Low-loss III-V photonics and high efficiency grating couplers incorporating low-index AlOx layers

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***Abstract*— A SGC with 30% coupling efficiency is designed for a QD-GaAs-based optoelectronics integration platform using thin oxidized $Al_{0.98}Ga_{0.02}As$ layers to overcome the otherwise poor refractive index contrast. coupling efficiency increased from 10% for the unoxidized equivalent and is suitable for outcoupling in active-passive integrated platforms.**

Keywords—Quantum Dots, photonic integration

I. Introduction

Efficient surface grating couplers (SGC) have been proposed and demonstrated in Silicon On Insulator (SOI) waveguides WG, achieving over 33% efficiency [1]. If these couplers could be fabricated in III-V WG, they could be integrated with and used to test other optical components in a III-V optoelectronic integration platform at the wafer level. Additionally, efficient III-V surface-normal couplers could be matched with grating-based silicon surface-normal couplers, allowing for integration of III-V edge emitting sources and gain components into silicon photonics. However, due to the lack of index contrast, creating high-efficiency surface-normal grating couplers using III-V materials is challenging. Typically, this requires the use of components that are hundreds of micrometers long, such as distributed feedback (DFB), distributed Bragg reflectors (DBR), distributed reflectors (DR), or out couplers (OC).

SOI WG can effectively utilize short gratings due to the significant contrast between the Si WG core and the cladding indices. In contrast, gratings in III-V waveguide are constructed on layers with a relatively weak vertical refractive index contrast ($\Delta n \approx 0.2$), which induces a relatively high propagation loss $1dBcm$ in single-mode WG [2]. Due to this, the achievable performance of individual devices has been limited. In principle, GaAs-based epi-structures incorporating high aluminium content AlGaAs layers positioned between the WG and the substrate can be used to improve optical confinement by forming a low-index AlOx layer by selective oxidation. However, in such a process, oxidation of layers above a certain thickness and over large areas can lead to delamination of the epi-layers. To create manufacturable structures requires reducing the strain by optimizing the AlOx layer thickness such that it provides a sufficiently low-loss structure without compromising the structural integrity.

Here we investigate the possibility of creating short, efficient surface grating couplers SGC for single growth step III-V optoelectronic integration, while commenting that such structures would also enable hybrid external cavity III-V/Si on-chip lasers to be built without the need to modify the Silicon Photonics fabrication process.

a.

b.

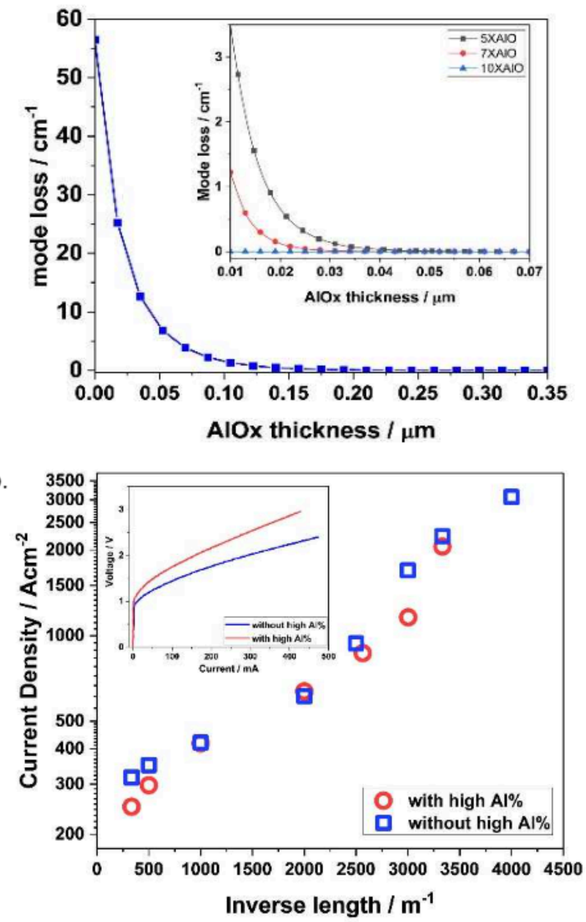

Figure 1:a. Mode loss as a function of AlO thickness (inset: as a function of the multi-AlO thin layer). b. laser threshold current density as a function of the inverse cavity length (inset: voltage – current) with and without a high Al% layer.

For a single growth step III-V platform containing an oxidizable layer we require active devices to function in regions where the $Al_{0.98}Ga_{0.02}As$ is unoxidized and where other devices benefit from the low index AlOx layers where selective spatial oxidation is used. Here we demonstrate electrically pumped laser devices and surface grating coupler on the same material stack.

We compare the operation of lasers with and without high $Al_{0.98}Ga_{0.02}As$ layers and surface grating couplers where the material is oxidized to increase the refractive index contrast and where the material is unoxidised.

