Aluminum-containing quantum wells in the COBRA Generic Photonic Integration Platform

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Aluminum-quaternary (Al-Q) quantum wells offer enhanced carrier confinement and the possibility of efficient uncooled operation for photonic integrated circuits. The technology has additionally been mastered in combination with selective area growth (SAG) technology at III-V Lab to tune the band gaps of AlInGaAs quantum well structures with wide variations in the band-edge across the wafer. In this work we incorporate Al-Q wells within the generic integration platform which uses epitaxial regrowth to combine active and passive devices. The challenge is to ensure minimal defect creation and oxidation during the regrowth. This work presents the fabrication of Al-Q devices by following the standard COBRA process.

Introduction

The COBRA institute has developed a generic platform which enables circuit design to be decoupled from the photonic integration technology. This is expected to enable new products to leverage the technology advances made in the telecommunications sector through the creation of basic building blocks (BBs) such as gain blocks, waveguides and phase modulators. The combination of these BBs constitute more complex building blocks, such as lasers, interferometers and modulators and a broad range of possible circuits, fulfilling a very broad range of functions [1].
The combination of new selective area growth techniques from III-V Labs [2] and active-passive generic integration at COBRA are expected to provide a step change in design freedom as designers will be able to define the wavelength and band-edge at the mask level with unprecedented functionality. So far however, the active-passive platform from COBRA has used Phosphorous quaternary active layers, while the selective area growth platform from III-V Labs has used Aluminum quaternary active layers.
As a first step to combining Aluminum-quaternary selective area growth with active-passive photonic integration, we study the incorporation of Aluminum quaternary layers in the quantum well (QW) structure of active devices of the generic integration platform. Compared to Phosphorous quaternary QW, the Aluminum-based band-gap structure provides a higher band offset in the conduction band compared to the valence band, enhancing charge carrier confinement (see Figure 1). Due to the higher mobility of electrons, the concentration of carriers in the QW is more even. Thus the recombination rate may be optimized and provide a higher gain [3]. Electrons are more susceptible to leakage via thermionic emission so a higher confinement allows improved performance at higher temperatures (typically uncooled operation) [4].

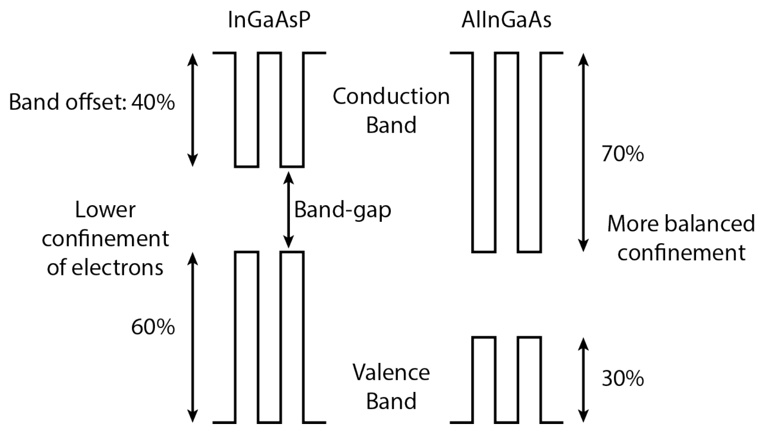

Figure 1: Schematic of the different band-gap structures of quantum wells for the InGaAsP and the AlInGaAs materials systems.

Experiment

The use of aluminum based materials in photonic chips is a challenge due to the possibility of their oxidation during the fabrication. It gives rise to surface defects and non-crystalline interfaces, leading to compromised fabrication stability and optical performance. The integration of active and passive devices on the COBRA platform is obtained using the butt-joint technique. It consists of growing an active layer stack, protecting small areas with a hard mask, etching the active material around the protected areas, and re-growing a passive layer stack on the wafer, in-filling around the active material. After etching the active layer stack, the wafer is placed in a neutral nitrogen gas environment until the regrowth to avoid its contact with oxygen.

After the passive regrowth and the growth of a top cladding layer of InP and a conducting contact layer over the wafer, the waveguides are defined by depositing a protective mask pattern and etching the rest of the wafer with an Inductively Coupled Plasma (ICP) tool. To make sure that the QW in our structure are not exposed to air during the waveguide etch, all active components are shallow etched, which means that the waveguide core layer is not etched completely. In this way, we can keep a thin layer of InGaAsP covering the QW in order to protect them from air (see Figure 2).

Another important aspect in the patterning of the waveguide is the inhomogeneity of the etch at the edges of the waveguide. The required proper electrical and optical confinements for the waveguides are obtained by etching the whole InP top cladding layer above the core quaternary layers. Nevertheless, the bottom corners of the etched areas experience an edge effect, and as a result have locally modified depth where the light is guided. Since the effective depth of etch is lower on the sides of the waveguide, a margin has to be taken during the fabrication to be sure to etch the whole InP cladding layer.

Therefore, the etch should neither be too deep and reach the quantum wells, nor be too shallow and not etch all the InP on the sides of the waveguides. The Figure 2 illustrates these two constraints. The Separate Confinement Heterostructure (SCH) layer above the active layer provides sufficient margin to stop the etch and stay within these two constraints.

