

Towards the Integration of C-band Amplifiers on Silicon Nitride Waveguides via Transfer Printing

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Abstract: We demonstrate a strategy for the integration of C-band operating amplifiers on a silicon-nitride-on-insulator platform. A layer of hydrogenated amorphous silicon is used to bridge the index contrast between the nitride and the active device. © 2019 The Author(s)

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1. Introduction

The optimization of silicon nitride (Si_3N_4) based waveguide platforms has enabled the fabrication of highly performant optical on-chip components such as arrayed waveguide gratings [1] or high-Q ring resonators [2] at telecom wavelengths. This is due to the combination of a medium high index contrast with silicon oxide ($\Delta n \sim 0.5$ around 1550 nm), which allows for compact PICs, and ultra-low waveguide losses [2]. However, since the refractive index of silicon nitride (~ 2 around 1550 nm) is much lower than that of indium phosphide (InP), it is challenging to make use of the adiabatic coupling schemes developed for the heterogeneous integration of amplifiers on the silicon-on-insulator (SOI) photonic platform [3, 4]. Therefore, in most device demonstrations with ultra-low loss Si_3N_4 , light is typically coupled to the Si_3N_4 circuit through edge-coupling. A major drawback of the edge-coupling method is that it becomes very cumbersome to interface multiple active devices to the passive PIC. It does not allow for dense integration of active components, as opposed to e.g. the transfer printing method. In this paper, we overcome the index contrast between Si_3N_4 and transfer printed III/V-based amplifiers operating at telecom wavelengths, by means of an intermediate layer of hydrogenated amorphous silicon (a-Si:H). The total excess loss caused by the a-Si:H waveguide and including the coupling sections, remains below 2 dB. InP/InAlGaAs multiple-quantum-well (MQW) amplifiers were transfer printed successfully on the a-Si:H waveguides using an intermediate adhesive BCB layer. Transparency was achieved, however net amplification was out of reach for the current design due to the high thermal impedance of the device caused by the thick buried oxide layer.

2. Design and fabrication

The refractive index of the hydrogenated amorphous silicon is 3.37 at 1550 nm. Optimal coupling from the silicon nitride to the a-Si:H waveguide can be achieved with thinner layers of a-Si:H, whereas for optimal coupling from the a-Si:H to the InP/InAlGaAs-stack of the amplifier (described in [5]), thick a-Si:H waveguides are needed. Simulations indicate that a 500 nm thick a-Si:H layer is suitable for coupling in both ways, with the restrictions of our fabrication technology taken into account. A layer of 100 nm silicon oxide (SiO_2) is added between the Si_3N_4 and the a-Si:H to reduce the impact of lateral misalignment of the a-Si:H taper tip. The simulated transmission for the fundamental TE mode in a 3 μm wide Si_3N_4 waveguide at an a-Si:H tip of 500 nm high and 120 nm wide is $> 97\%$, including a potential lateral misalignment of 150 nm. The coupling efficiency from a 3 μm wide a-Si:H waveguide to a 600 nm wide tip of the III/V-stack can be $> 95\%$ for BCB layer thicknesses > 60 nm.

The layers of hydrogenated amorphous silicon and silicon oxide are deposited on top of the silicon nitride chip using Plasma Enhanced Chemical Vapour Deposition (PECVD). In this demonstration, the circuit was patterned using two consecutive steps of e-beam lithography (EBL) and reactive ion etching. First, the transfer printing locations are defined in the a-Si:H layer. The SiO_2 layer serves as a buffer to protect the Si_3N_4 during the etching process. Afterwards, the underlying Si_3N_4 layer is patterned using a second EBL step. The design is schematically shown in Fig. 1a and the actual fabricated device is shown in Fig. 1b. The alignment of the two layers can be done with a precision below 150 nm, as shown in Fig. 1c. The losses arising from coupling to the a-Si:H layer were measured by cascading different numbers of tapers. A piecewise linear taper (shown in Fig. 1a) from a 130 nm tip to a 3 μm wide waveguide has 0.65 dB loss per taper. InP/InAlGaAs-based amplifiers can be integrated on top of the a-Si waveguides through transfer printing [5]. Seventeen amplifiers were transfer printed on the sample and

