10TH INTERNATIONAL CONFERENCE ON NITRIDE SEMICONDUCTORS (ICNS 10)

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INTRODUCTION

The International Conference on Nitride Semiconductors (ICNS) is one of the major conferences in the field of nitrides semiconductors, and is held biannually, alternating with the International Workshop on Nitrides (IWN). This year, the tenth ICNS session was held in Washington DC, USA, from August 25th - 30th. About 900 abstracts were presented with a ratio of about 1:4 for oral presentations. The presentations were split into four main categories, namely "Bulk and film growth", "Optical devices: visible", "Optical devices: UV", and "Electrical devices".

My research focuses on the characterisation of the structure of InGaN/GaN quantum wells in order to improve the performance of light emitting diodes (LEDs). Therefore this report aims to present the latest research related to bulk and film growth and to efficiency droop. In a first part I will present a few selected talks about bulk and film growth. In a second part I will present a few talks dealing with the efficiency droop phenomenon, in particular those discussing the origin of droop and those looking for ways to resolve it.

BULK AND FILM GROWTH

Stacking fault luminescence in GaN: emission energies, spontaneous polarization and field screening[1]

J. Laehnemann, Paul-Drude-Institut fuer Festkoerperelektronik

Micro-cathodoluminescence and micro-photoluminescence were performed on strain-free GaN micro-crystals grown on top of GaN nanowires on Si substrates. Intrinsic and extrinsic stacking faults can be found in the crystals and the emission of each type of stacking fault can be revealed by photoluminescence: 3.42eV, 3.35eV and 3.29eV for I_1-type, I_2-type and E-type stacking faults respectively.

From the transition energies associated with each type of stacking fault, the spontaneous piezoelectric coefficient of GaN can be determined with almost no assumptions. The strength of the spontaneous piezoelectric field in GaN is found to be -0.022 ± 0.007 C/m^2.

Emission of stair rod dislocations in a-plane GaN identified by scanning transmission electron microscopy cathodoluminescence

F. Bertram, University of Magdeburg

Scanning transmission electron microscopy together with cathodoluminescence were performed at liquid helium temperature on a-plane GaN. As expected for non-polar samples, the structure contains a high density of defects such as basal plane stacking faults (BSFs) type I_1, type I_2 or type E as well as prismatic stacking faults (PSF).

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[1] Lahnemann *et al.*, Phys. Rev. B **86**, 081302 (2012).

It is found that the sample emission is dominated by the stacking faults. The combination of the two techniques established that BSFs type I_1 dominate the emission, while PSF, BSF type I_2 and BSF type E are responsible for a low intensity cathodoluminescence signal at lower energy than that of BSFs type I_1.

A reduced emission intensity is observed in the vicinity of the partial dislocations at the boundaries of the stacking faults, suggesting they are optically inactive.

Dislocations can be found at the intersection of a BSF and a PSF, namely stair-rod dislocations. It is observed that such dislocations are optically active, with an emission at 3.28eV.

The effect of well width fluctuations and barrier growth temperature on carrier recombination in InGaN/GaN quantum well structures.

F. Massabuau, University of Cambridge

InGaN/GaN quantum well structures and light emitting diodes were grown by MOCVD using four different growth recipes in order to separate the effects of gross well width fluctuations and of quantum barrier growth temperature on device performance.

Transmission electron microscopy confirms the presence of gross well width fluctuations when the InGaN quantum well is directly exposed to a high temperature during growth.

Photoluminescence and electroluminescence reveal that the structures exhibiting gross well width fluctuations have a higher internal quantum efficiency than the structures with continuous quantum wells.

Temperature dependent electroluminescence reveals that the gross well width fluctuations provide an increased energy barrier to non-radiative recombination at defective sites. Finally it is shown that the device performance at high input current density (i.e. droop) is not affected by the quantum well morphology.

Intrinsic degradation mechanism of nearly lattice matched InAlN layers grown on GaN substrates [2]

G. Perillat-Merceroz, Ecole polytechnique fédérale de Lausanne (EPFL)

The presence of V-defects on InAlN grown by MOVPE on c-plane free-standing GaN was investigated. Several InAlN samples were grown, with different thicknesses (from 2 to 500 nm), and compositions so that the samples could be almost lattice-matched under either compressive or tensile strain.

Hillocks were observed at the surface of the thin layers and progressively V-pits occured as the InAlN layer becomes thicker. The presence of V-pits is not linked to the strain state of the layer and it is observed that the density of pits is two orders of magnitude higher than the threading dislocation density suggesting they are unrelated to dislocations.

Energy Dispersive X-ray reveals that the facets of the pits are In-poor while the vertical external boundaries of the defects are In-rich.

Finally a formation mechanism was proposed based on the nucleation of hillocks after they reached a critical thickness.

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[2] Perillat-Merceroz *et al.*, J Appl Phys **113** 063506 (2013).