The experience collected with the generic fabrication process provides us a good estimation of the etching edge effect during the waveguides definition, and thus the control of

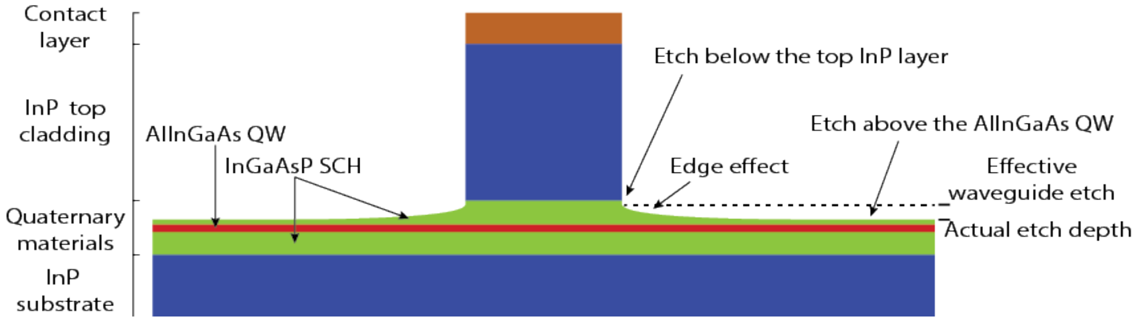

Figure 2: Schematic of a waveguide etching constraints to insure a proper waveguide definition and avoid aluminum quaternary material oxidation.

the etch is possible. A series of measurements of the exact depth of each layers by selective wet etching are performed prior to the fabrication process in order to make sure that the definition of the waveguide will fulfill the constraints described above.

Results

The whole fabrication process has been carried out on several wafers containing aluminum based quantum wells. First, the selective etch of the active layer stack and the regrowth of a passive layer stack next to it has been experimented and showed no observable interface defect, as it has already been reported in [5]. This regrowth has been successfully repeated on other wafers without difficulty.
After the top cladding layer growth, the definition of the waveguides by ICP etching has been performed, taking special care not to expose the aluminum quaternary materials to air. Finally, the rest of the standard fabrication used in the COBRA platform have been processed. The result is presented in Figure 3 with the cross section of the side of a waveguide defined in the active layer stack. The different layers of InP, InGaAsP and AlInGaAs, polymer, and metal are clearly distinguishable. One can observe that the etching of this shallow type waveguide is stopped few tens of nm above the aluminum based materials, thus insuring its protection from contact with air during the whole fabrication. The edge effect next to the sidewall is clearly visible as well, the etch depth being reduced progressively when getting closer to the waveguide. Nevertheless, one can notice that the whole InP cladding layer has been etched successfully. Thus, control in the depth of etch and a good knowledge of the etching effects allowed us to avoid any oxidation of the aluminum containing materials, and to define the desired waveguide structure which will provide efficient guiding of the light and confinement of injected current.
Furthermore, a defect free interface between the active layer stack and the passive layer stack has been obtained. The right picture of Figure 3 shows this interface, located further on the side of the waveguide. A similar quality of interface is expected at the butt-joint location (in the direction of light propagation), since similar fabrication conditions provided the very good interface reported in [5]. This butt-joint interface should constitute a low loss transition between the active and passive devices.

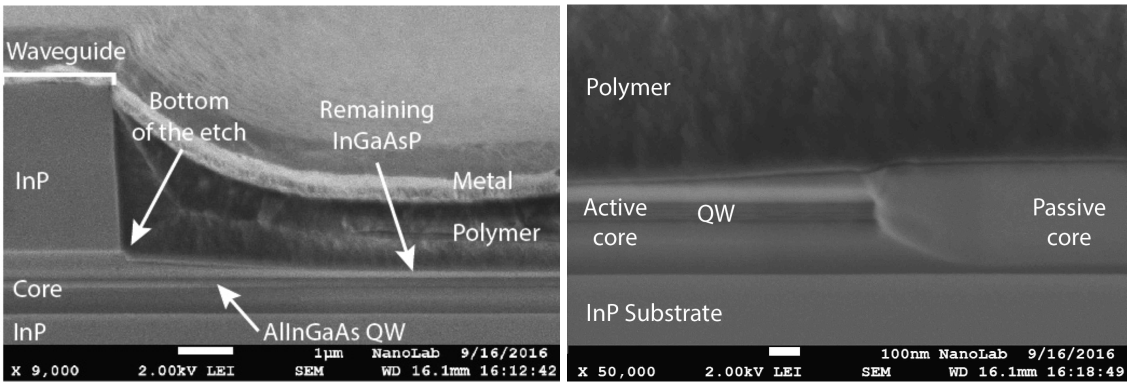

Figure 3: On the left: SEM picture of the cross section of a waveguide. On the right: Defect free interface between the active and passive layer stack observable further on the side of the waveguide.

Conclusion

The joint fabrication between the III-V Lab active layer stack and the COBRA active-passive integration process shows a high compatibility so far, which is promising for implementing several new features. Active and passive waveguides with the same structure as in standard circuits made in the COBRA platform have been produced with aluminum QW for the first time. Since the two topologies are very similar, a direct comparison of devices performance with P-quaternary and Al-quaternary materials QW can be performed.

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