Conference Report

13th International Conference on Nitride Semiconductors (ICNS-13 2019)

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Introduction

The 13th International Conference on Nitride Semiconductors (ICNS) took place in Bellevue, Washington State, USA from 7th to 12th July 2019. This conference is held biennially, alternating with International Workshop on Nitrides (IWN). These two conferences are the largest events in the field of nitride semiconductors. This conference included over 800 attendees, eight plenary talks, 363 oral presentations and 371 posters.

There were overall thirteen topics including: ‘Light Emitting Devices’, ‘Electronic Devices’, ‘Photovoltaics, Energy Harvesting and Photo Detectors’, ‘Sensors, Actuators and Acoustic Devices’, ‘Processing, Fabrication and Thermal Management’, ‘Bulk Growth’, ‘Epitaxial Growth’, ‘Nanostructures and Nano-Devices’, ‘Optical and Electronic Properties’, ‘Defect Characterization and Engineering’, ‘Structural Analysis’, ‘Theory and Simulation’ and ‘New Materials and Device Concepts’. Three rump sessions were arranged on 10th afternoon, featuring ‘Visible Emitters’, ‘Electronic Devices’ and ‘UV Emitters’.

Below I outline the content of a range of talks and posters that were of particular interest to me.

General Trends in the Nitride Community

Based on the posters and presentations I have seen at the ICNS-13 conference it seems to me that UV light emitters are currently a popular research topic. The efficiency of UVB and UVC devices is still significantly lagging behind devices operating at larger wavelengths. Lasers are another popular research area, of which the vertical-cavity surface-emitting lasers (VCSELs) are particularly interesting to the research community. Tunnel junctions seem to have become a very popular tool in in the community. The most widely reported use is a means to enhance carrier injection and current spreading in optoelectronic devices. Within a certain subset of the nitride community there is also a strong focus on-polar/semi-polar devices. Regarding the study of defects in nitrides, point defects are the most intensively studied defects in ICNS-13. Their characterisation was-presented in almost all the sessions on light emitting devices.

Plenary Talks

- **Nicolas Grandjean, ÉPFL: Underlayer and surface defects**
- **Zetian Mi, University of Michigan: III-nitride nanocrystals**
- Shigefusa Chichibu, Tohoku University: Vacancy complexes
- Shuji Nakamura, UCSB: Nonpolar/semipolar lasers
- Umesh Mishra, UCSB: GaN HEMTs
- Zlatko Sitar, NC State University: AlGaN growth
- Martin Strassburg, OSRAM: Industrial LED development
- Jun Suda, Nagoya University: Vertical GaN power devices

Efficiency of Nitride LEDs – Impact of Point and Extended Defects
Nicolas Grandjean, École Polytechnique Fédérale de Lausanne

One extraordinary feature of InGaN/GaN heterostructures is their exceptionally high internal quantum efficiency (IQE) despite a huge dislocation density. Grandjean suggested that a dramatic drop in IQE can be seen for GaN when threading dislocation density is larger than 10^7 cm^{-2}, and for InGaN when threading dislocation density is larger than 10^8 cm^{-2}. In the presentation, he mainly reviews the physical impact and rationale of an InGaN containing layer underneath the quantum well (QW) active region – the underlayer. He provided evidence that the growth of this underlayer captures defects present at the GaN surface, preventing them from incorporating in the InGaN QW where they create non-radiative recombination centers (NRCs). Since either an InAlN or InGaN underlayer may be used to increase the IQE, indium is thought to be responsible for the surface defect suppression. From PL decay measurements, the activation energy of these surface defect is estimated to be about 3.6 eV, which is close to the energy of GaN decomposition. He then suggested that these surface defects might be nitrogen vacancies, which segregate in GaN but form NRCs in InGaN.

Emerging Applications of III-Nitride Nanocrystals

Zetian Mi, University of Michigan, Ann Arbor

Compared to conventional III-nitride epilayers and quantum wells, III-nitride nanocrystals in theory have the advantage of being dislocation-free despite being grown on foreign substrates. Mi reported the first achievement of Mg dopant-free AlGaN/h-BN nanowire LED, which exhibit 80% electrical efficiency at 20 A/cm^2. The thin layer of h-BN with point defects, such as acceptor-like B vacancies, can serve as a highly conductive, DUV-transparent p-type layer. The hole mobility and concentration for the h-BN are reported to be 16 cm^2/V·S and 10^{20} respectively.

