# Engineering the heterogeneously integrated III-V/SOI tunable laser

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Recently reported state-of-the-art adhesively bonded III-V/Silicon laser diodes are fabricated using the adhesive DVS-BCB. The efficiency of the laser is mostly related to the coupling efficiency between the III-V and SOI waveguide layer. In this paper, an adiabatically tapered heterogeneously integrated III-V laser is engineered for high coupling efficiency, while at the same time resulting in a short length device and the optimum structure with respect to the fabrication tolerances. Moreover, a tunable laser design in order to demonstrate suitability of this technique in the realization of an array of single wavelength lasers is presented and discussed.

## Introduction

Photonic integrated circuits offer the potential of realizing low-cost, compact optical functions. Silicon-on-insulator (SOI) is a promising material platform for this photonic integration, as one can rely on the massive electronics processing infrastructure to process the optical components. However, the integration of a Si laser is hampered by its indirect bandgap. Silicon Raman lasers have been demonstrated but external optical pumps are required [1]. Recently, some research groups proposed to integrate a direct bandgap III-V material on top of a SOI waveguide substrate to achieve stimulated light emission and to couple this stimulated emission to the underlying SOI waveguide circuit. This technique, semiconductor wafer bonding, allows the dense integration of high-quality III-V epitaxial layers on top of a Si platform by transferring the III-V layer stack from its original growth substrate to the SOI wafer.

Recently, several devices based on evanescent coupling were demonstrated. The first, hybrid III-V/SOI Fabry-Perot laser (emitting at 1.55μm), was reported in 2006 [2], followed by a DBR [3] and DFB lasers [4], in 2008. These devices were based on molecular wafer bonding procedure, which is based on van der Waals forces and as this is a short-range force, sub-nm rms roughness of the surfaces is required. Therefore, this technique may not be robust enough for fabrication where such strict requirements are difficult to meet. In the second approach, heterogeneous integration based on DVS-BCB adhesive bonding as an alternative method is actively pursued in the photonics research group at Ghent University [4].The major challenge in this method is the light coupling from the top active III-V layer into the bottom SOI waveguides because of the additional polymer layer between them. For realizing highly efficient coupling and compact devices, we introduce an adiabatically tapered coupler for III-V layers and SOI waveguides. Finally we also introduce a tunable single mode laser based on this technique, useful for telecom applications.

## Adiabatic III-V/silicon taper Laser Design

In the adhesive BCB bonding method, the epitaxial III-V structure is bonded on top of the SOI waveguide, using a spincoated DVS-BCB adhesive layer. The adiabatic taper III-V/silicon laser and the general layout of the structure are given in Figure 1. It comprises the n-type InP spacer layer and the mesa structure on top of it. The mesa is

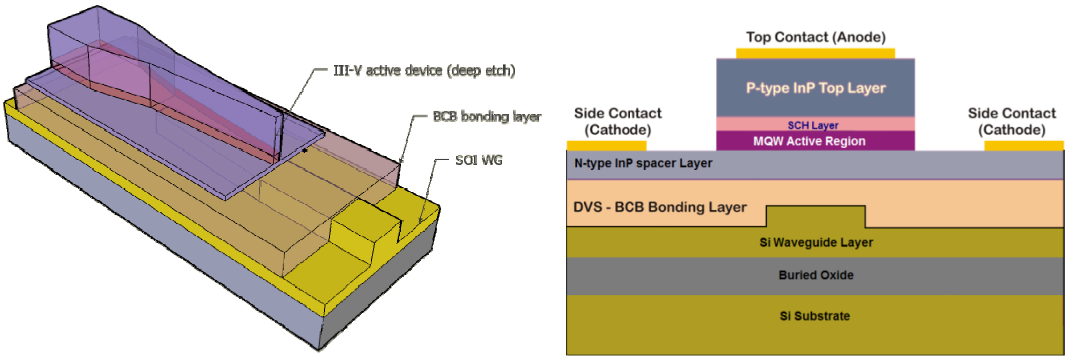


Figure 1.The schematic of adiabatic tapered III-V/silicon laser and cross-section

made of the multiple quantum well (MQW) region (emitting at $\lambda = 1.55$ µm), a separate confinement heterostructure (SCH) layer, a p-type InP top cladding layer and an ohmic contact. The efficiency of the laser is related not only to the losses of the waveguide, but also to the coupling efficiency of the two waveguides. The coupling efficiency of the two tapered optical waveguides depends on the thickness of the BCB layer, which is part of bonding process, the length of the tapered waveguide and other geometrical parameters which should be considered in the real structure. Furthermore, the fabrication tolerances and the overall size should be considered when selecting the optimal design. In our design, the underlying rib waveguide is fabricated on a standard SOI platform, with the length of L, tapering from 1 µm width to 400nm. In reverse direction over that, two tapers for III-V, one of them from 2µm width to 900nm width (length of L1), another from 900nm width to 500nm width again with the length L (Figure 2).

