Heterogeneous Silicon/InP Semiconductor Optical Amplifiers with High Gain and High Saturation Power

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Abstract: High gain and high power SOAs on the heterogeneous silicon photonics platform are integrated by varying the waveguide width underneath the gain section. 25.5 dB of gain and 16 dBm output power are achieved.

OCIS codes: (130.3120) Integrated optics devices; (250.5300) Photonic integrated circuits

1. Introduction

Silicon photonics has been an area of increasing interest for metro and data center applications. Because of its compatibility with CMOS manufacturing, silicon photonics holds the promise of high volume and low cost manufacturing to meet rising demand for bandwidth in data center, metro, and other short reach data transmission applications. Silicon lacks the capability to interact with light efficiently, but combination of silicon with III-V material III-V chips over a selective area of a silicon photonic wafer can overcome this limitation.

The semiconductor optical amplifier (SOA) is one example of an optical component that can be added to a silicon photonic integrated circuit (PIC) by the addition of III-V semiconductors. Widely tunable lasers benefit from the addition of an SOA, since it allows the laser bias condition to be optimized for emission wavelength and SMSR independently from the output power. Alternatively, an SOA may be used in a receiver to increase sensitivity and reduce the number of fiber amplifiers in the network [2].

At the gain peak wavelength, the gain coefficient of the amplifier is written as [3]

$$g = \frac{g_0}{1 + P_{in} / P_{sat}} \qquad (1)$$

The gain produced by an SOA will decrease with increasing input power. This is referred to as gain saturation, where g_0 is the unsaturated gain, Pin is the input power, and P_{sat} is the input power at which the gain has fallen to half of g_0. An expression for the input saturation power can be derived from the laser rate equations:

$$P_{sat} = \frac{Ah\nu}{a\Gamma_{xy}\tau} \qquad (2)$$

where $h\nu$ is the photon energy, a is the differential gain, Γ_{xy} is the quantum well confinement factor, A is the cross section area of the active region, and τ is the photon lifetime. Reducing Γ_{xy} will increase P_{sat}, however, the unsaturated gain also depends on Γ_{xy}, and so controlling P_{sat} by Γ_{xy} introduces a tradeoff between the unsaturated gain and the saturation power.

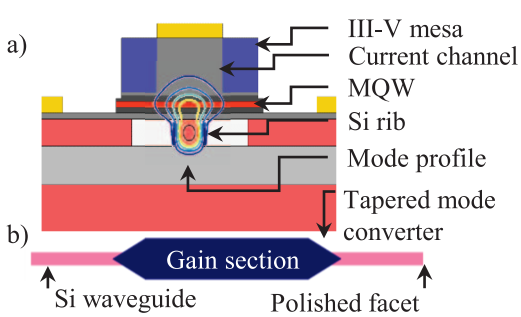

Fig. 1. a) Cross section of gain region b) plan-view schematic of amplifier

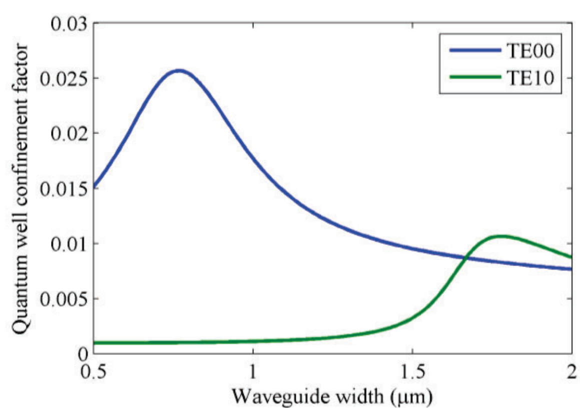

Fig. 2. Simulation of confinement factor versus waveguide width

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2. Design and Fabrication

The amplifiers are similar in design and fabrication to the devices described in [4]. A III-V chip is directly bonded to individual dies on a processed silicon-on-insulator wafer. The III-V mesa in the active region 26 μm wide with a central current channel formed with hydrogen implantation to confine the carriers to an area with high overlap with the optical mode, as shown schematically in cross section and plan view in Figure 1a).

