Optically pumped lasing from InP membranes grown on silicon-on-insulator by tunnel epitaxy

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***Abstract* — We present a lateral tunnel epitaxy technique to grow InP membranes atop silicon waveguides on silicon-on-insulator substrates. Uniform InP membranes extending hundreds of micrometers in length can be achieved. Room temperature optically pumped lasing was also realized, showcasing the excellent crystal quality.**

Keywords* — *Silicon photonics, MOCVD epitaxy, III-V on silicon, III-V membrane photonics

I. Introduction

Monolithic integration of compact III-V lasers with silicon waveguides is crucial for advancing silicon photonics. Compared to wafer bonding or micro-transfer printing methods, selective area heteroepitaxy offers advantages including reduced cost and improved scalability. However, there are fundamental material challenges to grow III-V lasers directly onto silicon photonics platforms without involving thick buffer layers. [1] Recent advancements have shown promise in overcoming these limitations by growing III-Vs laterally in geometrically confined cavities. [2-5] Nevertheless, significant effort are needed to achieve electrically injected lasers with efficient coupling to silicon waveguides. Here, we present a tunnel epitaxy technique to grow InP membranes directly above silicon waveguides on silicon-on-insulator (SOI) substrates. These uniform InP membranes, with dimensions of several hundred micrometers in length and a few micrometers in width, are free of anti-phase boundaries (APBs) and have a very low density of threading dislocations. Under optical pumping, we demonstrate room temperature lasing with a threshold of 110 μJ/cm^2.

II. Results and Discussion

Figure 1a illustrates the schematic of the tunnel epitaxy method for the growth of III-V membranes on SOI substrates. A silicon V-groove is formed inside an etched cavity surrounded by SiN and SiO_2 dielectrics. We then performed metal-organic chemical vapor deposition (MOCVD) to grow InP within the cavity forming membranes above the silicon waveguides and the SiO_2 cladding. This approach places the InP membranes directly atop the silicon waveguides, separated by a thin SiN gate layer — a structure closely resembling the currently used heterogeneously bonded InP membranes. The microscope image in Figure 1b displays the epitaxial InP membranes situated inside the cavities. The InP membranes exhibit a smooth growth front with very few visible pits or irregularities, demonstrating the high quality and uniformity of the growth process.

The use of silicon V-grooves inside the growth cavity is important for preventing antiphase domains. Figure 2a shows the crystal diagram of zincblende III-V growth originating from the silicon V-grooves and laterally evolving into extended membranes. The surface silicon atoms of the silicon V-groove are derived from the same face-centered cubic (FCC) lattice (Silicon FCC lattice 1), even when surface steps are present. This lattice uniformity prevents the formation of APBs during the epitaxial growth process. After the top SiN layer was

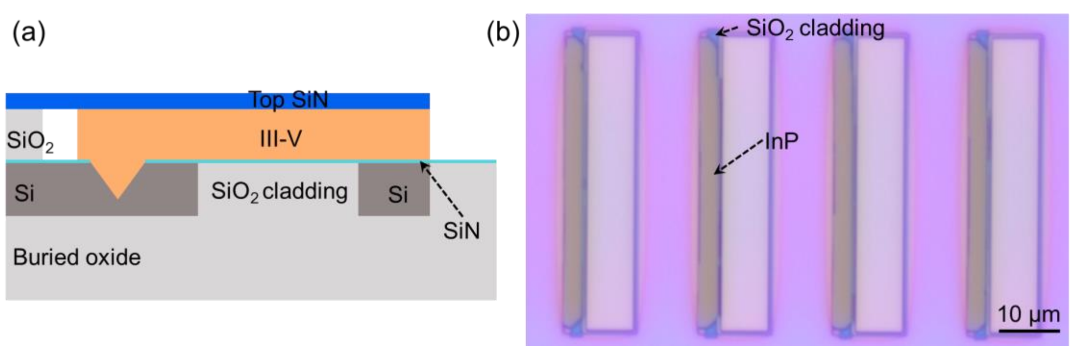

Figure 1. (a) Schematic illustration of the lateral tunnel epitaxy process for III-V membranes on SOI substrates. (b) Optical microscope image of the as-grown InP membranes on SOI. The underlying SiO_2 cladding layer is also visible.

