Title	Extended InGaAs photodiode integrated on SOI waveguide circuit for 2 µm waveband
Authors	Arafat, Yeasir;Justice, John;Gocalińska, Agnieszka;Atar, Fatih;Russel, Eoin;Roycroft, Brendan;O'Faolain, Liam;Pelucchi, Emanuele;Gunning, Fatima;Corbett, Brian
Publication date	2024-06-10
Original Citation	Arafat, Y., Justice, J., Gocalińska, A., Atar, F., Russel, E., Roycroft, B., O'Faolain, L., Pelucchi, E., Gunning, F. and Corbett, B. (2024) 'Extended InGaAs photodiode integrated on SOI waveguide circuit for 2 µm waveband', 2024 IEEE Silicon Photonics Conference (SiPhotonics), Tokyo Bay, Japan, 15-18 April, pp. 1-2. https://doi.org/10.1109/SiPhotonics60897.2024.10543485
Type of publication	Conference item
Link to publisher's version	10.1109/SiPhotonics60897.2024.10543485
Rights	© 2024, IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.
Download date	2026-08-29 13:44:41
Item downloaded from	https://hdl.handle.net/10468/16846

Extended InGaAs photodiode integrated on SOI waveguide circuit for 2 µm waveband

Yeasir Arafat
Tyndall National Institute
Cork T12R5CP, Ireland
yeasir.arafat@tyndall.ie

John Justice
Tyndall National Institute
Cork T12R5CP, Ireland
john.justice@tyndall.ie

Agnieszka Gocalińska
Tyndall National Institute
Cork T12R5CP, Ireland
czoppa@gmail.com

Fatih Atar
Tyndall National Institute
Cork T12R5CP, Ireland
fatih.atar@tyndall.ie

Eoin Russel
Tyndall National Institute
Cork T12R5CP, Ireland
eoin.russel@tyndall.ie

Brendan Roycroft
Tyndall National Institute
Cork T12R5CP, Ireland
brendan.roycroft@tyndall.ie

Liam O'Faolain
Munster Technological University
Cork T12P928, Ireland
william.whelan-curtin@mtu.ie

Emanuele Pelucchi
Tyndall National Institute
Cork T12R5CP, Ireland
emanuele.pelucchi@tyndall.ie

Fatima Gunning
Tyndall National Institute
Cork T12R5CP, Ireland
fatima.gunning@tyndall.ie

Brian Corbett
Tyndall National Institute
Cork T12R5CP, Ireland
brian.corbett@tyndall.ie

***Abstract*— We demonstrate micro transfer printing of 2 µm bandgap photodiodes onto SOI. The integrated photodiode has a dark current below 15 nA and responsivity of 0.45 A/W at a reverse bias voltage of 2 V.**

Keywords—Photonics, Photodetector, Silicon photonics, Integrated Photonics, Transfer-Printing

I. Introduction

Integrated silicon photonics exhibit enormous potential for optical communication, sensing and biomedical applications. In terms of sensing, the short-wave infrared (SWIR) is an excellent wavelength range due to strong absorption features of important molecules in this waveband such as H_2O, CO_2, CH_4, NH_3, lactate, amongst others [1-3]. For photonics chip-based applications, photodetectors (PD) are one of the key elements. Heterogeneous integration of waveguide-based PD on silicon-on-insulator (SOI) platform in the 2 µm wavelength range has been demonstrated through the wafer-bonding process [4]. Micro transfer printing is another integration approach which has advantages in terms of efficient material usage and low temperature processing. In the transfer printing process, III-V devices are pre-fabricated on their native substrate where, at the end of the processing steps devices are released while anchored with tethers. Then, with a polydimethylsiloxane stamp, the devices are picked by breaking the tethers and then transferred onto flat non-native substrates [5]. In this work, we present micro transfer printed multi-quantum well (MQW) PD absorbing in the 2 µm band onto a SOI platform.

II. Design and Fabrication

A p-i-n structure with the intrinsic region containing 25 strain-balanced InGaAs MQWs is grown on an InP substrate by metal organic chemical vapor deposition. The bandgap of the MQW is 1975 nm. The structure contains a 500 nm thick InAlAs sacrificial layer to enable the device release. The fabrication of the coupon uses the following steps: A ring contact (Ti/Pt/Au) is made to the p-side and the p-type InGaAs contact layer is wet etched using the metal as mask. Mesas with diameters from 50 to 100 µm are dry etched using a SiNx hard mask. Ohmic contacts are made on the etched n-side. The device coupon (500 µm x 300 µm) is defined using a SiN hard mask followed by a $Cl_2/CH_4/H_2$ etch process. A grating structure around the coupons is patterned and etched into the substrate. Tethers are lithographically defined using photoresist and the devices are undercut using $FeCl_3 : H_2O$.

