MOVPE Selective Area Growth applied to the integration of a AlGaInAs based Electroabsorption Modulator with a spot-size converter

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Abstract

Thicknesses and compositions of (AlGaIn)As-based layers grown by low pressure metal organic vapor phase epitaxy (LP-MOVPE) in the regime of selective area growth (SAG) have been measured and calculated. The aim of this parametrical study is the integration of spot-size converters (SSC) at both side of an AlGaInAs multi-quantum well (MQW) Electroabsorption Modulator (EAM). The challenge of this approach is to achieve a high thickness enhancement ratio (R) together with high selectivity on the SiO_2 mask stripes. In this study, we have grown InAs, GaAs and AlAs binary bulk layers on patterned InAs, GaAs and GaAs substrates respectively, in order to calculate separately the vapor phase diffusion length (D/k) of the indium, gallium and aluminum species. These D/k parameters have been used in our computational model for SAG-MOVPE and applied to GaInAs, AlInAs and AlGaInAs layers, deposited on patterned InP substrate in the same growth conditions as those of the binary layers. The good agreement between simulation and experiment, together with the perfect selectivity obtained for all the different alloys, hold for the integration feasibility of an EAM with a SSC in the AlGaInAs system with R values higher than 2.5.

Introduction

Electroabsorption modulators based on III-V semiconductor multi-quantum wells are promising candidates for a variety of long haul and/or high bit rate telecommunication applications because they feature large absorption variations at low driving voltages. Recently, InGaAlAs system based structures have been particularly attractive to fabricate such modulators [1-3]. In a previous study [3], we have presented a new InGaAlAs/InGaAs QW structure aiming at enhanced excitonic absorption in a large spectral range, low polarization dependent loss and over 40 Gbit/s bandwidth. However, these discrete components often suffer from high coupling losses with the optical fiber, due to large confinement factor of aluminum containing active material. To overcome this problem, it has been chosen to use the application of MOVPE selective area growth to the realization of efficient optical mode converters at both sides of the EA Modulator. These spot-size converters lead to the reduction of the assembly complexity in low-cost modules using relaxed alignment tolerance with a single-mode fiber [4]. The objective is to grow the EAM and the SSC during the same epitaxial run. For this purpose, the EAM part of the device must be selectively grown inside the opened area between two SiO_2 mask stripes. Outside, along the axis of the EAM, the smooth decreasing of the thickness and of the optical indexes forms the SSC part of the device (Fig. 1). In order to predict the effects of the oxide pad geometry on the composition and the thicknesses of the MQW heterostructure layers, especially in the longitudinal direction, a 3D model has been developed and compared with the experimental data.

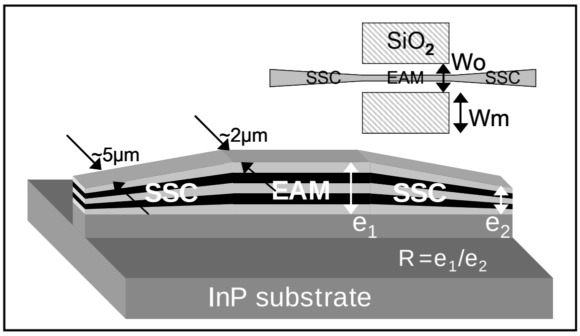

Fig. 1: Schematic structure of the EAM integrated with the spot-size converters.

Experimental

In the present study, we use an horizontal low pressure MOVPE AIX200/4 reactor, with TMAl, TMGa, TMIn, AsH_3 and PH_3 as precursors. SAG structures were grown between two 800 µm long SiO_2 mask stripes. The stripe width (Wm) was varied from 20 to 160 µm and the opened area (Wo) between two mask stripes from 20 to 60 µm. The grown AlGaInAs SAG was evaluated with 2 µm diameter spot micro-photoluminescence (PL) using HeNe laser and InGaAs photodetector (Scantek setup). 3-dimensional thickness maps have been obtained, based on white light interferometric images providing vertical and lateral dimensional resolutions of ~0.5 nm and ~0.5 µm respectively (ATOS setup).

