Micro-transfer printing of InP SOAs on advanced silicon photonics platform for C-band pre-amplified receivers

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ABSTRACT

We present a C-band pre-amplified receiver on an advanced silicon photonics platform, consisting of an indium phosphide semiconductor optical amplifier (InP SOA) integrated via micro-transfer printing (μTP), connected to a ring filter and a 50 GHz germanium photodiode (Ge PD). The InP SOA provides 8.1 dB small-signal gain at 1550.3 nm for an injection current of 95 mA. The ring filter has a 25 dB extinction ratio and a 3 dB bandwidth of 1.45 nm to suppress the amplified spontaneous emission (ASE) noise from the SOA. In the 30 Gbps non-return-to-zero (NRZ) signal transmission experiment, the device exhibits a sensitivity of -18 dBm at a bit-error rate (BER) of 10^{-6} for an SOA injection current of 95 mA, showing a 7 dB improvement compared to the reference Ge PD.

Keywords: Micro-transfer printing, semiconductor optical amplifier, receiver, sensitivity

1. INTRODUCTION

A pre-amplified receiver, which includes an SOA and high-speed PD technologies, is particularly valuable for high-speed, high-sensitivity applications, including data center networks, high-speed access networks, etc. By leveraging the well-established CMOS fabrication infrastructure, foundries can manufacture silicon photonics chips with high throughput, with integrated high-speed Ge PDs. However, silicon photonics can not provide on-chip optical amplification. Thus, most pre-amplified receivers are made up of discrete components[1] or are integrated on the InP platform.[2,3] Micro-transfer printing (μTP), a technology available under license from X-Celeprint, Ltd., is a heterogenous integration technology that is compatible with the back-end process of silicon photonics platforms, enabling to bring in the III-V optical gain section.[4] In this work, we present a C-band pre-amplified receiver on imec's iSiPP50G silicon photonics platform leveraging micro-transfer printing technology. The 50 GHz bandwidth Ge PD is from the process design kit (PDK). An InP SOA is integrated in front of the PD using μTP to provide optical gain, thus improving sensitivity of the receiver. A dual micro ring resonator (DMRR) is connected in between of the PD and the SOA to filter out ASE noise.

2. DESIGN AND FABRICATION

Fig. 1(a) shows the schematic cross-section view of the pre-amplified receiver. Imec's iSiPP50G silicon photonics platform provides the high speed Ge PD (with 50 GHz 3-dB bandwidth), the grating coupler, the bond pads and the tungsten heater for the ring filter tuning on 220 nm SOI. A 1 mm long InP SOA is transfer-printed on top of the waveguide, where a 160 nm poly-Si layer on top of the 220nm crystalline Si is adopted to enable efficient coupling between the III-V gain section and silicon. A benzo-cyclo-butene (DVS-BCB) bonding layer is used here for high-quality adhesive bonding. The n and p contacts of the SOA are connected to the neighboring bond pads, which can be routed to the chip edge for wire-bonding.

The process flow of the SOA integration is illustrated in Fig. 1(b). First, the silicon photonics chip is post-processed. The back-end stack has been partially removed in the silicon photonics back-end process, leaving a 3.4

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um SiO_2 layer at the coupling region. RIE dry etch and BOE wet etch are used to fully open the back-end layer stack, creating a recess reaching the poly-Si layer. Then the DVS-BCB is spray coated on the chip, resulting in a thin layer of 50 nm in the recess. The second step is the SOA μTP with an X-Celeprint μTP-100 tool. A PDMS stamp is used to pick-up the pre-fabricated SOA coupon from an InP source substrate. The SOA is then aligned with the waveguide and printed into the recess. Post-printing processes, including RIE oxygen plasma to remove the photo-resist encapsulation on the SOA coupon, BCB curing at 270 °C, and 1 um Au deposition for electrical connection, complete the process.

The microscope image of a resulting device is presented in Fig. 1(c). The inset shows the DMRR filter, with 2 rings cascaded to obtain higher extinction ratio[5] for better ASE noise suppression. The SOA is connected to the in-port and the Ge PD is connected to the drop-port.

