International Workshop on Nitride Semiconductors 2022

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This year's international workshop on nitride semiconductors (IWN) took place in Berlin, Germany from October 9th to 14th 2022. It was a well-attended conference with more than 800 participants from 32 countries presenting their work. Along with the traditional growth and characterisations session, the focus of the conference has mainly been on 3 different topics which are ultraviolet (UV) - light emitting diodes (LEDs), micro-LEDs for the green and red spectral region, and transistors. As my research work concentrates on the development of cubic zincblende (zb) GaN for micro-LEDs due to which I mainly focused on talks and presentations related to the micro-LEDs and zb GaN. Some of the presentations that I was interested in are as follows:

Micro-LEDs

InGaN lattice constant engineering for long wavelength nitride emitters

Plenary talk by Stacia Keller, University of California Santa Barbara, USA

One of the main challenges now plaguing the nitride LED community is its inability to achieve higher efficiencies in green and red wavelengths. To date, the efficiency of green wavelength emissions is nearly half that of blue, which is well known as a 'green gap'. When we go into the micro regime, the traditional red wavelength emitters i.e., group-III phosphides are not efficient as they suffer from a high rate of non-radiative surface recombinations. Using III-nitrides can help breach this gap. However, the difficulty in incorporating higher In content into the quantum wells and strain management to reduce the quantum confined Stark effect remains a challenge.

Different concepts on how one can overcome these challenges are discussed by Prof. Stacia Keller. One such concept is the use of a porous GaN which reduces the stiffness of the layer, leading to partial/full relaxation of the templates. This was achieved by growing a few hundred nanometers of InGaN on top of highly doped n-GaN layer on sapphire substrates. The template was then processed to form stripes/fins for uniaxial relaxation and square tiles for biaxial relaxation. The porosification was performed by electrochemical etching from the sides of the n-GaN region. These porous GaN can be used as templates to grow LED structures as they help in reducing strain challenges, which enables incorporating high In alloy concentrations into the active layers to achieve green and red emissions. Other porous GaN approaches by ’Porotech’, a Cambridge University-based start-up company, were highlighted, where they demonstrated early µ-LED displays based on porous GaN templates. Overall, the talk by Stacia Keller has shown that porous InGaN pseudo substrates can help reduce the lattice mismatch between quantum wells and surrounding materials, which reduces the quantum confined Stark effect and helps incorporate In with higher concentrations.

Red to Blue wavelength -tunable light emitting diode

Poster presentation by

Mikołaj Żak, Institute of high pressure physics of the Polish Academy of Science, Poland

For the micro-LED applications in the advanced display technology, achieving multi-wavelength emission from a single device is a game changer. One such single tuneable micro-LED was presented by Mikołaj Żak where doping engineering of the InGaN active region was performed. Heavy p and n doping of the order of 10^{19} cm^{-3} was implemented to bend the conduction and valence bands inside the quantum well creating two additional separated potential minima. By varying the applied voltage from low to high, energy states can be controlled allowing tunable light emissions ranging from around 650 to 482 nm. This helps to achieve white light using a single device by colour mixing.

The other concepts for micro-LED fabrications highlighted throughout the conference include using partially relaxed templates, planar InAlGaN structures, free standing InGaN platelets, sapphire nano-membranes, and 3D core shell micro-LEDs.

Zincblende GaN

Impact of AlN buffer layers on MBE grown cubic GaN layers

Poster presentation by M. F. Zscherp, Justus-Liebig-University Giessen, Germany

Cubic zb GaN, which is a metastable phase, is a potential answer to address the green gap problem and achieve longer wavelength emissions. However, growing zb phase of GaN leads to high density of stacking faults, misfit dislocations, and wurtzite inclusions. Using zb-

AlN as thin buffer layers helps reduce the lattice mismatch between zb-GaN and 3C-SiC significantly. This is due to the preferential formation of wz-AlN over zb-AlN as a result of lower formation energies.

Despite the challenge, Zscherp presented a detailed study on how growth of thin AlN buffer layers, using molecular beam epitaxy (MBE), helps to improve the quality of zb-GaN epilayers. For this purpose, they compared growth of GaN on 3C-SiC without any buffer layer, with a thin AlN buffer layer and one with Al flashing followed by the growth of an AlN buffer layer. Overall, the growth of GaN on 3C-SiC with Al flashing followed by thin AlN growth led to high phase purity, reduced root mean square surface roughness, reduced defect density, and improved optical properties.

