ring is selected to have a coupling length of 9 µm, and a radius of 5 µm. The gaps are chosen to be 205 nm between the waveguide and the ring, and 340 nm between the rings. The ring resonators have a free spectral range of 11 nm. In this experiment, a commercial C-band surface illuminated photodiode design was adapted to enable transfer printing (i.e. the inclusion of an InAlAs release layer below the p-i-n layer stack). Photodiodes with 10 µm aperture were realized on a 75 x 75 µm coupon, which were released from the III-V substrate by underetching the InAlAs release layer, while being anchored to the substrate using photoresist tethers. More about the transfer printing process of III-V on SOI can be found in [3]. The photodiodes are to be printed on a silicon photonic grating coupler structure and therefore operate by bottom surface illumination. Tetris-brick alignment markers were added to the silicon photonic target structure to aid the high-alignment accuracy transfer-printing.

III. Processing

The passive silicon waveguide circuit was processed in imec's 200mm pilot line through a multi-project wafer run. The post-processing is performed on the standard passive SOI devices with 1.2 µm top oxide layer. Micro-ring heaters were defined by depositing ~350 µm long, 2 µm wide and spiral-shaped Ti /Au wires (see inset in Fig. 2).

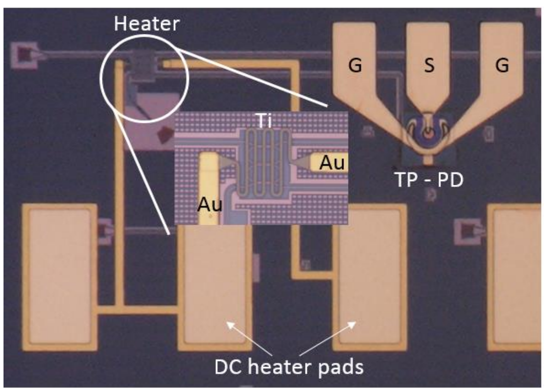

Fig. 2. A microscopic image of the one receiver channel after post-processing.

In a second step the above described photodiodes were transfer printed onto the grating coupler of each of the 4 channels, using a DVS-BCB adhesive bonding layer. After the printing the photoresist anchoring layer is removed by a ~35 minutes oxygen plasma. Then a ~4 µm thick DVS-BCB layer is spin-coated and fully cured at 280ºC to encapsulate the devices. Next, the DVS-BCB is etched back to access the photodiode electrodes and ~1 µm thick Au tracks are deposited to form GSG contact pads. Last, the DVS-BCB was fully etched at the contact pads of the heaters to access the metal pads for DC probing. Fig. 2 shows the top-view of the receiver channel 1 after finishing the post-processing.

IV. Measurement results

Static I-V characteristics of the transfer printed device were measured. The devices have a dark current of about 20 nA at -2 V, with a series resistance of about 4 Ω. The waveguide-referred responsivity of the detectors is >0.5 A/W (at -2V bias) over the C-band. The ring resonator filters show a flat pass-band with a 1dB bandwidth of 0.74 nm.

Large-signal measurements were performed for every receiver channel. An arbitrary waveform generator (AWG) is used to generate a non-return-to-zero (NRZ) pseudo-random-bit-sequence (PRBS) with a pattern length of 2^9-1 at 25Gbit/s. A $LiNbO_3$ modulator was used in the experiments. The photodiode was biased at -1.5 V and the radio frequency output was connected to an oscilloscope through a bias-T. By applying a separate DC bias to the heaters, the resonance wavelength of every channel was tuned to obtain a 2.5nm channel spacing and eye diagrams at all four channels were measured. Fig. 3 shows open eye-diagrams at 25 Gbit/s for every channel.

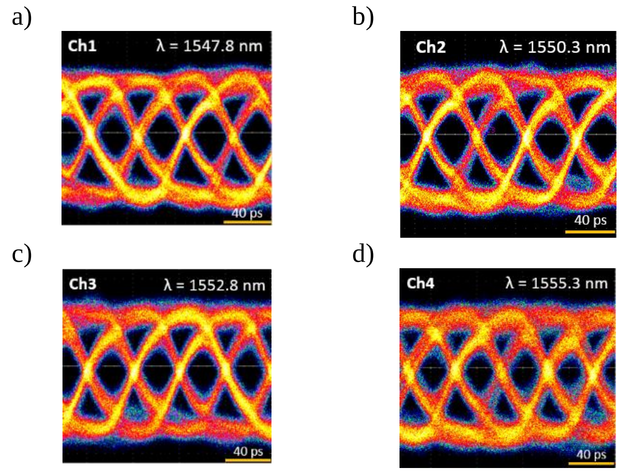

Fig. 3. Eye diagrams of each channel at 25 Gbit/s by tuning the resonance of the micro-ring. The applied electrical power on the rings: a) 0 mW; b) 30 mW; c) 56 mW; d) 83.6 mW.

Conclusions

In this paper we demonstrated a C-band 4x25Gbit/s micro-ring resonator receiver with flat-top transmission characteristics by transfer printing commercial III-V p-i-n photodetectors. Using a heater, the resonance wavelength of each filter was tuned to achieve a channel spacing of Δλ = 2.5 nm. Open eye diagrams at 25 Gbit/s were obtained for each channel of the receiver. This demonstrates cost-effective and time-effective realization of III-V/Si photonic integrated circuits. While demonstrated on die-level, the technique is scalable to wafer level.

References

[1] X. Feng, M. A. Meitl, J. A. Rogers, et al. "Competing Fracture in Kinetically Controlled Transfer Printing". Langmuir, **23**, 12555-12560, 2007.

[2] P. De Heyn, et al. "Fabrication-Tolerant Four-Channel Wavelength-Division-Multiplexing Filter Based on Collectively Tuned Si Microrings", JLT, Vol. **31**, no. 16, p. 2785 - 2792, 2013.

[3] A. De Groote, et al. , "Transfer-printing-based integration of single-mode waveguide-coupled III-V-on-silicon broadband light emitters", Optics Express, vol. **24** No. 13, p.13754-13762, 2016.