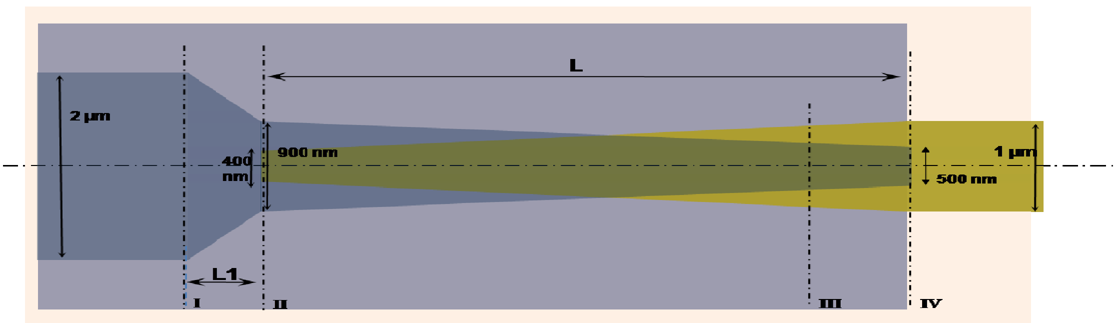


Figure 2.The layout of adiabatic tapered III-V/silicon for the first design

## Optical Property of device and discussion

A fully vectorial mode finder software, FIMMWAVE, was used for the studying the optical properties of the device. The forward power (FWP) of the fundamental mode (TE) was calculated for various taper lengths as well as different thicknesses of BCB. In order to find the optimum length we consider a simple structure with two linear tapers for III-V and one linear for SOI waveguide (Figure 2) as described above. The results of these simulations, given as plots of the forward power (left to right) for the fundamental mode versus taper length with different BCB thicknesses are shown in Figure 3 a, b. Results of these simulations show the optimum length for high coupling for the first linear taper is around 20um (independent of bonding layer thickness) and for the second part, where the light is actually coupled from the III-V to the silicon waveguide, a taper with a length in the range of 100um to 150um results in a near to 100% mode coupling, provided that the BCB thickness is less than 100 nm. For illustration, the mode profile in different cross-sections for L1=20µm, L=150µm and BCB thickness=80nm is presented in Figure 3c.

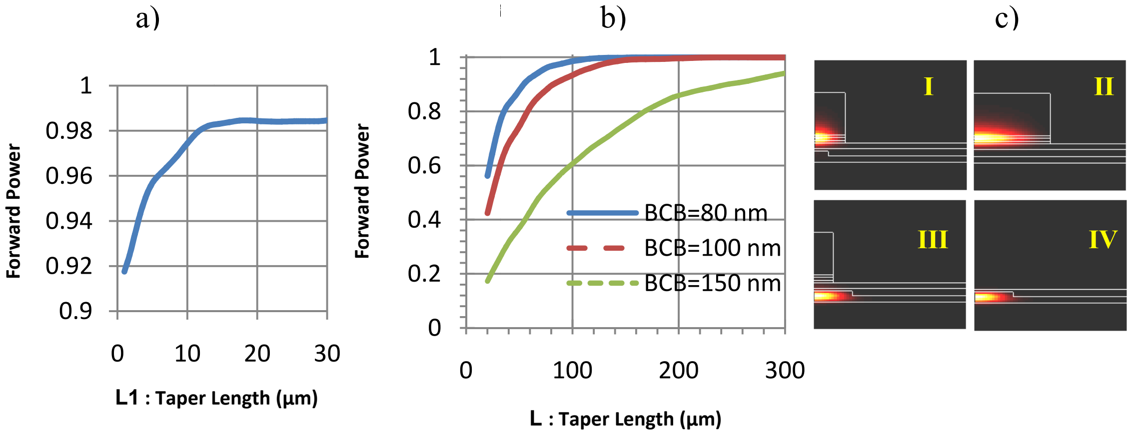


Figure 3.Forward power for the fundamental mode for various taper length a) first taper b) second taper for different value of BCB thickness c) an example for fundamental mode profile in four different cross-sections are shown in figure 2.

These results show a very good coupling from top bottom during the propagation from left to right. The study of lateral misalignment for two vertical tapers is very important especially from the fabrication point of view. If we consider a lateral shift y from the III-V waveguide with respect to the Si waveguide resulting from the fabrication process (Figure 4 a), the results for the forward power to the Si WG versus different values of y are presented in Figure 4 b.

