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Improved fabrication process for III-V based Optical Interconnects on Silicon

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***Abstract*—We present a controllable bonding method and a self-aligned process for III-V based optical interconnects on Silicon. Optical interconnects are demonstrated with microdisk lasers with either ultra-low threshold current or record high slope efficiency.**

***Keywords*—optical interconnect; silicon-on-insulator; heterogeneous integration; microdisk laser**

I. INTRODUCTION

Electrical interconnects are expected to form a major bottleneck in future integrated electronic circuits. Optical interconnects have been proposed as a possible solution to overcome this bottleneck [1]. Silicon-on-insulator (SOI) is considered an interesting platform for optical interconnects given its CMOS compatibility. Numerous devices have already been demonstrated on SOI, but integrating light sources and detectors on silicon is challenging. A possible route is heterogeneous integration of III-V material with silicon through a bonding process. Recently, we demonstrated a simple fabrication scheme that enables compact integration of III-V based microlasers and detectors on silicon, using a single epitaxial structure that contains layers for both the laser and detector [2]. In this fabrication scheme all the processing steps for the laser and detector are carried out simultaneously except for the etching of the detector mesa.

In this paper, we present improvements in this fabrication process to enhance the performance of the devices and show experimental results of optical interconnects processed using this new approach.

II. DESIGN AND TECHNOLOGY

A microscope image of the optical interconnect and a schematic representation of the cross-sections of the microdisk laser and detector are shown in Fig. 1(a-b). The link consists of a microdisk laser with a diameter of 7.5 µm which is connected to detectors with a mesa width of 5 µm and a length of 60 µm, through a silicon waveguide. As the microdisk supports clockwise and counterclockwise modes, detectors are placed on both sides of the microdisk.

Two critical steps in the fabrication process are the control of the bonding layer thickness and the alignment of the top contact with respect to the microdisk.

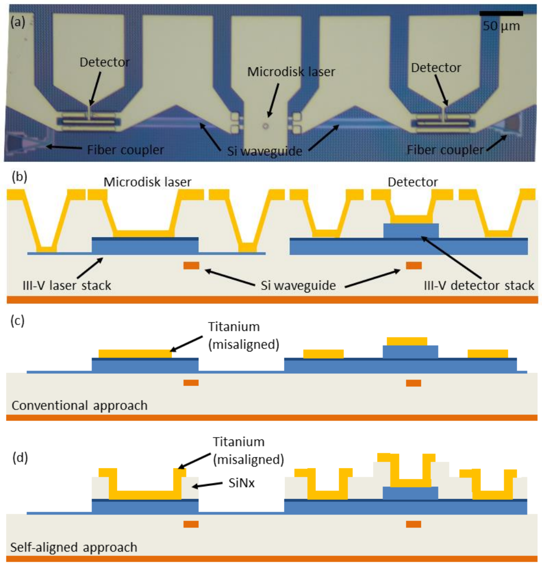

Figure 1. (a) microscope image of the optical interconnect (b) schematic representation of the cross-section of the microdisk laser and detector (c) conventional approach for top contact resulting in misalignment (d) self-aligned process for top contact resulting in perfect alignment.

The coupling strength between the III-V devices and the waveguide depends exponentially on the gap. Therefore, accurate control of this gap is required. An adhesive bonding process using BCB was used to bond III-V on silicon. However, instead of controlling the gap height with the BCB solution or the applied pressure during bonding, we here control the thickness by etching back the top oxide on the SOI sample. In order to achieve a uniform and reproducible bonding layer thickness we use a cold bonding process developed by [3] with a highly-diluted BCB solution that results in a reproducible BCB thickness of ~40 nm. The actual gap between the waveguide and the III-V devices is controlled by varying the thickness of the top oxide. SOI with top oxide that is planarized using CMP is readily available through ePIXfab with a standard thickness of 1.25 µm above the waveguide. A BHF wet etch is used to etch back the top oxide to the desired thickness. A cross section showing the bonding thickness is displayed in Fig. 2(a). From this figure it can be seen that the total gap between the waveguide and III-V is ~112 nm consisting of a ~38 nm thick BCB layer and a ~74 nm oxide layer.

