Heterogeneously Integrated Laser on a Silicon Nitride Platform via Micro-Transfer Printing

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Abstract: We demonstrate the first heterogeneously integrated laser around 1550 nm on a silicon-nitride-on-insulator chip. Single-mode lasing at room temperature is achieved in a silicon nitride cavity comprising an adiabatically tapered III-V amplifier.

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1. Introduction

Over the past decades, telecommunication networks have grown to accommodate the exponentially increasing demand for data traffic. This evolution has been a major driver for the development of integrated photonics technologies, such as the silicon-on-insulator (SOI) and monolithic indium phosphide (InP) platforms. More recently, the silicon-nitride-on-insulator platform has emerged as a suitable platform for life-sciences applications. Silicon nitride (Si_3N_4) has a large transparency window and a lower index contrast with silicon oxide (SiO_2) than Si or InP, leading to a higher interaction of the optical mode with its surroundings. These qualities make Si_3N_4 an interesting material for sensing. Furthermore, ultra-low losses can be achieved in Si_3N_4 waveguides, allowing for long on-chip interaction lengths for sensors or long cavities for low-noise lasers. However, due to its lower refractive index, it is not straightforward to interface integrated III-V light sources with the passive Si_3N_4 circuits. Most commonly, hybrid integration techniques such as butt-coupling are used in device demonstrations [1, 2]. More recently, also flip-chip integration of a gain-chip in an etched recess on a Si_3N_4-chip was demonstrated [3]. To date, no laser sources operating around 1550 nm were heterogeneously integrated on a Si_3N_4-based chip. In this paper, we demonstrate the first single-chip, heterogeneously integrated, single-mode laser on silicon nitride using the micro-transfer printing method [4]. An InP/InAlGaAs-based semiconductor optical amplifier (SOA) is transfer printed on an intermediate waveguide layer of hydrogenated amorphous silicon (a-Si:H) and evanescently coupled to a Si_3N_4 ring cavity. In this first demonstration, over 100 µW waveguide-coupled output power is achieved at room temperature. Using the micro-transfer printing method, multiple material stacks could be heterogeneously integrated on the same chip, increasing the available functionalities on the silicon-nitride-on-insulator platform.

2. Design and fabrication

For applications around 1550 nm that require low waveguide losses, low-pressure chemical vapor deposited (LPCVD) stoichiometric Si_3N_4 is a better candidate than plasma-enhanced chemical vapor deposited (PECVD) Si_3N_4, since the N-H absorption peak at 1520 nm can be avoided in the former. To overcome the large index mismatch between Si_3N_4 ($n \simeq 2$) and InP-based gain materials ($n \simeq 3.2 - 3.5$) around 1550 nm, a 370 nm thick intermediate layer of hydrogenated amorphous silicon ($n \simeq 3.4$) is deposited on top of the Si_3N_4 using PECVD. In our approach, the blank Si_3N_4 wafer (300 nm Si_3N_4 on 3.3 µm SiO_2) was first covered with a-Si:H and subsequently patterned using two steps of e-beam lithography and reactive ion etching. An InP/InAlGaAs-based SOA [5] is transfer printed on the defined a-Si:H waveguide. The light is coupled from the Si_3N_4 layer to the amplifier via the intermediate a-Si:H layer using two linear tapers. The width of the a-Si:H at the taper tip is targeted around 130 nm, which is compatible with deep-UV lithography. The tapering structure is schematically shown in Fig. 1a. The laser consists of a 1 cm long spiral in the Si_3N_4 layer, adiabatically coupled to both ends of a 1150 µm long amplifier with a central gain section of 700 µm. Around 17% of the power in the cavity is extracted using a directional coupler. The schematic layout of the cavity is shown in Fig. 1b. A focused-ion-beam cross-section of the structure at the center of the amplifier is shown in Fig. 1c, together with a schematic drawing of the layer stack.

3. Measurement results

The device was measured at 15 °C, 20 °C and 25 °C. The voltage-current (V-I) and light-current (L-I) curves are shown in Fig. 2a. As expected, the lasing threshold current increases with the device temperature. The slope