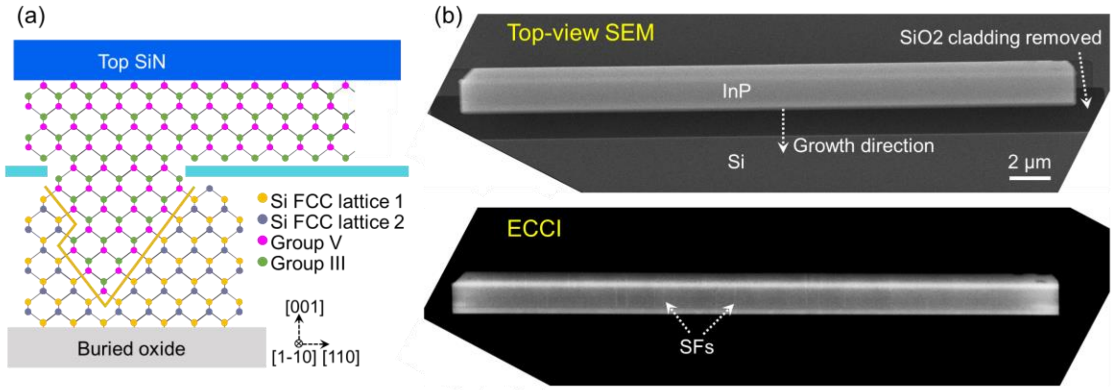

Figure 2. (a) Crystal diagram of the lateral tunnel epitaxy process for III-V membranes on SOI substrates. (b) Combined top-view SEM and ECCI images of an InP membrane, with both the top SiN layer and the underlying SiO_2 cladding removed.

removed, the InP membrenes were characterised by the scanning electron microscopy (SEM) and electron channeling contrast imaging (ECCI) , as seen in Figure 2b. The ECCI analysis confirmed the absence of APBs and the membranes are nearly dislocation free with only a few stacking faults (SFs) parallel to the growth direction. These SFs tend to extend through the entire InP membranes, preventing the introduction of partial dislocations within the epitaxial structure, making them benign to device performance. These results demonstrate the advantage of the lateral tunnel epitaxy method in growing high crystal quality materials with minimum buffer layers.

The InP membranes were transferred to a SiO_2/Si substrate and optically pumped using a pulse laser at room temperature. Under low excitation power, Fabry-Pérot (FP) resonances were observed (Figure 3). Once the threshold was exceeded, lasing occurred, demonstrating the high optical quality of the InP membranes.

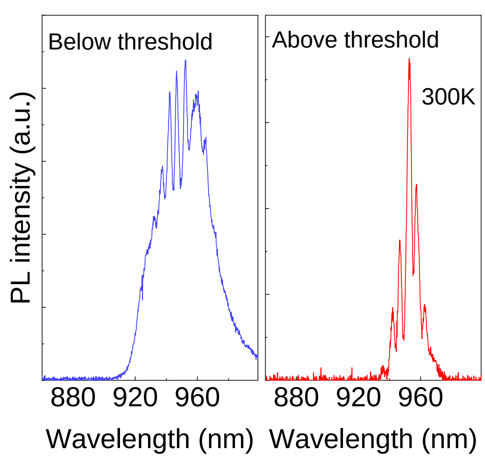

Figure 3. Room temperature lasing spectra of the optically pumped InP membrane laser below and above threshold.

III. Conclusions

In conclusion, we have demonstrated the epitaxial growth of large-area, uniform InP membranes directly on top of silicon waveguides. These membranes closely resemble heterogeneously bonded InP membranes integrated with silicon waveguides and demonstrate high crystalline and optical quality. The tunnel epitaxy technique thus offers a promising pathway for the monolithic integration of high-performance membrane lasers and electrical-optical modulators.

Acknowledgment

This work was supported by Engineering and Physical Sciences Research Council (grant number EP/T01105X/1), the Future Compound Semiconductor Manufacturing Hub (EP/P006973/1), and alongside funding from Rockley Photonics prosperity partnership (EP/R003076/1). D. J. Thomson acknowledges funding from the Royal Society for his University Research Fellowship (UF150325).

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