

Low loss InP membrane photonic integrated circuits enabled by 193-nm deep UV lithography

Citation for published version (APA):

van Engelen, J., Reniers, S., Bolk, J., Williams, K., van der Tol, J., & Jiao, Y. (2019). Low loss InP membrane photonic integrated circuits enabled by 193-nm deep UV lithography. In *2019 Compound Semiconductor Week, CSW 2019 - Proceedings* Article 8819069 Institute of Electrical and Electronics Engineers. <https://doi.org/10.1109/ICIPRM.2019.8819069>

DOI:

[10.1109/ICIPRM.2019.8819069](https://doi.org/10.1109/ICIPRM.2019.8819069)

Document status and date:

Published: 19/05/2019

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.

Low Loss InP Membrane Photonic Integrated Circuits Enabled by 193-nm Deep UV Lithography

Jorn van Engelen, Sander Reniers, Jeroen Bolk, Kevin Williams, Jos van der Tol, Yuqing Jiao
Photonic Integration Group, Institute for Photonic Integration (former COBRA institute),
Eindhoven University of Technology, Netherlands
j.p.v.engelen@tue.nl

Abstract—For the first time we demonstrate the application of 193 nm optical lithography to InP-Membrane-on-Silicon (IMOS) passive nanophotonic integrated circuits. A record low propagation loss of 1.3 ± 0.1 dB/cm is demonstrated in a Mach-Zehnder interferometer (MZI) circuit and a microring resonator Q-factor up to $62 \cdot 10^3$ with 4 nm FSR is measured.

Keywords—*photonic integrated circuit; propagation loss; Mach-Zehnder interferometer; microring resonator*

In silicon photonics low surface roughness and excellent uniformity are achieved by state-of-the-art 193 nm optical lithography [1]. Recently we demonstrated low-excess-loss arrayed waveguide grating on a microphotonic InP platform [2]. We expect that the same methods will have a high impact on InP nanophotonics, where so far the losses have been limited to 2.5 dB/cm [3]. Silicon-on-insulator (SOI) waveguides with comparable dimensions and mode confinement typically achieve 1.5 dB/cm [4]. In this work for the first time we evaluate the use of 193 nm scanner lithography for InP nanofabrication by fabricating a test-cell for propagation loss analysis in the IMOS platform [5].

For the fabrication a 300 nm InP waveguide layer and a 300 nm InGaAs etch-stop layer are grown epitaxially on a 3" InP substrate. A silicon nitride hardmask is deposited and a tri-layer photoresist stack is spun. The wafer is then exposed with an ASML PAS5500/1100B scanner lithography tool. This lithography tool is modified to be, to our knowledge, the only scanner in the world to expose features down to 100 nm with 15 nm overlay accuracy on 3" InP substrates at high speeds [2]. The pattern is first transferred to the silicon nitride hardmask, then to InP using a RIE process [3]. This forms 120 nm deep fiber coupler gratings. The hardmask is removed and the above process repeated to pattern 280 nm deep waveguide trenches. A 600 nm thick silicon oxide layer is deposited and the InP wafer is bonded to a Si wafer using BCB. The substrate and etch-stop layer are removed in a wet-chemical process. The resulting cross-section is shown in Fig. 1. Using this process MZI (Fig. 2) and microring resonators (Fig. 3) measurement structures are fabricated. The measurement results of these structures are discussed next.

MZI structures with 400 nm waveguide width and different path length differences are measured. The transmission spectrum of a structure with $\Delta L = 1774 \mu\text{m}$ is shown in Fig. 4. The transmission spectra of the MZI structures are fitted to an analytical model and the resulting propagation loss α is shown in Table 1. The average propagation loss is 1.3 ± 0.1 dB/cm which, to the knowledge of the authors, is the lowest reported to date for InP nanophotonic waveguides of these dimensions.

Microring resonators with 450 nm waveguide width, 24 μm radius and different bus-to-ring spacing are measured. The radius corresponds to a free spectral range (FSR) of 4 nm. The transmission spectra around resonance are shown in Fig. 5. These spectra are fitted to an analytical model of the rings [6] and the propagation loss can be isolated from the self-coupling coefficient by measuring identical rings with different bus-to-ring spacing. The propagation loss α is shown in Table 2 for the different rings. It is not clear why the ring with 300 nm spacing has significantly higher propagation loss. We suspect that this is caused by a fabrication defect. The average propagation loss of the other rings is 1.8 ± 0.1 dB/cm. This is higher than in the MZI even though the waveguide is wider. Higher overlap of the mode with the sidewall due to the curvature and the smaller feature size in the coupling region are suspect. The Q-factor is derived from the full width half maximum (FWHM): $Q\text{-factor} = \lambda / \text{FWHM}$ and shown in Table 2 for the different rings. The ring with the largest spacing (400 nm) achieves a Q-factor of $62 \cdot 10^3$.

In conclusion, we have demonstrated for the first time the application of 193 nm lithography to InP passive membrane nanophotonic ICs. Propagation loss of 1.3 ± 0.1 dB/cm and microring resonator Q-factor up to $62 \cdot 10^3$ with 4 nm FSR were demonstrated.

