11th International Conference on Nitride Semiconductors

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Introduction

The eleventh International Conference on Nitride Semiconductors (ICNS) took place this year in Beijing, China from 30th August to 4th September. This conference is held biennially, alternating with International Workshop on Nitrides (IWN). These conferences constitute two of the largest events in the field of nitride semiconductors. The conference was attended by approximately one thousand delegates, and featured 6 plenary talks, 56 invited talks, 190 contributed oral presentations and 491 poster presentations. Four symposia ran concurrently in the areas of 'Growth', 'Basic Physics', 'Optical Devices' and 'Electronic Devices'.

Below I briefly outline some of the presentations, which I found particularly interesting.

Selected Presentations

M. Horton- **Experimental and Theoretical Study of In Segregation to Dislocations on InGaN** (Oral presentation)

$In_xGa_{1-x}N$ is notable for its very high threading dislocation densities, of which the a-type ('edge') and a+c-type ('mixed') predominate. The electronic properties of the dislocations are determined by the bonding around the dislocation core, therefore this study set out to determine In segregation around dislocation cores as this change in composition would affect the electronic properties of dislocations, and therefore device performance. The bandgap of $In_xGa_{1-x}N$ is highly sensitive to In composition, and a high degree of segregation can affect exciton localization.

Dislocations are associated with areas of compressive and tensile strain; as In atoms are larger than the host Ga atom, it was hypothesized that In segregation to the tensile regions could relieve some of this strain.

Equilibrium microstructures were simulated for different compositions using a LAMMPS molecular dynamics code[1], using empirical Stillinger-Weber-style classical potentials (these have previously been shown to be accurate when studying the $In_xGa_{1-x}N$ system). For a-type dislocations, the simulations produced an In-rich region and corresponding depleted region. For the a+c type even larger enriched and depleted regions were simulated. Further more, structures predicted by Density Functional Theory simulations agree well with these classical structures.

In order to test these theoretical predictions an $In_xGa_{1-x}N$ epilayers of composition $x = 0.06 \pm 0.01$ was grown by MOVPE on a c-plane low defect density template. This was studied in an aberration-corrected Titan G2 ChemiSTEM electron microscope using energy-dispersive X-ray spectroscopy (EDXS) and high-resolution high-angle annular dark field scanning transmission electron microscopy (HAADF-STEM). An In-rich streak is indeed observed using the EDX analysis, and geometric phase analysis shows a corresponding region of tensile strain.

S. Mohn- **The Role of Oxygen for the Polarity Inversion of III-Nitrides on Sapphire Investigated by HR-TEM and STEM** (Oral and Poster Presentations)

There exists an asymmetry in the III-nitride unit cell such that two orientations are possible: 'metal-polar' if a metal atom terminates the structure or 'N-polar' if an N atom terminates the structure. The polarity of a sample is determined by the growth parameters, but the mechanism by which this occurs is not yet fully understood. Improved crystalline quality is achieved on growth of metal-polar structures due to lower incorporation of impurities.

In order to achieve N-polar structures the sapphire can be 'nitrided', which leads to a chemical conversion of the Al_2O_3 to AlN. Consequent epitaxy leads to N-polar epilayers. Metal-polar structures can be achieved by initial deposition of a low temperature AlN buffer layer, followed by high temperature epitaxy.

This work focused on the inversion of polarity observed in samples grown by the nitridation technique: close to the buffer layer the structure was observed to be N-polar, while far away from the interface was Al-polar. The polarity can be easily determined atomic layer by layer using HRTEM (with Cs aberration correction), and an inversion domain boundary is seen over

[1] Plimpton, S. Fast parallel algorithms for short-range molecular dynamics. J. Comput. Phys. 1995, 117, 1−19.

two monolayers. A change in structure is observed in these monolayers, which corresponds to that of rhombohedral Al_9O_3. It is therefore believed that a transition in fractional occupancy probabilities takes place over this domain.

C. Ren- **Direct Evidence for Dislocation-Based Whisker Formation in GaN-Based Microdisk Lasers** (Oral presentation)

Microdisks utilize whispering gallery modes to create optical standing waves which enhance the local field strength and optical density of states. This has the effect of increasing the rate of spontaneous emission of a QD or QW. The ability of a cavity to confine light is assessed by it's 'quality factor', Q. Achieving a high Q factor in nitride devices has been difficult; this work identified the cause of this to be individual threading dislocations.

