A Platform for Integrated Photonics

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***Abstract*—We report on essential elements of an integrated photonics platform based on InGaAs Quantum Dots with oxidizable AlGaAs layers and that is suitable for growth on Silicon. We focus on laser performance and also discuss an active-to-passive interface-coupler and an enhanced surface-grating-coupler.**

***Keywords*—InGaAs Quantum Dots, Photonic Integration**

I. INTRODUCTION

A number of different approaches are being pursued to realise large-scale photonic integrated circuits (PICs), including hybrid and heterogenous integration. Here we focus on one route to integration of active and passive structures on a III-V InAs Quantum Dot (QD) platform that can be epitaxially grown on silicon, for mechanical strength. Incorporating high-efficiency active regions (for e.g. lasers and detectors) and transparent low-loss regions (for waveguides) and a low-loss interface between them is a significant challenge in achieving this integration. Approaches to the latter include evanescent coupling, butt coupling, or the use of surface-emitting lasers and photodiodes.

Here, we introduce III-V-based epi-structures containing high aluminium-content $Al_{0.98}Ga_{0.02}As$ layers between the waveguide and the substrate. This structure can enhance optical confinement by creating a low-index AlOx layer through selective spatial oxidation, improve the performance of surface grating couplers and enable post-growth selective area manipulation of local device function. In the following we describe the development of high performance lasers on this platform and introduce the additional functionalities it provides.

The epi-layer stack we will use for this work is shown in Fig. 1 and is here grown on a GaAs substrate. Such structures are compatible with growth on silicon [1], where the use of the higher refractive index contrast available with $Al_{0.98}Ga_{0.02}As$ facilitates the use of thinner cladding layers reducing the likelihood of thermal-expansion-mismatch-induced cracking. To reduce complexity and cost we aim for a single growth step process and so we require active devices to function in regions where the $Al_{0.98}Ga_{0.02}As$ is unoxidized so passive devices can benefit from the low-index AlO_x layers induced by selective area oxidation. The first step is therefore to develop oxidisable layers that provide sufficient optical confinement for laser operation without incurring significant additional electrical resistance. We will compare the operation of lasers fabricated from material epi-layers grown to two design options to those without high $Al_{0.98}Ga_{0.02}As$ layers.

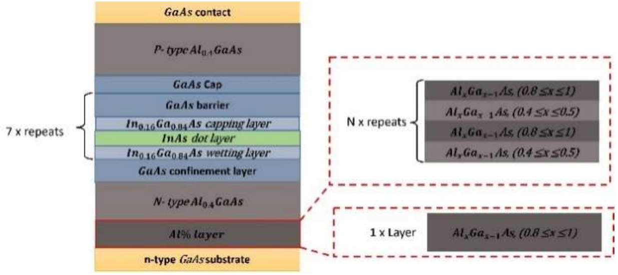

Fig. 1. Schema of epi-structure including options for high Al content oxidisable layers

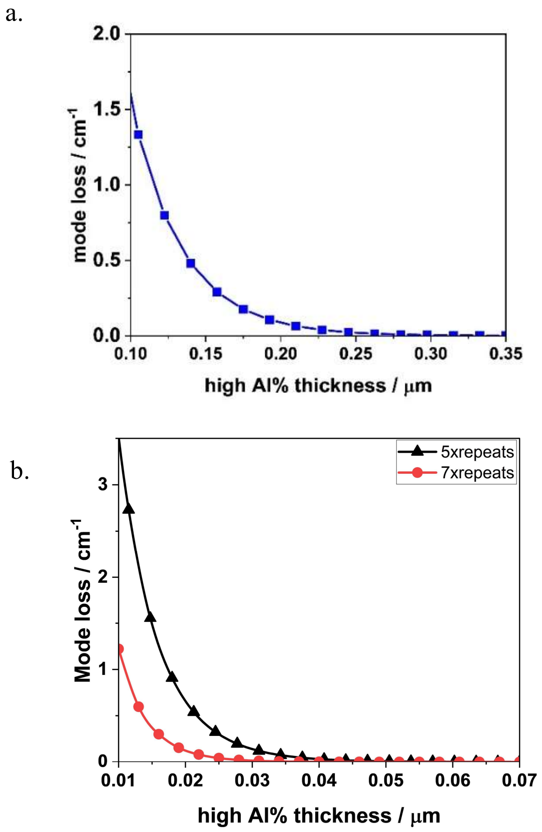

Fig. 2. Calculated mode loss of optical mode using a) a single thick layer or b) multiple thin layers of $Al_{0.98}Ga_{0.02}As$ as illustrated in Fig 1.

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II. RESULTS

To optimize the thickness of the AlO_x layer for the fundamental TE mode using the epi-structure shown in Fig. 1, Fimmwave software from Photon Design has been used by implementing the finite-different-method (FDM). The Perfectly Matched Layer (PML) is used underneath the waveguide to model the substrate TE mode loss. The mode loss is calculated for both waveguide options, including single-thick AlO_x layer and repeated-thin AlO_x layers, as illustrated in Fig.1.

