International Workshop on Nitrides 2018 – Conference report

Stephen Church, University of Manchester

The international workshop on Nitrides 2018 (IWN2018) was hosted in Kanazawa city, Ishikawa prefecture, Japan between Sunday 11th November and Friday 16th November. The meeting included oral and poster presentations regarding the most recent developments in the Nitride community, with reports from research groups worldwide.

I would like to thank the UKNC for providing funding enabling me to attend and develop my knowledge of the nitride community.

The sessions were separated into several categories. The first involved the growth of all aspects of nitrides and their alloys. The second was entitled characterisation, which included optical, electrical and structural characterisation of defects and heterostructures. There were also separate sessions on the development and performance of optical and electrical devices. I will report on several presentations from the different sessions of the conference.

PL-1 (Plenary) Transformative Electronics for Realizing Sustainable, Smart, Secure and Safe Society

Hiroshi Amano

Institute of Materials and Systems for Sustainability, Nagoya University, Japan

The conference was opened with a talk by Prof. Amano, one of the Nobel Laureates who received the prize in Physics in 2014. The talk focussed upon the current and potential impact of GaN-based devices and how these can improve the society in which we live.

GaN has the potential to result in a significant change in the rate of global CO_2 production, which is critical in limiting global warming and the resultant climate change. A major issue regarding this is the rapidly increasing global population, which leads to an increased demand for energy. Additionally, the average amount of energy consumed by the individual is also increasing. These two effects emphasize the need for change either in the production of our energy, to generate less C02, or the efficiency in which we use it. It is in this second aspect which GaN-based technologies can have a significant impact.

However, the nature of innovation is that it takes a significant amount of time, 30 years or so, for scientific developments to have a direct impact upon the industrial sector. Such a time-delay was experienced in the InGaN/GaN based LED technology which Prof. Amano helped to pioneer. Ideally such a change would occur on the scale of 10 years, which would improve the rate at which commercial technologies advance, and also make investment in science a more tantalising prospect for industrial entities. With the intention of facilitating such a change, Prof. Amano has created a global consortium for GaN research and applications, with members from all aspects of the community.

Prof. Amano then focussed on some of the more impactful applications of GaN technologies: firstly, in the treatment of water. This is a large problem worldwide as over 600 million people still don't have access to a stable supply of clean water. This is likely to become even more of a problem due to global warming, which tends to increase the number of bacteria and viruses in drinking water.

One way of removing these organisms is to expose them to UV light. This ionising radiation damages the bacterial DNA and therefore prevents reproduction of the organism. Previously this has been performed with a Hg-based vapour lamp, however, such devices are very large and have a relatively short lifetime of <2000 hours. AlGaN-based deep UV LEDs have the potential to dramatically improve these systems, with lifetimes up to 45,000 hours. Additionally the LEDs are compact, are free of Hg and can provide a high dose of energy, >30 mJ/cm^2, which is significantly above the damage threshold for the bacteria.

There are several technical aspects which must be considered when designing such a system. For example, the transparency of the water is very important, since the entire volume must be exposed to a sufficient dose in order to be sterilised and safe to drink. Therefore an initial filtering step must be performed to remove debris and ensure the water is clear. Additionally, the appropriate emission wavelength must be chosen to maximise the transmission through the water. A significant advantage of the AlGaN system is that the system parameters, such as the QW width and alloy fraction can be adjusted to change the emission wavelength. The transmission is optimum at around 260nm, however the efficiency of the LEDs is lower for shorter wavelengths. Therefore the current optimum wavelength to use is 280nm, which is a balance between transmission and LED efficiency. This means that there is still room for significant improvement in the LED systems, once the efficiency of short wavelengths have been improved.

GaN technologies are also critical to the improvement of current LED displays. In such devices, InGaN-based LEDs act as a backlight for an LCD, where the overall efficiency is only around 5% due to the need to filter and polarise the light, which throws away a significant portion of the emission. Significant improvements can be made to this by either producing polarised LED systems, or by switching to a device consisting of a matrix of micro-LEDs, removing the need to filter the light. The major issue with this approach is the cost of the device, which is predominantly due to the large number of LEDs required. For example, an 8K screen would require around 99 million different LEDs. Another problem with this system is the production of an In-GaN based red LED for such a system, for which the efficiencies tend to be very low.