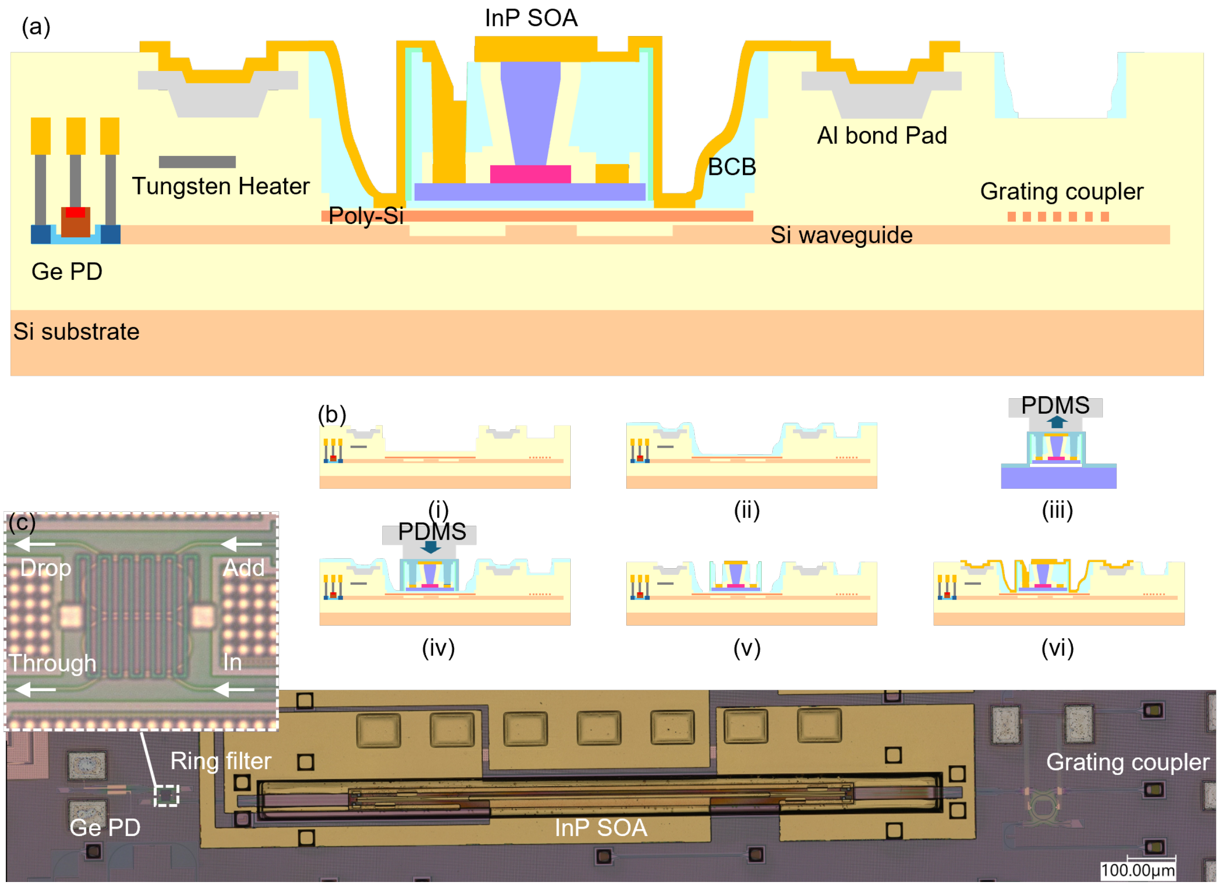

Figure 1. A C-band pre-amplifed receiver with transfer-printed InP SOA on imec's iSiPP50G silicon photonics platform. (a) Schematic of the device cross-section. (b) Process flow of the SOA integration using μTP. (c) Microscope image of a fabricated device.

