). The SOA current injection and temperature were constant and set at I_{SOA} = 450 mA and $T_{HEATSINK}$ = 18 °C respectively. The laser provides with a single-mode output with side mode suppression ratio (SMSR) of at least 30 dB over the wavelength range of 31 nm at at around 2027 nm.

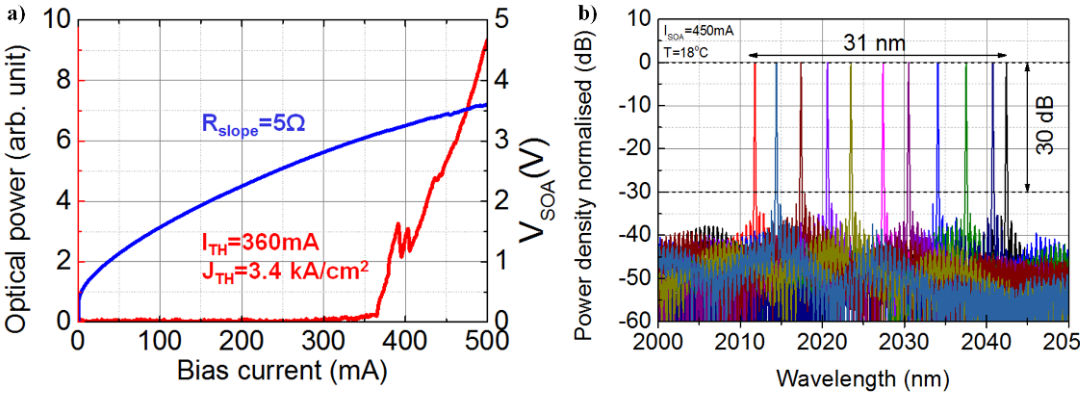

Fig. 2. (a) LVI characteristics: fiber coupled average optical power in red and voltage drop over the SOA as a function of the SOA current. (b) Optical spectra recorded using an optical spectrum analyzer for three different sets of reverse biases applied to the ERMs. Both the injection current into the SOA section and temperature were kept constant at I_{SOA}=450 mA and T= 18°C respectively.

Summary

A fully functional photonic integrated circuit designed following the generic integration approach and fabricated using monolithic active-passive integration technology developed for wavelengths around 2µm has been presented. The laser provides a single longitudinal mode output at wavelengths around 2025 nm and shows a tuning range spanning over of 31 nm.

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References

[1] M. Smit, X. Leijtens, H. Ambrosius, E. Bente, J. van der Tol, B. Smalbrugge, T. de Vries, E.-J. Geluk, J. Bolk, R. van Veldhoven, L. Augustin, P. Thijs, D. D'Agostino, H. Rabbani, K. Lawniczuk, S. Stopinski, S. Tahvili, A. Corradi, E. Kleijn, D. Dzibrou, M. Felicetti, E. Bitincka, V. Moskalenko, J. Zhao, R. Santos, G. Gilardi, W. Yao, K. Williams, P. Stabile, P. Kuindersma, J. Pello, S. Bhat, Y. Jiao, D. Heiss, G. Roelkens, M. Wale, P. Firth, F. Soares, N. Grote, M. Schell, H. Debregeas, M. Achouche, J.-L. Gentner, A. Bakker, T. Korthorst, D. Gallagher, A. Dabbs, A. Melloni, F. Morichetti, D. Melati, A. Wonfor, R. Penty, R. Broeke, B. Musk, and D. Robbins, "An introduction to InP-based generic integration technology," *Semicond. Sci. Technol.*, vol. 29, no. 8, p. 083001, Jun. 2014.

[2] B. W. Tilma, Y. Jiao, J. Kotani, B. Smalbrugge, H. P. M. M. Ambrosius, P. J. Thijs, X. J. M. Leijtens, R. Notzel, M. K. Smit, and E. A. J. M. Bente, "Integrated Tunable Quantum-Dot Laser for Optical Coherence Tomography in the 1.7µm Wavelength Region," *IEEE J. Quantum Electron.*, vol. 48, no. 2, pp. 87–98, Feb. 2012.

[3] T. Sato, M. Mitsuhara, T. Watanabe, and Y. Kondo, "Surfactant-mediated growth of InGaAs multiple-quantum-well lasers emitting at 2.1 µm by metalorganic vapor phase epitaxy," *Appl. Phys. Lett.*, vol. 87, no. 21, pp. 211903–211903–3, Nov. 2005.

[4] M. Razeghi, N. Bandyopadhyay, Y. Bai, Q. Lu, and S. Slivken, "Recent advances in mid infrared (3-5µm) Quantum Cascade Lasers," *Opt. Mater. Express*, vol. 3, no. 11, p. 1872, Nov. 2013.

[5] S. Latkowski, P. Thijs, P. J. van Veldhoven, H. Rabbani-Haghighi, M. K. Smit, and E. A. J. M. Bente, "Small signal modal gain measurement of ridge waveguide semiconductor optical amplifiers operating at 2 µm suitable for active-passive integration," in *2013 IEEE Photonics Conference (IPC)*, 2013, pp. 258–259.

[6] S. Latkowski and D. Lenstra, "Lasers in InP generic photonic integration technology platforms," *Adv. Opt. Technol.*, vol. 4, no. 2, pp. 179–188, Apr. 2015.

[7] S. Latkowski, M. Smit, and E. A. J. M. Bente, "Integrated tunable semiconductor laser geometry based on asymmetric Mach-Zehnder interferometers for gas sensing applications," in *Proceedings of the 17th Annual Symposium of the IEEE Photonics Society Benelux Chapter*, Mons, Belgium, 2012.

[8] "NanoLab@TU/e." [Online]. Available: http://www.tue.nl/en/research/research-institutes/research-institutes/nanolabtue/. [Accessed: 13-May-2015].