INTERNATIONAL WORKSHOP ON NITRIDE SEMICONDUCTORS
FABIEN MASSABUAU, UNIVERISTY OF CAMBRIDGE

INTRODUCTION

The eighth international workshop on nitrides (IWN) was held this year in Poland from August 24th to August 29th. This conference, held biannually, is one of the major events in the field of nitride semiconductors. About a thousand researchers and exhibitors gathered this year in the Centennial Hall in Wroclaw to attend the 7 plenary talks, 70 invited talks, 180 contributed talks and numerous poster presentations. The contributions were spread over four different symposia, namely "Basic Physics & Characterization", "Optical Devices", "Growth" and "Electronic Devices".

My research investigates the nanostructure of InGaN quantum wells and its impact on the efficiency of light emitting diodes. Therefore in this report I will present is a selection of presentations related to my work.

SELECTED PRESENTATIONS

Photoluminescence of InGaN/GaN quantum wells grown on c-plane substrates with locally variable miscut

P. Drozdz (University of Warsaw)

This study investigates InGaN/GaN quantum wells grown by metal organic vapour phase epitaxy on locally misoriented GaN pseudo-substrates. Regions of local miscut of the size of 50-150 μm were fabricated by photolithography followed by ion etching. Hence *c*-plane samples with misorientations as high as about 2^{o} were generated along the *a*- and *m*-directions. The samples were investigated by atomic force microscopy and time-resolved photoluminescence.

Atomic force microscopy performed at the surface of the multiple quantum well samples revealed the presence of atomic steps. These steps are observed to run perpendicular to the miscut direction and to be evenly spaced.

Photoluminescence showed that the peak energy of the samples changes with the miscut, irrespectively of the miscut direction, with a blueshift of the emission reported for increasing misorientations. This suggests that the electron-hole separation may depend on the miscut, in which case the miscut is expected to affect the carrier recombination lifetime. Indeed, time-resolved photoluminescence showed that the radiative and non-radiative decay times decrease for increasing miscut.

These results can be explained by the reduced incorporation of indium on the inclined facets of the substrate, but also by the poorer crystal quality associated with an increased misorientation.

Indium incorporation dependent on substrate miscut in InGaN/GaN quantum wells grown in polar and semipolar substrate orientations

M. Sarzynski (Institute of High Pressure Physics)

This study investigates InGaN/GaN quantum wells grown by metal organic vapour phase epitaxy on locally misoriented substrates. Regions of local miscuts were preparated on (0001) polar and $(20\bar{2}1)$ semi-polar substrates using the same method as Drozdz *et al.* (see presentation above). Miscuts towards $\langle 11\bar{2}0\rangle$ and $\langle 1\bar{1}00\rangle$ were prepared on the (0001)-oriented substrates, while miscuts towards $\langle 11\bar{2}0\rangle$, $\langle 1\bar{1}04\rangle$ and $\langle \bar{1}104\rangle$ were fabricated on the $(20\bar{2}1)$-oriented substrates. The samples were investigated by atomic force microscopy, micro-photoluminescence, cathodoluminescence and X-ray diffraction.

For the samples grown on (0001)-oriented substrates, an increase of miscut is associated with a decrease in photoluminescence emission wavelength, irrespectively to the miscut direction. This result is confirmed by X-ray diffraction where reduction of indium content is reported on regions with higher misorientations.

For the samples grown on $(20\bar{2}1)$-oriented substrates with a miscut towards the $\langle 11\bar{2}0\rangle$-direction, a slight decrease in photoluminescence wavelength related to a slight decrease in composition is reported. On the other hand, no variation of the composition but a decrease in photoluminescence wavelength are reported for miscut directions towards $\langle 1\bar{1}04\rangle$. This effect can be explained by the modification of the internal electric field induced by the miscut.

Investigation of unintentional indium incorporation into GaN barriers of InGaN/GaN quantum well structures

F. Massabuau (University of Cambridge)

InGaN quantum well samples were grown on *c*-plane sapphire substrates by metal organic vapour phase epitaxy using different GaN barrier growth methods. High-resolution transmission microscopy (using geometric phase analysis) was employed to characterise the composition profile of the quantum wells and a Schrödinger-Poisson calculator was used to see the impact of the compositional profile on the band structure of light emitting diodes.

The composition profile across the quantum well, obtained by geometric phase analysis, reveals a deviation from what is nominally assumed by the growth (*i.e.* rectangular profile). The actual profile consists of a first indium content bump located at the lower quantum well interface, followed by a plateau region and by an indium tail penetrating into the GaN barrier. The indium tail, due to indium segregation, was found to decay exponentially into the following GaN barrier, with a decay constant strongly related to the growth method employed, *i.e.* to the temperature and length of the GaN capping layer deposited on top of the quantum well.

The impact of such tail on the emission properties on a single quantum well light emitting diode was simulated using a Schrödinger-Poisson calculator. It was found that the presence of a tail resulted in a greater penetration of the electron wavefunction into the GaN barrier, thus leading to a decrease in the electron-hole confinement and therefore to a lower radiative recombination rate. On the other hand, a smooth quantum well upper interface results in a lower energy barrier for holes, therefore improving the hole injection into the active region of the device.