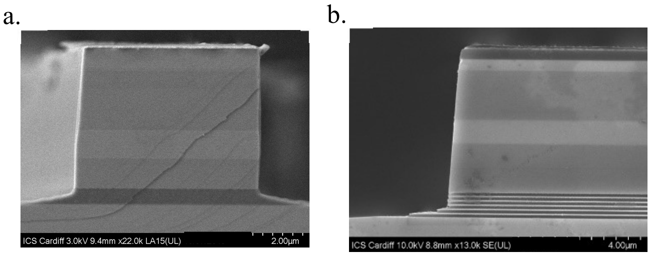

Fig. 3. : SEM of a. single-thick layer and b. multi-layer design indicating position and use of layers when oxidised.

The simulation results of Fig. 2 indicates that using multiple thin layers of oxidised $Al_{0.98}Ga_{0.02}As$ is as effective as using a single-thick layer of AlO_x in reducing loss. However, thin layers are less likely to delaminate after oxidation due to stress. Fig. 3 displays examples of fabricated structures undergoing wet oxidation, where delamination can be present for single-thick oxide layers, but the repeated-thin layers show no delamination. These results demonstrate that the oxidization rate of repeated-thin layers is more stable.

A surface-grating-coupler based III-V waveguide incorporating thin-repeated oxidised high Al% layers is designed and fabricated to investigate the impact of these layers on the waveguide's passive performance. The results show that the coupling efficiency of grating couplers improves significantly, achieving a comparable coupling to Si-based grating couplers, i.e., a 30% increase compared to unoxidized couplers, which only offer a 10% increase [2]. Additionally, the leakage loss to the substrate is reduced to approximately 25%, which is a considerable improvement compared to the leakage loss of unoxidized couplers, which is around 70%.

To investigate the impact of un-oxidised high Al% layers on laser performance, a standard Fabry-Perot laser with a 50 µm waveguide width is fabricated. Two identical structures are used, one with a high Al% layer while the other replaces the high Al% layers with an $Al_{0.4}Ga_{1-x}As$ extended cladding layer. Fig. 4 depicts the threshold current density of cleaved facet devices as a function of the inverse laser cavity length. These devices operate with pulsed current at a 0.5% duty cycle and room temperature. The results show that devices fabricated with or without a single-thick high Al% layer have similar threshold current. However, those with thin repeated high Al% layers demonstrate lower current density in the structure with high Al% layers. This is due to the low optical loss in these structures with these layers. The inset shows I-V measurements, which indicate that the device with a single-thick high Al% layer has higher resistance than the repeat sample without this layer. For the samples with multiple thin layers of $Al_{0.98}Ga_{0.02}As$ the difference I-V curves is much less significant.

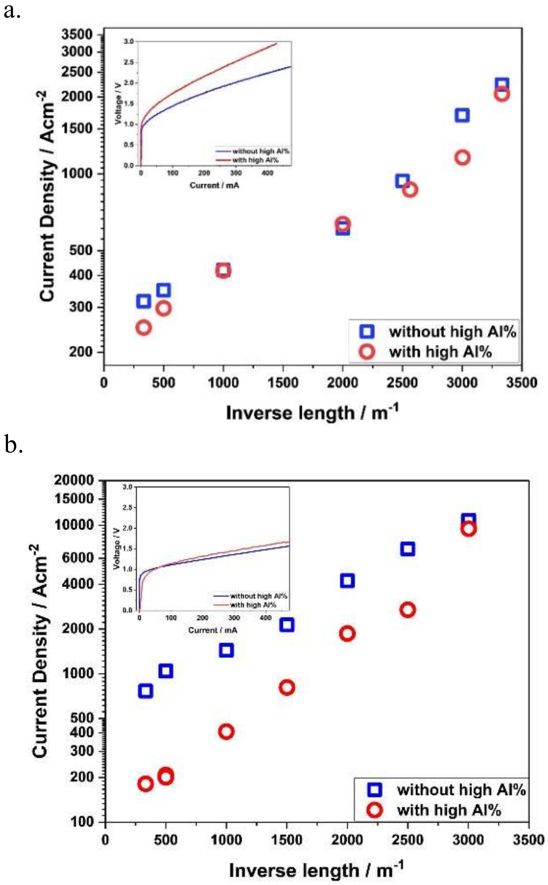

Fig. 4. Laser threshold current density as a function of the inverse cavity length (inset: voltage – current) a. for single-thick high Al% layer and b. for thin repeated high Al% layers devices compared to devices without high Al% layers

In summary, we have successfully demonstrated the growth of a III-V single-step structure for an integrated photonic platform that combines active and passive functionalities. Incorporating high Al% layers above the substrate improves the laser performance, where these layers remain unoxidized. This benefits the active component and improved the passive waveguide through the spatial oxide formation on the high Al% layers. We also report the use of these layers in surface grating couplers and in the interface between passive and active sections. This material platform shows great potential for photonic integrated circuits (PICs).

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