Selective area growth of cubic Gallium Nitride in nanoscopic Silicon Dioxide mask

Poster presentation by D.J. As, Paderborn University, Germany

Selective area growth is an interesting way to grow a material where one can achieve high aspect ratios. Prof. As presented the work of his group on growing zb-GaN on nano lithographed 3C-SiC (001) pseudo substrates via MBE. Growth of zb-GaN on these substrates led to an increase in growth temperatures to realise zb-GaN. They mentioned that the growth temperatures for the zb-GaN growth on these pseudo substrates were around 930°C to achieve high phase pure zb-GaN compared to the traditional growth temperatures of 720 - 760°C. The grown films showed good optical properties and high phase purities.

Efficiency droop in zincblende InGaN/GaN Quantum Wells

Abstract talk by D. J. Binks, University of Manchester, UK

Efficiency droop is an important phenomenon where increasing current density above a certain threshold leads to a reduced increase of the light output as a result of a reduction in the radiative recombination efficiency. This is a well-known challenge in wz-GaN based LEDs. However, this phenomenon in zb quantum wells is not fully explored. Dr. Binks presented their work on studying droop effects in zb InGaN/GaN based multi quantum well structures. The photoluminescence of a series of single quantum well with well thickness of 2.5 nm and multi quantum well samples with varying quantum well thickness of 2.5 nm, 5 nm and 7.5 nm were compared using continuous wave and pulsed lase excitation with varying current densities at low temperature (10 K). They have shown that there is an increase in the onset of droop with increasing quantum well thickness. The onset of droop was consistent between the single quantum well and multi quantum well samples. A difference in the onset of droop by 3 orders of magnitude was observed, which was attributed to a 2-step droop process.

Other Topics

Apart from these topics, other topics which were discussed in the conference which gained my attention are as follows:

On the origin of the yellow luminescence band in GaN

Invited talk by M. A. Reshchikov, Virginia Commonwealth University, USA

Yellow luminescence is a well-known defect luminescence observed at ~2.2 eV in the photoluminescence or cathodoluminescence spectrum of unintentionally doped and/or impurity doped GaN. The identity of this defect luminescence has been controversial, with carbon-related point defect being responsible in C-doped GaN and a Ga vacancy or Ga vacancy-oxygen complex responsible in unintentionally doped GaN. Prof. Reshchikov presented experimental evidence that the yellow luminescence band is caused by the C_N acceptor in undoped, Si- and C- doped GaN. It was highlighted that other possible candidates for the yellow band, such as V_{Ga}, $V_{Ga}O_N$, C_NO_N, and C_NSi_{Ga}, cannot be observed in the PL.

Probing Individual Nonradiative Point Defects in InGaN/GaN Quantum Wells using Time Resolved Cathodoluminescence

Abstract talk by

T. F. K. Weatherley, Ecole Polytechnique Fédérale de Lausanne, Switzerland

Point defects are known to be acting as non-radiative recombination centres, which hampers the light output efficiencies of multi quantum well LED structures. One can grow InGaN underlayers to reduce the density of these point defects but these underlayers trap nitrogen vacancy related surface defects. An interesting talk was given by T. F. K. Weatherley where a study on the impact of a single point defect has been presented. Careful growth of the structure was performed, where a 3-monolayer thin single InGaN quantum well was grown to reduce the point defect density. This structure was grown on a free standing GaN substrate to reduce the overall defect density. All the possible steps were taken to minimise the defect density and to be able to isolate a single point defect. Cathodoluminescence (CL) measurements were shown where regions with point defects revealed dark spots in panchromatic images. A single point defect has been isolated and studied with time resolved CL where the point defect led to reduced carrier lifetimes at room temperature and is also affecting the carrier lifetimes at low temperatures. Simulation results were also presented supporting and proving that the experimental data is accurate in identifying the behaviour of a single point defect.

Conclusion

Overall, I am very thankful to the UKNC for granting me the travel bursary that provided me an excellent opportunity to interact with experts in the field and fellow researchers. This allowed me to test out my ideas and learn about the current state of art research work on several research topics, which enabled me to broaden my knowledge and network in the field.