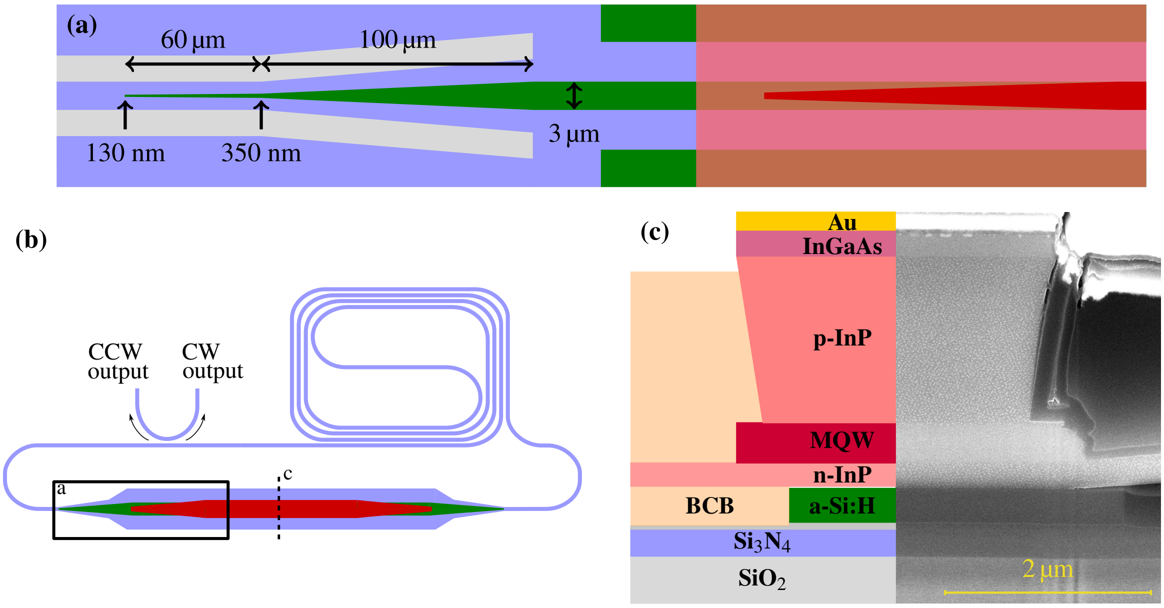

Fig. 1: Schematic layout of the laser cavity and the adiabatic coupling scheme. **(a)** Linear tapering structure. **(b)** Ring laser cavity design. The dashed line indicates the location of the cross-section. **(c)** Schematic drawing of the material stack (left) and SEM image of a cross-section of the device at the center of the amplifier section (right).

efficiency at 15 °C is 13.6 µW/mA. At 20 °C, it is 15.8 µW/mA between threshold and 80 mA. Single-mode lasing with over 100 µW waveguide-coupled output power is achieved at each temperature, with side-mode suppression ratios > 30 dB, as shown in Fig. 2b. The differential series resistance of the device is 20 Ω at a current of 70 mA.

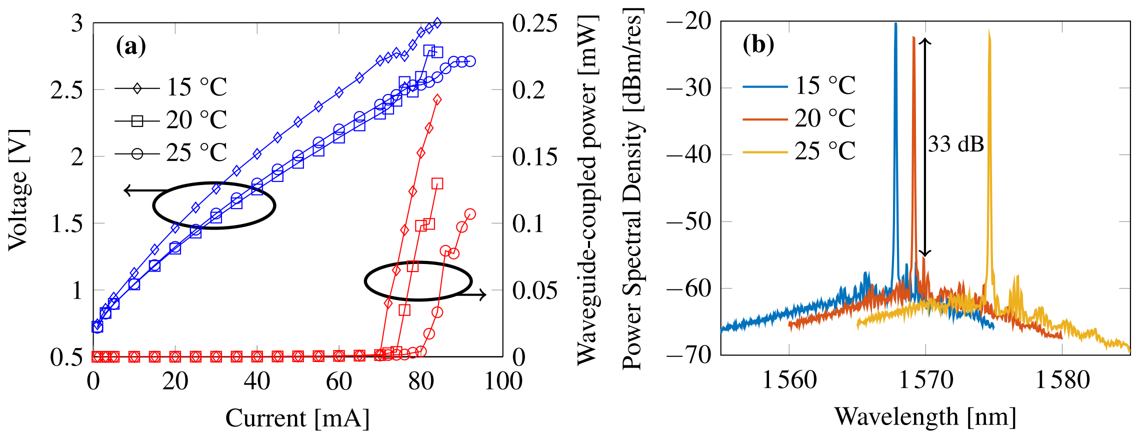

Fig. 2: Basic characterization of the device. **(a)** V-I and L-I curves. **(b)** Measured spectra above threshold.

4. Conclusion

We demonstrate the first heterogeneously integrated laser on a silicon nitride waveguide platform using micro-transfer printing. Further optimization is still possible, i.a. by reducing the device's series resistance, enabling more complex, fully integrated functionalities on Si_3N_4-based platforms.

References

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