Growth of InGaAs/ (Al)GaAs Layers for Laser Manufacturing using 4 inch GaAs Substrate

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Abstract

Heterojunction InGaAs/ AlGaAs laser diodes emitting at 900-1000 nm have been widely employed in various industrial applications. They are directly used for material processing such as heat conduction welding, deep penetration welding or hardening of industrial work-pieces. Furthermore these laser diodes are essential for pumping fibre lasers to replace CO_2 lasers [1-2]. Essential for further acceptance of those III-V laser devices is reflected by both, the reduction in cost requesting higher yield based on enhanced productivity for manufacturing technology, as well as improvement on performance regarding electrical, structural and optical properties of the devices. Growth on 4 inch GaAs substrates exhibits the potential to increase productivity and reduce costs compared to standard manufacturing on 3 inch substrates. But growth on larger substrate size also requires higher demands on process tuning and hardware configurations to assure high reproducibility, homogeneity and material quality for laser device related layers.

We present comprehensive investigations on InGaAs Single Quantum Well (SQW) structures and complete InGaAs/ (Al)GaAs laser device structures using Photoluminescence (PL) measurements as well as in-situ monitoring techniques. In addition electrical characterization of 4 inch GaAs substrates [100] without mis-orientation ("cut-off") and with orientation [100] 6° off towards [111] / Ga-face [0-1-1] have been done. Furthermore we present numerical models predicting the impact from different process parameters on growth results.

INTRODUCTION

The epitaxial growth for this investigation was performed using a multi-wafer horizontal flow MOCVD system (AIX 2800G4 TM Planetary Reactor®, 4 inch wafer configuration). Substrates of both (0 degree vs. 6° cut off) orientations were used for simultaneous deposition. Strict separation of the flows for the different precursor materials (Metal Organics (MO) from group III: TMGa, TMAl, TMIn vs. group V: AsH_3) allows control of convective and diffusion transport to the growth surface. Details regarding this set-up can be taken from Figure 1.

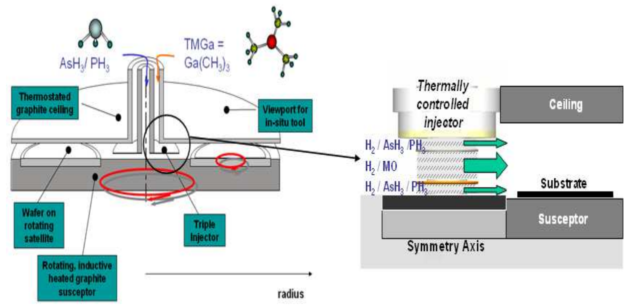

Figure 1: Schematic for flow-injection inside the reaction chamber separating group V and group III precursor materials providing additional flow-tuning.

RESULTS

MODELLING

Numerical modelling of the flow field, the growth chemistry and the temperature conditions in the process chamber allows a straightforward process development [3]. An example for optimization using flow modelling is shown in Figure 2. Here the influence of different total flows on the growth profile of $Al_{0.5}Ga_{0.5}As$ Layers is calculated. Different total flows will change the shape of the depletion curves and therefore the growth rate distribution. The insert on the upper right shows the resulting growth profiles for rotated substrates. The depletion radius examined here is the entire susceptor radius of more than 300 mm.

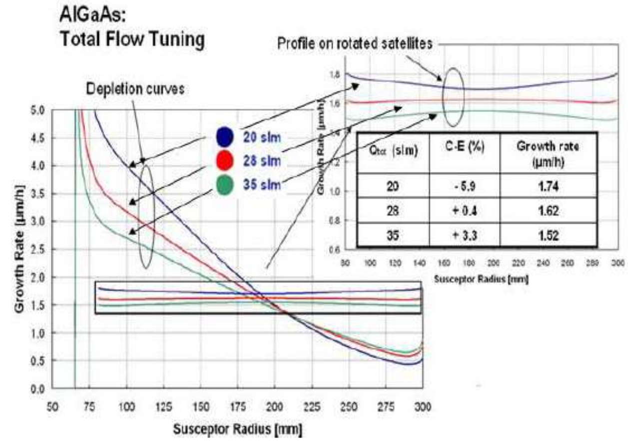

Figure 2: Modelling of growth rate depletion along susceptor radius for $Al_{0.5}Ga_{0.5}As$ Layers

The application of modelling leads to a well controlled process conduction without spending effort on growing various test samples for adjustment. To verify modelling predictions we grew $Al_{0.5}Ga_{0.5}As$ Layers with total flows of 20 slm and 28 slm. The thickness mappings are presented in Figure 3.
Modelling results are in good accordance to experimental results. As predicted a total flow of 20 slm results in a concave shaped thickness profile while a total flow of 28 slm leads to a slightly convex thickness profile. The center-to-edge deviations are - 4.7 % (20 slm) and + 1.1 % (28 slm) respectively. Modelling calculations predicted values of – 5.9 % (20 slm) and + 0.4 % (28 slm). Growth time for both $Al_{0.5}Ga_{0.5}As$ Layers was 30 minutes. This results in a growth rate of 1.72 µm/h for both samples. This value is in good accordance to the calculated 1.74 µm/h for a total flow of 20 slm and a little higher than the estimated 1.62 µm/h for the 28 slm total flow case.