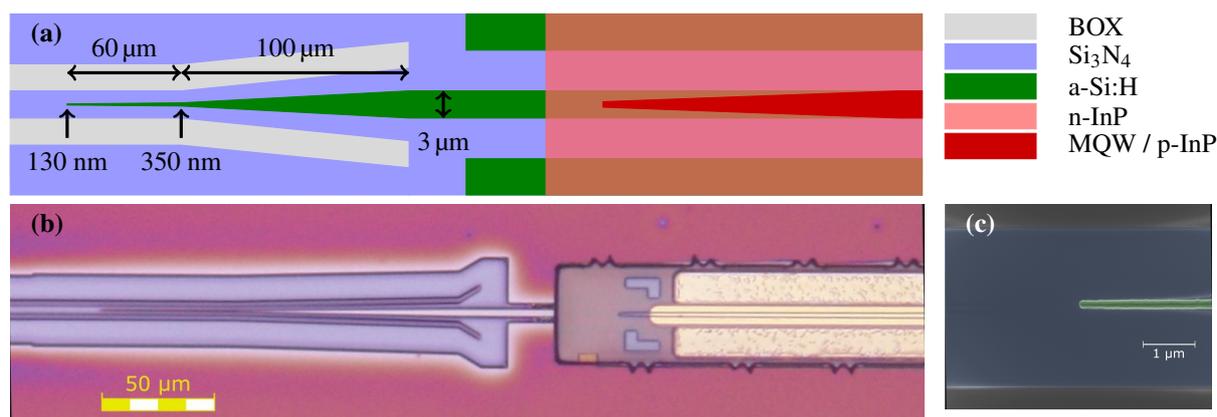


Fig. 1: (a) Schematic top view of the taper from the Si₃N₄ waveguide to the amplifier. (b) Microscope image of a fabricated device after transfer printing. (c) False color SEM image of the a-Si:H taper tip on the Si₃N₄ waveguide.

characterized. For one amplifier, the printing failed. The electrical characterization of the printed amplifiers, as well as the power of the fiber coupled amplified spontaneous emission, is shown in Fig. 2a. The results show that the transfer printing process on the a-Si:H waveguides is reproducible. The net gain of three amplifiers, compared to a Si₃N₄ waveguide without a-Si:H waveguide on top, is shown in Fig. 2b. The amplifier gain compensated all the coupling losses, although no net gain was achieved on this sample. One possible reason for the low gain is that the buried oxide (BOX) underneath the Si₃N₄ layer is 8 μm thick and the thermal impedance of the stack is too high. A reduced BOX thickness should improve the performance of the device.

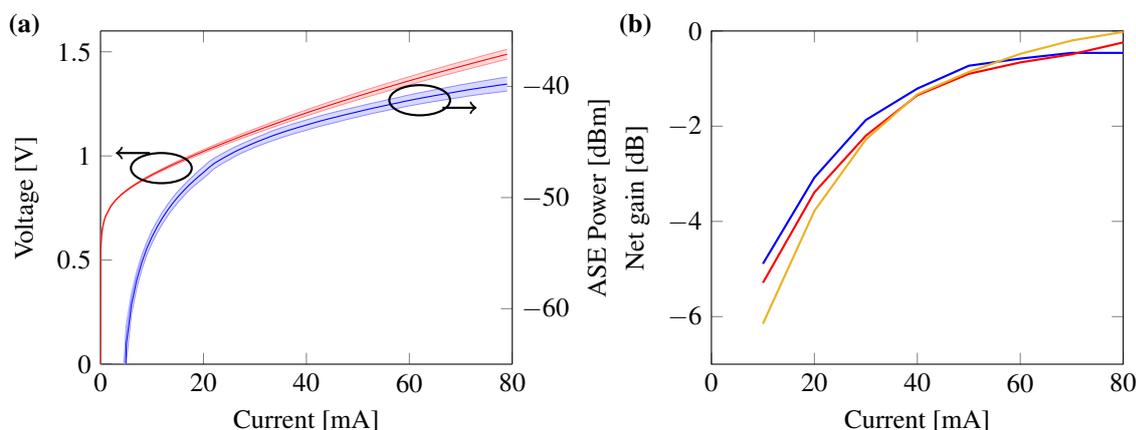


Fig. 2: Basic characterization of the transfer printed amplifiers. (a) The I-V curves and amplified spontaneous emission power for 17 tested amplifiers. The shaded area indicates the standard deviation of the measured values. (b) Net gain of three amplifiers, compared to a reference Si₃N₄ waveguide without a-Si waveguide on top.

3. Conclusion

We demonstrate transfer printing of a III/V-based amplifier on a silicon nitride waveguide using an intermediate layer of hydrogenated amorphous silicon.

References

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