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GaN-Based Materials for Blue Emitting Device Structures Grown in Multiwafer Planetary® Reactors

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Using optimised growth processes for an AIX 2000 HT Planetary® Reactor a high material quality and high potential device yield are demonstrated. Doping levels for GaN single layers from $1 \cdot 10^{20}$ cm^{-3} free electrons to semi-insulating to $1 \cdot 10^{18}$ cm^{-3} free holes with state-of-the-art layer resistance uniformities especially for n-type layers are shown. Both AlGaN and GaInN with composition homogeneities of better than 1 nm photoluminescence peak-wavelength standard deviation are displayed. Finally, examination of optically pumped laser action in simple double-hetero structures is quoted to prove the quality of the material.

1 Introduction

As device structures of GaN based materials are produced for commercial application in LEDs and Lasers [1], tools for industrial mass production become necessary. These machines are required to provide material with state-of-the-art characteristics while maintaining high throughput, high reproducibility, high growth efficiency and good uniformity of individual layers for maximal yield of the production line. The AIXTRON multiwafer MOVPE systems with the Planetary® Reactor design are uniquely suited to meet these specifications. The growth processes are continuously optimised regarding total pressure, growth temperature and precursor flows to meet the material quality requirements while the reactor design ensures high yield.

2 Sample Preparation

All GaN based structures discussed here were grown with a GaN nucleation layer on sapphire substrates in the (0001) surface orientation. The layers were produced in a AIX 2000 HT Planetary® Reactor where the uniformity of the layer characteristics is ensured by a two fold rotation of the substrates: up to 7 sattelite disks carrying 2” substrates are rotated by the Gas Foil Rotation® principle while the main disk is turned by mechanical drive. The precursors NH_3, TEGa, TMGa, TMAl, TMIn, SiH_4 and Cp_2Mg are injected in the center of the main disk together with N_2 or H_2 as carrier gas, seperated in an upper and a lower flow for MO and hydride precursors respectively. Reactor temperatures up to 1200°C and total pressures between 50 and 1000 mbar were used for the growth processes.

3 Electrical characterization

Non intentionally doped GaN layers are semi-insulating or lightly n-type with background electron concentrations below $5 \cdot 10^{16}$ cm^{-3}. Intentional n-type doping is obtained by introducing SiH_4 into the gas phase. Free electron concentrations of up to $1 \cdot 10^{20}$ cm^{-3} have been obtained. Figure 1 shows a topology of the sheet resistance of a highly n-doped 0.5 µm thick GaN layer mapped by a Lehighton inductive meassurement setup. The average sheet resistance is 15.75 Ω/square with a standard deviation of 0.86 %. This indicates excellent doping uniformities taking into account that both thickness distribution and doping homogeneity contribute to this value (see Section 4). Intentional p-type doping has been achieved by using Cp_2Mg as precursor for the acceptor. With Mg concentrations of more than $1 \cdot 10^{20}$ cm^{-3} hole concentrations up to $1 \cdot 10^{18}$ cm^{-3} are obtained. Uniformities for p-type carrier density with a standard deviation around 10 % have been found, revealing incorporation uniformity as well as influences of the activation process.

4 Thickness measurement

The layer thickness of single layer GaN on sapphire structures are routinely examined by white light interference evaluation on a Waterloo PLM 100 wafer mapper system. Figure 2 shows a mapping of a single layer GaN on sapphire wafer - the average thickness is 2.44 µm with a standard deviation of 0.75 %. Usual variations for all nitride based materials are in the range of 2 % standard deviation.

5 Composition homogeneity of ternary compounds

The Waterloo PLM 100 photoluminescence (PL) mapper was used to study the distribution of the peak wavelength of the bandgap related emission line of ternary layers at room temperature. Structures of GaInN and AlGaN layers on a GaN buffer on sapphire have been thus examined. Figure 3a shows the wafer mapping (left) and wavelength distribution (right) for a GaInN layer with an estimated average of 6 to 8 % InN in the lattice - the average wavelength is 382.44 nm with a standard deviation of 0.94 nm. For a AlGaN layer with roughly 8 to 12 % AlN (S) an average peak wavelength of 340.31 nm and a standard deviation of 0.26 nm were found - see Figure 3b. The standard deviation for emitted intensity is typically less than 10 % for both ternary systems.

6 Material property qualification by device fabrication

A simple double-hetero (DH) structure consisting of a 10 nm GaN cap, 50 nm GaInN with ca. 16 % InN (S) and 1.6 µm GaN buffer was cleaved into roughly 1 mm wide pieces and exposed to high intensity optical pumping with a pulsed N_2 laser. [2] At excitation densities up to 1 MW/cm^2 the emission from that sample was found to concentrate into a single lasing mode at 78 K, as shown in Figure 4. This lasing action without a Fabry-Perot cavity is evidence of the high optical quality and high gain coefficient of the sample.

7 Conclusion

Electrical and optical measurements prove our GaN material and its ternary alloys to be of high quality. Doping and ternary compositions have been shown to have state-of-the-art homogeneity, except for p-type GaN where the growth process and activation of the acceptors require further optimisation. These characterization results combined with the high yield due to the unique design of the AIXTRON Planetary® Reactors prove these systems to be an optimal tool for GaN based LED and - in future - laser mass production.