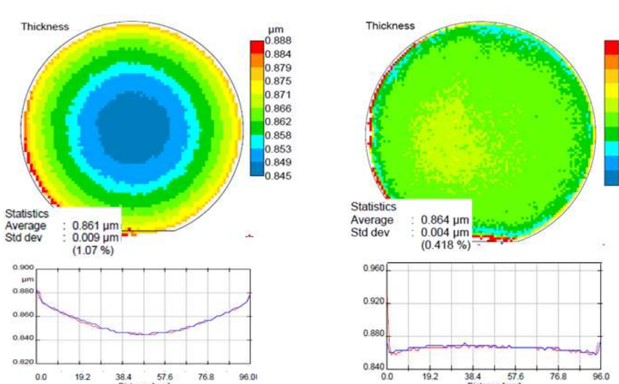

Figure 3: Thickness mappings for $Al_{0.5}Ga_{0.5}As$ Layers using a total flow of 20 slm (left) and 28 slm (right)

EXPERIMENTAL

INGAAS QUANTUM WELL

Figure 4 exhibits the photoluminescence (PL) wavelength and Full Width Half Maximum (FWHM) mapping of an InGaAs SQW structure grown on exact 4"GaAs substrate. Process parameters have been determined in good accordance to modelling results. Samples have been excited with a 532nm cw laser diode at a power density of 1.0mW/cm^2. The resolution of the wavelength mapping is 0.48nm. The PL wavelength mapping shows very uniform wavelength distribution at a emission wavelength of 922.0 nm on the complete 4 inch substrate with almost no deviation. This can be correlated to a homogeneous Indium incorporation and a constant quantum well thickness across the substrate. The average FWHM value is always below 23 meV indicating a high crystalline quality without any defects for the 4 inch substrate

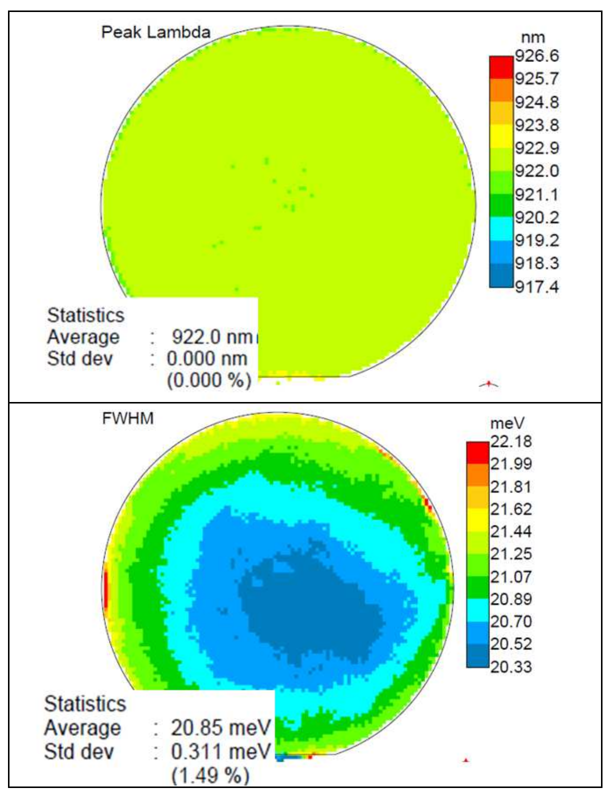

Fig. 4: Photoluminescence wavelength mapping of an InGaAs QW structure on exact orientated 4"GaAs substrate (Top) and respective FWHM mapping (Bottom)

INGAAS/ALGAAS LASER

Epitaxial growth was performed at 680°C reactor temperature and 50mbar total pressure with H_2 as carrier gas. Only the contact layer at the top of the structure was grown at 560°C to support the incorporation of doping element Carbon to achieve the required p-doping level. All other process parameters are based on modelling predictions. The laser structure consists of an optical active strained single InGaAs Single Quantum Well (SQW) embedded in high Al-content AlGaAs waveguides with confinement and cladding layers of different Al- and doping-concentrations as indicated in Figure 4. The total time for the laser structure growth including heating up and cooling down cycles is two hours. Surface temperature and growth rate is monitored by in-situ reflectometry at 952 nm wavelength. Oscillation frequency is linked to a change in growth rate. A degradation in surface morphology would lead to a decreased reflectivity signal value. Accordingly, the in-situ signal allows to analyze each layer regarding growth rate and surface morphology. As shown in Fig. 5 (right) no difference in oscillation period indicating different growth rates or different reflectivity signal values related to different surface morphology is observed for both types of substrate.

