Micro-Transfer-Printed III-V-on-Si Semiconductor Optical Amplifier with 15 dBm Output Saturation Power

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***Abstract*—We demonstrate a high-saturation power III-V-on-Si semiconductor optical amplifier (SOA) with a tapered design realized using micro-transfer-printing integration technology. The SOA provides a 9 dB small-signal gain and an output saturation power of 15 dBm at the wavelength of 1573 nm.**

***Index Terms*—Silicon Photonics, micro-transfer-printing, semiconductor optical amplifier**

I. Introduction

Silicon photonics (SiPh) leverages CMOS fabrication infrastructure to realize photonic integrated circuits (PICs) on 200 mm or 300 mm Silicon-on-Insulator (SOI) wafers with high yield and uniformity. III-V semiconductors have been introduced to SiPh, as Si does not provide optical gain. The integration of III-V-on-Si high output saturation power semiconductor optical amplifiers (SOAs) is a must for SiPh to be the leading platform for high volume applications such as coherent optical communications, LiDAR, sensing and spectroscopy, etc.

In this work, we used micro-transfer-printing (μTP) to integrate pre-fabricated InP SOAs [1] with a tapered design on a silicon waveguide within a SOI PIC. This design relies on a hybrid III-V/Si optical mode [2], reducing the confinement in the active region, as well as a reduced power density towards the right side of the SOA, resulting in an increased output saturation power.

II. Design

The design consists of 4 sections (left to right), as shown in Fig. 1(a): 1- a taper for evanescent partial coupling from single-mode Si waveguide to III-V, 2- a narrower side, which results in higher gain for a given injection current, 3- a wider side, which provides lower power density, resulting in higher output saturation power, and 4- an inverted taper for coupling the light from III-V to the single-mode Si waveguide. The Si waveguide width underneath the III-V is consistently 2 μm wider than multi-quantum well (MQW) layers to keep the confinement in the active region low over all the fourth parts. A stitched microscope image of the fabricated III-V coupon is shown in Fig. 1(b).

III. Characterization

To characterize the SOA, the sample was placed on a 20°C temperature-controlled stage. The device under test is optically probed using cleaved standard single mode fibers on a fiber stage. To have a better control over the narrow-side and the wide-side of the SOA, separate probe needles are used to electrically drive each side of the amplifier, simultaneously. An electric isolation section is used to individually drive both segments. The left/right SOA section has a differential resistance of 11/9 Ω, while injecting 100 mA in each segment.

The gain spectrum for 2 dBm optical input power is shown in Fig. 2. The dip in the gain curve is attributed to the interference of two propagating modes in the SOA, which are excited by a slight misalignment of the transfer printed SOA. At the wavelength of 1573 nm, which corresponds to the wavelength of maximum optical gain, the small-signal gain of 9.4 dB and an output saturation power of 15.4 dBm were extracted by fitting a curve to the experimental data according to (1), As shown in Fig. 3.

$$G(P_{in}) = G_0 \frac{1 + {}^{P_{in}}/_{P_s}}{1 + G_0 {}^{P_{in}}/_{P_s}} \tag{1}$$