3. MEASUREMENT RESULTS

During measurements, the sample was placed on a thermoelectric cooler (TEC), which was set to 20 °C. Performance of key components, including the InP SOA, the ring filter and the Ge PD, were characterized. Fig. 2(a) shows the voltage-current curve of the SOA, as well as the calculated differential resistance, which is 10 Ω at a bias current of 95 mA. The SOA gain is presented in Fig. 2(b). In the measured pre-amplified receiver, the heater was not actuated. The peak wavelength of the ring filter transmission at the drop-port is 1550.3 nm, at which the SOA gain was measured. The transparency current of the SOA is 54 mA. With 95 mA current injected, the SOA can provide 8.1 dB on-chip gain. The transmission in Fig. 2(c) was measured at the drop-port of a reference ring filter. By implementing the cascaded-rings configuration, this ring filter obtains an extinction ratio over 25 dB. The 3-dB bandwidth and the free spectral range (FSR) are 1.45 nm and 11.83 nm, respectively. The Ge PD responsivity as a function of wavelength was measured on a reference device, the result of which is shown in Fig. 2(d). At the wavelength of 1550.3 nm, the PD has a responsivity of 1.2 A/W.

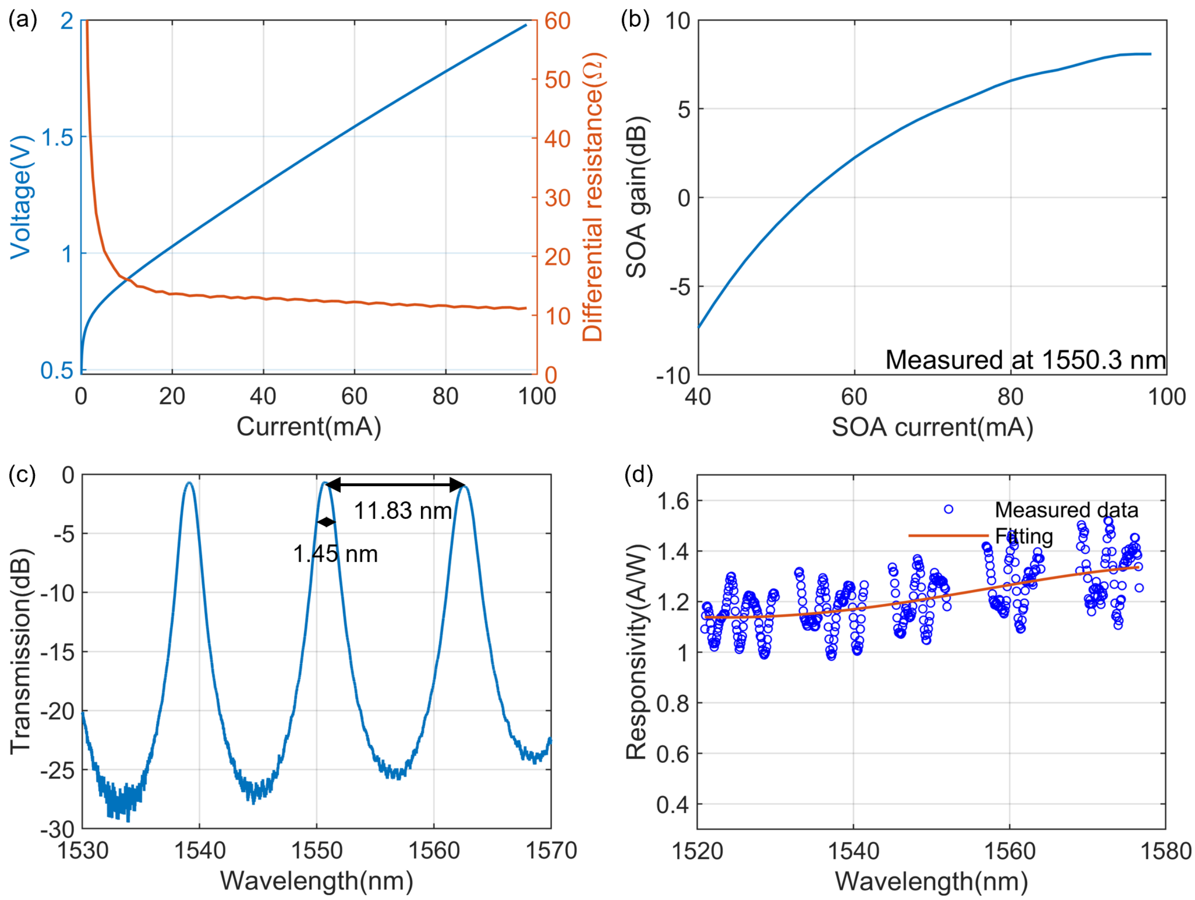

Figure 2. Performance of key components of the pre-amplified receiver at 20 °C. (a) Measured voltage-current curve and the calculated differential resistance of the SOA. (b) SOA gain as a function of the SOA bias current, which was measured at the wavelength of 1550.3 nm, aligned with the transmission peak of the ring filter of the pre-amplified receiver. (c) Transmission at the drop-port of a reference ring filter. (d) Responsivity of a reference Ge PD.

