ICNS report

William Fieldhouse-Allen

I would like to sincerely thank the UKNC for allowing me to attend this conference. The opportunity to engage with researchers from around the world and learn about the latest advances in nitride materials has been invaluable for my future research endeavours. The wide range of topics, techniques, and ideas presented throughout the week has greatly broadened my understanding and will help me design my upcoming experiments. Additionally, presenting my work to an international audience and discussing it during the poster sessions was an enriching experience.

The ICNS-15 conference was held in Malmö, Sweden, from 6th to 12th July and brought together around 800 researchers from 37 countries. As a biennial event alternating with the International Workshop on Nitrides (IWN), this year marked the 30th anniversary of ICNS, featuring a rich program of approximately 770 presentations. These included eight plenary lectures, invited talks, contributed talks, and over 460 posters, covering four main themes: growth, physics and characterisation, electronic devices, and optical devices. The conference provided an excellent platform for sharing recent breakthroughs and fostering collaboration within the nitride semiconductor community.

I will discuss talks I found particularly interesting below.

Key Talks

Free and bound excitons in AlN

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In aluminium nitride, photoluminescence (PL) measurements reveal strong emission lines associated with free and bound excitons. The P_x and P_y exciton transitions are split due to spin–orbit coupling, while the P_z exciton transition lies significantly higher in energy, by approximately 250 meV. The P_z exciton also experiences strong polarisation fields, which affect its optical properties. Polarisation-resolved PL spectra show a broad emission component polarised parallel to the c-axis (associated with P_z-like states) and a narrower feature polarised perpendicular to the c-axis, attributed to a distinct excitonic transition. Temperature-dependent PL analysis using an Arrhenius

plot, in which the PL intensity is plotted as a function of inverse temperature to extract activation energies, indicates that the exciton signal increases at low temperature before decreasing or stabilising at higher temperature, while the full width at half maximum broadens as temperature rises. This behaviour is consistent with free-exciton dynamics.

Ultra-high-pressure annealing with a carbon capping layer for activation of Mg ion-implanted GaN

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In the fabrication of GaN-based power devices, achieving effective p-type doping through Mg ion implantation requires both high activation of the implanted Mg atoms and suppression of thermal decomposition during post-implantation annealing. Ultra-high-pressure annealing has been shown to meet these requirements by performing the annealing under ~500 MPa of N_2, which shifts the thermodynamic equilibrium to prevent GaN decomposition. Traditionally, GaN powders are used to protect the wafer surface during UHPA by maintaining a local Ga and N environment, but this approach is undesirable for industrial-scale processing as it suffers from poor in-plane uniformity, low throughput, and limited reproducibility. In this work, the researchers proposed an alternative: a sputtered carbon capping layer (C-cap) applied to Mg-implanted GaN. This C-cap can be batch-processed, provides good m-plane uniformity, and avoids the handling issues of GaN powders. Mg and N ions were co-implanted to produce 600 nm box profiles with concentrations of ~10^{19} cm^{-3} in homoepitaxial n-type GaN (0001). UHPA at 1300 °C for 60–120 minutes under 500 MPa N_2 was then performed with the C-cap in place. After annealing, the C-cap was removed via heat treatment in O_2 at 800 °C, which oxidised it to CO_2 while leaving a thin oxide film that was subsequently removed by HF treatment. Auger electron spectroscopy confirmed complete cap removal, and scanning electron microscopy showed smooth, homogeneous surfaces even after 120 minutes of ultra-high-pressure annealing. Hall-effect measurements indicated nearly complete substitutional activation of Mg, with p-type conductivity comparable to prior ultra-high-pressure annealing processes using GaN powders or MOCVD-grown Mg-doped GaN. The results demonstrate that the C-cap method is thermally stable, easy to remove, enables sufficient Mg activation, and may be more industrially scalable than the conventional GaN powder approach.

First-principles description of ferroelectric nitrides

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Polarisation fields are central to the behaviour of nitride semiconductors, influencing both optoelectronic device efficiency and the performance of transistor heterostructures. The speaker discussed how first-principles calculations, within the Modern Theory of Polarisation, can clarify long-standing confusion over how spontaneous polarisation in wurtzite structures should be referenced. Historically, many simulations have used zincblende (zb) as the reference structure for spontaneous polarisation. While zb GaN has no *net* formal polarisation by symmetry, it still has a large formal polarisation value in the Modern Theory framework; therefore, using it as a reference leads to substantial errors in calculated polarisation magnitudes and even sign, particularly for alloys such as AlScN. In 2016, the speaker proposed a more appropriate reference: the layered-hexagonal phase, which corresponds to the wurtzite structure with an internal parameter u = 0.5 (cation–cation separation along c-axis). Comparing this to the relaxed wurtzite value (u = 0.382) yields a formal polarisation difference of ~1.3 C/m^2. Using layered-hexagonal as a reference produces results that agree far better with experimental measurements of strained structures and ferroelectric switching behaviour.

