Heterogenous Silicon Photonics Switch Fabric Integrated with SOAs and PDs enabled by Micro-Transfer Printing

Ye Chen,[1,2] Senbiao Qin,[1,2] Emadreza Soltanian,[1,2] Laurens Bogaert,[1,2] Jing Zhang,[1,2] and Günther Roelkens[1,2]

[1] Photonics Research Group, INTEC, Ghent University - imec, Ghent, Belgium
[2] Center for Nano and Biophotonics, Ghent University - imec, Ghent, Belgium

We present a III-V on Silicon photonic switch fabric designed for on-chip optical switching and routing, featuring self-calibration and on-chip optical loss compensation. The 4 × 4 switch fabric follows a Benes architecture and consists of several key subunits: 2 × 2 tunable optical switches based on Mach-Zehnder interferometers, micro-transfer printed III-V monitor photodiodes (PDs), and semiconductor optical amplifiers (SOAs). The Silicon photonic circuits were fabricated on a 400 nm Silicon-on-Insulator (SOI) platform using electron beam lithography, while the heterogeneous integration of InP-based SOAs and InGaAs PDs was achieved via micro-transfer printing. The integration of III-V SOAs and PDs addresses the absence of C-band optical gain and detection in native Silicon platforms, enabling functionalities such as on-chip optical amplification and detection on an otherwise passive Silicon photonics platform.

Introduction

With the massively increasing computing demands in fields such as AI, traditional electrical interconnections run into its reach limits. Therefore optical interconnections are regarded as a promising solution. On-chip optical switch fabrics play a crucial role in addressing the growing demand for high-speed and high-bandwidth communication systems, providing a flexible and reconfigurable infrastructure for managing the flow of optical signals. By integrating SOAs[1] and PDs [2] onto the switch fabric using MTP[3][4], a feedback loop can be established within the fabric for monitoring its operation and calibration, while booster SOAs compensate for on-chip loss at each optical output.

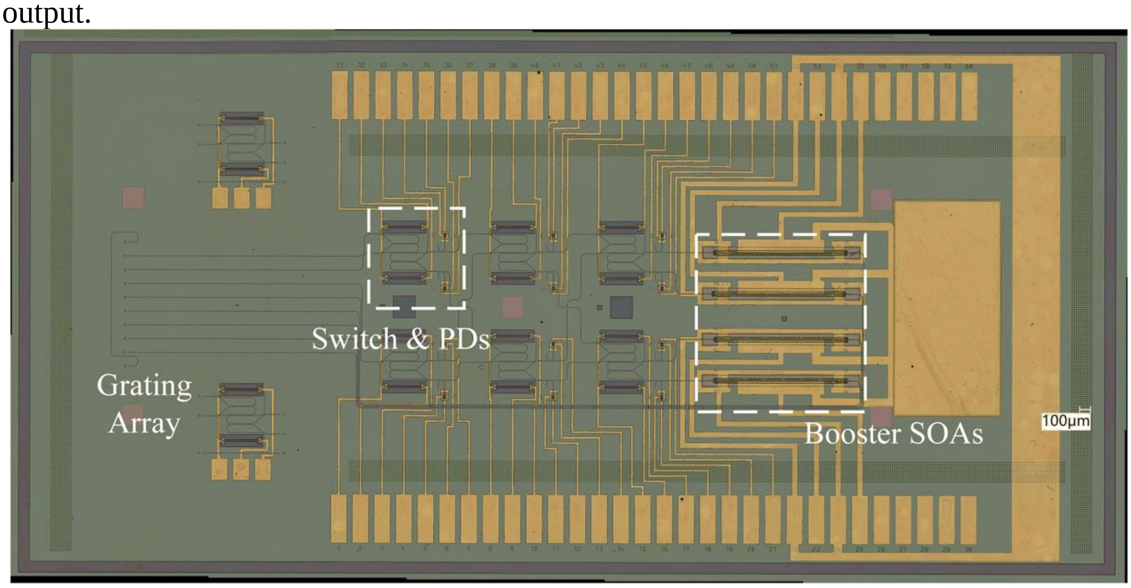


Fig. 1: Microscope photo of the switch fabric with transfer printed PDs and SOAs;

Fabric Design and Fabrication

The 6 switch units were connected using waveguide crossings and were layed out in a Benes topology. 1 % optical power was tapped out to the PD for on-chip monitoring of the output for each port of the switch unit using a 1:99 directional coupler. As the on-chip signal booster, 4 SOAs were placed after the 4 optical ports respectively.

