

IMOS integrated photonics for free-space sensing and communications

Citation for published version (APA):

Jiao, Y., Kashi, A. A., Wang, Y., Pogoretskiy, V., & Williams, K. (2019). IMOS integrated photonics for free-space sensing and communications. In *2019 Asia Communications and Photonics Conference, ACP 2019 - Proceedings* Optical Society of America (OSA).

Document status and date:

Published: 01/11/2019

Document Version:

Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

IMOS Integrated Photonics for Free-space Sensing and Communications

Yuqing Jiao, Amir Abbas Kashi, Yi Wang, Vadim Pogoretskiy, Kevin Williams

*Institute for Photonic Integration (IPI), Eindhoven University of Technology, P.O.Box 513, 5600 MB Eindhoven, The Netherlands
y.jiao@tue.nl*

Abstract: Photonic integration in a thin InP membrane can offer optical antennas and interferometers monolithically integrated with lasers and detectors. Such approach, with high density and scalability, has shown high potential for applications of free-space sensing and communications. © 2019 The Author(s)

OCIS codes: 130.0130, 140.5960, 250.5300, 280.4788, 060.2605.

1. Introduction

The photonic integrated circuits (PICs) bring the benefit of high performance in compact size to sensing and communications [1]. The ability to generate highly concentrated and controllable optical free-space beams within the PIC is regarded as a key to various applications, such as the light detection and ranging (LiDAR) [2], optical wireless communication (OWC) [3] and handheld medical imaging systems [4]. The InP membrane on silicon (IMOS) platform [5] has recently shown high potential in such free-space applications. It combines high-performance active, grating antennas and interferometry in a monolithic InP membrane layer, providing a versatile tool for constructing scalable, steerable and miniaturized optical wireless transceivers and sensors. In this contribution we discuss the recent demonstrations in the IMOS platform for free-space applications.

2. IMOS Integrated Photonics

The IMOS platform consists of a micron-thick membrane made from InP material system. The membrane is bonded onto a silicon carrier wafer with about 2 μm thick optical buffer layer in between. All active and passive photonic functionalities are realized within this membrane layer. The active-passive integration is achieved with a twin-guide structure where active and passive waveguiding layers evanescently couple with each other [6]. Deep and shallow etching into the passive waveguiding layer create highly confined optical waveguides (400 nm \times 300 nm) as well as a series of grating and photonic crystal structures. With possible regrowth technology, additional functional layers (for instance the uni-travelling carrier (UTC) photodiode layerstack) can be realized. A schematic illustration of the platform is shown in Fig. 1.

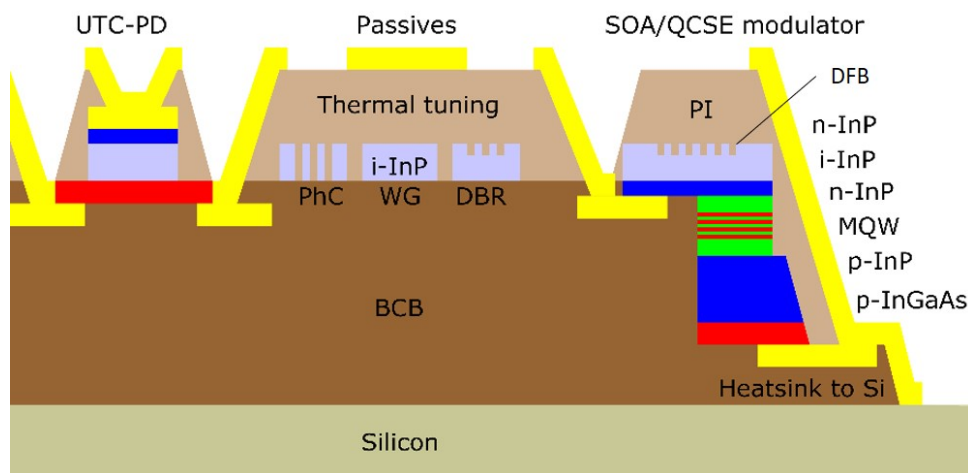


Fig. 1. Schematic illustration of the IMOS integrated photonics platform [6].

