Towards a heterogeneous III-V/SOI single wavelength tunable laser

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Heterogeneous integration of III-V active material based on DVS-BCB adhesive bonding is actively reported in state-of-the-art hybrid lasers. The major challenge in this method is the light coupling from the top active layer into the bottom SOI waveguides because of the low index layer between them. In this paper, we introduce some new methods for making a high efficiency and compact coupler; finally we propose an electrically pumped amplifier as well as a tunable single mode laser based on this technique for telecom applications.

Introduction

In recent years, silicon photonics has emerged as a state-of-the-art technology suitable for industrial-scale fabrication of high-performance photonic integrated circuits. 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]. This situation has driven research to the heterogeneous integration of III-V on silicon. One of the heterogeneous integration approaches is the use of wafer bonding techniques [2-3]. In such an approach, III-V dies are bonded on a SOI wafer, and then processed to fabricate lasers lithographically aligned to silicon waveguides. Recently reported state-of-the-art adhesively bonded III-V/Silicon laser diodes are fabricated using the adhesive DVS-BCB [3]. The critical issues of hybrid III-V/SOI lasers is to design a laser structure, able to generate light in III-V materials and then to couple it efficiently from the III-V material to a silicon waveguide underneath. One of the proposed solutions is based on evanescent coupling, in which the optical mode is mainly confined to the silicon waveguide and interacts through its evanescent tail with the multi-quantum wells layer [3]. Another solution is to use a double tapered structure, incorporating mode transformers in both the III-V and silicon waveguides [4]. Mode coupling occurs in the tapered region, while light generation and amplification take place in a single mode III-V waveguide. In this paper, we report the first demonstration of such a hybrid III-V/Si laser. Finally, we introduce a tunable single mode laser based on this technique and also a new design for a compact hybrid laser without any tapering section.

Device structure

The major challenge in the adhesive BCB bonding method is the optical 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. If we consider half of the device structure Fig.1, the structure can be divided into three parts. In the section (1), there is a III-V waveguide that provides optical gain. At right side of it, there is a coupling region that couples light from one guide to the other. The section (3) is a silicon waveguide without III-V on top.

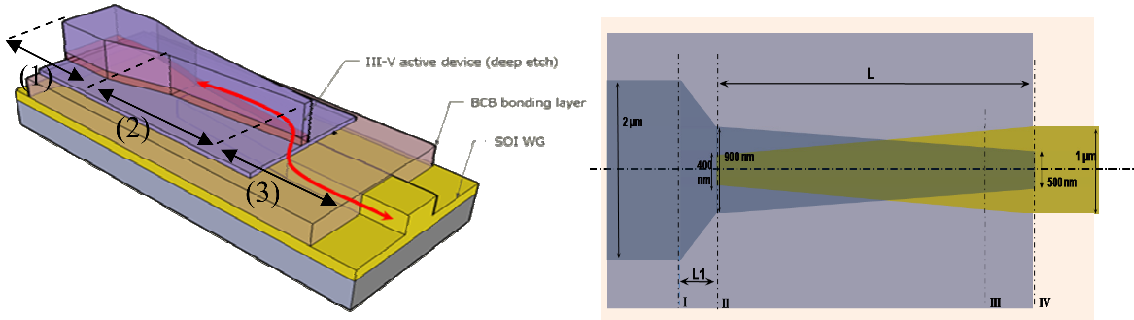
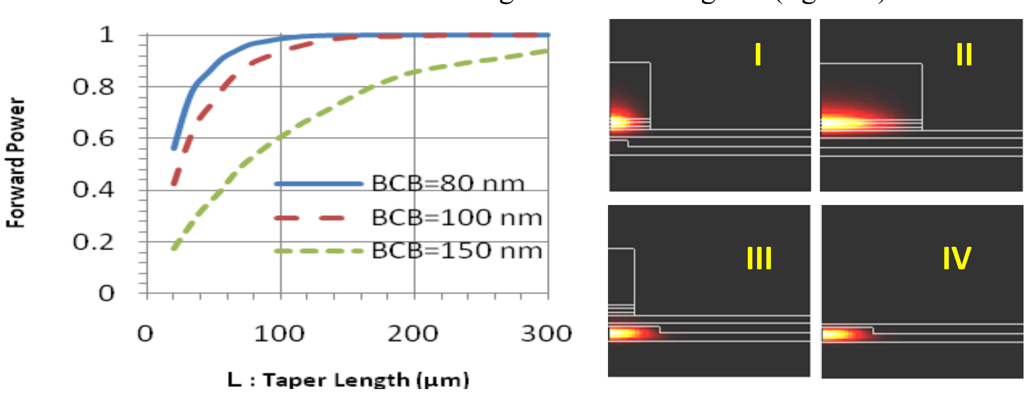


Fig 1.The schematic of adiabatic tapered III-V/silicon laser and layout for design

The III-V region has a multiple quantum well (QW) double heterostructure, which consists of a p-InGaAs contact layer, a p-InP clad, 6 InGaAsP QW surrounded by two InGaAsP separate confinement heterostructure (SCH) layers, and an n-InP layer. The QWs consist of six 8nm thick 1.55Q-InGaAsP well layers separated by 10nm thick 1.17Q-InGaAsP barrier layers. The thickness of both SCH layers is 100nm and the thickness of the n-InP layer is 200nm.The SOI substrate (200mm wafer manufactured by SOITEC) is composed of a mono-crystalline silicon layer (thickness of 400nm) on top of a 2µm thick buried oxide layer on a silicon substrate. The silicon rib waveguides have a height of 400nm, an etch depth of 180nm and a width of 1µm.