Results and discussion

To determine the appropriate growth conditions in the regime of SAG, the main and constant criterion is to avoid any polycrystal deposition on the mask surface. This selectivity is essential since the deposited polycrystal means lost material in the opened area, and, therefore, irreproducible process with unpredictable thickness and composition. In this way, we confirm some previous work reporting better selectivity with SiO_2 masks than with SiNx masks [5]. The second criterion was to obtain higher growth enhancement ratio (R) than 2.5, together with a very short SSC length. This is typically obtained for Wm > 100 µm and for growth conditions in which the selectivity on the mask stripes degrades for aluminum containing materials. Therefore, a tradeoff should be

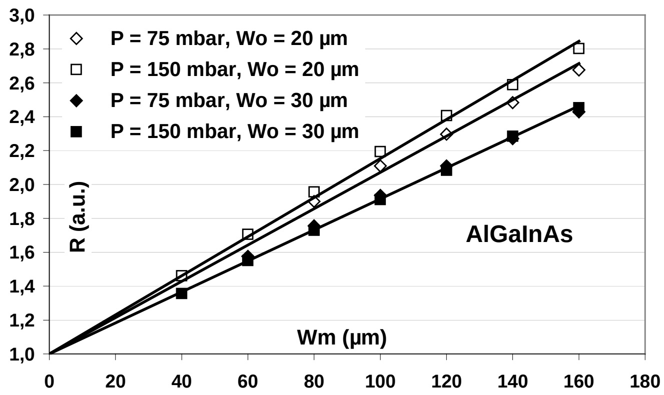

Fig. 2 : R versus Wm for different reactor pressure P and for Wo = 20 and 30 µm.

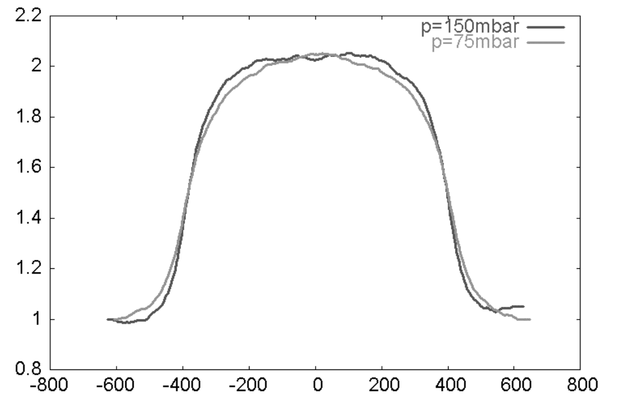

Fig. 3 : Flatness and length of the AlGaInAs thickness profile versus reactor pressure for a cross section along the optical cavity.

achieved, fully compatible with the mask design of the complete devices. On figure 2, R versus Wm are reported for two reactor pressures (P = 75 and 150 mbar) and for two opened area widths (Wo = 20 and 30 µm). Little changes are observed between those two reactor pressures. Nevertheless, the shape of the thickness profile inside the mask stripe is flatter and the SSC length is shorter for a higher pressures (figure 3). For this reason, the pressure P has been fixed at 150 mbar in the following experiments.

On the figure 4 are reported the R values function of Wm, for different materials at constant V/III ratio at the vapor/solid interface (same AsH_3 flow : 50 sccm and same growth temperature : 650°C). The growth rate for the

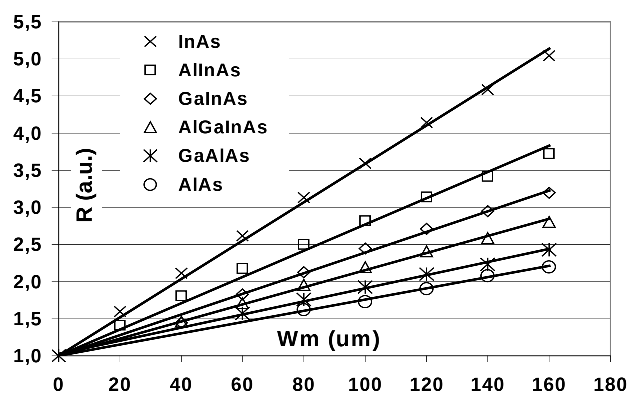

Fig. 4 : R versus Wm for different materials taken from the AlGaInAs material family.

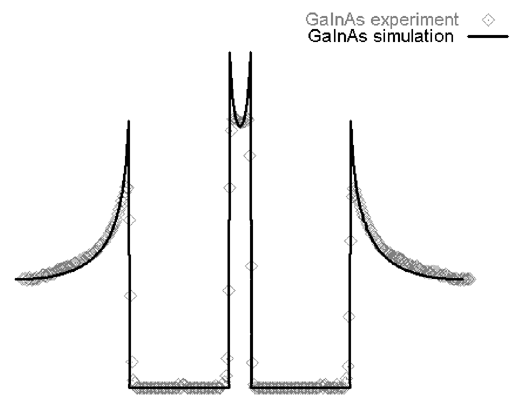

Fig. 5 : calculated and simulated thickness variation of a GaInAs strained bulk layer.