The most important element, semiconductor optical amplifier (SOA), has been demonstrated recently with high gain efficiency [7]. Various laser circuits have been built based on the SOA and were demonstrated, including 25

nm microring-based tunable laser [8] and 60 dB side mode suppression ratio (SMSR) single-frequency distributed feedback (DFB) laser [9]. UTC photodiode with electrical 3 dB bandwidth beyond 67 GHz has been realized using a double-sided design and processing scheme [10]. The ultrafast dynamics together with high responsivity (0.7 A/W) make it attractive for optical wireless and millimeter-wave communications. The passive elements demonstrated on IMOS platform further enable functional circuitries such as interferometers, wavelength routers, filters and cavities [5].

3. Recent Demonstrations for Free Space

An OWC receiver circuit consisting of a grating-based optical antenna and an ultrafast UTC photodiode has been proposed and investigated [11, 12]. The fabricated device is shown in Fig. 2(a). The novelty of the proposed circuit is the separation of the optical interface (by using the grating antenna for the capturing of the free-space beam) and the signal detection (by using the UTC photodiode for the conversion of the optical signal into electrical domain). The speed-efficiency bottleneck existing in the conventional top-illuminated photodiodes is eliminated. The circuit has been experimentally verified in a simulated OWC in-door application scenario, using a 2.4 km optical fiber for simulating the fiber distribution network in the building and a 2 m free-space path for the distance between the OWC transmitter on the ceiling and the receiver. The final collimated beam diameter is about 10 μm , which is chosen to match to the size of the grating antenna used. Transmission experiment using 40 GBit/s on-off keying (OOK) signal was carried out, showing a lowest bit error rate (BER) of 7×10^{-10} at optimal wavelength of 1550 nm and beam incident angle of 7.5° with respect to the chip surface normal, as shown in Fig. 2(b). It is the highest data rate ever reported so far from a single OWC receiver. Further investigation on the operation window revealed a 3 dB field of view (FoV) of 7.5° and an optical bandwidth of 30 nm.

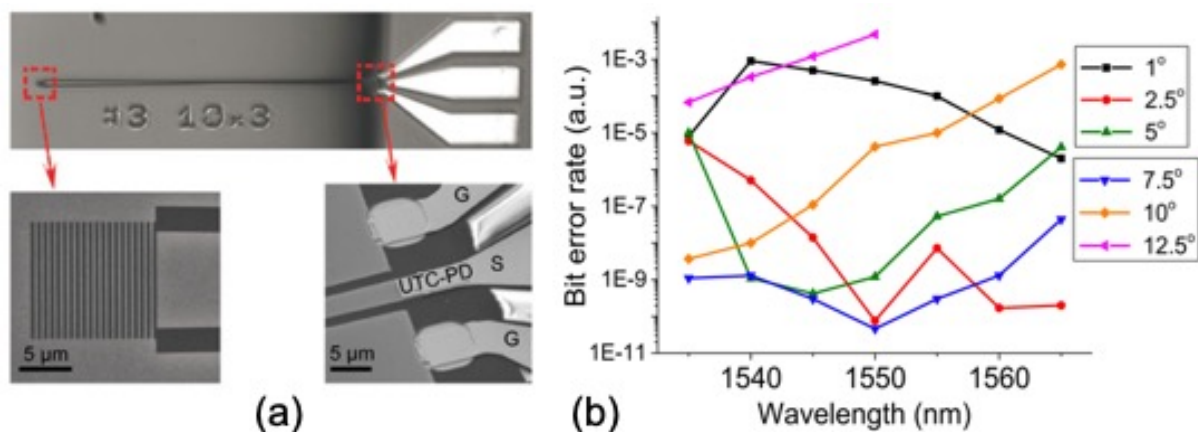


Fig. 2. (a) Microscope picture of the OWC receiver, with the insets showing detailed pictures of the grating antenna and the UTC photodiode. (b) The BER as function of the wavelength and the beam incident angle. [12].

The efficiency of the optical interface (the grating antenna) is crucial to the overall circuit performance. High efficiency of the free-space beam capturing will be beneficial to the total power budget of the OWC link, therefore making the device more sensitive and reliable. Design efforts have been made to improve the grating coupling efficiency. It is found out that a metal reflector underneath the grating will significantly enhance the efficiency, since the metal layer will force all the downward-diffracted light back to the upward direction without introducing much additional loss. An efficiency of 75 % has been demonstrated recently on IMOS platform using this concept [13], while for conventional gratings the efficiency is only around 30 %.

