14th International Conference on Nitride Semiconductors, Fukuoka, Japan

Conference Report

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Introduction

The fourteenth international conference on nitride semiconductors held in Fukuoka, Japan from 12^{th} till 17^{th} November is considered one of the most reputable conferences in the nitride community. Being a biannual conference, it registered more than 1200 attendees from more than 15 countries. Broadly, the conference is focused on growth, characterization, optical and electronic devices. However, to address the current technological needs, fields such as micro-LEDs, UV-LEDs and LDs, VCSELs, and vertical electron devices were also added to the existing format. Overall, the conference was divided into seventy sessions, each comprising more than five oral presentations.

Since, I am working in the area of epitaxial growth using MOCVD. My interest was to attend talks which were focused on understanding the growth physics of aluminium gallium nitride (AlGaN) and its application to UV LEDs/Laser diodes. With special attention to approaches improve the quality of an AlGaN template. Additionally, I was keen in understanding the mechanism of magnesium doping in the GaN or AlGaN layer.

Plenary Talks

The plenary session by *Hiroshi Amano* started with tribute to late Nobel laureate *Isamu Akasaki*, one of the pioneers of blue light emitting diodes (*b*LEDs). The presentation elaborated on the details of timeline, motivation and all the relevant research work, leading up to the first realization of *b*LEDs. In addition to that, various state of the art results on technological advancements were presented, but the one which stood out from the rest was the third generation GaN bulk substrates developed by sodium flux method achieving dislocation density of $\leq 10^4$ cm^{-2}.

In the following plenary session, *Debdeep Jena* discussed the fundamentals of polarization in III-Nitride materials and its implications on electronic and photonic devices. Moreover, emphasis was directed on a new class of nitride materials realized by alloying of transition metals with AlN. These materials show strong piezoelectric properties, have high dielectric constant and switchable electronic properties which make them highly desirable for applications in logic and memory devices.

Invited talks

GaN Quantum Dots in Resonant Cavity Micropillars as deep UV Single Photon Sources *Juergen Christen*
(University of Magdeburg, Germany)

The intent to realize a deep UV single-photon source utilizing the Purcell effect leads to embedding a GaN self-assembled Quantum dots (SAQDs) in a resonant micro-cavity structure.

In the cavity, top and bottom *Bragg* mirrors can provide one dimensional confinement, in addition to the three-dimensional carrier confinement achieved in the QDs. However, the problem during the growth of *Stranski–Krastanov* QDs wetting layer is formed, this wetting layer has lower energy band gap than the QDs, which results in recombination of the photo-excited carrier in the wetting layer which acts as a quantum well effectively reducing spontaneous light emission intensity from the QDs. This was overcome by implementation of a two-step QDs growth approach combining a) 2 nm thick GaN layer growth with b) 30 second growth interruption allowing for desorption of the wetting layer. Eventually, single-photon emission was realized in the temperature range from 6 K till 110 K.

Recent Progress of Bulk GaN Growth by Na-Flux Method *Yusuke Mori (Osaka University, Japan)*

Earlier, high quality bulk GaN crystals pioneered in Poland were grown in high pressure and high temperature (10000 atm and 1500 °C) conditions making them costly and less suitable for mass production. *Yamane* realized the first GaN crystals using Ga-Na melt at a relatively moderate temperature of 750-900 °C in nitrogen overpressure of ~50 bar by overcoming the problem of nitrogen solubility in sodium. However, further improvement to achieve high quality, large dimension bulk GaN crystals was carried out by *Yusuke*. This proved to be quite challenging in the initial stage of development, due to the inability to control the nucleation process. It was discovered that presence of carbon can suppress GaN polycrystal formation at the liquid-gas interface. This led to the development of first generation GaN substrates by liquid phase epitaxy (LPE) using Na-flux with three orders of magnitude reduced dislocation density of 10^5-10^6 cm^{-2} compared to ELO GaN overgrowth. In the last two decades, further efforts were concentrated which led to two more improved generations of substrates, effectively achieving 2-inch bulk GaN crystals with dislocation density in the range of 10^3-10^4 cm^{-2}.

Nanoscale investigation of point defects and carrier dynamics in InGaN/GaN quantum wells *Nicolas Grandjean (EPFL, Switzerland)*

Generally, dislocations are considered as the main cause of poor light emission efficiency of the III-Nitride material. Nevertheless, recent investigation conducted by the group headed by Nicolas, on InGaN/GaN quantum wells (QWs) found the presence of point defects (PD). The nature of the point defect being uncertain, yet related to the growth temperature of the buffer. Effectively these PDs act as non-radiative recombination centres, resulting in compromised light emission capability. In the study, it was found that these point defects can be accumulated/absorbed in an indium-containing underlayer (UL). Further detailed carrier dynamics study found the presence of two types of PDs: Type-I) which are independent of the presence of UL, and Type-II) strongly dependent on the presence of UL. Overall, presence of high density of type-II PDs influences the non-radiative lifetime which directly affects the macroscopic optical properties of InGaN/GaN QWs.

