

Heterogeneous Integration of InP Devices on Silicon

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Abstract — In the paper, we review our work on heterogeneous integration of InP photonic devices on silicon. We elaborate on two integration technologies that have been widely explored in the Photonics Research group, i.e. the relatively mature adhesive bonding based integration scheme and a newly demonstrated buffer-less epitaxial growth approach. Based on these techniques, we describe a broad range of photonic devices including mode-locked lasers, high speed directly modulated distributed feedback lasers, electro-absorption modulators, photodetectors, superluminescent light emitting diodes, etc.

Keywords—heterogeneous integration; epitaxial growth; optical communication; photonic integration, optical sensing

I. INTRODUCTION

Emerging as an attractive integrated photonics platform, silicon photonics uses 200mm or 300mm CMOS fabrication infrastructure to manufacture compact photonic ICs with capability of mass production and hence low cost¹. In addition, the co-integration of electronics with photonics is also becoming a reality². While 56Gbps photodetectors and optical modulators are readily available³, an efficient way of light generation on chip becomes the fundamental limit that hinders the wide adoption of silicon photonics. Here, we review two technologies that can integrate InP-based laser sources and other opto-electronic components on silicon in a scalable way.

II. HETEROGENEOUS INTEGRATION TECHNOLOGIES

Over the past decade, the bonding technology has been well-developed⁴. By using adhesive agents, benzocyclobutene (BCB) in this case, we are able to realize wafer scale integration of InP-based epitaxial layer structures on silicon with high yield, and an example of a silicon photonic chip with multiple bonded InP dies can be found in Fig. 1. After the III-V material is bonded onto silicon photonic ICs, the post-processed photonic components are lithographically aligned to the underlying silicon waveguide circuit (see Fig. 1). As a near-/mid-term solution, the adhesive bonding technology suits well the primary target of silicon photonics, i.e. optical interconnects, with the possibility of scaling from the first commercially available 4x28G transceivers to 400G or 1.6T transceivers by integrating arrays of III-V lasers on silicon in a cost-effective way. We will elaborate on some photonic devices that were demonstrated in the past few years, including single wavelength InP DFB lasers, tunable extended cavity lasers, multi-wavelength lasers, modelocked lasers, but also electro-absorption modulators and photodetectors (see an example of MLL in Fig. 2). Also GaAs VCSELs have recently been integrated onto a silicon photonics platform. Beyond the field of optical interconnects, silicon photonics is expected to also have an impact on the field of optical sensing. Such optical spectroscopic sensor systems integrated on a silicon chip require the integration of light sources and photodetectors operating at wavelengths outside the telecommunication wavelength window. In this paper we will present the integration of broadband waveguide coupled LEDs and spectrometer photodetector arrays covering the 1.5 to 4 μm wavelength range (see an example of type II InP QW photodiodes in Fig. 3).

As a long-term solution, the possibility of growing III-V materials directly on silicon enables to fully benefit from the economies of scale offered by processing in advanced CMOS foundries on large wafers. For this to become reality considerable hurdles need to be overcome: the large lattice mismatch ($\epsilon_{\text{InP/Si}} = 8.06\%$), the difference in thermal expansion and the different polarity of the materials result in large densities of crystal defects. Recently, boosted by the renewed interest of the electronics industry in using high-mobility compound semiconductors in next-generation CMOS, considerable progress has been made on low-defect-density direct growth of III-Vs on silicon. Well-optimized epitaxial technology confines the defect layer within 20 nm at the interface of InP and silicon. Such buffer-less growth techniques has led to the recent demonstration of an InP DFB laser array grown directly on silicon (Fig. 4)⁵. The possibility of using well-established in-plane laser configuration and the top-down integration scheme provide a route towards the monolithic integration of dense arrays of III-V laser sources with Si photonic circuits.

III. REFERENCES

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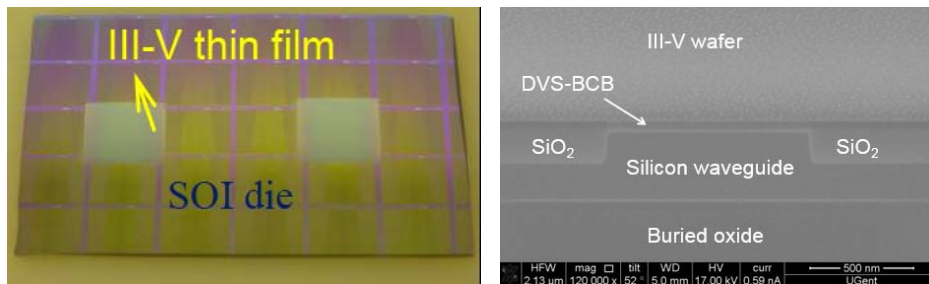


Fig. 1 (left) Multiple InP dies bonded on a silicon photonic IC. (right) A scanning electron microscope (SEM) image of the cross-section of the InP wafer bonded on top of a silicon waveguide.