A 400 nm thick silicon on 3 µm buried oxide SOI wafer is used to reasise the passive waveguides. The fabrication used electron beam lithography and reactive ion etching to achieve the minimum feature size of 225 nm. The waveguide is patterned using a 400 nm deep etch while the grating coupler uses a 157 nm shallow etch to obtain a peak response around 1960 nm with a coupling efficiency of -6.5 dB and a 3 dB bandwidth of 42 nm. Photodiodes with a mesa diameter of 50 µm are transfer printed and aligned onto waveguides containing grating couplers. A 1 µm thick layer of polymer (intervia) coating is used as an adhesion promoter during the transfer printing process. Figure 1(a) shows a schematic and image of the transfer printed PD on the SOI waveguide circuit. For the measurement, light is injected to the grating coupler using a single-mode fibre at an angle of 15 degrees and fine DC probes are used to measure the photocurrent of the devices shown in Fig. 1(b).

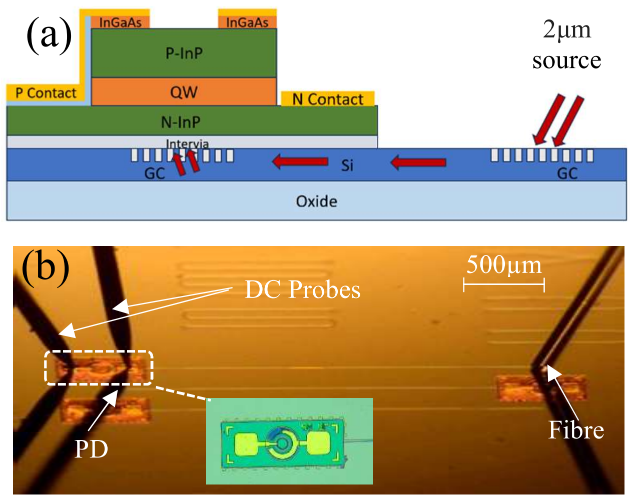

Figure 1: (a) Schematic of transfer printed PD on SOI (b) Characterization setup of printed PD and inset optical image of transferred device.

III. Results and Discussion

The absorption of the PD for different wavelengths is measured by using a tuneable light source based on xenon-