Atomic-level chemical ordering in wurtzite InGaN alloys along c-plane direction in InGaN/GaN nanowire heterostructure has also been reported. Mi suggested that the preferential site occupation of In-atoms into reduced N-coordination sites at vicinal surface facets can be related to surface site energetics. The prevalence of ordering can be explained by a combination of nonflat growth front in the heterostructure and in-plane strain relaxation of alloy relative to the underlying GaN.

He also reported site-controlled epitaxy of AlGaN nanowire arrays with Al incorporation varied across nearly the entire compositional range. Al-rich shell is spontaneously formed on the nanowire, suppressing surface recombination. IQE is measured up to 45% at room temperature. Additionally, by exploiting the two-dimensional band-edge resonant effect of the photonic nanocrystal array, a stable two-dimensional cavity mode (standing wave) can be formed with nearly zero group velocity. This can lead to strong gain enhancement for laser applications.

At the end, he reported using III-nitride nanocrystal for high efficiency artificial photosynthesis with stability larger than 500 hours at an efficiency level significantly above natural photosynthesis.

Selected Talks

LEE Enhancement in AlGaN UVC LED Using Photonic Crystal (invited oral presentation)

Hideki Hirayama, RIKEN

The main cause of the reduction of wall-plug efficiency (WPE) in DUV-LEDs is a significant reduction in light-extraction efficiency (LEE) owing to high light absorption by p-type contact layer. Conventional LEE can be as low as 6%, resulting in a WPE of only 3%.

Hirayama reported several means to address this. The first is to use a transparent p-AlGaN contact layer to reduce absorption but this can lead to high operating voltage, due to an increased resistance. The second is to fabricate a photonic crystal (PhC) reflector on p-contact layer. The photonic band gap is highly dependent on the fill factor of air holes. He reported that, by introducing a PhC reflector with a fill factor of 0.32, the external quantum efficiency (EQE) of 273nm UVC-LEDs was increased by about 1.7 times. He also reported a p-type Ni/Mg electrode with reflectivity of 80%. Combining PhC with Ni/Mg electrode, the estimated reflectivity exceeds 90%.

Controlling Defects in AlGaN and AlN for High efficiency Deep UV (invited oral presentation)

Tim Wernicke, Technische Universität Berlin

The control of threading dislocations and point defects densities in AlGaN alloys is critical for the realization of highly efficient UV-LEDs with AlN mole fraction beyond 50%, which pushes the wavelength far below 265 nm. Wernicke reported that the density of dislocation loops, which strongly reduced the light output of UV-LEDs, increases with compressive strain (Ga-content) as well as with layer thickness.

He also reported that the conductivity in n-AlGaN suffers from incorporation of both carbon impurities and group III vacancies, which both act as acceptor type defects compensating the silicon donors. By reducing emission wavelength of UVC-LEDs from 260 nm to 217 nm, EQE can decrease from >1% to 5×10^{-4} %. The drop in efficiency is attributed to point defects as the density of threading dislocation and the band offsets within the QWs were controlled.

Epitaxy and Performance of VCSEL Structures (invited oral presentation)
Tetsuya Takeuchi, Meijo University

Most of the GaN-based VCSELs contain two dielectric distributed Bragg reflectors (DBRs) or a combination of a top dielectric DBR and a bottom undoped semiconductor DBR. Due to the lack of conductive bottom DBRs, VCSELs require a thick cavity for double intra-cavity contacts, which leads to low optical confinement factor. As for conductive GaN-based DBRs, there is usually a trade-off between high reflectivity and resistivity.
Takeuchi reported a 40-paired n-type conductive AlInN/GaN bottom DBR, which showed a peak reflectivity over 99.8% and a series resistance of 17 Ω. 4.0λ-cavity VCSEL using this bottom DBR showed a light output power of 1.8mW with a low differential resistance of 90 Ω.