Recent Progress of Deep Ultraviolet Laser Diodes on AlN substrate *Maki Kushimoto (Nagoya University, Japan)*

Sterilization and fluorescence applications require low-cost, efficient, high power UV light sources. AlGaN is a promising material for UVC light sources, but it suffers with various material limitations and challenges. In the recent years, many technological breakthroughs such as: a) development of single crystal AlN substrates, b) improvement in AlGaN crystal quality, and c) hole injection technique-based polarization doping demonstrated by Maki's group, helped realization of first pulsed lasing at room temperature. Although the current density was high, further efforts were directed, to understand and overcome the issues limiting continuous wave (CW) lasing. Firstly, the optical confinement was improved which led to reduction in threshold current density while lowering the drive voltage. Secondly, using tilted mesa side walls to overcome the defects formed due to shear stress generated during the fabrication process of mesa on a highly strained epitaxial layer. These modifications implementation resulted in further reduction of threshold current density and realization of UVC CW lasing at room temperature.

Rump Session

Will deep UV LEDs and LDs become as good as blue LEDs and LDs by evolution or revolution?

In the discussion, Lumileds led the presentation with "the history of blue LED evolution from 1994 till date". Followed by Osram, forecasting the development of UV LEDs. Overall, projecting to achieve wall plug efficiency (WPE) ~25 % at ~230 nm by 2026, making UVC LEDs a more viable alternative than UV Lamps. Prof. *Kneissl* outlined the current trends, challenges and limitations which are holding back the UVC LEDs.

Oral Talks

Effect of the quantum well number on the efficiency and lifetime of AlGaN-based 233 nm and 226 nm far-UVC LEDs *Marcel Shilling*
(Technische Universität Berlin, Germany)

Most disinfection applications require UV light sources to have efficient, high output power, and narrowband bandwidth. UVC LEDs intend to replace mercury-based UV lamps for many general and specific applications. This is only possible if, improvement in their wall plug efficiency and L_{70} lifetime is attained. An approach would be to increase the light emission from the active region by increasing the number of quantum wells (QWs), which will result in increased output power of the UVC LEDs. To test this theory experiment was conducted by varying the number of quantum wells in the active region. In conclusion, an increase in output power and lifetime of the LEDs emitting at 233 nm was observed with an increase in the number of QWs. While the output power for LEDs emitting at 226 nm did not increase, the lifetime does increase. The observed behaviour is due to the enhanced carrier confinement resulting in improvement in injection efficiency. Eventually, the reduced charge carrier density in the active region enables extending the lifetime of the LEDs.

MOCVD of AlGaN-MQWs Grown on Strain Relaxed Superlattice DBR Buffer Layers toward UV top-emission LEDs *Hisashi Yamada*
(The National Institute of Advanced Industrial Science and Technology, Japan)

Generally, UV LEDs are bottom (substrate) emitting because of the unavailability of a low resistance, transparent, top contact layer. Unwillingly *p*-GaN as a top contact layer is used and the penalty for this choice is paid by absorption of a significant amount of UV light. As well as due to varying refractive indices at various interfaces (such as substrate/buffer and substrate/air) considerable amount of light is reflected in a bottom emitting LEDs which reduces the output power. So, normally for various applications top emitting LEDs are preferred over bottom. Design of a distributed *Bragg* reflector (DBR) is crucial to achieve a top emission in a UV LED. Normally, heteroepitaxial growth of *u*/*n*-AlGaN on a substrate leads to strain relaxation, eventually generating huge amounts of dislocations and compromising the morphology of the surface. To prevent this, a mostly strain-relaxed superlattice (SRSL) buffer layer is used. In this work, SRSL was designed to work as a DBR as well, then 2 μm thick *n*-AlGaN was grown. Further, MQW stack was grown on the *n*-AlGaN layer to test the optical and material quality. Results show intense PL spectra at 280 nm with full width half maximum (FWHM) of 7 nm.

Relaxed AlGaN on native AlN and GaN substrates realized via heteroepitaxial FACELO *Jack Almeter*

(North Carolina State University, United States of America)

Epitaxial growth of micro devices for optoelectronic and power electronic applications, is often carried on a native substrate also known as homo epitaxy, which provides lattice and thermal expansion coefficient matching. The absence of a native substrate in case of AlGaN makes it a challenge to grow thick, strain-free and high quality AlGaN layers across the entire compositional range. Available single crystal substrates of GaN and AlN are not beneficial because AlGaN growth on the former results in cracking whereas on the latter leads to plastic relaxation which generates huge amounts of dislocations. In III-Nitride materials, the wurtzite primary slip system is non-functional because of the absence of a resolved shear strain. Activating the secondary slip system during growth is an approach to resolve shear stress while relaxing the heteroepitaxial strain by gliding the misfit dislocations along the semipolar direction. This was accomplished by AlGaN overgrowth on semipolar facets formed after growth of GaN (and AlN) on a maskless patterned single crystal substrate GaN (and AlN) with low dislocation density. Overall smooth, thick (>5 µm), heteroepitaxial relaxed AlGaN epilayers were realized.

Conclusion

I am thankful to UK Nitrides Consortium for the financial support, which helped me present my research findings in the conference while covering my expenses for the trip. This opportunity helped me receive the best student award at ICNS-14 for my oral presentation, meanwhile learning about the current research trends.