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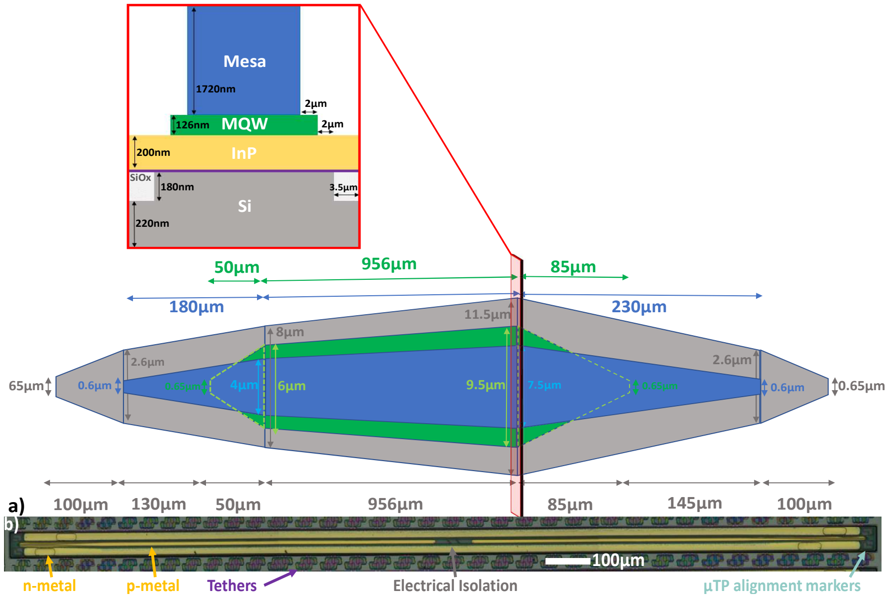

Fig. 1: (a) Detailed schematic of the hybrid III-V-on-Si tapered SOA design (Top view), indicating p-InP mesa, active area and silicon waveguide underneath. The widest part cross-section is shown in the inset (not to scale), (b) Microscope image of a coupon on its native InP source substrate.

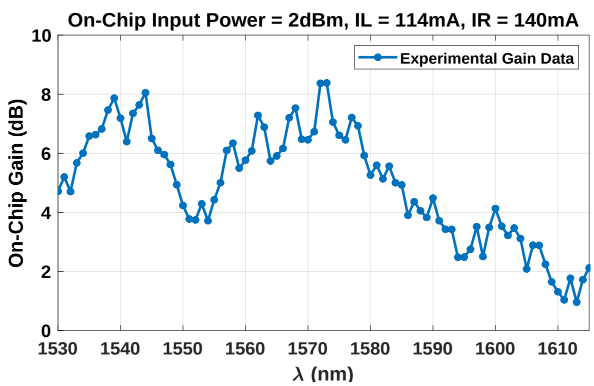

Fig. 2: Small-signal gain as a function of wavelength, while the on-chip input power is +2.0 dBm and the pump current of the left and right sides are 114 mA and 140 mA, respectively.

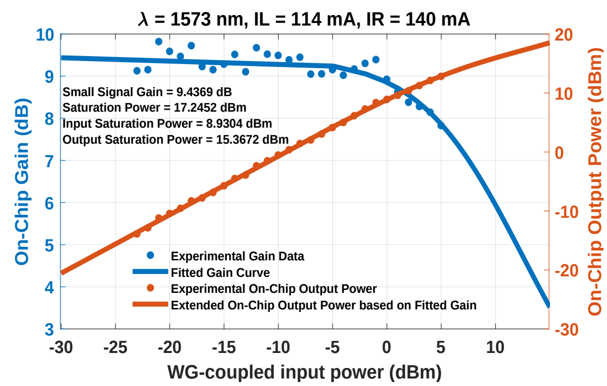

Fig. 3: The gain as function of on-chip optical input power (left side). The on-chip output power as function of the input power (right side). The points are measured values, the lines are fitted curves. The pump current of the left and right sides are 114 mA and 140 mA, respectively.

Equation (1) relates the SOA gain factor G to the input power P_{in}, material gain saturation power P_s, and small-signal gain G_0 [2].

IV. Conclusion

We demonstrated a tapered μTP-ed III-V-on-Si SOA with an on-chip output saturation power of 15 dBm. μTP allows for densely integrating different non-native components on a SiPh platform with minimal disruption to the SiPh process flow in a high-throughput manner, while requiring no singulation and handling of individual III-V chips. The possibility of co-integration of the presented SOAs with the recently demonstrated μTP narrow linewidth widely tunable III-V-on-silicon lasers [3] and transmitter [4] as an optical output power booster, can lead to the required high output power for e.g. coherent optical communications.

References

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