The coupling efficiency of the two tapered optical waveguides depends on the thickness of the BCB layer, which is determined by the bonding process, the length of the tapered waveguide and other geometrical parameters which should be considered in the real structure. In our design, the underlying rib waveguide with the length of L, is tapering from 1 µm width to 400nm. In reverse direction over that, the design consists of two tapers for III-V, one of them from 2µm width to 900nm width (length of L1), and another from 900nm width to 500nm width again with the length L (figure 1).



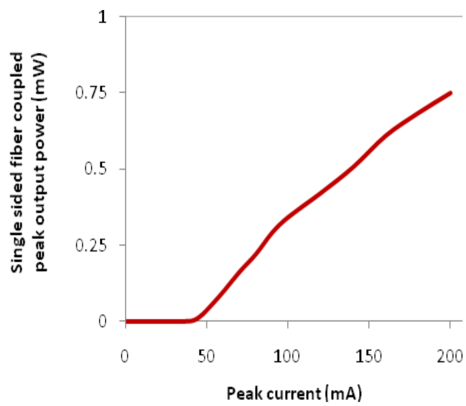
a) b)

Figure3. a) Forward power for the fundamental mode for various taper length and different value of BCB thickness b) an example for fundamental mode profile in four different cross-sections are shown in Fig1.

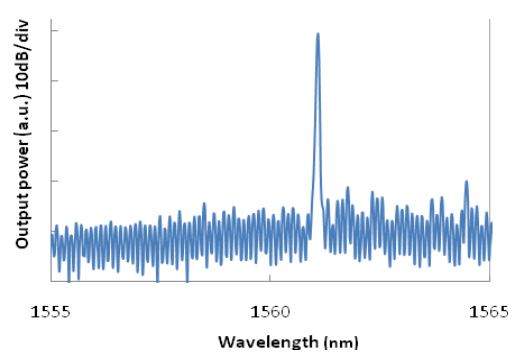
A fully vectorial mode finder software, FIMMWAVE, was used for studying the optical properties of the device. The first results of these simulations, given as plots of the forward power (left to right) for the fundamental mode versus taper length with different BCB thicknesses are shown in Figure 3 a, b. Furthermore, the fabrication tolerances and the overall size should be considered when selecting the optimal design [4].

Experimental results

The first design was the hybrid III-V/silicon amplifiers without any cavity structures in the SOI. In order to have a Fabry-Perot hybrid III-V/silicon laser, after the fabrication process for the III-V layer, the mirrors on the passive SOI waveguides are formed by cleaving the SOI wafer. The device is mounted on a temperature controlled stage set to 20°C. The output laser beam is collected by a lens fiber coupled to the silicon waveguide cleaved facet. The coupling losses are estimated to be higher than 5dB. The L-I curve is shown in figure 2a. The laser is electrically pulse-pumped up to 200mA, with a pulse period and width of 10µs and 180ns. The device has a lasing threshold of 45mA and a maximum fiber coupled power of 0.75 mW at both sides. The series resistance is 12 Ohms. The lasing spectrum is shown in figure 2b [5].



a)



b)

Figure3. a) Fiber coupled laser power as a function of drive current (L-I curve) under pulsed operation at 20°C. b) Optical spectrum of the laser driven at 55mA

New designs

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 (Figure 4 a). 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 in the ring resonator.

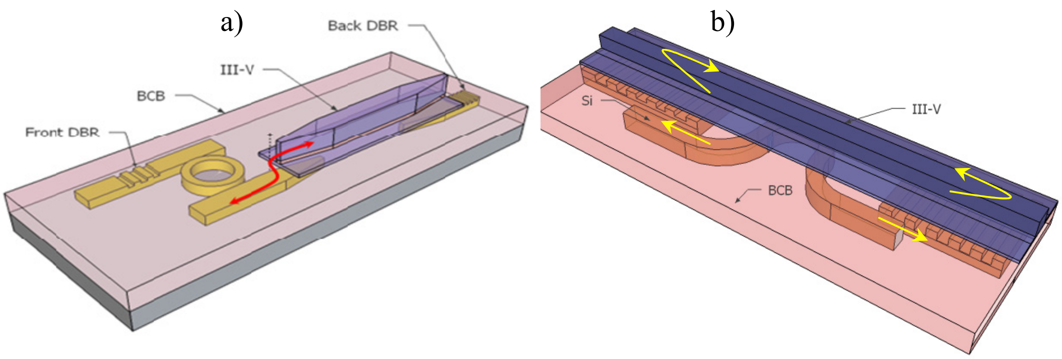


Figure 4.The schematic of a) adiabatically tapered heterogeneously integrated III-V/Si for a single mode laser b) active DBR with the evanescent coupling waveguide in the center of laser cavity

Adiabatic tapers provide very high efficiency coupling with the very low losses. However, the main challenge is the fabrication of the required, narrow tapering tips in III-V waveguides. Another solution is shown in Figure. 4b. In this new design, two active DBR gratings were considered with ~100% reflection for the laser cavity and the evanescent coupling interface is positioned within the laser cavity to achieve the laser output power. One of the main advantages of this device is that all patterns defining the laser cavity can be defined in the optical passive material, resulting in an easier manufacturing and more accurate hybrid laser. Such a hybrid laser design offers much simpler device fabrication, since light coupling elements, like tapers which can be very challenging for fabrication, are not needed. Also, this helps to reduce the device footprint and achieve more compact devices.

Conclusion

We propose an adiabatically double tapered III-V/Silicon laser, based on BCB bonding. Moreover, we achieved laser action under pulsed regime with a threshold current of 45mA and a fiber coupled output power near 1mW. In our future work, we will fabricate a tunable single mode laser according to this design.Also the new type of hybrid laser without any tapered waveguide will be demonstrated.

Acknowledgments

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