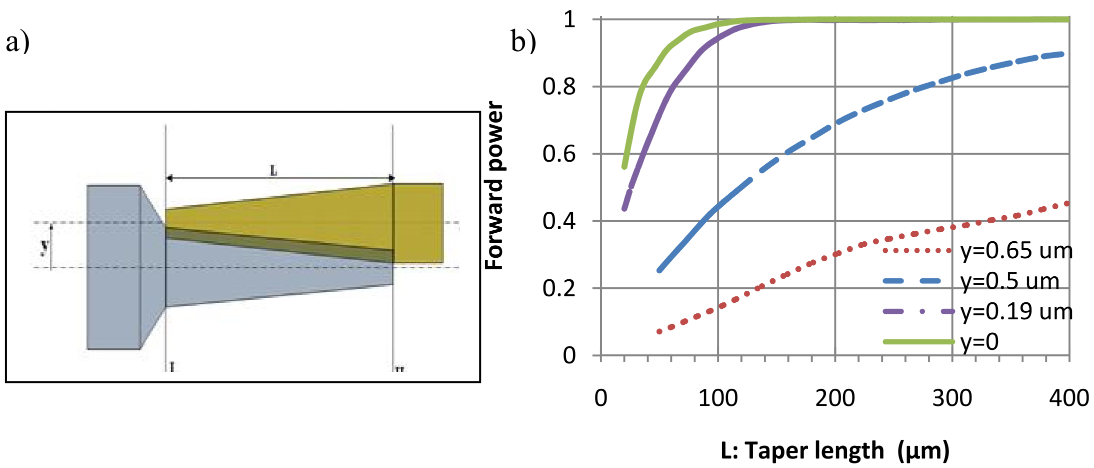


Figure 4.a) the layout for the lateral misalignment of y b) the forward power of fundamental mode versus the taper length of L for different values of y and BCB thickness 80nm.

Compact optical functions are very important and particularly for integrated photonics applications. In the design described above, we employed a simple two step linear taper. For decreasing the footprint of adiabatic taper structures, optimum functions could be find [5]. As an alternative, we investigated a multi-step taper, consisting of several piecewise linear taper sections. As an example just with choosing a three step linear taper for the III-V waveguide and a one step linear taper for the Si waveguide and suitable lengths for them, we achieved a coupling efficiency around 100% with the parameters in Figures 5 (total taper length of only 43.9um).

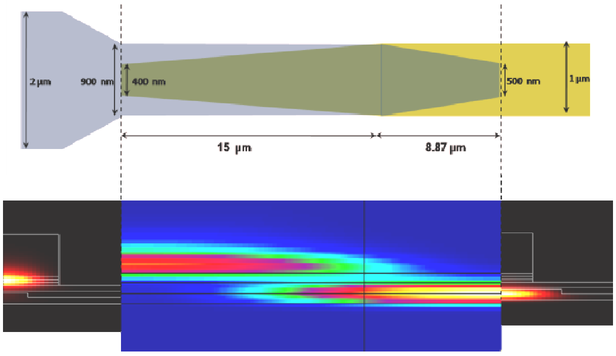


Figure 5.a mode transfer structure with optimize taper length.

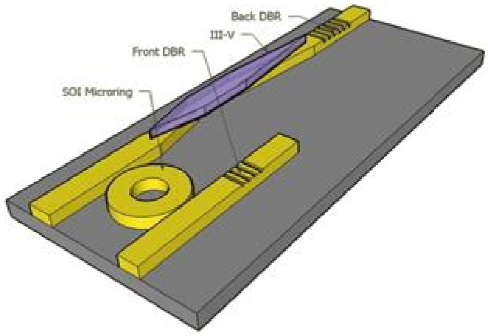


Figure 6.The schematic of adiabatically tapered heterogeneously integrated III-V/Si for a single mode laser.

Making a tunable laser in this structure offers several promising advantages since we can define the laser cavity in the SOI waveguide by employing DBR gratings or other wavelength selective components. This gives a very high accuracy and possibly low cost. In this paper, we introduce a preliminarily design for a single mode laser with two DBR gratings and one microring resonator in this approach (Figure 6). Here we introduced a preliminary design for a single mode laser with two DBR gratings and a single microring resonator using this approach (Figure 6). In this laser, we consider a back DBR grating with reflection near to 1 and bandwidth of 50nm; on the other side there are a wavelength selective microring with FSR of around 25nm and a front reflector with DBR grating. The reflectivity of the front DBR grating should be 0.4-0.7 to achieve a good laser output power into the rest of the integrated components. For tuning the wavelength one can either use carrier injection or the thermo-optic effect.

## Conclusion

In this paper we propose an adiabatically tapered III-V/Silicon laser, based on BCB bonding. From extensive simulations we derived the optimal values for taper length and width for acceptable range of the BCB layer thicknesses and taking into account reasonable fabrication tolerances. In our future work, we will fabricate a tunable single mode laser according to this design and characterize it.

## Acknowledgments

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