A second source of confusion in the literature comes from how piezoelectric polarisation is treated. Many calculations have used the 'proper' piezoelectric constant, which is valid for zero internal electric field, whereas the 'improper' constant should be used when a finite internal field exists. Using the wrong form can accidentally cancel or exacerbate the reference-structure error (which explains why older models sometimes agreed with experiment despite having incorrect assumptions). The choice of reference and piezoelectric treatment is particularly critical in cases of high indium content, partially relaxed layers, interfaces with non-polar materials, and ferroelectric switching systems, where error cancellation cannot be relied upon.

The role of dislocations in etching porous GaN

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The speaker discussed electrochemical etching of GaN, which can be used to produce porous structures with tuneable optical and mechanical properties. For example, the refractive index of GaN can be reduced from ~2.4 (dense) to ~1 (air) by increasing porosity, enabling applications in photonics such as distributed Bragg reflectors. Conventional understanding is that in n-type GaN, electrochemical etching proceeds

via oxidation driven by holes generated through Zener tunnelling at high electric fields, with threading dislocations initiating pore formation by locally enhancing the field. This would mean that the pore density should match the dislocation density. However, the experimental data challenge this. In highly doped GaN, even very short etches (as little as 2.4 s) produce a pore density far exceeding the dislocation density, with uniform pit nucleation across the surface and no clear link to threading dislocations. At lower doping densities and lower voltages, pores preferentially start at threading dislocations, propagating along them and branching out. In these conditions, the initial surface pit density versus voltage shows a plateau near the dislocation density, as expected for threading dislocation-mediated initiation.

The effect of an undoped GaN cap was also studied. Increasing the cap thickness from 5 nm to 250 nm significantly reduced the starting pore density; with the thickest caps, pore initiation was effectively suppressed, consistent with tunnelling being blocked by the wide depletion region.

The speaker proposed an updated model: at low doping, dislocations serve as etching pathways even through undoped material, while at high doping, pore nucleation is widespread and not limited by dislocation density. This suggests that high electric field concentration at threading dislocations is not the only route to porous GaN; other possibilities include locally higher dopant incorporation near threading dislocation cores, strained or dangling bonds, or mid-gap states. Understanding these mechanisms is important for designing porous GaN structures with controlled morphology for device applications.

Migration process of defects from high-temperature GaN buffer into InGaN/GaN quantum wells

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The talk examined how surface defects originating from high-temperature GaN buffer layers migrate into InGaN/GaN quantum wells (QWs), where they form non-radiative recombination centres that reduce efficiency. Two possible migration mechanisms were considered: diffusion, where defects move through the crystal driven by a concentration gradient, and surface segregation, where defects preferentially migrate toward the growth surface during epitaxy. In both models, the defect concentration in an intervening InGaN underlayer would decrease exponentially with increasing thickness, making it hard to tell them apart from thickness dependence alone.

To distinguish between them, the speaker compared two experimental strategies. First, in a growth interruption test, samples were grown with varying interruption times before QW deposition. If diffusion dominated, longer interruptions would allow more time for

defects from the high-temperature GaN layer to diffuse into the QW, reducing emission. For surface segregation, no such time dependence is expected. Measurements showed no change in photoluminescence efficiency or SIMS profiles with increasing interruption time, indicating that diffusion is not the primary pathway. Care was taken to use freestanding GaN substrates to avoid sapphire-induced V-pits, which could otherwise complicate defect identification.

The second strategy was a layer-position test: introducing a high-temperature GaN ‘defect source’ layer either below or above the QW. Diffusion would allow defects to migrate in both directions, while surface segregation should move defects only toward the surface (+c direction). Samples with high-temperature GaN beneath the QW showed a clear efficiency drop, consistent with upward migration of defects into the QW. In contrast, samples with high-temperature GaN above the QW showed no degradation, indicating that defects did not migrate downward. This directional behaviour strongly supports surface segregation as the dominant mechanism for defect incorporation into InGaN QWs grown on high-temperature GaN buffers.