Heterogeneous Integration of Uni-Travelling-Carrier Photodiodes using Micro-Transfer-Printing on a Silicon-Nitride Platform

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High-speed photodiodes often compromise responsivity in exchange for a reduced footprint. However, using waveguide photodiodes circumvents this limitation [1]. We combine uni-travelling-carrier photodiodes (UTC PDs) on a silicon nitride (SiN) photonic platform to achieve both high responsivity and high speed detectors. The SiN-platform has excellent properties such as low-loss waveguides and does not suffer from two-photon absorption at high optical power. A high responsivity is obtained through evanescent coupling of waveguide UTC photodiodes to SiN waveguides while still maintaining a small footprint.

The devices are integrated using the micro-transfer-printing (μ TP) technology for hybrid integration of different material platforms [2]. First, photodiode chiplets are made in an InP/InGaAs-technology using a standard fabrication flow. The epitaxial layer stack is adapted from [3] and includes a 500 nm thick sacrificial InAlAs release layer. This material is used for its excellent selective underetching properties [4]. Figure 1a summarizes the processing steps to create a waveguide-coupled UTC PD. (i) Photodiodes are made on the source wafer. (ii) The InAlAs release layer is anisotropically etched using a hard mask. (iii) A new SiN layer is deposited and patterned to create tethers to the InP-substrate. The device is under-etched (isotropic) to create a suspended coupon. (iv) The coupon is transfer-printed on a SiN target chip. (v) Vias are etched and metal connections are made.

Fig. 1 (a) Fabrication steps, (b) IV-curves for different incident on-chip powers, and (c) SEM-image of a $2\mu\text{m} \times 10\mu\text{m}$ waveguide-coupled UTC PD.

The waveguide-coupled PDs show a responsivity of 0.80 A/W for a bias voltage of -1 V , illuminated at 1550 nm . This corresponds to an external quantum efficiency of 65% . We believe this can be further increased for longer devices or by incorporating a reflection-reducing design in the InP subcollector. The IV-characteristic for a PD with an active area of $2\mu\text{m} \times 10\mu\text{m}$ is shown in Figure 1b. High dark currents of $10\text{--}20\mu\text{A}$ and $20\text{--}50\mu\text{A}$, at respectively -0.5 V and -1.0 V biasing, are thought to be a result of surface leakage currents, and are currently being investigated and remedied. Given the small surface area of $20\mu\text{m}^2$ and the average measured series resistance of 30Ω , a high intrinsic bandwidth is expected. This will be verified using RF photoresponse measurements in the near future.

References

- [1] Q. Yu, J. Gao, N. Ye, B. Chen, K. Sun, L. Xie, K. Srinivasan, M. Zervas, G. Navickaite, M. Geiselmann, and A. Beling, "Heterogeneous photodiodes on silicon nitride waveguides", *Opt. Express* **28**, 14824 (2020).
- [2] J. Zhang, G. Muliuk, J. Juvert, S. Kumari, J. Goyvaerts, B. Haq, C. Op de Beeck, B. Kuyken, G. Morthier, D. Van Thourhout, R. Baets, G. Lepage, P. Verheyen, J. Van Campenhout, A. Gocalinska, J. O'Callaghan, E. Pelucchi, K. Thomas, B. Corbett, A. J. Trindade, and G. Roelkens, "III-V-on-Si photonic integrated circuits realized using micro-transfer-printing", *APL Photonics* **4**, 110803 (2019).
- [3] P. Latzel, F. Pavanello, M. Billet, S. Bretin, A. Beck, M. Vanwolleghem, C. Coinon, X. Wallart, E. Peytavit, G. Ducournau, M. Zaknounge, and J. F. Lampin, "Generation of mW Level in the 300-GHz Band Using Resonant-Cavity-Enhanced Unitraveling Carrier Photodiodes", *IEEE Trans. Terahertz Sci. Technol.* **7**, 800–807 (2017).
- [4] J. O'Callaghan, R. Loi, E. E. Mura, B. Roycroft, A. J. Trindade, K. Thomas, A. Gocalinska, E. Pelucchi, J. Zhang, G. Roelkens, C. A. Bower, and B. Corbett, "Comparison of InGaAs and InAlAs sacrificial layers for release of InP-based devices", *Opt. Mater. Express* **7**, 4408 (2017).