International Workshop on Nitride Semiconductors

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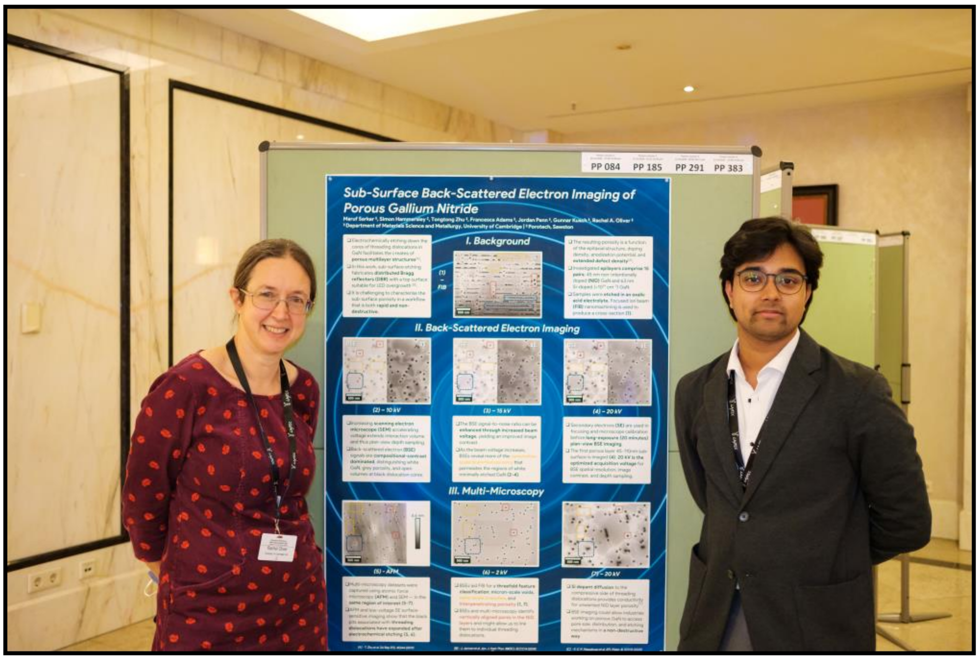
Maruf Sarkar, Cambridge Centre for Gallium Nitride

Department of Materials Science and Metallurgy, University of Cambridge

My PhD aims to develop microscopy techniques for the nanoscale characterisation of porous gallium nitride semiconductors. Two-dimensional imaging via sub-surface back-scattered electron imaging in the scanning electron microscope. Three-dimensional imaging via slice-and-view tomography in the focused ion beam - scanning electron microscope.

With financial assistance from Robinson College and the United Kingdom Nitrides Consortium, I attended the International Workshop on Nitride (IWN) Semiconductors in Berlin, Germany – October 09-14. It was a venue for plenary talks, presentations, and posters covering: characterisation and fundamental physics, electronic devices, growth, novel materials and nanostructures, and optical devices. IWN 2022 welcomed 813 participants from 32 countries. 55% of the 813 were students; 22% of the 813 were female. Finally, I offer a brief glimpse into my experience at the conference, including the presented poster entitled *sub-surface back-scattered electron imaging of porous gallium nitride*: https://twitter.com/maruf_sarkar/status/1581564761031905280.



Professor Rachel A. Oliver (left)

Maruf Sarkar (right)

Selected plenary talks

InGaN lattice constant engineering for long wavelength nitride emitters

Stacia Keller (University of California Santa Barbara)

There is a rising demand for RGB micro-LEDs for display applications and a corresponding rise in interest for nitride LEDs that emit wavelengths beyond green and toward red. To achieve these yellow and red wavelengths, one must design around the lattice mismatch between GaN and InN. Stacia presented alternative fabrication methods for relaxed InGaN substrates: coalescence of relaxed III-nitride nano-features, graded-relaxed InGaN base layers grown by molecular beam epitaxy, and compliant (In,Ga)N on porous-GaN tile arrays - the lattermost will be highlighted.

Electrochemical etching of n-type GaN has been developed for porous GaN distributed Bragg reflector manufacture and lift-off through electropolishing - to name a few applications. This porosity is associated with a decrease in hardness and elastic modulus. The example of InGaN relaxation via porous GaN describes how the porosification of a sub-surface n+ GaN layer can be etched and contributes to full- or partial-relaxation of an InGaN top layer. This holds for a micro-LED compatible tiled structure that uses square tiles for biaxial relaxation. The method leads to the desired V-defects reduction and no indication of additional threading dislocation formation in regrown layers.