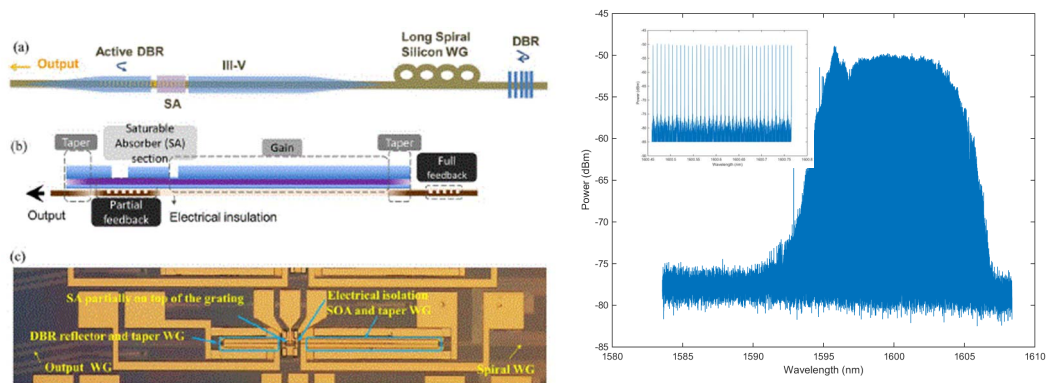


Fig. 2 (left) Layout of the III-V-on-silicon mode-locked laser cavity: (a) top view; (b) longitudinal cross-section. A microscope image of the fabricated device is shown in (c). (right) High-resolution optical spectrum of the ps output pulse (20 MHz spectral resolution). Insert shows a zoom-in image of the optical spectrum, representing an optical frequency comb with 1 GHz spacing.

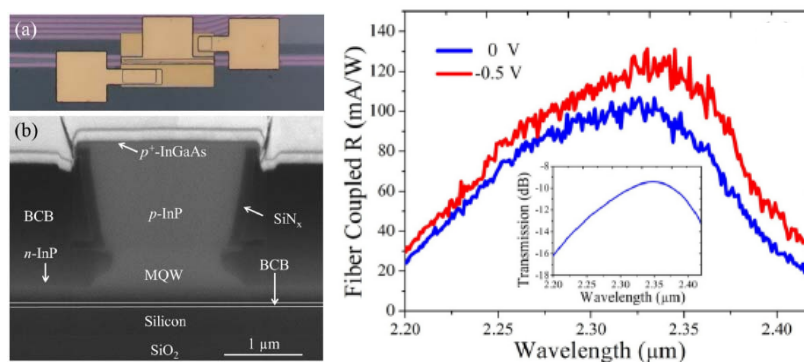


Fig. 3 (left) (a) Microscope image of the heterogeneously integrated type-II quantum well photodiode; (b) SEM image of the cross section of the fabricated devices. (right) Dependence of the fiber coupled responsivity (R) on the input laser wavelength under reverse bias of 0 V and 0.5 V, the inset figure shows the grating coupler efficiency as a reference.

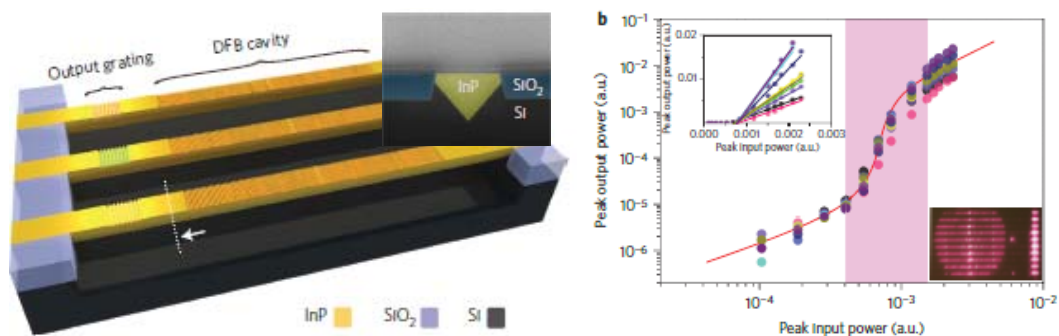


Fig. 4 (left) Schematic plot of the InP DFB laser array integrated on silicon. Insert: SEM image of a InP-on-Si waveguide (right) Measured L-L curves of an array of ten DFB lasers. Inset (top): linear-scale version of the ten log-scale L-L curves presented in the main panel. Inset (bottom): camera-recorded photoluminescence image of ten working lasers under a large-area pumping condition.