Varying the effective index in the respective waveguide will change the confinement factor in that waveguide proportionally, and affect the other waveguide inversely. By increasing the width of the silicon waveguide, the relative confinement in the InP quantum wells will decrease. The variation of the quantum-well confinement factor for the two modes with the highest confinement factor in those layers is shown in Figure 2.

Four waveguide widths were selected for the experiment, between 0.95 μm and 1.6 μm. Waveguides narrower than 0.95 μm risk the propagation loss increasing as the mode expands into the doped contact layers. The amplifiers are 2 mm in length. This is the cause of the reduced confinement factor for very narrow waveguides.

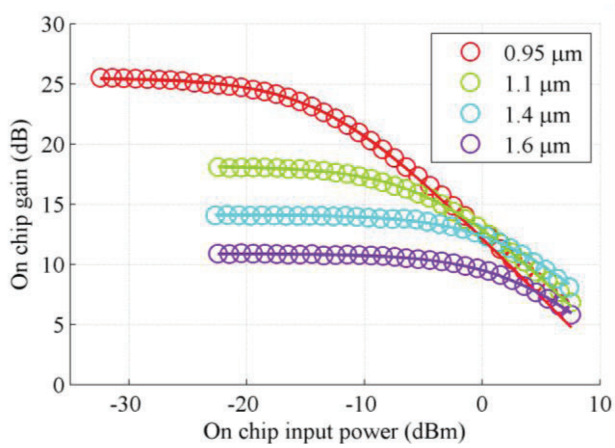

Fig. 3. Gain versus input power measurement (circles) and fit (lines)

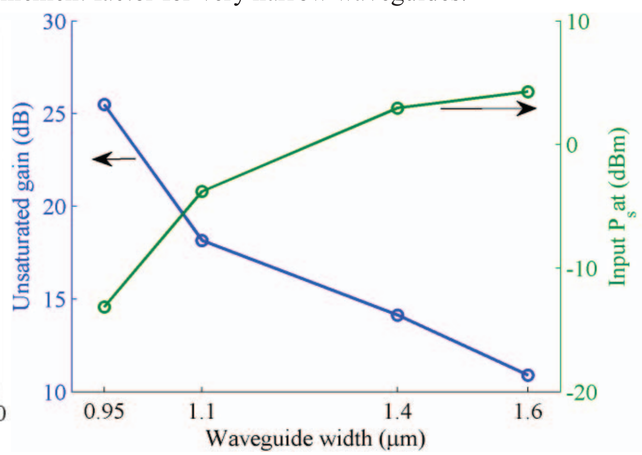

Fig. 4: Extracted *g0* and P_{sat}

3. Test Results

Characterization of the devices was performed at 1.55 μm wavelength under continuous-wave illumination by injecting light from a single-wavelength laser through the device with a pair of tapered fibers and measuring the increase in power. The input power of the single-wavelength laser was swept with a variable optical attenuator. The data from this measurement is shown in Figure 3 for each SOA design. The measured gain data is fitted using Equation 1 to extract the unsaturated gain and the input saturation power. The fitted g_0 and P_{sat} are shown in Figure 4. The narrowest waveguide width SOA, 0.95 μm, has 25.5 dB (12.25 dB/mm) of unsaturated gain and -13 dBm P_{sat}, while the widest waveguide width SOA has only 11 dB of gain, but 4.25 dBm P_{sat}. The 1.4 μm waveguide SOA attained the highest output power, 16 dBm. The amplifiers were all operated at 240 mA drive current. The decrease in gain of the 1.6 μm SOA is due to the increased confinement factor of TE10 relative to the fundamental mode, as discussed previously. The gain is limited due to self heating of the device.

4. Conclusion

Semiconductor optical amplifiers with high gain and high saturation power have been integrated on a single chip. Control of the confinement factor tradeoff between the two characteristics can be achieved with the variation of the silicon waveguide width. Unsaturated gain of 25.5 dB from the narrowest waveguide SOA and input saturation power of 4.25 dBm from the widest waveguide were demonstrated, with 65 nm of 3 dB bandwidth. One device showed 16 dBm of maximum output power, which is the highest that has been demonstrated in a silicon/InP SOA. Because the input and output are both passive silicon waveguides, these amplifiers can be seamlessly integrated with other heterogeneous Si/InP devices. The authors acknowledge the DODOS program for funding this research.

5. References

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