References

- [1] S.K. Selvaraja, et. al, "Highly uniform and low-loss passive silicon photonics devices using a 300mm CMOS platform," *Optical Fibre Communication Conference (OFC)*, paper Th2A.33, 2014.
- [2] J. Bolk, et. al., "Deep UV Lithography Process in Generic InP Integration for Arrayed Waveguide Gratings," *IEEE Photonics Technology Letters*, vol. 30(13), pp. 1222-1225, 2018.
- [3] Y. Jiao, et. al., "Vertical and Smooth Single-Step Reactive Ion Etching Process for InP Membrane Waveguides," *Journal of The Electrochemical Society*, 162(8), E90-E95, 2015.
- [4] A. Rahim, et. al., "Expanding the Silicon Photonics Portfolio with Silicon Nitride Photonic Integrated Circuits," *Journal of Lightwave Technology*, vol. 35(4), 2017.
- [5] J.J.G.M. van der Tol, et. al., "Indium Phosphide Integrated Photonics in Membranes," *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 24(1), 2018.
- [6] W. Bogaerts, et. al., "Silicon microring resonators," *Laser Photonics Rev.*, vol. 6(1), pp. 47-73, 2012.

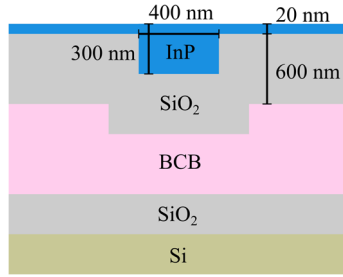


Fig. 1. Schematic cross-section of the InP membrane waveguide used in this publication. The waveguide width is 400 nm in the MZI and 450 nm in the microring resonators.

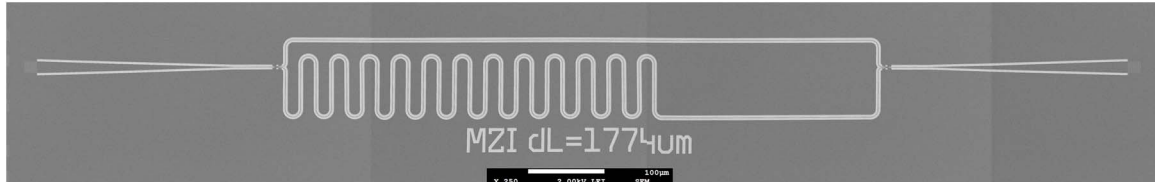


Fig. 2. Overlapped SEM images of the silicon nitride hardmask for the waveguide trenches of the fabricated MZI.

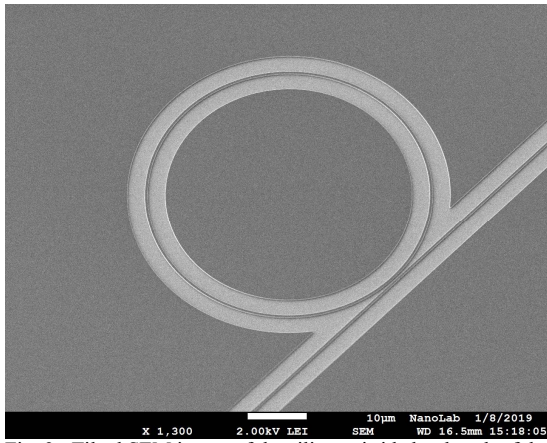


Fig. 3. Tilted SEM image of the silicon nitride hardmask of the waveguide trenches of the fabricated microring resonator.

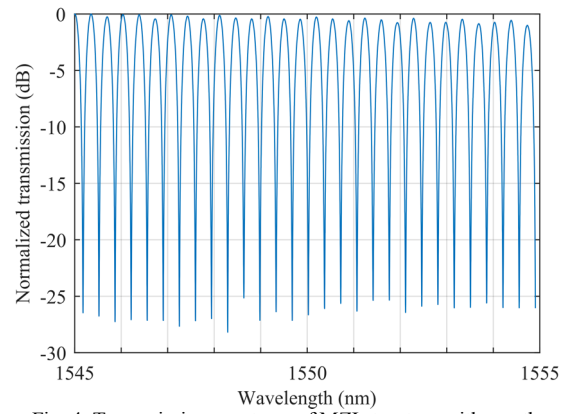


Fig. 4. Transmission spectrum of MZI structure with a path length difference in the arms of 1774 um.

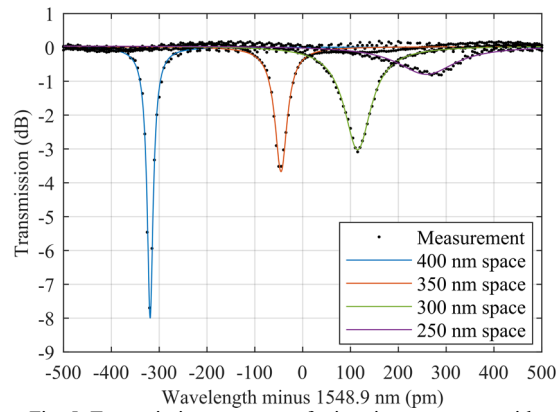


Fig. 5. Transmission spectrum of microring resonators with different spacing between the ring and the bus waveguide. The measurement points (dots) are fitted (lines).

Table 1. Propagation loss of MZI structures with different path lengths.

ΔL (um)	α (dB/cm)
1345	1.31
1774	1.15
2202	1.40

Table 2. Propagation loss and Q factor of rings with 24 um radius and 450 nm waveguide width and varying spacing between ring and bus waveguide.

Spacing (nm)	α (dB/cm)	Q-factor (-)
250	1.79	$10 \cdot 10^3$
300	3.04	$19 \cdot 10^3$
350	1.68	$40 \cdot 10^3$
400	1.84	$62 \cdot 10^3$