Unveiling the anti-surfactant effect of Si in GaN epitaxy by aberration corrected transmission electron microscopy

T. Markurt, Leibniz Institute for Crystal Growth

Transmission electron microscopy combined with simulations was used in order to understand the anti-surfactant effect of Si on GaN, usually referred to as "SiN_x" mask. It is shown that the "SiN_x" mask at the surface of GaN is in fact a $SiGaN_3$ mask. The Si and Ga cations are shown to be positioned in a $\sqrt{3} \times \sqrt{3}\, R30^o$ unit cell, together with a Ga vacancy.

It is reported by density functional theory calculations that a single monolayer of $SiGaN_3$ mask is the most favourable arrangement of GaN in Si-rich conditions. Moreover, it shows that the anti-surfactant effect of Si on GaN comes from the dangling bonds at a Ga vacancy.

High indium content InGaN layers with uniform composition, full misfit strain relaxation, and high light emission efficiency

A. Fischer, Arizona State University

50 nm thick InGaN layers were grown by metal modulated epitaxy, with various indium compositions (22%, 45%, 60% and 66%) and characterised by transmission electron microscopy, X-ray diffraction and photoluminescence.

Transmission electron microscopy reveals that while the sample with 22% of indium has a very high density of threading dislocations, the layer with 45% of indium has a high density of stacking faults, and those with higher indium content (60 and 66%) surprisingly exhibit a low defect density. On these last two samples, Moiré fringes can be observed at the GaN/InGaN interface, suggesting that misfit strain relaxation occurs at the early stages of InGaN growth. These two epilayers also exhibit an increased photoluminescence emission compared to the others. Based on ω-scan broadening, no phase separation in the layers could be detected by X-ray diffraction, suggesting that only random alloy fluctuations occur in the material.

Based on critical thickness analysis, the 60% and 66% indium content layers are expected to relax strain at the very first monolayer. Therefore a strain-free InGaN layer with low density of defects is subsequently deposited on top of it.

EFFICIENCY DROOP

Progress in nonpolar and semipolar GaN based materials and light emitters (Title as announced in the program) [3]

J. Speck, University of California

Electron emission spectroscopy was employed to detect Auger electrons from an InGaN/GaN light emitting diode. High energy electrons were measured when the device efficiency drops, thus suggesting an Auger process occurring in the active region.

The intensity of this hot carrier signal was found to be proportional to the missing current in the device. Therefore is can be inferred that Auger recombination is the main cause of efficiency droop in GaN-based light emitting diodes.

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[3] Iveland *et al.,* Phys. Rev. Lett. **110**, 177406 (2013).

Correlation between the onset of high injection and the onset of efficiency droop in GaInN light emitting diodes [4]

E. Fred Schubert, Rensselaer Polytechnic Institute

GaN-based light emitting diodes were characterised by electroluminescence. Contrary to photoluminescence where only Auger recombination can account for the loss of efficiency at high power, this technique takes into account an additional loss mechanism: carrier leakage.

The onset of high injection regime and the onset of efficiency droop were recorded at different temperatures. A temperature independent voltage difference of 0.3 V is found between the two onsets. This suggests that an electric field is built when the device reaches its high injection regime, and that this field extracts carriers from the active region to the p-type region.

Suppression of Auger stimulated efficiency droop in nitride based light emitting diodes [5]

R. Vaxenburg, Technion-Israel Institute of Technology

The effect of InGaN quantum well design on the Auger recombination rate has been investigated. It is found that a sharp, rectangular quantum well results in a high Auger coefficient, possibly explaining the efficiency droop. On the other hand a smooth-confining quantum well reduces the Auger recombination rate and is thus expected to result in a higher device efficiency.

Role of p-InGaN layer in enhancing hole transport and distribution in InGaN/GaN multiple quantum wells of visible III-Nitride light emitting diodes

R. Dupuis, Georgia Institute of Technology

Hole transport and carrier distribution inhomogeneities can account for the efficiency droop in InGaN/GaN quantum well light emitting diodes.

It is first observed that most of the light emitted from a quantum well structure comes from the quantum wells located close to the p-region of the device. Therefore this study investigates how the design, in particular the composition and thickness, of the electron blocking layer and of the p-type region can improve the device performance by providing a better carrier distribution in the active region.

It is found that a better homogeneity of carrier distribution is achieved when the p-doped region contains a slight amount of indium, typically 3.5%.

Finally, by comparing InAlN electron blocking layers with different thicknesses, it is shown that an InAlN electron blocking layer of 15nm provides the best internal quantum efficiency.

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[4] Meyaard *et al.*, Appl. Phys. Lett. **102** 251114 (2013).

[5] Vaxenburg *et al.*, Appl. Phys. Lett. **102**, 031120 (2013).

CONCLUSION

I would like to thank the UKNC for giving me the opportunity to attend this conference. The variety of topics, techniques and ideas addressed throughout the week will most certainly be extremely useful to me in order to build a better knowledge on the material and to design my next experiments. It was also a great experience to give a talk in front of the international community. The poster sessions were the perfect occasion to discuss with people from so many different backgrounds, getting interested in their research, and interesting them in my own.

Next year, IWN 2014 will be held in Wroclaw in Poland and ICNS 11 will be held, the year after, in Beijing in China.