CR3-1 (Invited) Free excitons in III-nitride quantum wells at room temperature: Dynamics of formation and recombination

Andreas Hangleiter

Institute of Applied Physics and Laboratory for Emerging Nanometrology, Technische Universitat Braunschweig, Germany

Prof. Hangleiter’s invited talk focussed upon the dynamics of carriers within InGaN/GaN quantum wells. According to the author, excitons exist within the quantum wells in thermal equilibrium with free carriers. Through the combined use of room temperature THz and time-resolved photoluminescence, the author was able to interpret some fast (10’s ps) dynamics as the formation of excitons from the thermal cooling of free carriers via the emission of phonons. Under the studied conditions, approximately 40% of the carriers were present in excitonic form. These results were supported by a model developed by the author, which also shows that the exciton fraction increases as the excitation power density increases. However, for very high carrier densities the screening of the Coulomb interaction will become important. These effects happen on a much shorter timescale than recombination and can therefore be affected by a phonon bottleneck, due to the comparatively long phonon lifetime.

OD5 -4 (Oral) The Impact of In Clustering on the Optical Properties of InGaN/GaN Single Quantum Well Light Emitting Diodes

Matthias Auf Der Maur et al.

Department of Electronics Engineering, University of Rome Tor Vergata, Italy

Dr. Auf der Maur reported on modelling work which extends the picture of Indium fluctuations within an InGaN/GaN QW, as studied by other groups. The authors argue that by considering a random alloy (as other groups do), one cannot explain why the radiative rate in the QW increases with temperature (for blue QWs) and remains approximately constant for the green. Additionally, the inhomogeneity caused by a random alloy is insufficient to explain the width of the electroluminescence of LEDs.

The authors therefore extended this by studying a clustered alloy system using an empirical tight binding model to study a 20% Indium single QW with a thickness of 3 nm in a 10 by 10 nm supercell. Increasing the degree of clustering broadens the band edge and results in a redshifted emission, along with a reduced electron hole wavefunction overlap due to the presence of independently localised electrons and holes. A 40% random alloy results in a comparable emission spectrum to that observed experimentally, along with the observed changes in radiative rate with temperature. However, the authors are quick to stress that such a highly clustered alloy is not observed experimentally.

OD12 -1 (Invited) InGaN underlayer in LEDs: a trap for non-radiative defects

Nicolas Grandjean et al.

EPFL, Switzerland

Prof. Grandjean's invited talk was based upon a topic of much study within the community: why does the introduction of a InGaN layer underneath the active region of an LED dramatically improve the effciency such that they can exceed 90%? The authors eliminated the possibility of this being due to changes in the LED injection efficiency by exciting the QWs directly in a photoluminescence experiment. The change in efficiency is therefore caused by an improvement in the IQE.

The authors went further to eliminate other possible causes: one common explanation for this effect is due to the formation of V-pits which prevent carriers from reaching dislocations. However, the authors observed that, on a free standing GaN substrate, no V-pits are present with or without the UL, and yet the same improvement in IQE is observed. The authors therefore conclude that V-pits have nothing to do with the IQE improvement. There are also no major changes in the surface structure. There is no shift in the PL emission energy caused by the UL. This suggests that there is a minimal change in the strain state of the QW. Finally, the authors investigate the effect of changing electric fields due to fermi level pinning at the surface, again concluding that this was not responsible for the IQE improvement.

The authors propose a different mechanism for the IQE improvement: the gettering of point defects by the UL. These defects would act as non-radiative recombination centers within the QW, and therefore their removal would improve the IQE. It is the presence of Indium which creates these non-radiative centers: the InGaN UL therefore generates these defects in the UL, rather than the QW. The authors observe a direct improvement in the efficiency of the QW emission and an increase in the effective QW lifetime as the thickness of the UL is increased, which is consistent with the reduction of non-radiative recombination. The authors are convinced that it is the presence of Indium which causes this effect, and therefore a InAlN UL would also work.

The nature of the point defects is still up for debate: however, the authors were able to eliminate common impurities, and propose that N vacancies are responsible.

LN2-8 (Oral) InAlN underlayer for high efficiency near UV LEDs

Camille Haller et al.

EPFL, Switzerland

This talk continued on from the results reported by Prof. Grandjean in OD12-1, studying why ULs improve the efficiency of InGaN/GaN QW emission, with a focus on near UV LEDs with a relatively small Indium content. In these systems, traditional InGaN ULs can absorb a portion of the QW-emission and therefore significantly reduce the extraction efficiency. The authors therefore recommend using an InAlN UL instead. This removes the parasitic absorption effect whilst allowing a significantly larger Indium fraction in the UL, which should further improve the ULs ability to getter defects.

The authors observe an improved IQE from 9 to 32% due to the UL. However, one issue with this material is that a thick UL structure will usually have a relatively rough surface. To remove this effect, a super lattice structure was used instead, which further increased the IQE to 68%.

OD5-2 (Invited) Efficiency of III-Nitride LEDs: Defect assisted droop and the green gap

Aurelien David et al.

Soraa Inc., United States of America

The author reported on measurements regarding the origin of the efficiency droop, which is a current hot topic among the nitride community. The authors studied the carrier dynamics using a different method to the norm. This was achieved by exciting QWs with sub-barrier continuous wave laser radiation. The intensity of the excitation was modulated and the response of the photoluminescence was recorded in order to measure the differential carrier lifetime.