binary alloys was 0.1 nm/s. InAs on InAs, and GaAs and AlAs on GaAs, have been epitaxied to measure separately their thickness variations. From these measurements and their comparison to the model prediction, we have calculated the diffusion length D/k of the In, Ga and Al precursor in the gas phase. The values obtained are In : D/k

≈ 14 µm, Ga : D/k ≈ 55 µm and Al : D/k ≈ 80 µm. This present model is based on the vapor phase transport model [6]. These coefficients were used without any further adjustment, to calculate the ternary and quaternary thickness and composition variations. In the case of GaInAs (figure 5), the agreement between simulation and experiment is remarkable.

To reduce the polarization sensitivity of an EAM, the GaInAs MQW layers have to be tensile strained to adjust the light-hole and heavy-hole transitions. As these layers are in the masked part of the wafer, between the mask stripes, the GaInAs layers in the field part of the wafer, far from the mask stripe, should be even more rich in gallium and therefore more tensile strained. The variation of strain, that is to say the variation of composition, is that which is obtained for R values above 2.5, consequently for Wm values superior to 100µm. In order to calibrate the EAM well composition, we have deposited by SAG a thin film of $Ga_{0.65}In_{0.35}As$ material ($\Delta a/a$ = -14000 ppm). On figure 6 are reported the measured micro-photoluminescence peak wavelengths for the electron/light-hole and electron/heavy-hole transitions versus Wm. The PL was measured at the center of the gap region. From these measurements, we deduced the GaInAs composition for each Wm value (fig. 7, circle and triangle dots). For the same Wm values, we calculated the GaInAs compositions with our computational model for SAG. One can see that the agreement between our model prediction and the experimental data is very good.

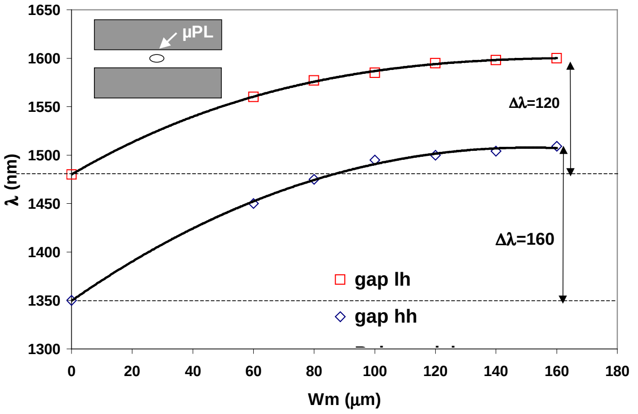

Fig. 6 : dependence of PL peak wavelength (heavy-hole and ligth-hole transitions) on mask width Wm, in case of GaInAs tensile strained bulk material.

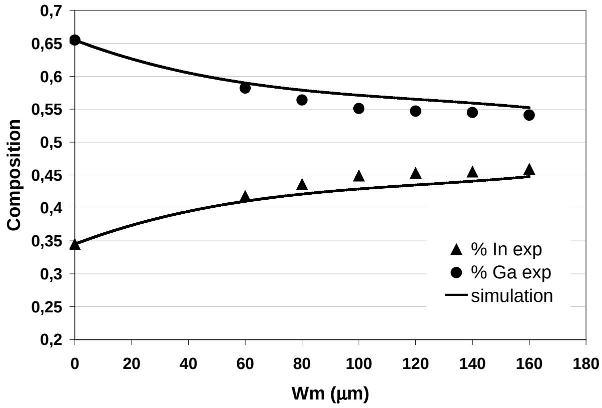

Fig. 7 : measured (dots) and simulated (lines) dependence of alloy composition on mask width in case of GaInAs selectively grown bulk layer.

Conclusion

With the aim of integrating an EAM with SSCs, we investigated the SAG of AlGaInAs by MOVPE. We have grown different layers taken among the AlGaInAs material family, selectively in the presence of SiO_2 patterned masks on InAs, InP and GaAs substrates, depending of the grown material. We had the constant objective to achieve very selective growth even with wide mask stripes (Wm > 100 µm) in order to obtain high growth enhancement ratio (R > 2.5 for AlGaInAs/InP). For these growth conditions, we determined the diffusion coefficients D/k for each species (Al, Ga and In) and applied them to the calculation of AlGaInAs and GaInAs thickness profiles. The excellent agreement of the calculated values compared to the measured ones and the excellent quality of the selectively grown materials indicate that SAG of AlGaInAs is expected to lead to devices with excellent properties.

References

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