The high-speed data reception characteristics of the pre-amplified receiver are measured via eye diagrams test. A 30 Gbps NRZ signal with a pseudo-random binary sequence (PRBS) with a length of $2^7 - 1$ is generated at the wavelength of 1550.3 nm, using a C-band tunable laser, a 40 Gbit/s MZM modulator and an arbitrary waveform generator (AWG). The signal is detected by the pre-amplified receiver, in which the Ge PD is operating at -2 V bias voltage. The pre-amplified receiver is connected to a SHF S807 RF amplifier. The signal is then sent to a sampling oscilloscope to show the eye diagram. As shown in Fig. 3(a), when the received optical power is - 13.2 dBm, the eye diagram with a reference Ge PD only has a signal-to-noise ratio (SNR) of 3.43. By implementing the SOA and injecting 62 mA current, which corresponds to 2.8 dB optical gain, the SNR can be improved to 5.95. When the injected current is further increased to 95 mA (8.1 dB optical gain), a SNR of 7.95 is achieved. Besides, the BER results for different SOA currents are studied, which is presented in Fig. 3(b). For a reference Ge PD, a received optical power of -11 dBm is needed to have a BER of 10^{-6}. While it is - 18 dBm received optical power for a pre-amplified receiver with an SOA current of 95 mA (8.1 dB gain) to obtain the same BER performance, which means the integrated SOA improves the receiver sensivity by 7 dB.

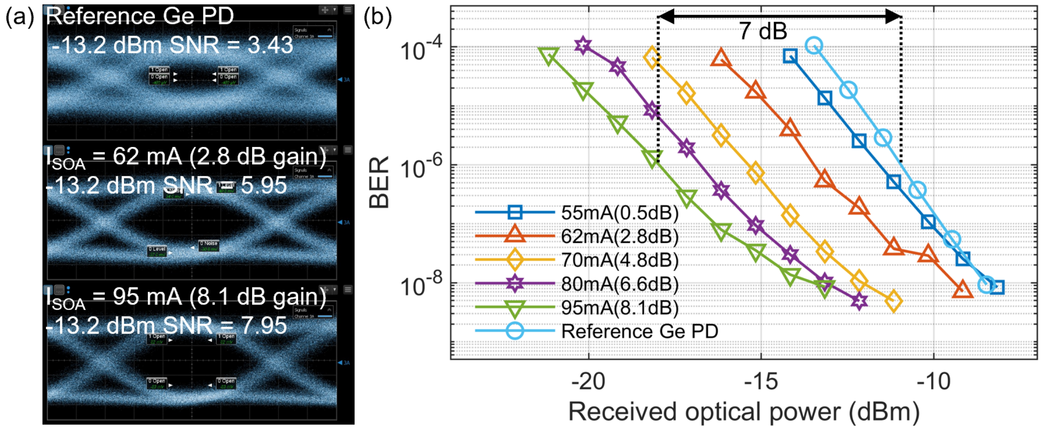

Figure 3. The measured high-speed performance of the pre-amplified receiver when operating at -2 V PD bias voltage, comparing with a reference Ge PD. (a) The measured eye diagrams of a 30 Gbps NRZ signal for different SOA currents at a received optical power of -13.2 dBm. (b) The measured BER results for different SOA currents.

4. CONCLUSION

We have demonstrated a C-band pre-amplified receiver on an advanced silicon photonics platform. By leveraging the μTP technique, we integrated an InP SOA in front of a 50 GHz bandwidth Ge PD, implemented on a well-established silicon photonics platform. The on-chip SOA can provide 8.1 dB optical gain at the wavelength of 1550.3 nm, which leads to a 7 dB sensitivity improvement at a BER of 10^{-6} for a 30 Gbps NRZ signal compared to a reference Ge PD.

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