The authors used this technique to extract A, B and C coefficients from measurements at different current densities. Whilst the A coefficient was constant, it was observed that the B and C coefficients increase at high currents due to screening of the polarisation fields. As more indium was introduced into the QWs, the B and C coefficients dropped, as did A but at a reduced rate.

The authors also studied samples with the same composition and thickness, but with a different number of point defects. It was observed that B was unchanged by this, the A coefficient increased as expected, but C also increased. The authors explained this as there being two separate channels for Auger recombination: an intrinsic channel and an extrinsic, which is assisted by point defects. However, the mechanism for the extrinsic channel is currently unknown.

LN2-7 (Oral) The physics of luminescence in InGaN: Interplay between carrier localization and Coulomb interaction

Aurelien David et al.

Soraa Inc., United States of America

The authors reported on a combined theoretical and experimental study on the carrier dynamics in InGaN/GaN LEDs. It is known that carrier localisation has an important effect in InGaN/GAN QWs at low temperature, and some authors have previously investigated the impact of the Coulomb interaction as well. The authors of this work focussed on LEDs to determine if these effects are important when considering LEDs at room temperature.

The authors presented some interesting PLE results on an InGaN/GaN c-plane LED. Under no external bias, the QW absorption edge is very broad. When a reverse bias was applied, the internal polarisation fields were cancelled out and the absorption edge became more narrow. Additionally a strong excitonic feature was then observed in the spectrum, which is very similar to observations on non-polar m-plane InGaN/GaN QWs.

Modelling work shows that the width of the electroluminescence peak can only be fully accounted for by including the effect of alloy fluctuations. However, the carrier dynamics are heavily impacted by the Coulomb interaction between electrons and holes. This Coulomb effect is more prominent for narrower QWs and results in an enhancement of the IQE at low carrier densities. As the carrier density is increased, the Coulomb effect is screened, which lowers the radiative B coefficient and removes this enhancement.

ThP-CR-1 (Poster) Impact of alloy disorder on Auger recombination in single InGaN/GaN core-shell microrods

Wei Liu et al.

EPFL, Switzerland

The authors studied InGaN/GaN core-shell microrods using high power micro-photoluminescence at low temperature. The authors reported single exponential PL time decays which get faster in the high power regime. This observation correlates with a reduced PL efficiency, which the authors attributed to the onset of efficiency droop due to Auger recombination. This was dominant above a carrier density of 10^{12} cm^{-2}. In the droop regime, the high energy side of the PL spectrum broadened, which the authors attribute to recombination in less localised states. The authors also observed a change in the Auger recombination rate at different points on the same microrod. The Auger coefficient increased in regions of higher alloy disorder, which suggests that Auger recombination is enhanced by the alloy disorder. A similar result was obtained for AlGaN/GaN QWs, which raises some questions as there would be no alloy fluctuations in the QWs in that case.

ThP-CR-25 (Poster) Dislocations as porosification channels in mesoporous GaN DBRs – a depth-dependent plan-view TEM study

Fabien C-P Massabuauet al.

Department of Materials Science and Metallurgy, University of Cambridge

The authors used electrochemical etching to create layers of porous GaN. These are layers can act as distributed Bragg reflectors and therefore could prove useful as a bottom layer in an LED structure to improve the light extraction efficiency. Interestingly, this technique requires no pre-treatment of the GaN, which suggests that the porosification is dependent upon native defects in the sample.

To investigate this further, the authors used a method of depth-dependent plan-view STEM to study the structure of the porous GaN. These results showed that dislocations can be observed at the center of a majority of the pores, which strongly indicates that the porosification is mediated by the dislocations. Some dislocations were active throughout the sample thickness, whereas others became inactive. This resulted in a pore morphology which varied depending upon the depth in the sample. Deeper in the sample the pore domain size was therefore much larger due to there being a higher density of active dislocations.

MoP-OD-9 (Poster) Magnetic-tuned PL polarization of InGaN/GaN MQWs by CoFeB ferromagnetic cap layer

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The authors studied the photoluminescence of a-plane non polar InGaN/GaN QWs, grown with a cap layer consisting of CoFeB. This cap layer was magnetised, applying a magnetic field across the QWs. The strength of the magnetic field was controlled by changing the thickness of the cap layer, which had a significant effect on the PL spectrum. With no cap layer, the emission was 30% polarised, which was increased by up to 40% by including the cap layer. This change had no appreciable impact upon the IQE, whilst resulting in a blue shift of up to 100 meV of the emission. However, the intensity of the emission reduced dramatically, caused by the reduced extraction efficiency, which was the result of having an opaque metal layer on the sample surface.