The process flow of the heterogeneous integration on the 400 nm SOI platform in this work is presented in Fig. 2:

1) *SOI patterning:* The waveguide structures on the 400 nm SOI platform were defined by e-beam lithography and a single-step etching process using reactive-ion etching (RIE). 180 nm etch depth was used to form the rib waveguide (Fig. 2 (b)).
2) *Heater definition:* The Ti heater was deposited by using image reversal patterning and lift-off (Fig. 2 (c)).
3) *AlO_x deposition:* An etch stop layer was also defined by image reversal pattern photo-lithography and lift-off (Fig. 2 (d)). A 50 nm layer of AlO_x was deposited to protect the recesses for MTP, the heaters and especially the contact pads.
4) *Recess opening:* The coupon recess and contact via were etched simultaneously to avoid an additional processing step. Therefore, the etching control not only impacted recess quality but also determined the contact between heaters and metallization.
5) *Transfer printing:* The pre-processing of the MTP samples was finished and was followed by the spray-coating of BCB on the processed samples (Fig. 2 (h)). The III-V coupons were printed by an X-Celeprint μTP-100 lab-scale printer as presented in Fig.2 (i).
6) *Fully etched trench:* The deep trench was etched into the silicon substrate (Fig. 2 (k), which decreased thermal crosstalk and increased the heater efficiency.
7) *Metallization:* A layer of 40 nm Ti and 1000 nm Au was used as the metallization (Fig. 2 (i)) to pattern electrical connections.

Practical results

As two active building blocks of the switch fabric, the PD and SOA were characterized independently. The dark current of PD presented in Fig. 3 (a) was 0.7 μA and 0.16 μA at -3.0 V and -1.0 V bias voltage, respectively. Fig. 3 (b) shows the photocurrent as a function of on-chip input power. At a wavelength of 1550 nm, the waveguide referenced external quantum efficiency was 40%.

The input-dependent on-chip gain is plotted in Fig. 4 (b), where the small signal gain G_0 and saturation power can be extracted, which is 6.75 dB and 5 mW at 140 mA bias current. The wavelength-dependent on-chip gain of the SOAs for various bias currents is plotted in Fig. 4 (c).

