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UKNC Bursary Report

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Introduction

The 15th International Conference on Nitride Semiconductor (ICNS) was held in Malmö, Sweden, from 06th to 11th this year. As a biennial conference, it focused on the recent developments of Nitride semiconductors as usual, featuring 9 plenary, 3 poster sessions and oral presentations across various categories, including growth, physics and characterization, optical devices and electronic devices.

I am grateful to the UKNC for awarding me a student bursary to attend this conference. This event aligns closely with my PhD research and represents an excellent opportunity for networking, receiving feedback, and learning about the latest developments in this field. Below, I summarize some of the research I found most interesting.

Pyramidal Micro-LEDs Delivering RGB in Single Materials Systems

Lisa Rullik, Polar Light Technologies AB, Teknikringen 7, 58330 Linköping, Sweden.

Polar Light Technologies is a Swedish based start-up in Linköping. They aim at developing RGB full colour emission within a single materials system using hexagonal GaN pyramids with InGaN quantum wells. Comparing with the conventional c-plane devices, growth of micro-pyramids can not only reduce the lattice mismatch induced strain and the quantum confine stark effect, but also avoiding the side walls damages from the dry etch. Additionally, the pyramidal structure can improve the light extraction efficiency.

In this talk, key technical achievements were highlighted. The team demonstrated emission at 470 nm (blue), 520 nm (green), and 625 nm (red). In terms of light emission angle, the pyramidal structure has 58% light within ± 20° showed a stronger forward-directed output than that of the planar devices 10-20% within 100°. The company also shared their development roadmap, outlining milestones such as achieving full RGB emission by December 2024, fabricating red micro-LED vertical displays (320 × 180 resolution, 9.9 μm pitch) by May 2025, and ultimately realizing monolithic RGB integration on a single wafer by 2028. Intermediate goals include sub-micron LED fabrication by the end of 2025 and dual-colour emission by 2026.

This work is highly relevant to my own research on micro-pyramid-based LEDs. Polar Light's progress serves as an important validation of the feasibility of RGB emission in a single material system, reinforcing the potential of this approach. Their challenges, such as pyramid non-uniformity observed in SEM images, closely mirror issues I have encountered and addressed in my work. Additionally, their projected timeline for monolithic RGB integration aligns with my anticipated graduation in 2028, providing a useful benchmark for adjusting my research schedule. Currently, I have successfully demonstrated blue and green emission on individual wafers and am now focusing on full LED structures based on micro-pyramids. The presentation, though lacking in detailed methodologies, offered valuable insights into the current state and future direction of micro-LED technology. I think observe the progress of potential competitors and collaborators at this conference was highly valuable.

Leakage Current in Pyramidal GaN mirco-Light-Emitting Diodes

Andrei Vorobiev[1,2], [1]**Polar Light Technologies AB, Teknikringen 7, 58330 Linköping, Sweden. [2]Chalmers University of Technology, SE-412,96, Göteborg, Sweden.**

The poster presents a study on leakage current behaviour in pyramidal GaN micro-light-emitting diodes including both truncated and non-truncated pyramids structures, to identify the influence of apex geometry on electrical performance. TEM analysis revealed that threading dislocations terminate at the apex of truncated pyramids, creating leakage pathways that increase current flow outside the intended active region. In contrast, non-truncated pyramids exhibit fewer apex defects, which improves electrical insulation and optical quality. Cathodoluminescence spectra further showed that non-truncated pyramids have stronger and sharper blue emission, indicating better material quality. Current–voltage measurements confirmed that truncated micro-LEDs suffer from higher leakage, and simulations supported the idea that dislocations at the apex are the dominant source.

The study demonstrated how threading dislocations at the truncated apex can lead to increased leakage and degraded performance. This information is particularly relevant to my own research, as I plan to fabricate micro-LED devices using both truncated and non-truncated pyramid structures. Understanding the origin and impact of leakage current will help guide my design choices and process optimizations, especially in terms of minimizing defect-related current paths and maximizing optical quality.

A Bottom-Up InGaN Technology for Ultra-High Brightness red, green, and blue Micro-LEDs

Martin Berg, Ideon Alfa 3, tr Scheelevägen 15, 223 63, Lund, Sweden.

Hexagem was founded in 2015 as a spin out from Lund university the research directed by Professor Lars Samuelson on GaN coalescence technology. In this oral presentation, they shared detailed characterization of their red-emitting micro-LED devices, highlighting their performance under high current density operation.