ACKNOWLEDGMENTS

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FIGURES

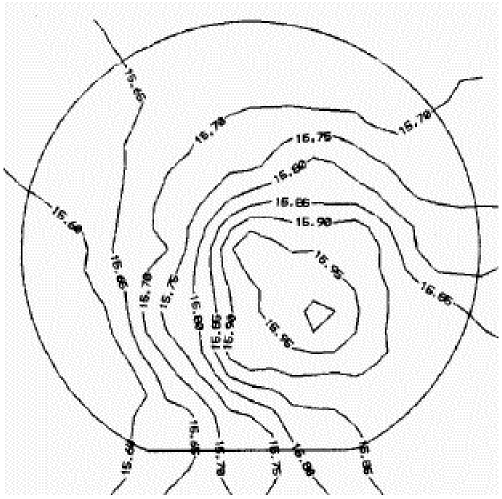

Figure 1. Sheet resistance mapping of a 0.5 µm GaN:Si layer on c-plane sapphire: average resistance is 15.75 Ω/square with a standard deviation of 0.86 %

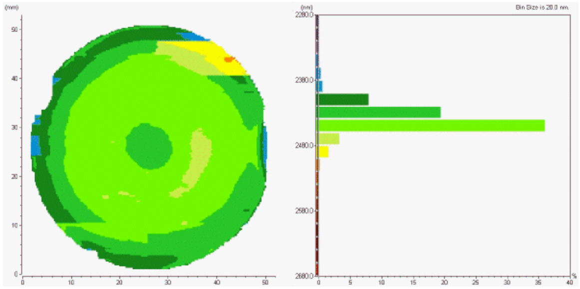

Figure 2. Thickness mapping of a GaN layer on sapphire substrate: average thickness is 2.44 µm with a standard deviation of 0.75%

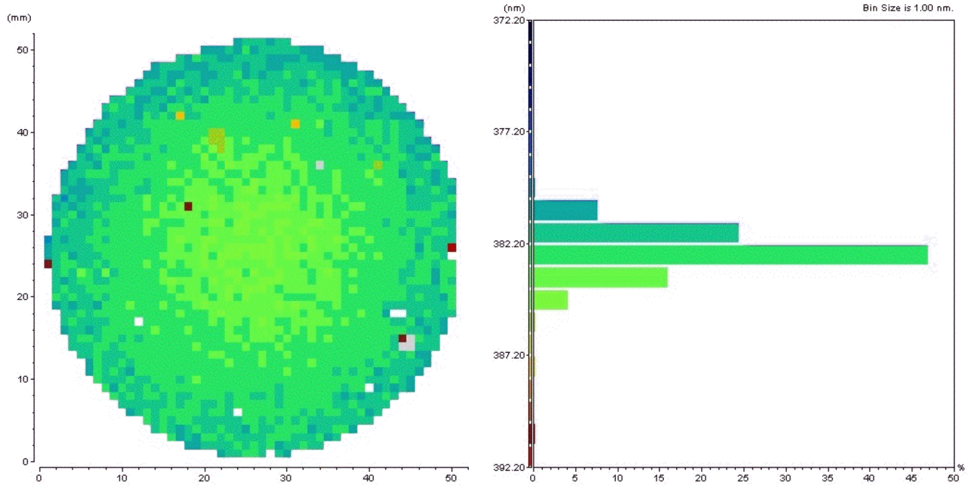

Figure 3a. RT PL peak wavelength mapping of a full 2” wafer GaInN/GaN heterostructure and wavelength distribution: average wavelength is 382.44 nm with a standard deviation of 0.94 nm (distribution bin size is 1 nm)

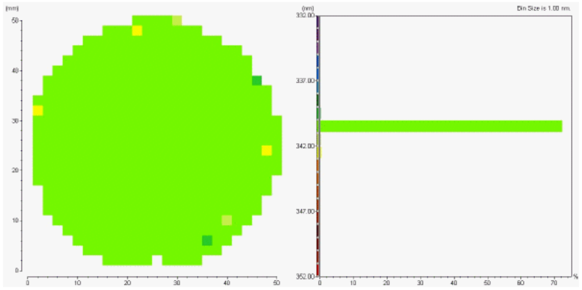

Figure 3b. RT PL peak wavelength mapping of a full 2” wafer AlGaN/GaN heterostructure and wavelength distribution: average wavelength is 340.31 nm with a standard deviation of 0.26 nm (distribution bin size is 1 nm)

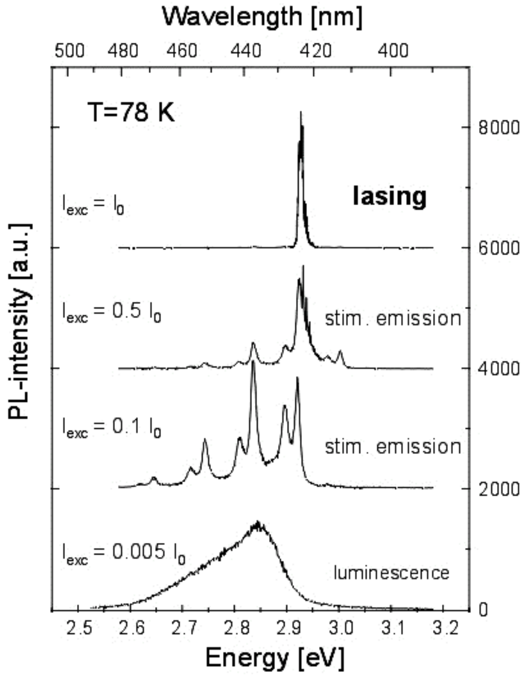

Figure 4. stimulated emission and LT laser action by optical pumping with increasing excitation intensity of a simple GaN/ GaInN DH structure [3]