In-situ curvature measurements applied to MOVPE-based growth of edge-emitting diode lasers

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Abstract

We apply in-situ curvature measurements to GaAs/AlGaAs based edge emitting diode laser growth. Along with an increased overall AlGaAs thickness the room temperature convex wafer bow increases as well. Since this is mainly caused by the thermal expansion mismatch between GaAs and AlAs we make use of tensile strained $Al_{0.85}Ga_{0.15}As_yP_{1-y}$ cladding layers to partly compensate for the negative curvature swing during the cool down phase.

INTRODUCTION

Near-infrared edge emitting semiconductor diode lasers designed for high output powers are preferably realized in the GaAs/AlGaAs material system. By broadening the vertical intensity distribution across the cavity, facet load decreases which allows for higher optical output powers. However, this approach requires vertical layer sequences with overall thicknesses above 6 µm.

Although the room temperature lattice mismatch of ~0.14% between AlAs and GaAs appears to be rather small, overall thicknesses larger than 6 µm can lead to convex wafer bow with an absolute radius of curvature below 6 m. This can cause issues during wafer processing, especially in terms of wafer thinning down to around 100 µm, which is required to obtain terrace–free cleaved facets, which in turn is required for highly reliable laser devices. Furthermore, 10 mm wide laser diode bars soldered on a sub-mount tend to suffer from early device failure if the bow of the bar gets too large. Therefore, wafer bow and overall strain in such semiconductor diode lasers, primarily consisting of $Al_xGa_{1-x}As$ waveguide and cladding layers, are to be minimized.

Our favored approach to achieve the above is to partially substitute the arsenic atoms in the $Al_xGa_{1-x}As$ cladding layers with smaller phosphorus atoms. As a result, the lattice constant will decrease and lower the compressive strain. At typical growth temperatures of 700-800°C, $Al_xGa_{1-x}As$ layers show a much lower compressive strain of ≤0.02%, much lower in comparison to the one at room temperature. Thus, a typical phosphorus mole fraction of 1-4% will cause the growing $Al_xGa_{1-x}As_yP_{1-y}$ layer to be under tensile strain. In order to prevent formation of dislocations or even cracks during growth the strain-dependent critical thickness must not be exceeded. As the wafer curvature is a suited indication regarding this critical parameter it is continuously monitored during growth.

EXPERIMENTAL

Epitaxial growth was carried out using metal organic vapor phase epitaxy (MOVPE) in a 5×4" planetary reactor (AIX2400G3) using standard precursors (trimethylgallium, trimethylaluminum, trimethylindium, arsine, phosphine, disilane). Growth processes employing strain compensation schemes are ideally monitored and adjusted by using in-situ curvature measurements. The MOVPE system is therefore equipped with a LayTec EpiCurve®TT AR 3W in-situ metrology system, capable of measuring reflectivities (at 950 nm, 633 nm and 405 nm), wafer temperature (emissivity corrected pyrometry at 950 nm) as well as the curvature of the wafer surface. The latter is measured by means of laser deflectometry using three incident, parallel laser beams reflected by the wafer surface. (s. Fig. 1).

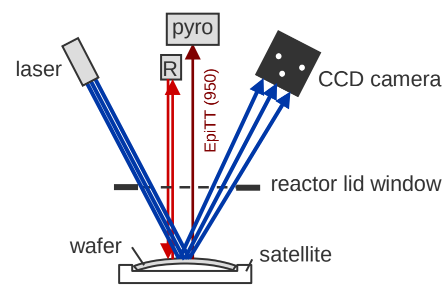

Figure 1: Schematic of the in-situ measurement setup attached to the MOVPE system.

RESULTS

Fig. 2a shows measured XRD Ω-2Θ scans from the 004 reflection obtained for a series of test samples containing $Al_{0.85}Ga_{0.15}As_yP_{1-y}$ layers grown on top of an $Al_{0.85}Ga_{0.15}As$ layer. These samples were made for calibrating purposes prior to actual device growth. The highest intensity peak in each curve is related to the GaAs substrate, while the left-

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most peak belongs to the $Al_{0.85}Ga_{0.15}As$ layer. The signature related to the $Al_{0.85}Ga_{0.15}As_yP_{1-y}$-layer is flagged with a vertical arrow. In order to determine the amount of incorporated phosphorus simulated XRD Ω-2Θ scans from the 004 reflection were fitted to the measured ones (vertical lines in Fig. 2a). The obtained P mole fraction $1\text{-}y_{solid}$ in the $Al_{0.85}Ga_{0.15}As_yP_{1-y}$-layer is linearly dependent on the vapor phase composition $1\text{-}y_{vapor}$ (Fig. 2b).

