

A novel III-V-on-Si distributed feedback laser design

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Abstract- In this paper we present a new design for III-V-on-silicon distributed feedback lasers. One of the main advantages of the design is that all structures defining the laser cavity are defined in the silicon, resulting in an easier manufacturing and more accurately controlled laser wavelength. Such a hybrid laser design offers much simpler device fabrication, since light coupling elements, like spot-size converters, are not needed. This also reduces the device footprint.

Keywords: III-V-on-silicon laser; heterogeneous integration; DFB

I. INTRODUCTION

Silicon-On-Insulator (SOI) is gaining interest as a novel platform for integrated optical circuits, since its large refractive index contrast allows for ultra-compact devices. The interest in this technology stems however mostly from the expectation that the maturity and low cost of CMOS-technology can be applied for advanced photonics products. However, the integration of a silicon laser is hampered by silicon's indirect bandgap. Building light sources, and in particular laser sources, on integrated silicon circuits is a big challenge. In that sense the heterogeneous integration of III-V/silicon lasers combines the best of two worlds. In spite of the rapid progress in this technology since about 2006, the design and fabrication of hybrid silicon lasers present specific challenges and trade-offs. There are many choices to be made, both in terms of the cavity structure, the optical coupling between the silicon waveguide and the III-V waveguide and the technological approach. A relatively large variety of device approaches have been reported in the past years [1]. Two main technologies are used to heterogeneously integrate III-V epitaxial layer stacks on a silicon waveguide circuit: molecular bonding and adhesive bonding. We focus on an adhesive die-to-wafer and wafer-to-wafer bonding process, based on DVS-BCB as a bonding agent, given more relaxed requirements on the III-V wafer surface quality (contamination, particles, roughness). This principle has proven to work in several different configurations [1][2]. A promising reported method to achieve a high performance laser cavity is to use an intra-cavity double taper structure, using taper-based mode transformers in both the III-V and silicon waveguides [2]. However, the fabrication of taper-based mode converters is not straightforward because of the narrow tips required and the strong dependence of the performance on alignment accuracy. In this paper we propose a new approach to obtain a compact, efficient and single mode hybrid silicon laser, based on an active DBR grating which requires no complex coupling structures such as narrow-tip tapers in the III-V process.

II. LASER CAVITY DESIGN

The hybrid platform consists of an SOI substrate with a slab of III-V material bonded on top and a thin DVS-BCB bonding layer in between. An optimal laser cavity design should consist of a section where the optical mode is completely confined to the III-V waveguide layer, while the wavelength selective feedback is provided by structures defined in the silicon, thereby taking advantage of the resolution and accuracy of lithography tools in CMOS fabs. Of course, the laser emission should also be coupled efficiently into the silicon waveguide layer.

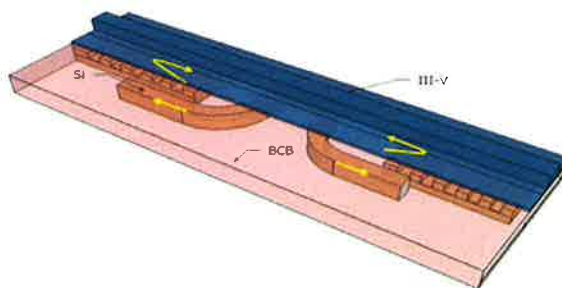


Figure 1: Schematic of the active DBR with the evanescent coupling waveguide in the center of the laser cavity

It would thus be beneficial to think of cavities that do not use an adiabatic taper to couple light between the III-V layer and the silicon waveguides. Besides using resonant cavities in the silicon [3], this can be realized in a DBR-based cavity by using two active DBR gratings with nearly 100% reflection to define the laser cavity and where an evanescent coupling interface is positioned within the laser cavity as the laser output as shown in Figure 1. This hybrid laser design offers much simpler device fabrication and helps to reduce the device footprint.

III. SIMULATION RESULTS

We have simulated the use of DBR reflectors extensively in the context of these hybrid silicon lasers. In a cross-sectional view of the structure, two waveguides can be identified: one in the silicon DBR grating and one in the active layer with a DVS-BCB intermediate layer, as shown in Fig 2. The III-V region used in the simulation has a multiple quantum well (QW) double heterostructure, which consists of a p-InGaAs contact layer, a p-InP clad, 6 InGaAsP QWs surrounded by two

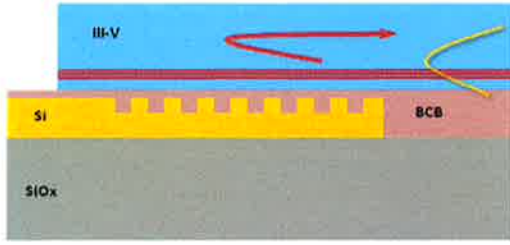


Figure 2: Schematic view of a hybrid DBR reflector in a hybrid silicon laser.

InGaAsP separate confinement heterostructure (SCH) layers, and an n-InP layer. The simulated QW region consists of six 8nm thick InGaAsP (1.55 μ m bandgap wavelength) well layers separated by 10nm thick InGaAsP ($E_g=1.17\mu$ m bandgap wavelength) barrier layers. The thickness of both SCH layers is 100nm and the thickness of the n-InP and p-InP layers are 200nm and 1500nm respectively. The SOI is composed of a mono-crystalline silicon layer (thickness of 400nm) on top of a 2 μ m thick buried oxide layer on a silicon substrate. The silicon rib grating has a height of 400nm, an etch depth of 180nm and a width of 3 μ m for the DBR parts. Simulations were performed for the cavity reflectors and the coupling section. A 2D simulation based on the open-source eigenmode solver CAMFR [4] to calculate the first-order to first-order mode reflection of the active waveguide is shown in Figure 3, showing the power reflection as a function of the number of periods and the DVS-BCB thickness, for a grating period of 240nm (for Bragg reflection at 1.55 μ m), 50% duty cycle and an etch depth of 180nm. The coupling constant κ for two different silicon waveguide heights and two different grating etch depths versus DVS-BCB thickness is plotted in Figure 4.