II. Results

To enhance the confinement of the III-V WG mode, we incorporated high-aluminium AlGaAs layers above the substrate. The Finite Difference Mode method (FDM) from Fimmwave commercial software was used to optimize the AlOx layer's thickness for the fundamental TE mode. Figure 1 a. demonstrate that utilizing several high aluminum thin layers results in as low a loss as a thick AlO layer but without any delamination. In Figure 1 b., there is a slight increase in device resistance in the structure that includes a high Al% layer directly above the substrate. The performance of the QD laser is similar with or without the high Al% layer.

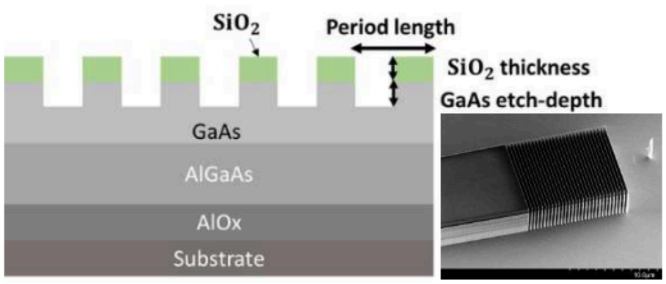

Figure 2: Layout of the grating coupler structure with a definition of the different parameters of the design and fabricated device

Figure 2 shows the SGC structure; the structure comprises a GaAs/AlGaAs waveguide placed on top of the AlO layer, with a layer of SiO_2 [3] on the top of GaAs grating teeth.

The SGC was optimized using the Finite Difference Time Domain 2D-FDTD method using OmniSim software from photon design for the central wavelength of 1.31μm, and TE polarization is assumed. The calculated maximum coupling efficiency at the 1.31 μm wavelength was 0.403 μm period length. Moreover, incorporating AlO layers into the WG resulted in a 23% increase in coupling efficiency for all period lengths compared to the SGC without these layers. By implementing a thin SiO_2 layer to a surface grating on a III-V structure with a lower AlO layer (as shown in Figure 2 with results in Figure 3), the coupling efficiency of grating couplers is significantly improved, achieving a 30% increase compared to the 10% for unoxidized coupler. Additionally, leakage loss to the substrate is reduced to approximately 20%, which is a substantial improvement compared to the 30% leakage loss of the oxidized coupler (as shown in Figure 3b).

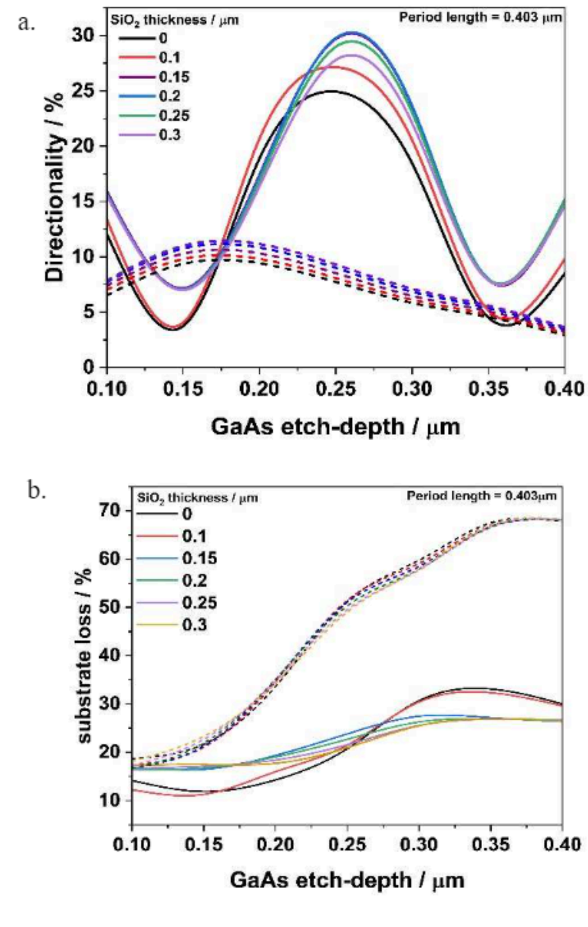

Figure 3: Influence of oxidized layers and SiO_2 layer thickness a. on the fiber coupling efficiency spectrum, b. on the substrate leakage loss for the SGC with AlO layer (solid line) and without oxidation (dotted line)

Effective SGCs, as pictured in Figure 2 (right), couple light with up to 30% efficiency over a relatively narrow acceptance angle as expected following the simulations.

In summary we have demonstrated surface grating couplers in a III-V platform suitable for optoelectronic integration, as demonstrated by laser operation in the same epitaxial structure, which is also compatible with growth on Silicon.

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