Top contact alignment is difficult because due to the size requirement there is almost no tolerance; the top contact needs to be large enough to suppress higher order radial modes present in a microdisk, while at the same time it should be small enough such that it does not cause too much optical absorption of the fundamental (lasing) mode. Clearly, any misalignment of the top contact will result in substantial losses for the lasing mode. Therefore, we propose and demonstrate here a self-aligned process for the top contact of the microdisk that is still compatible with the approach to fabricate the laser and detector simultaneously as can be seen in Fig. 1(c-d). The basic principle is that a ring instead of a full disk shape is defined in the SiNx hard mask for III-V etching. The center hole of the ring is then covered with Titanium, which acts both as contact metal to the III-V and as etch mask for the III-V disk etch. The result after III-V etching is displayed in Fig. 2(b-c), where in (b) the etched disk is shown under an angle to see the SiNx and III-V sidewalls, while (c) shows a top view from which it is clear that the misalignment of the Titanium is compensated by the self-aligned process as only the area inside the ring contacts to the III-V.

III. EXPERIMENTAL RESULTS AND OUTLOOK

Several optical links were fabricated and the results from two identical designs on samples with different gap between the waveguide and III-V are presented here. Sample 1 had a target bonding layer thickness of 200nm while in sample 2 250 nm was targeted. First the detectors were characterized by injecting light from an external laser source into the waveguides via the grating couplers. Then, knowing the performance of the detectors, the full optical link was measured, from which the microdisk laser performance can then be deduced. The responsivity of the detectors on sample 1 was found to be 0.69 A/W. Dark currents of 50 nA were measured at a reverse bias of 1 V. For sample 2 responsivities of 0.56 A/W and dark currents of 20 nA were measured. To characterize the full optical links the detected photocurrent at the detectors was measured versus the drive current applied to the microdisk laser. The results are shown in Fig. 3. The solid lines represent the link on sample 1, while the dashed lines represent the link of sample 2. The black and red lines correspond with the left and right detectors respectively. The threshold current of sample 1 is 0.45 mA and the maximum slope efficiency is 40 µA/mA. Taking the responsivity of the detectors into account a laser slope efficiency of 57 µW/mA is found, which is the highest ever measured for these devices. The same link on sample 2 has a threshold current of 0.22 mA and a maximum slope efficiency of 16 µA/mA. Again, correcting for the detector responsivity this yields 28.6 µW/mA. In this case a record low threshold current is achieved for these microdisks. If we compare the result from the two samples we find that sample 1 has a better slope efficiency, but at the cost of a higher threshold current. This is as expected because the thinner gap on sample 1 results in stronger coupling. Finally, a small-signal modulation was applied to the link of sample 1 and a maximum bandwidth of 7.6 GHz was measured.

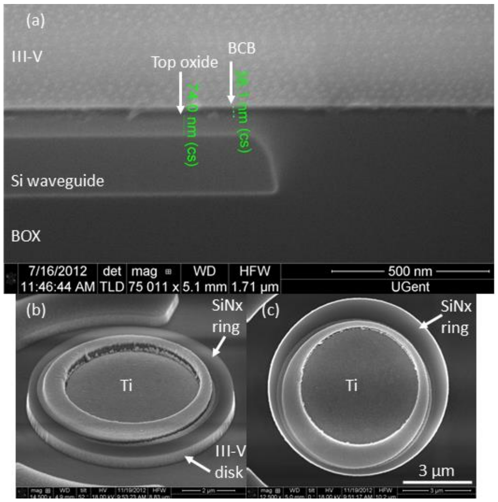

Figure 2. (a) X-SEM showing the gap between III-V and the silicon waveguide (b) SEM under an angle showing the III-V disk resulting from the self-aligned process (c) top view SEM showing the self-aligned top contact.

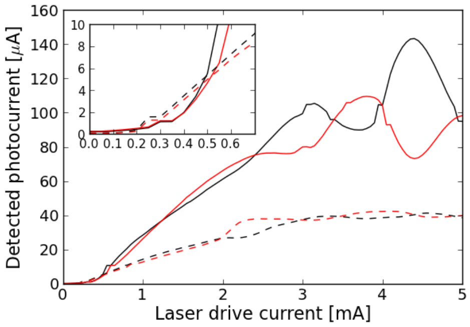

Figure 3. Current versus current plot of the optical interconnects from sample 1 (solid) and sample 2 (dashed). Black and red lines correspond with left and right outputs. Inset: zoom of the threshold currents.

ACKNOWLEDGMENT

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