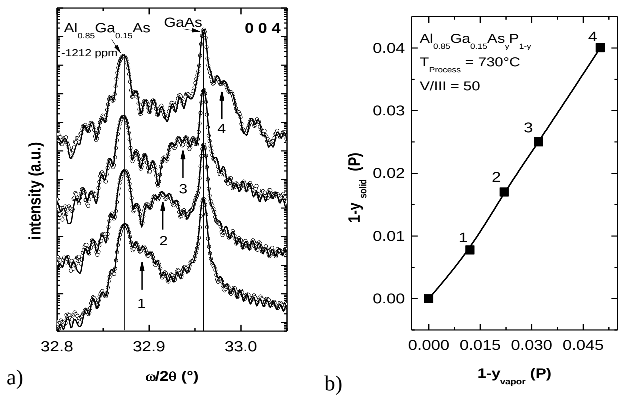

Figure 2: (a) - Measured (dots) and simulated (lines) XRD Ω-2Θ scans for different $Al_{0.85}Ga_{0.15}As/Al_{0.85}Ga_{0.15}As_yP_{1-y}$ test samples. Vertical arrows indicate the $Al_{0.85}Ga_{0.15}As_yP_{1-y}$ peak position; (b) - Observed dependency for incorporated phosphorus ($1\text{-}y_{solid}$) on the injected vapor phase ratio ($1\text{-}y_{vapor}$).

Based on the above mentioned experimental results edge emitting diode laser structures were grown by adding 1.5% of P to the $Al_{0.85}Ga_{0.15}As$ cladding layers. Fig. 3 (left axis) shows measured curvature transients for structures A and B (symbols, slightly oscillating curves), containing $Al_{0.85}Ga_{0.15}As$ and $Al_{0.85}Ga_{0.15}As_{0.985}P_{0.015}$ cladding layers, respectively. Solid lines in Fig. 3 refer to simulated curvature transients including a third vertical layer structure

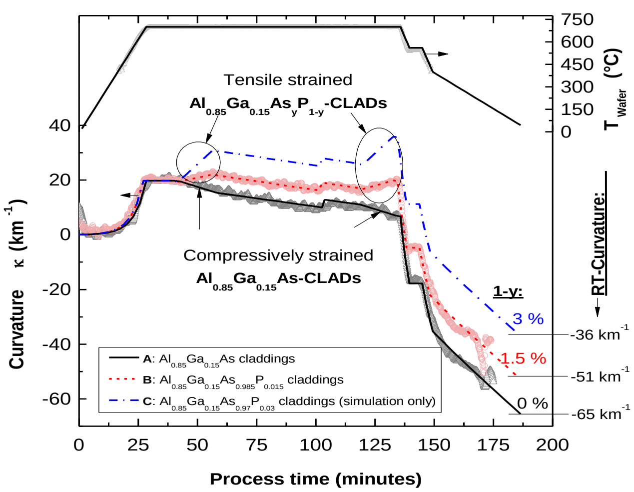

Figure 3: Measured and simulated in-situ curvature transients for the growth of the vertical layer structure of an edge emitting diode laser comprising $Al_xGa_{1-x}As_yP_{1-y}$-claddings with 0%, 1.5% and 3% incorporated phosphorus.

where we increased the P mole fraction in the $Al_{0.85}Ga_{0.15}As_yP_{1-y}$ cladding layers to 3%. All layer structures contain a tensile strained $GaAs_yP_{1-y}$ single quantum well layer (SQW, Fig. 3 at ~100 minutes). Simulated curvature transients were calculated using Stoney's equation [1, 2].

With reference to the process temperature over time graph (Fig. 3, upper section), the plotted curvature transients (Fig. 3, lower section) have in common that most of the compressive strain causing the room temperature bow is being introduced during the cool down phase (see Fig. 3 T_{WAFER} plotted on the right axis, process time >140 minutes), due to differences in the linear thermal expansion coefficients of GaAs and AlAs [3].

As we cannot change this characteristic cool down curvature swing without changing the electro-optical properties of the diode laser itself, we tried to offset part of it by introducing structure B, which contains $Al_{0.85}Ga_{0.15}As_{0.985}P_{0.015}$ cladding layers and resembles a strain compensation scheme very similar to the one used in [4]. The agreement between measured and simulated curvature for structures A and B is quite good. Furthermore, the room temperature curvature of structure B is reduced from -65 km^{-1} to -51 km^{-1}.

Finally, a proposed layer structure C, making use of $Al_{0.85}Ga_{0.15}As_{0.97}P_{0.03}$ cladding layers, is represented by its simulated curvature transient in Fig. 3 as well. As this transient suggests, further increasing the phosphorus mole fraction to 3% is expected to reduce the room temperature curvature down to -36 km^{-1}, which is to be verified.

CONCLUSIONS

We successfully reduced the room temperature curvature of an edge emitting diode laser structure by using less compressively strained $Al_{0.85}Ga_{0.15}As_{0.985}P_{0.015}$ alloys as a drop-in replacement for the $Al_{0.85}Ga_{0.15}As$ cladding layers. This allows for a partial reduction of the convex wafer bow, which is induced by thermal stress during cool down due to different thermal expansion of GaAs and AlAs.

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ACRONYMS

MOVPE: Metalorganic vapor phase epitaxy
XRD: X-ray diffraction
CLAD: Cladding layer