The electrical measurements reveal that the devices exhibit high-quality diode behaviour with an ideality factor of approximately 1.4 and very low reverse leakage, confirming efficient carrier transport and minimal defect-assisted leakage paths. The electroluminescence spectra, measured over a wide range of current densities (3.5–3800 A/cm^2), remain sharply defined with a Gaussian profile and a FWHM of 50 nm at 20 A/cm^2, suggesting minimal spectral broadening even under high injection conditions. One of the main challenges in red InGaN LEDs is the unavoidable blue shift of the emission wavelength at high current densities. To address this, their strategy is to design the emission peak to be sufficiently long at low currents so that even with blue shift, the emission remains in the deep red region. Their devices exhibit a shift from around 690 nm down to approximately 635 nm as current increases, with a dominant red wavelength above 630 nm sustained at 100 A/cm^2.

In terms of colour quality, the micro-LEDs maintain over 98% colour purity up to 200–300 A/cm^2. Despite this, droop remains low, only about 5% drop in efficiency from peak to 200 A/cm^2, which suggests good carrier confinement and minimized non-radiative losses. The internal quantum efficiency (IQE) is estimated to reach around 60% for sub-micron devices emitting at 637 nm, inferred from the integrated PL ratio at 300 K vs 8 K. However, when asked about the external quantum efficiency (EQE), the presenter admitted that it remains below 1%, and no further details were disclosed, suggesting this is still a major challenge to be addressed.

The information from this presentation will be valuable for my own research, especially as I plan to fabricate micro-LEDs based on both truncated and non-truncated pyramid structures. Understanding the relationship between shape, current density, and emission characteristics helps guide design decisions for optimizing optical performance and minimizing losses.

High-temperature performance of InGaN-based red micro-light-emitting diodes using an epitaxial tunnel junction contact

Zhe Zhuang, School of Integrated Circuits, Nanjing University, Suzhou, 215163, China.

In this presentation, the speaker introduced their recent work on InGaN-based amber micro-LEDs with a diameter of 40 µm, utilizing an epitaxial tunnel junction (TJ) contact structure. The devices achieved impressive performance, with external quantum efficiency (EQE) and wall-plug efficiency (WPE) reaching 0.935% and 4.3%, respectively, at a current density of 1 A/cm^2. These results are attributed to near-ideal carrier injection enabled by the tunnel junction and the high crystal quality of the amber quantum wells (QWs).

An interesting observation discussed was the improvement in carrier injection with increasing temperature. This enhancement was explained by two factors: increased tunneling probability across the TJ and better acceptor ionization in the p-GaN layer at elevated temperatures, both of which facilitate more efficient hole injection.

The group also carried out a comprehensive analysis of the epitaxial wafer structure, including the substrate, buffer layers, GaN template, QWs, and the p-type GaN. For the GaN template, they employed a decomposition layer and a GaN decomposition stop layer grown at three different temperatures. At high temperatures, the InGaN decomposition layer broke down, forming voids that contributed to strain relaxation, which is a key mechanism to improve material quality for red-emitting structures.

In terms of the barrier layers, they systematically studied the effect of Al content and found that devices incorporating $Al_{0.05}GaN$ in the barriers yielded the highest on-wafer wall-plug efficiency. For the QWs, they examined the impact of growth pressure and observed that increasing the pressure from 200 Torr to 550 Torr resulted in a 54 nm redshift in emission peak wavelength. This redshift was attributed to higher indium incorporation, as elevated pressure reduces indium desorption during growth. As expected, they also noted that longer-wavelength emission was associated with broader emission spectra, consistent with the general trend of increasing full-width at half maximum (FWHM) with increased indium content.

This talk provided valuable insight into the key material and process optimizations required for fabricating efficient red InGaN micro-LEDs, which are traditionally challenging due to the difficulty of incorporating high In content. The systematic evaluation of tunnel junctions, barrier composition, and pressure tuning highlighted the importance of carefully controlling both electrical and optical properties at the epitaxial level. Although my primary focus is on increasing the emission wavelength, this work has nonetheless deepened my understanding of which aspects of epitaxial design and device architecture are critical when developing semi-polar red InGaN micro-LEDs. Maybe some similar optimization can be used on these platelets and full pyramids structures.