4. Conclusion

Recent advancement of active and passive devices in the IMOS platform has enabled novel circuits for free-space optical communications. The first demonstration of an OWC receiver on IMOS has already shown appealing performance and has achieved records. The monolithic laser/photodiode integration with grating antennas and other passive circuitries can be well suited for a wide range of free-space communication and sensing applications.

References

1. S. Arafin and L. A. Coldren, "Advanced inp photonic integrated circuits for communication and sensing," *IEEE J. Sel. Top. Quantum Electron.* **24**, 1–12 (2018).
2. M. J. R. Heck, "Highly integrated optical phased arrays: photonic integrated circuits for optical beam shaping and beam steering," *Nanophotonics* **0** (2016).
3. Y. Jiao and Z. Cao, "Photonic integration technologies for indoor optical wireless communications," *SCIENCE CHINA Inf. Sci.* **61**, 080404 (2018).
4. B. I. Akca, V. Nguyen, J. Kalkman, N. Ismail, G. Sengo, S. Fei, A. Driessen, T. G. van Leeuwen, M. Pollnau, K. Worhoff, and R. M. de Ridder, "Toward spectral-domain optical coherence tomography on a chip," *IEEE J. Sel. Top. Quantum Electron.* **18**, 1223–1233 (2012).
5. J. J. G. M. v. d. Tol, Y. Jiao, L. Shen, A. Millan-Mejia, V. Pogoretskii, J. P. v. Engelen, and M. K. Smit, "Indium phosphide integrated photonics in membranes," *IEEE J. Sel. Top. Quantum Electron.* **24**, 6100809 (2018).
6. V. Pogoretskiy, J. P. v. Engelen, J. J. G. M. v. d. Tol, and Y. Jiao, "Towards a fully integrated indium-phosphide membrane on silicon photonics platform," in *Proceedings Volume 10823, Nanophotonics and Micro/Nano Optics IV*, vol. 10823 (SPIE, 2018), p. 7.
7. V. Pogoretskiy, J. van Engelen, J. van der Tol, A. Higuera-Rodriguez, M. Smit, and Y. Jiao, "An integrated soa-building block for an inp-membrane platform," in *Advanced Photonics 2017 (IPR, NOMA, Sensors, Networks, SPPCom, PS)*, (Optical Society of America), OSA Technical Digest (online), p. JW4A.1 Post-deadline Paper.
8. V. Pogoretskiy, J. v. d. Tol, M. Smit, and Y. Jiao, "Monolithically integrated widely tunable laser on an inp membrane circuits," in *24th OptoElectronics and Communications Conference (OECC 2019)*, pp. Paper WD2–2.
9. V. Pogoretskiy, J. v. d. Tol, and Y. Jiao, "Low noise monolithically integrated membrane dfb laser on silicon," in *Compound Semiconductor Week (CSW 2019)*, (Nara, Japan), pp. Paper MoA3–8.
10. L. Shen, Y. Jiao, W. Yao, Z. Cao, J. v. Engelen, J. v. d. Tol, G. Roelkens, and M. Smit, "High-bandwidth uni-traveling carrier waveguide photodetector on an inp-membrane-on-silicon platform," *Opt. Express* **24**, 8290–8301 (2016).
11. Z. Cao, L. Shen, Y. Jiao, X. Zhao, and A. Koonen, "200 gbps ook transmission over an indoor optical wireless link enabled by an integrated cascaded aperture optical receiver," in *Optical Fiber Communication Conference Postdeadline Papers*, (Optical Society of America), OSA Technical Digest (online), p. Th5A.6.
12. Z. Cao, Y. Jiao, L. Shen, X. Zhao, R. Stabile, J. J. G. M. V. d. Tol, and T. Koonen, "Ultra-high throughput indoor infrared wireless communication system enabled by a cascaded aperture optical receiver fabricated on inp membrane," *J. Light. Technol.* **36**, 57–67 (2017).
13. A. A. Kashi, J. v. d. Tol, K. Williams, and Y. Jiao, "High-efficiency deep-etched apodized focusing grating coupler with metal back-reflector on an inp-membrane," in *24th OptoElectronics and Communications Conference (OECC 2019)*, pp. Paper WE1–3.