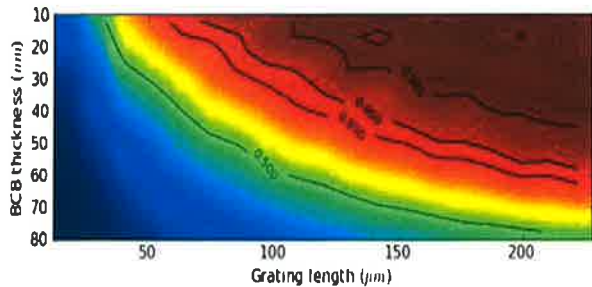


Figure 3: Grating reflection as a function of the number of grating periods and DVS-BCB thickness

For the coupling section a 3D FDTD simulation [5] was performed, to study coupling in the bent waveguide structures and to study the parasitic reflections due to this perturbation in the middle of the cavity. We used the same III-V waveguide with the same epi layers and 2.5 μ m waveguide width. A 400nm high silicon waveguide, 1.5 μ m wide, bending radius of 30 μ m and different coupling length (L) are considered for the simulations. These simulations show that the power fraction reflected into the III-V waveguide because of the coupling section is very low (<-30dB, for a DVS-BCB thickness of 60nm). Figure 5 shows the power coupled to the silicon waveguide underneath versus length for a DVS-BCB thickness of 60nm. The coupling efficiency decreases with increasing coupling length due to the fact that the coupler is a strongly

asynchronous directional coupler. It turns out that the coupling is at its maximum when the length of the straight coupling section is of zero length due to the coupling that occurs in the bending parts of the coupler section.

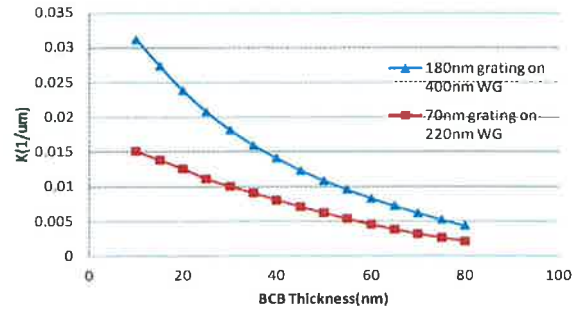


Figure 4: Coupling constant κ for a hybrid grating simulated for different grating cross-sections versus DVS-BCB thickness

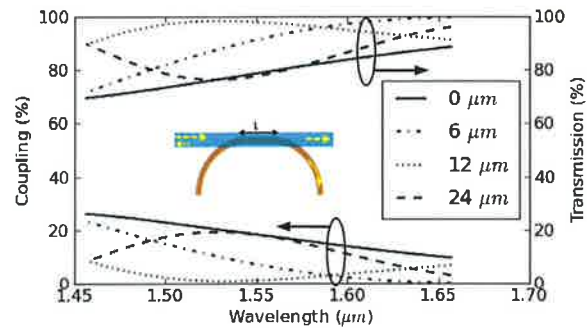


Figure 5: 3D-FDTD simulation results on the evanescent coupling for different coupling lengths L

IV. CONCLUSIONS

A new concept was proposed for the realization of III-V on silicon hybrid lasers, providing high optical confinement in the III-V waveguide layer, while the wavelength selective feedback elements are implemented in the silicon. This opens up a route towards the large volume realization of single mode lasers with precisely defined emission wavelength on a silicon waveguide platform.

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Thursday, 19 April 2012 / Hall-Auditorium. Poster 2.

15:30h – 17:00h

- *A novel III-V-on-Si distributed feedback laser design (ID 197)*

In this paper we present a new design for III-V-on-silicon distributed feedback lasers. One of the main advantages of the design is that all structures defining the laser cavity are defined in the silicon, resulting in an easier manufacturing and more accurately controlled laser wavelength. Such a hybrid laser design offers much simpler device fabrication, since light coupling elements, like spot-size converters, are not needed. This also reduces the device footprint.

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- *Polarization converter post-processing for integrated polarization independent SOA (ID 160)*

Post-processing of a polarization converter (PC) in an experimental industrial generic foundry process is demonstrated. Insertion of the PC halfway an SOA reduced its polarization dependence from 14 dB to 3 dB.

M.Felicetti; J.van der Tol; E.Geluk; M.Smit; N.Whitbread; P.Williams

- *High gain fs-laser written Yb³⁺/Er³⁺-codoped phosphate glass waveguide (ID 80)*

In the present work we report a high gain femtosecond-laser directly written waveguide in an Er/Yb co-doped phosphate glass with a maximum internal gain per unit length of 4.1 dB/cm at 1535 nm.

A.Ferrer; J.del Hoyo; J.Solis; V.Berdejo; J.A.Valles; M.A.Rebolledo

- *Design of Efficient Photonic Sensors Based on Vernier Effect in near-IR (ID 25)*

Integrated architectures based on cascaded ring resonators through the Vernier effect have been theoretically investigated and optimized for sensing applications. Sensitivity higher than 100 $\mu\text{m}/\text{RIU}$ allows detection of lead Pb(II) in water (< 50 ppb) and m-xylene gas (< 60 ppm) to be achieved, exhibiting limits of detection as low as 3.5×10^{-6} RIU.

A.Tsarev; B.Troia; M.N.M. N. Passaro; F.De Leonardis



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