International Workshop on Nitride Semiconductors 2016 Conference Report

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INTRODUCTION

The 9th International Workshop on Nitride Semiconductors (IWN) took place from 2nd to 7th of October 2016, at the Hilton Orlando Lake Buena Vista Hotel, in Orlando, Florida, the United States of America. This biennial conference is one of the biggest international nitride meetings, and included 6 plenary, 67 invited, and 369 contributed talks, and 356 poster presentations this year. All contributions have been categorised in 12 topical workshops, covering diverse topics in growth, devices, light sources, nanostructures, and power electronics.

My research investigates the properties, performance, and potential applications of quantum dots based on non-polar nitrides. Therefore, I would like to present a selection of presentations related to these areas.

SELECTED PRESENTATIONS

The Extreme Emission Properties of III-Nitride Quantum Dots and the Effects of Extreme Environments on Those Properties (Oral)

– Mark J. Holmes

This presentation featured the highest temperature of single photon emission ever recorded in any system. At 350 K, the GaN/AlGaN dot-in-a-nanowire system that Prof. Holmes has developed over the past few years demonstrates sub-Poissonian photon statistics with an uncorrected $g^{(2)}(0)$ value of only 0.34 ± 0.14, thus fulfilling the requirement for single photon generation with an n = 1 Fock state at 77 °C. Prof. Holmes has also pointed out the curious fact that such a temperature is “hot enough to boil an egg”, and is crucial for applications in real life electronic systems, such as CPUs and data centres, which operate at temperatures higher than the ambient conditions, and are prone to unstable temperature changes. Prof. Holmes went on to show that apart from the highest temperature of single photon generation, his system also achieved emission at an unprecedented temperature of 400 K, which is the highest temperature at which any quantum dot system has ever demonstrated emission in photoluminescence measurements. At 400 K, the linewidth of the quantum dot emission has already been wider than typical quantum wells. Due to the much lower emission intensity, an autocorrelation measurement was not conducted. The underlying physics that permits such ground-breaking emission and single photon generation temperatures has been attributed to a combination of the strong carrier confinement arising from the large band offsets of the GaN/AlGaN system, the very small size of the quantum dot at the top of the nanowire, and the large exciton binding energy of nitride materials.

Electronic and Optical Properties of *c*- and *m*-Plane InGaN Quantum Wells: Influence of Structural Inhomogeneities and Random Alloy Fluctuations (Oral)

– Stefan Schulz

In this invited talk by Dr. Schulz, whose work has been focusing on the theoretical investigations of nitride nanostructure, local microstructure and random alloy fluctuations have been addressed for *c*- and *m*-plane InGaN quantum wells for the first time. Previous theoretical investigations of InGaN quantum wells have been mainly based on continuum approaches, which are unable to take carrier localisation effects into accounts. However, it has been experimentally shown that the local microstructure of quantum wells significantly affect their optical properties, such as the non-Varshni behaviour of peak emission energy changes with temperatures. Dr. Schulz employed an atomistic tight-binding model and showed effects that localised random alloys and structural inhomogeneities have on electron and hole wave functions. While the electron wave function is only slightly affected, strong hole localisation effects have been observed, leading to a broadening of the hole ground state transition energies. These results are in agreement with experimental findings in both polar and non-polar quantum wells, and are utilised to provide an explanation for the Stokes shift in the peak energy of the photoluminescence spectra. The much greater hole energy fluctuations than electrons have also been used to explain the non-exponential decay traces in experimental time-resolved analyses. This atomistic tight-binding model is thus one of the most accurate theoretical approaches to describe the real behaviour of these nanostructures.

Electron Microscopy and Tomography of Nitride Micro- and Nano-Devices (Oral)

– Rachel A. Oliver

The performance of nitride based nanostructures is significantly by their ability to be enhanced by cavity quantum electrodynamics (cQED). Microdisks and nanobeams are among the best candidates to achieve the enhancement through cQED for nitride devices. Dr. Oliver pointed out that theoretical simulations have predicted quality factors (Qs) way higher than experimental results, which indicate that there could be material defects acting as non-radiative escape pathways. In order to understand the origin of this discrepancy, electron microscopy and tomography were used to investigate the structural properties of these cavities. The team that Dr. Oliver leads was able to isolate a single whisker that connected the underside of a microdisk across the air gap, and investigated the structure of that whisker. Results showed that dislocations run through the whisker, which acted as ways for carrier escape, thus decreasing the Qs of microdisks. More interestingly, for the nanobeam structures, Dr. Oliver displayed cross-sections at different locations of the beam, and showed that the etching of to create holes in the nanobeam was not sufficient. This left incomplete photonic crystal devices that had much lower Qs than what would be otherwise expected. In both cases, 3D images have been reconstructed from the many cross sections of the nano-cavities, thus demonstrating the state-of-the-art electron microscopy and tomography techniques.

Transparent Conductive Nitride p-Contacts (Oral)

– Nicolas Grandjean

One challenge that nitride based electronic devices have been facing is the lack of efficient p-contacts. The current use of deep donor – magnesium – creates a large energy difference between the donor level and the conduction band. As such, only a few percent of the donors are active at room temperature, resulting in very low conductivities. In this talk, Prof. Grandjean reviewed their latest development and performance of tunnel junction (TJ)-based p-contacts, with micro-light emitting diodes (LEDs) and edge emitting laser diodes. TJs are designed in an attempt to avoid issues created by conventional p-type materials and to increase the performance of nitride light emitting devices. The growth of the transparent conductive nitride (TCN) was carried out via molecular beam epitaxy, and the resultant structures were characterised, revealing very low resistances on the order of $10^{-4}\ \Omega\ cm^{-2}$. These TCN contacts were then incorporated into both LEDs and edge emitting laser, where current confinement and injection have been demonstrated. Prof. Grandjean highlighted that the low resistance as a result of the use of TCN enabled excellent current spreading. Finally, the demonstration of lasing at 400 nm showed operation in continuous wave mode, with output powers ~ 100 mW. This talk is fascinating to me, as the next step of my PhD project is to develop electrically driven single photon sources. If it is possible to use TCN as the p-contact layer, there would possibly be much less dislocations in the samples, which could act as non-radiative pathways and negatively affect the performance at high temperatures. As such, I will follow up with Prof. Grandjean's latest publications on their development of p-contacts.