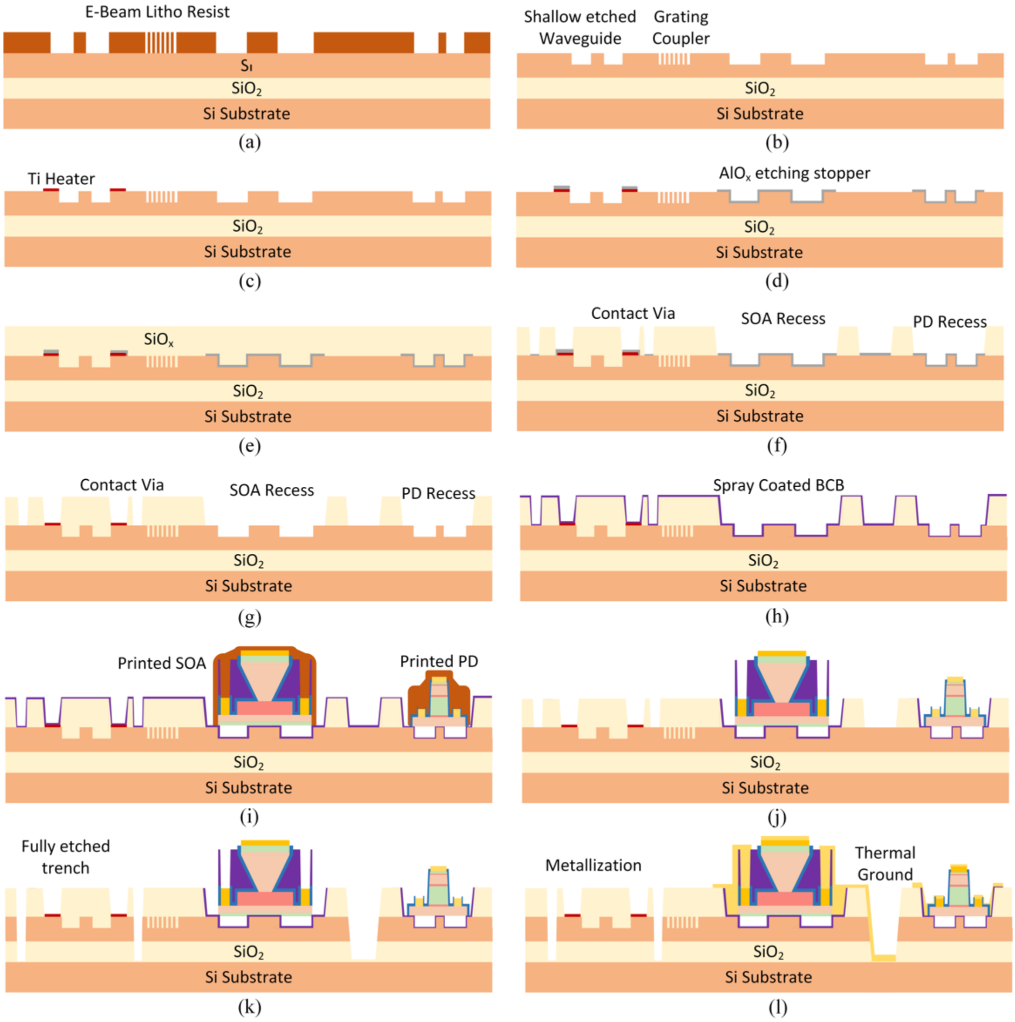


Figure 2: Plots of a) schematic of PD and TIA sides GSG pads and the taper metal connection and b) taper capacitance when the taper length is changed from 5 - 150 um

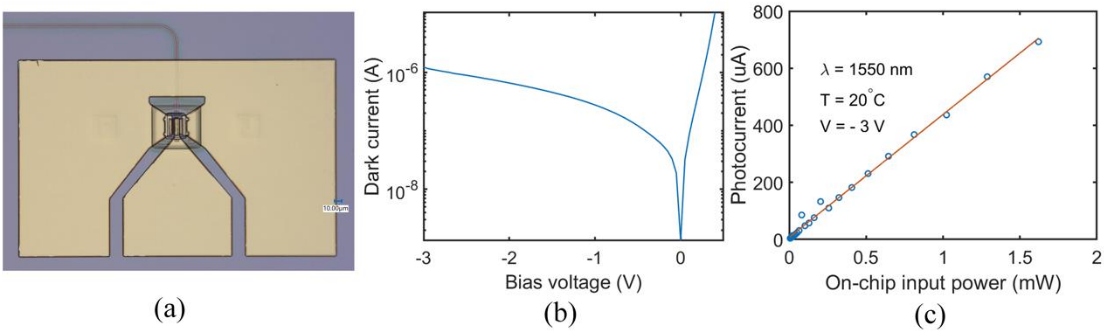
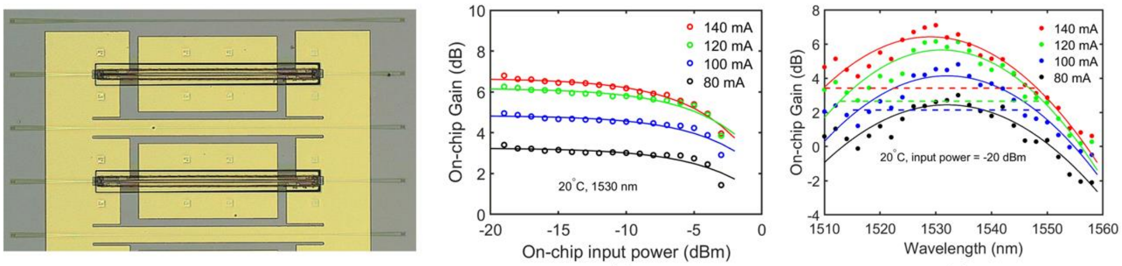


Figure 3: (a) The dark current under various bias voltages, as a function of wavelength; (b) the generated photocurrent with different on-chip input power.



(a) (b) (c)

Figure 4: (a) microscope picture of the transfer printed SOAs; (b) input-power dependence of the SOA gain; (c) wavelength-dependent gain of SOAs

Conclusion and future work

In this work, a heterogeneous integrated switch fabric was implemented by the micro-transfer printing technique, which enabled using a passive silicon photonics platform with on-chip optical gain and detection. The device building blocks were characterized. The future work is to finish the optical and electrical packaging and measurement of the switch.

References

[1] Soltanian E, Muliuk G, Uvin S, et al. Micro-transfer-printed narrow-linewidth III-V-on-Si double laser structure with a combined 110 nm tuning range, Optics Express, 2022, 30(22): 39329-39339.

[2] Qin S, Bogaert L, Zhang J, et al. Micro-transfer printing of O-band InP-InGaAs photodiodes on a silicon nitride photonic platform, 2024 IEEE Silicon Photonics Conference (SiPhotonics). IEEE, 2024: 1-2.

[3] Roelkens G, Zhang J, Bogaert L, et al. Present and future of micro-transfer printing for heterogeneous photonic integrated circuits, APL Photonics, 2024, 9(1).

[4] Zhang J, Bogaert L, Krückel C, et al. Micro-transfer printing InP C-band SOAs on advanced silicon photonics platform for lossless MZI switch fabrics and high-speed integrated transmitters, Optics Express, 2023, 31(26): 42807-42821.