Atomic scale investigations of the indium incorporation in the InGaN/GaN quantum wells by transmission electron microscopy

M. Korytov (CNRS)

The composition variation across an InGaN quantum well structure are investigated by means of high resolution transmission electron microscopy and dark-field electron holography[1]. The two methods were observed to give very similar results. It is noticed that the bottom interface of the quantum wells is abrupt with regard to the top interface. The indium tail observed at the upper interface of the quantum well, resulting in an indium penetration length into the GaN barrier of about 2 nm, is thought to arise from indium segregation during growth.

The influence of some growth parameters on the length of the indium tail has been explored. No measurable difference was observed when the temperature ramp, the growth time or the flow of NH_3 were altered. Finally, the flow rate of trimethylindium was found to have no impact on the indium tail, although it does affect the overall composition of the quantum well.

Atomic scale composition profiles of MOCVD grown InGaN/GaN quanum wells: Modelling and characterisation

S. Karpov (STR Group-Soft-Impact Ltd.)

This study presents a software modelling of the composition profile of InGaN quantum wells grown by metal organic chemical vapour deposition. The simulation software is based on a model of indium surface segregation which incorporates the dependence of the indium surfactant layer with the following parameters: growth temperature, III/V ratio, reactor type, etc.. To validate the results, this study uses samples fabricated by OSRAM and characterised using high-resolution transmission electron microscopy and dark-field holography, as presented above by Korytov *et al.*.

Elimination of trench defects and V-pits in InGaN-GaN structures

J. Smalc-Koziorowska (Institute of High Pressure Physics)

This study investigates the formation of defects - V-pits and trench defects - in blue-green-emitting InGaN quantum well structures as a function of the GaN barrier growth temperature.

Transmission electron microscopy observation of trench defects shows that trench defects originate from basal plane stacking faults located in the GaN barrier.

The temperature for the GaN barrier growth was varied between 780^{o}C and 880^{o}C. It was found that an increase of the GaN growth temperature resulted in a decrease in the formation of defects, with a suppression of the trench defects for a barrier grown at 830^{o}C, and a suppression of the V-pits for a barrier grown at 880^{o}C. Because both types of defect can be reduced using the same parameter, it is suggested that they share a common origin. Therefore it is concluded that trench defects may arise

[1] Hytch *et al.*, Ultarmicroscopy **111,** 1328 (2011)

from *a*-type dislocations emanating from the basal stacking fault or from the stacking mismatch boundary.

Critical thickness in InGaN/GaN heterostructure system as a function of dislocation density in underlying GaN layer

M. Iwaya (Meijo University)

This study performs in-situ crystal quality measurements in InGaN epilayers. A metal organic chemical vapour phase deposition reactor was equipped with a focussed X-ray beam diffractometer. This setup allows measurement of the full width at half maximum (FWHM) of the X-ray peaks (related to the dislocation density) as the material is grown.

It is observed that in the case of InGaN thick layers, with 13% of indium, the FWHM first decreases with increasing InGaN layer thickness until a value close to 100 nm, then increases as more material is deposited. The inflection point of the FWHM is shown to strongly depend on the nature of the substrate employed (about 100 nm for sapphire substrate, and 55 nm for GaN substrate).

Transmission electron microscopy performed on these samples reveals that, beyond the inflection point, the increase in FWHM is mainly due to the formation of an array of misfit dislocations. Such dislocation are mostly *(a+c)*-type, but *a*-type misfit dislocation start appearing for very thick layers, typically above 250 nm.

The critical thickness obtained with this experiment has been compared to theoretical models (Holec[2], Metthew and Blakesley[3], Fischer[4], etc.). The experimental critical thickness is observed to be about one order of magnitude larger than most of the models. In that, a better agreement is found with Fischer et al.'s model.

Suppression of thermal degradation of InGaN/GaN quantum wells in green laser diodes structures during epitaxial growth[5]

J. Liu (SINANO)

Green-emitting InGaN/GaN quantum well laser diodes were grown by metal organic vapour phase epitaxy.

Observation of the active region by transmission electron microscopy reveals the presence of indium platelets and voids, ascribed to thermal degradation during the growth of the p-GaN layer. Micro-photoluminescence shows the presence of dark spots, which also reflect the presence of local active region degradation following the growth of the p-doped GaN layer.

It was observed that active region degradation by formation of platelets or voids can be prevented by decreasing the growth temperature for the p-doped GaN layer from 1000°C to 900°C.

---

[2] Holec *et al.*, J. Crystal Growth **303**, 314 (2007)
[3] Matthew and Blakeslee, J. Crystal Growth **27**, 118 (1994)
[4] Fischer *et al.*, Phys. Rev. Lett. **73**, 2712 (1994)
[5] Li *et al.*, Appl. Phys. Lett. **103**, 152109 (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, ICNS 11 will be held in Beijing in China and IWN 2016 will be held, the year after, in Orlando in the United States.