Applicability of recent advances in material research performed in UltimateGaN

Herbert Naiditsch (Infineon Technologies)

It is no understatement to say that a future for humanity no longer defined, governed, and driven by fossil fuels is a matter of existential importance as our species finds its home world further gripped by the planetary disease of anthropogenic climate change. This threat exists with an exponentially increasing appetite for data traffic and information where each percentage point of efficiency has value. Through GaN research: these challenges can be overcome.

Ultimate GaN is an EU-driven, public-private Key Digital Technologies Joint Undertaking, funding innovation in electronic components and systems through 26 partners from 9 European countries. The die shrinks - that have enabled the long but recently faltering reign of Moore's law for Si - present unique problems for GaN. A higher power density, current density, and electric fields require fundamental material research – from defects up to the package thermal limitations - if we wish to overcome the challenges of GaN technologies. The fruits of this labour could be the usurping of Si, which is already starting to emerge.

Recent progress and prospects of micro-LEDs grown on sapphire nano-membranes

Euijoon Yoon (Seoul National University)

Should one be in the business of micro-LED displays, the following considerations will be front of mind: more LED chips per wafer, reduced processing steps, reduced production costs, and external quantum efficiency - in the service of superior performance, more affordable, and more numerous displays.

Sapphire nano-membranes were presented as a technology to assist the industry in moving away from past practices - such as the pick-and-place of LEDs. This is done by growing thin sapphire growth surfaces - over a sapphire substrate - used as an array of nano-substrates for the metal-organic vapour phase epitaxy of GaN micro-LEDs. The overgrown material is less defective and less strained on this thin nano-membrane. Lastly, LED flakes were introduced as a route towards large-area micro-LED displays. After the nano-membrane growth of micro-LEDs, they can be lifted off, collected, and bonded with a self-alignment that reduces process time. From a 6-inch wafer, with a target of one LED per pixel, one 8K TV or seven 4K TVs could be manufactured.

Selected presentations

Porous (Ga,In)N layers and LEDs made by selective area sublimation

Benjamin Damilano (Université Côte d'Azur)

The electrochemical approach to fabricating porous gallium nitride is often associated with the requirement for doped layers and the potential for additional processing steps. However, using nanomasking and selective-area sublimation under a vacuum, thin layers of GaN grown on silicon substrates can be porosified.

This alternative top-down etching methodology is performed in situ in the epitaxy reactor. The nanoscale pores produced are cylindrical in shape with a direction perpendicular to the surface with a preferential sublimation of GaN through threading dislocation cores. The initial GaN thickness and sublimation time are degrees of freedom that allow for control over the pore depth. Also, the selective area sublimation approach porosified more complicated structures such as InGaN/GaN single quantum wells; similar porous morphologies obtained to those described above. The nanoporous GaN layers show increased photoluminescence intensity, a wavelength redshift, and compressive stress relaxation. The porosity was strongly dependent on the choice of mask material. A doping-independent route towards porous GaN fabrication might open new avenues in device design.

Electrochemical etching of p-type GaN

Natalia Fiuczek (Institute of High-Pressure Physics)

The mechanisms that govern the electrochemical etching of n-type GaN and the vast array of device applications this can enable have been extensively investigated and will continue to do so. This study centres on the electrochemical etching of p-type Mg-doped GaN. The documented samples were etched under a constant bias and without external illumination – which might be the first report on porous GaN:Mg.

An attempt to overcome the difficulty in making ohmic contacts to p-type GaN via the use of an n-type topmost layer that contacts the voltage source. Additionally, a tunnel junction allowed for the injection of holes into the p-type layer with lateral etching proceeding at the p-GaN/solution interface. The range of voltages and their correlative porosities going from threshold etching bias to electropolishing was remarkably narrow. Finally, there was a discussion about a model that might describe the electrochemical etching of p-type GaN.

Study of electrooxidation of n-GaN in oxalic acid: porous nanostructure formation and chemical mechanism

Artem Shushanian (King Abdullah University of Science and Technology)

To perhaps have more precise control of the n-GaN anodic oxidation in oxalic acid – an investigation of porous n-GaN was presented. Whilst the process is well studied, the author sought to elucidate the chemical mechanism and electronic nature through a series of experiments within a voltage range of 5-20 V.

Ga ions generated were measured with coupled plasma-optical emission spectrometry; vapour phase products were quantified via gas chromatography. With increased bias, the expected pore size increase was reproduced. This is paired with a depiction of how the etching rate can increase with voltage and eventually plateau. The etching pathway was through etched threading dislocations leading to uniform branching current-orientated pores. Finally, a discussion of the reaction mechanism concluded that the process is six-electron and occurs through the intermediates formed by the adsorption of solvent on the GaN surface – specifically, the oxidation of oxalic anions on the anodic surface of n-GaN.