Single Polarized-Photons Emitted from Elongated III-Nitride Pyramidal Quantum Dots (Oral)

– Per O. Holtz

One of the most fascinating InGaN quantum dot systems is the pyramidal structures fabricated by Prof. Holtz group. In this *Late News* oral presentation, Prof. Holtz presented a review of the latest developments and the optical properties of his InGaN pyramidal quantum dots. Theoretical studies reveal that the small split-off energies of nitrides allow InGaN quantum dots to naturally exhibit higher degrees of optical linear polarisation than other semiconductor quantum dot systems, when they are subjected to the same shape anisotropies. However, the polarisation degrees and the axis of polarisation for *c*-plane nitrides dots are random, due to fluctuations of shape differences. In order to control these polarisation properties, Prof. Holtz modified the geometry of the pyramidal structures, and created elongated quantum dots. These are aligned along the longest diagonals of the hexagonal wurtzite crystal structure, which are 60° apart from one another. These modified geometries hence result in a much higher polarisation degree, and fixed polarisation axes, and are the first successful demonstrations of deterministic polarisation control in nitride quantum dots. Prof. Holtz also discussed that the non-elongated pyramidal quantum dots have demonstrated single photon emission with a high $g^{(2)}(0)$ of ~ 0.9. He explained that this is due to the very strong background emission, and went on to show how passivation of these structures has significantly reduced the background and $g^{(2)}(0)$ to 0.24. Furthermore, these systems have achieved an emission and antibunching temperature up to 80 K, a single photon generation temperature up to 50 K, and polarised photon emission up to 12 K.

Ultra-Low-Threshold Quantum Dot Micro-Ring Lasers (Oral)

– Danqing Wang

The observation of whispering gallery modes (WGMs) in microdisks has not only been fundamentally interesting, but also inspired the fabrication of devices such as quantum dot-based microdisk lasers. The low threshold of these lasers has been investigated both theoretically and experimentally in the recent years. In order to further reduce the lasing threshold, Miss Wang proposed that the centre of a microdisk can be removed, thus creating micro-ring structures with much less gain material. The rationale has been clearly illustrated in the animated presentation: As more central materials were removed, the surface area of the device increased. Hence, carriers would gradually be able to radiatively combine at the surface, rather than mostly non-radiatively recombine within the gain material. Furthermore, WGMs only exist at the edges of microdisks, and the removal of the central materials should not significantly affect the qualities of the WGMs themselves. Miss Wang went on to demonstrate that with increasing inner diameters of a micro-ring, the laser threshold indeed gradually decreases. A lowest threshold of 0.17 mJ cm^{-2} has been achieved, which is lower than previously report lasing thresholds based on microdisks structures.

Defect Reduction via Laterally Induced Growth of Semipolar (10-11) GaN on Patterned Silicon Substrates (Oral)

– Michel Khoury

Although non- and semi-polar planes of nitride can both be theoretically utilised to reduce the internal fields along the wurtzite (0001) direction, many challenges arise in the actual fabrication of these devices. On the other hand, while GaN grown on bulk nitride substrates have much lower defect densities, they are expensive and not suitable for large-scale manufacturing. In order to exploit the low cost of the mature microfabrication of Si, it is important to develop non- and semi-polar nitride growth techniques on Si substrates. In this particular talk, Dr. Khoury reported on their development of reduced defects of semi-polar (10-11) GaN grown on patterned Si substrates. The patterning of the (001) Si was carried out in an attempt to reveal the (111) facets. (0001) GaN growth is then proceeded parallel to these facets, and paused just before the coalescence of adjacent bands happened. Dr. Khoury pointed out that the next step – an in-situ treatment altering the direction of GaN growth – is crucial in the reduction of defects. After this treatment, the GaN material was grown parallel to the Si (001) direction, rather than the previous (111) direction, thereby minimising the amount of threading dislocations that bend and propagate to the surface. The samples were then characterised with transmission electron microscopy and cathodo-luminescence, both of which demonstrated reductions in threading dislocations and basal stacking faults.

CONCLUDING REMARKS

I would like to sincerely thank the UKNC for providing me with this invaluable opportunity to attend IWN 2016. This is the first time that I presented my work in an oral presentation to a diverse international audience. The talks from international experts in the same field gave me many insights and ideas which I hope to investigate further. During IWN 2016, I had the chance to engage in intellectual discussions with researchers in the field, such as Prof. Holmes and Prof. Holtz, whose names I had only been able to see on journal articles before. Fruitful discussions with Dr. Oliver and Prof. Holmes also resulted in finding appropriate explanations for distinct temperature performances of my quantum dot samples grown by different methods, and how the temperature evolution of linewidth should be more accurately modelled. As such, I am extremely grateful for being supported to attend this conference.

Next year, ICNS-12 will be held in Strasbourg France. The 10th IWN will be held in Kanazawa, Japan, in 2018.