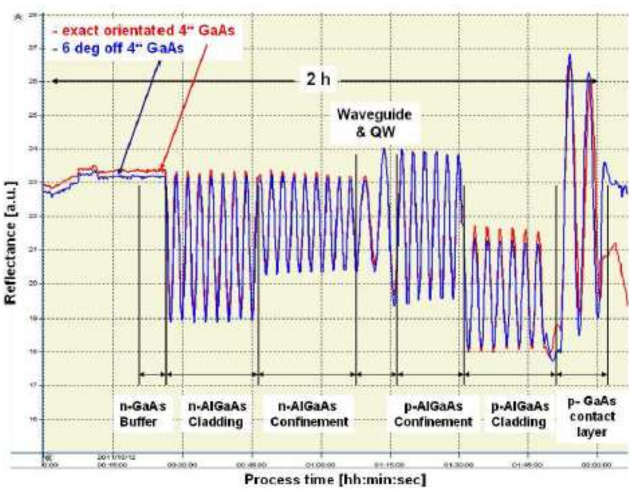

Figure 5: Reflectance Signal (952 nm Diode) during growth of an InGaAs laser structure grown on exact orientated and 6° off orientated substrate.

For industrial applications it is necessary to assure reproducible electrical and optical laser characteristics. This puts high demands on thickness uniformity and material composition for all layers. To investigate laser properties and reproducibility we processed Broad Area (BA) laser devices using two substrates out of the same run (Laser 1 and Laser 2). Furthermore we did characterization on laser devices processed on the center part and on the edge of each substrate. By choosing this approach we get on-substrate and substrate-to-substrate information. Figure 6 shows the P(I) characteristics and respective spectra for BA lasers with dimensions of 1000 µm x 100 µm. Lasers are measured as cleaved using pulsed excitation.

P(I) characteristics show almost no deviation. This indicates good on-substrate uniformity and high substrate-to-substrate reproducibility. The highest efficiency of 0.33 W/A per facet was measured for the laser device processed on the center piece of substrate 1. The lowest efficiency still is 0.29 W/A. The output power per facet is in the range of 1.0 W at a current of 4.0 A for all laser devices. No signs of degradation are visible. All devices exhibit threshold current densities in the range of 500 A/cm^2. Commercial InGaAs laser diodes with coated facets offer efficiencies of more than 0.8 W/A [4]. But our focus was not on device performance optimization but on demonstrating a modelling based epitaxy of laser structures providing consistent laser results.

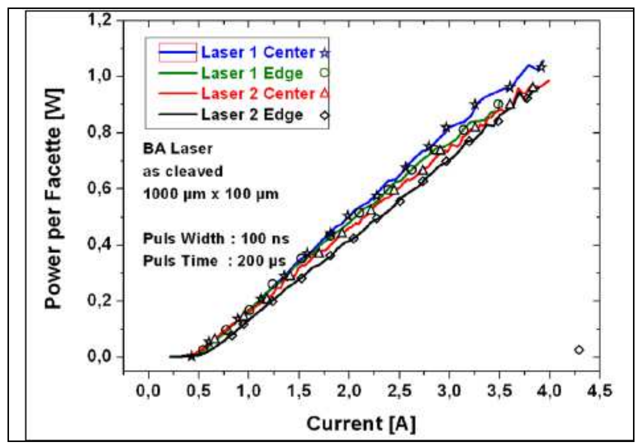

Figure 6: P(I) characteristics (left) of InGaAs BA laser devices with dimension 1000 µm x 100 µm.

To increase efficiency additional annealing steps, facet coating and optimization of device geometry would be necessary. To conclude the electrical characteristics of our BA laser devices demonstrate that a straight forward application of modelling allows to grow laser structures with consistent quality. The expensive and time consuming growth of a huge number of test samples is not necessary.

CONCLUSION

Support of modelling to speed-up setting appropriate process conditions for the growth of InGaAs/(Al)GaAs epitaxial laser structures on 4 inch substrates in a production system has been demonstrated to be very beneficial. Modelling predictions have been successfully verified by experimental results. AlGaAs test layers grown at different total flows show thickness profiles in good accordance to modelling calculations. Photoluminescence measurements on InGaAs SQW structures based on parameters derived by modelling gave very good results concerning uniformity and crystalline quality on 4 inch substrates.

The epitaxy of AlGaAs/ InGaAs SQW laser structures emitting at approx. 920 nm on 4 inch GaAs substrates show promising results for laser application. On-substrate and substrate-to-substrate reproducibility was demonstrated by electrical characterization of BA laser devices. Laser efficiencies, output power and threshold densities are almost equal for all processed laser devices.

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ACRONYMS

SQW:	Single Quantum Well
MOCVD:	Metal Organic Chemical Vapor Deposition
PL:	Photoluminescence
FWHM:	Full Width at Half Maximum
BA Laser:	Broad Area Laser