Self-Passivated High-Efficiency c-Plane Micro-LED Array without Singulation Fabricated on Sapphire Nano-Membrane Structures (invited oral presentation and poster presentation)
Euijoon Yoon, Seoul National University

The current micro-LED fabrication process is based on singulation (cutting micro-LEDs out from the wafer) by inductively coupled plasma (ICP) etching, which introduces ion damage resulting in non-radiative recombination at sidewalls. The EQE of micro-LED can be as low as 9.5%.
Yoon first reported a new method to grow sapphire nano-membrane structures (about 100 nm thick) by combining photolithography, atomic layer deposition of alumina and annealing. Discontinuous GaN platelets a few micrometres thick can be grown on top of the nano-membrane. The platelets are bordered by a major (0001) plane, and (11-20) and (1-101) planes at sidewalls. A self-passivated micro p-i-n LED structure then can be formed on the GaN template. Flip-chip bonding to the target substrate can be achieved simply by mechanical pressing to break the nano-pillars beneath the nano-membrane followed by annealing to form a p-type contact. This is a new strategy to fabricate high-efficiency micro-LEDs without singulation. Yoon suggested that the high EQE of their micro-LEDs is due to high crystal quality resulting from strain sharing by the thin sapphire nano-membrane as well as the LED structures with sloped facets.

Exploring the Fundamentals of Efficiency in III-N LEDs (invited oral presentation)

James Speck, University of California, Santa Barbara

By using temperature dependent electron emission spectroscopy, Speck reported that thermal droop in simple LEDs without any electron blocking layer (EBL) is due to carrier overshoot or leakage. While AlGaN EBLs can mitigate some of the effects of thermal droop, at temperatures above 135 °C it produces additional hot electrons. These hot electrons can be related to a high energy peak observed in the controlled measurements with electron emission spectroscopy and they are likely due to trap-assisted Auger recombination.

Measurements on low-efficiency LEDs, which should have very low carrier density in their active region, and commercially produced LED at very small currents show a clear high-energy peak at the same energy as electron-electron-hole Auger recombination in devices grown by MOCVD. Speck suggested that this proves even at low current densities, Auger process can still occur via trap-assisted pathways.

Physical Limits of Recombinations in III-Nitride LEDs (oral presentation and rump session)

Aurelien David, Soraa

David discussed new insights into the radiative and non-radiative recombinations in III-Nitride emitters. He first reported that high-current nonradiative recombination (droop) in III-nitride light emitters is comprised of two contributions that scale with the cube of the carrier density. One is the intrinsic recombination, which is most likely related to standard Auger scattering, whereas the other one is an extrinsic recombination that is proportional to the density of point defects. This extrinsic process may be caused by impurity-assisted Auger process. The presentations from David and Speck might reveal the same recombination process and be complementary with each other.

Second, he reported that non-radiative and radiative rates obey a remarkable scaling law, leading to maintained high efficiency despite very large variations in radiative rate. He then argued that the Quantum-Confined Stark Effect (QCSE) might not be as detrimental as it is conventionally considered, as the separation of the wavefunctions of the carriers not only reduces the radiative rate but also the non-radiative rate. At the end, he suggested that the effective way to reduce non-radiative recombination is to reduce the defect density and to grow high quality epitaxial materials.

Investigation of Hexagonal Inclusions in Zincblende GaN Using Cathodoluminescence and Electron Backsactter Diffraction in the SEM (poster presentation)

Jochen Brukbauer, University of Stathclyde

Zincblende (zb) GaN is one possible way to address the "green gap" problem due to its lower band gap compared to wurtzite (wz) GaN and zero internal electric field. Phase pure zb-GaN, according to XRD analysis, has been grown by MOVPE on (001) 3C-SiC/Si templates with a 4-degree miscut. In order to correlate the phases, present with light emission properties, the growth conditions were instead set to give a mixed phase film and the film was examined by cathodoluminescence (CL) and electron backscatter diffraction (EBSD).

Brukbauer reported that CL imaging at room temperature observed two emission peaks, 3.22 eV and 3.38 eV. They are associated with near band edge emission of zb- and wz- GaN respectively. Phase map can be produced by EBSPs and it shows that at least 69% of the sample is zb and 17% as wurtzite. EBSPs can also helped identify an anisotropy of the wz segments. Brukbauer suggested that wz inclusions are related to the formation of {111}-oriented facets, which are most likely related to the substrate miscut.

CL imaging combined with EBSD allows non-destructive structural and phase analysis correlated with emission properties.

Concluding Remarks

I would like to thank the UKNC for providing me with the great opportunity to attend the conference. The communication with researchers all around the world and the knowledge they shared with me are certainly beneficial for my future research work. The exposure to the broad and sophisticated nitride research was truly enlightening.

In 2020, IWN will be held in Berlin, Germany. In 2021, ICNS-14 will be held in Fukuoka, Japan.