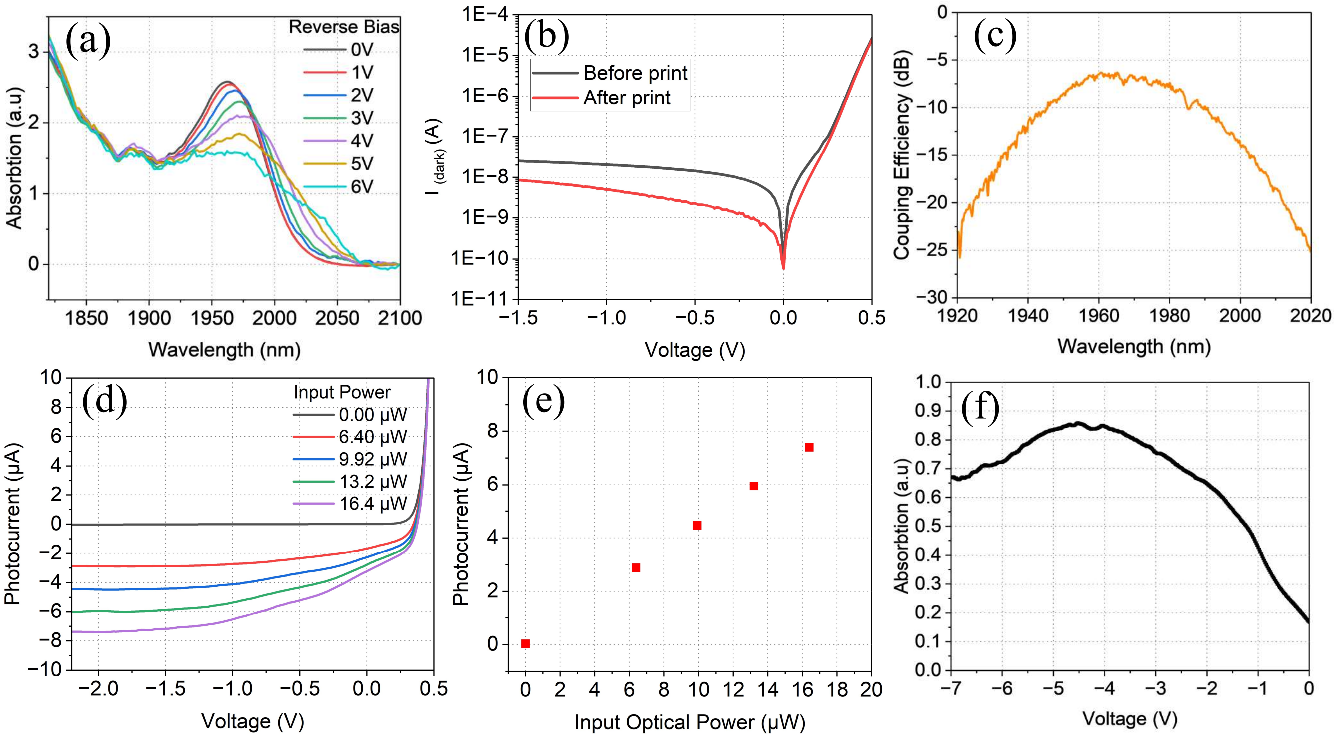

Figure 2: (a) Absorption vs wavelength sweep under different bias condition (b) Measured dark current before and after printing on SOI (c) Response of the grating coupler (d) Reverse bias characteristics under illumination with 1967 nm laser light through the grating coupler (e) Measured photocurrent for different input power at a reverse bias of 2 V (f) Measured change in absorption of printed device with bias due to QCSE under illumination of 2000 nm light .

quartz tungsten halogen source together with a monochromator. The absorption is measured by illuminating light normal to the top surface of the printed device. We measured a strong excitonic absorption peak at 1962 nm under zero bias condition (Fig. 2(a)). With a reverse bias electric field applied, the devices exhibit the quantum confined Stark effect (QCSE) with red shifting of the excitonic peak, peak broadening and change in absorption amplitude measured. The QCSE validates the absorption in the QW region. The dark current is measured for devices with a mesa diameter of 50 μm both on the InP substrate and after transfer printing on SOI (Fig. 2(b)). We measure an improvement in dark current, which confirms that the devices are not adversely affected by transfer printing. For the characterization of transfer printed devices, the grating coupler shown in Fig. 2(c) is considered, which has a coupling efficiency of -6.6 dB at 1967 nm. The response of the grating was characterized using a broadband emission from a thulium doped fibre amplifier based on a dual pump design [6]. The amplifier produces a broad amplified spontaneous emission spectrum ranging from 1600 nm to 2200 nm. A single mode laser operating at 1967 nm is used for the responsivity measurement of the printed device. Figure 2(d) shows the photocurrent measurement under different intensity of the input light through grating coupler using the single mode laser source at 1967 nm. The responsivity of the transfer printed PD is measured to be 0.45 A/W at 1967 nm. We observe the change of the photocurrent with input power is linear (Fig. 2(e)). The absorption of the printed device is also measured under illumination through grating coupler with a laser operating at 2000 nm. The observed change of the absorption amplitude under different bias conditions is due to the QCSE at that wavelength shown in Fig. 2(f).

IV. Conclusion

Strain balanced quantum well based photodetectors are realised for the 2 μm wavelength range. The devices are successfully iintegrated onto a SOI platform using micro transfer printing where light is grating coupled to the device. Transfer printing allows the reduction of the device footprint compared to flip-chip and the wafer bonding technique which leads to further cost reduction and dense integration. With the development of integrated light sources in the SWIR region on chip sensing can be realized both for healthcare and environmental application.

V. References

[1] F. Gunning and B. Corbett, “Time to Open the 2-μm Window?,” Optics & Photonics News 30(3), 42-47 (2019)

[2] A. Hänsel and M. J R Heck, “Opportunities for photonic integrated circuits in optical gas sensors”, 2020 *J. Phys. Photonics* 2 012002

[3] E. Russell, A. A. Ruth, B. Corbett, and F. C. Garcia Gunning, "Tunable dual optical frequency comb at 2 μm for CO_2 sensing," *Opt. Express* 31, 6304-6313 (2023)

[4] Ruijun Wang, Stephan Sprengel, Muhammad Muneeb, Gerhard Boehm, Roel Baets, Markus-Christian Amann, and Gunther Roelkens, "2 μm wavelength range InP-based type-II quantum well photodiodes heterogeneously integrated on silicon photonic integrated circuits," Opt. Express 23, 26834-26841 (2015)

[5] B. Corbett, R. Loi, J. O’Callaghan and G. Roelkens, “Transfer printing for silicon photonics,” In Semiconductors and Semimetals, Elsevier, vol. 99, pp. 43-70, 2018.

[6] E. Russell, N. Kavanagh, K. Shortiss and F. C. Garcia Gunning, "Development of thulium-doped fibre amplifiers for the 2um waveband." Fiber Lasers and Glass Photonics: Materials through Applications. Vol. 10683. SPIE, 2018.