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Abstract: Photonic membrane platforms attract a lot of research attention, because they can potentially enable integration of photonic and electronic components on a single chip. In membrane platforms photonic devices are usually separated from the substrate by a thick layer of insulator, so they suffer from inefficient heat sinking. We propose to bond membrane lasers on BCB and tune the bonding layer thickness to reduce the gap between the p-contact of the laser and the substrate, while an extra BCB layer is spun on the Si substrate to improve adhesion and reduce mechanical stress. This method enables direct heat sink from the membrane to the Si substrate on 3-inch wafer scale.

1. Introduction

Photonic integrated circuits (PICs) is a technology, which enables miniaturization, mass-manufacturability and reduced power consumption of optical devices. In membrane PICs, lasers and waveguides are fabricated on a thin (typically 300 nm) layer of semiconductor, which is adhesively bonded to a substrate wafer. One example of such a platform is InP membrane on Si (IMOS)[1], in which photonic devices are fabricated on InP wafer with epitaxial layers, then the wafer is bonded to a Si wafer and the InP substrate is removed. As the bonding layer is typically thermally insulating, a common problem for membrane lasers is power roll-off and red-shift of the gain due to Joule heating. Differential gain is also reduced at elevated temperatures, which is crucial for fabrication of lasers with high-speed direct modulation[2]. One way to overcome this is to create a gold via connection between one of the laser contacts to the Si substrate, however this approach requires extra lithography steps and complicates the general process flow. Another approach is to reduce the bonding layer as much as possible[3]. We designed the fabrication process flow in such a way, that the heat sink is naturally achieved on a full 3-inch wafer, while no additional mask layers are required.

2. Simulations

To simulate the thermal behavior, a finite-element solver in Lumerical commercial software is used. First we run an electrical-thermal coupled simulation which gives a heat power density generated inside the laser active layer above threshold. Based on this result, a thermal simulation which uses a point-like heat source in the center of the laser core is created (Figure 1a). Figure 1b shows, how the temperature distribution changes as the gap between the p-contact and the Si substrate is reduced.

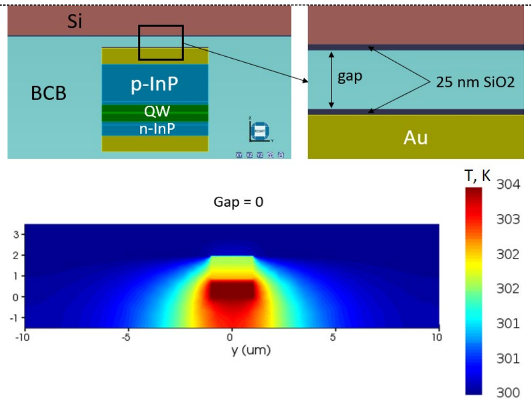

Figure 1a: FEM simulation of an SOA cross-section

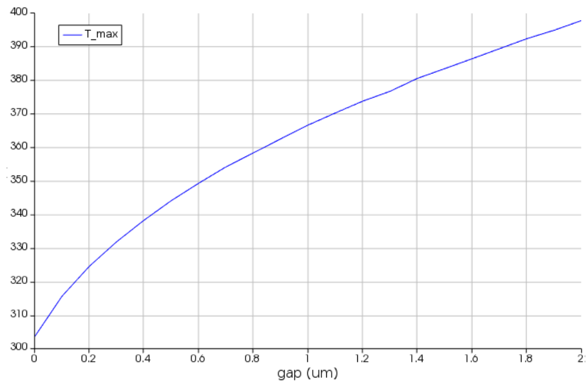

Figure 1b: Max temperature in simulation when the gap between p-contact and Si substrate is varied

3. Fabrication

In IMOS fabrication process flow, we intend to use optical scanner lithography before bonding to fabricate a mesa with p-contact and clear the p-doped layers everywhere on the wafer except from the SOA active region. With this sparse topology, the BCB layer, which is used as adhesive bonding layer, will efficiently planarize the wafer. By tuning the thickness of the BCB layer, we can thus tune the gap between the p-contact and substrate.

According to the Figure 1b, this gap should be 0-100 nm. The strain induced during the BCB curing due to different thermal expansion coefficients of Si and InP needs to be relieved. This might be achieved by spinning a layer of thin diluted BCB on the Si wafer. An expected laser cross-section is shown on Figure 2a.

The experiment was done on a dummy InP wafer without an etch-stop layer. Topology equivalent to the one used in real lasers (mesas and waveguides) was created by means of optical lithography, RIE and ICP etching. A layer of BCB with thickness of 900 nm was spun on the InP wafer and a layer of BCB with thickness 75 nm was spun on the Si wafer, after that 2 wafers were brought in contact and put under force of 700 N. Finally, the BCB was cured, and the InP substrate etched away in concentrated HCl.

The wafer was cleaved across the SOA-mimicking structures and the cross-section was studied in SEM. The images of a sample (Figure 2b) approximately 3 cm long show that along this length all structures achieved a gap of <100 nm between the gold layer and Si. The gold layer which corresponds to the p-contact of a real laser was in contact with Si wafer, separated from it by 25 nm of SiO2, 50 nm of BCB and another 25 nm of SiO2. The thermal conductance achieved is 0.0193 W/K for a 100 um laser.

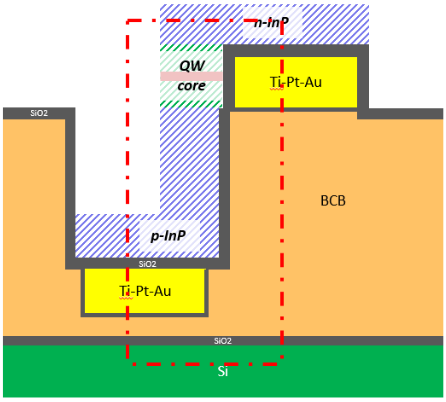

Figure 2a: Schematic cross-section. The expected laser shape is filled with diagonal stripes

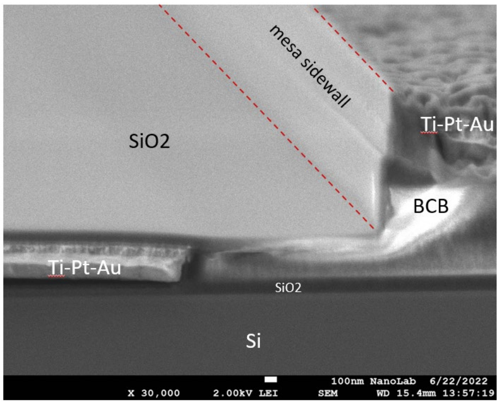

Figure 2b: SEM image of the wafer cross-section, where the topology mimics that of a real laser

4. Discussion

Repeating the experiment on a real epitaxial wafer revealed some risks related to this bonding method. One of the most important is that BCB works as stress reduction layer between Si and membrane, the lower the BCB thickness, the higher is stress in waveguides, and below some critical BCB thickness it may lead to membrane break for the most sensitive structures. Therefore, the thickness of BCB has to be increased to reduce the stress. A comparison of laser performance with and without a heat sink is required to finalize the experiment.

4. Conclusion

A method of heat sink fabrication for InP membrane lasers is proposed and tested on a dummy InP wafer. Simulations confirm that this method should enable very efficient heat extraction. It does not require extra fabrication steps and can be easily integrated into the existing process flow.

5. Acknowledgements

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6. References

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