Three layers of $In_xGa_{1-x}N$ QDs of approximate composition x = 0.2 were grown on n-doped c-plane GaN/Al_2O_3 pseudosubstrates of different dislocation densities. These were topped by a 200 nm $In_yGa_{1-y}N$/ $In_zGa_{1-z}N$ (y = 0.05, z = 0.065) sacrificial superlattice, a 10 nm GaN layer, then a 20nm $Al_{0.2}Ga_{0.8}N$ etch stop layer. Silica beads of approximate diameter 1 μm were deposited and photoelectrochemical wet etching used to produce disks. A photoelectrochemical etch was then performed to undercut the disk membrane. This enhances optical confinement in the vertical dimension.

Microdisks were analysed using cathodoluminescence in the scanning electron microscope (SEM-CL) and microphotoluminescence. Threading dislocations can be observed as dark spots in SEM-CL as they act as nonradiative recombination centres. Dislocations result in the presence of 'whiskers', which decorate the underside of a cavity. A linear relationship was established between the presence of a dislocation and formation of a whisker with gradient of 0.94 and R^2 of 0.53. Furthermore, a whisker was cut out using a Focused Ion Beam (FIB) in an SEM, and subsequently studied in a Transmission Electron Microscope (TEM). Using g.b analysis a threading dislocation was located running through the whisker.

Finite-difference time-domain (FDTD) simulations predict the highest Q modes to be limited to the periphery of the disk (the whispering gallery modes). Monochromatic CL images confirm this, showing increased emission at the periphery at wavelengths of 464 nm and 485 nm.

M. Holmes- **Measuring the Homogenous Emission Linewidths of Site-Controlled GaN Nanowire Quantum Dots** (Oral presentation)

The exact energies of excited states within a quantum dot depend on several factors that affect the confinement, including the dot geometry and material properties. Furthermore, the environment of the dot can lead to changes in the emission wavelength, known as spectral diffusion. This study measured and calculated the linewidth of emission from site-controlled quantum dots within nanowires.

Fourier spectroscopy was used to measure experimentally the evolution of linewidth with changing power. The linewidth was discovered to grow with the square root of the excitation power. It was discussed that this implies that the traps nearer in energy to the QD are therefore likely to dominate. This includes shallow donor defects and vacancy complexes.

Statistical analysis was also performed using a multivariate hypergeometric distribution, and the power dependent spectral diffusion broadening modelled. This showed good agreement with the experimental results.

F. Massabuau- **Multi-microscopy investigation of the optical properties of dislocations in InGaN** (Poster presentation)

The III-Nitrides are characterized by a high density of threading dislocations. However, they are particularly resilient to these dislocations, and it is generally accepted that they act as non-radiative recombination centres. This study investigated the optical and structural properties of dislocations using a correlative multi-microscopy approach.

A 136 nm layer of $In_{0.09}Ga_{0.91}N$ layer was grown by metal-organic vapour phase epitaxy (MOVPE), and exactly the same dislocations were studied by atomic force microscopy (AFM), scanning electron microscopy (SEM) with cathodoluminescence (CL) and transmission electron microscopy (TEM). The correlation between dislocation type, nearest neighbour distance, light emission from the V-pit, and structure of the dislocation core was studied in this way.

Isolated V-pits were observed to emit different wavelengths from different regions. In the centre the In-N chains and atomic condensates in the tensile region of the core are responsible for the emission. In the facets of the V-pits, strain relaxation leads to a redshift in the emission wavelength, and carrier trapping leads to a lower intensity emission.

It was also observed that CL emission properties were strongly related to nearest-neighbour distances. Clustered dislocations (<100nm between dislocations) displayed a redshift in wavelength and reduced intensity. This is due to the additional strain relaxation and the availability of additional non-radiative centres within carrier diffusion distance.

R. Martin- **Multimode Mapping of III-Nitrides in the Scanning Electron Microscope** (Invited Oral Presentation)

This talk discussed a method of a scanning electron microscope (SEM) in correlation with cathodoluminescence (CL), electron channelling contrast imaging (ECCI) and electron-beam-induced current (EBIC). Two set-ups exist: a FEG-SEM or an electron microprobe (EPMA), which enables different types of dislocation to be determined by switching channelling planes.

One example of the use of this technique described was GaN nanorods with a single InGaN layer. Real colour maps were produced using spectra and the CIE 1931 space, showing the different wavelength emission from different parts of the rods. Furthermore, emission of lower energy was observed from ridges and corners, which was assigned to a higher InN incorporation. Depth-resolved CL also gave an insight into the changes of roughness and InN incorporation at different layers. A rougher layer was observed on top, while at deeper levels a change in InN content and a smoother surface were observed.

Another example is the use of CL and EBIC in the study of LEDs. Quantum wells were grown by the 'quasi-two temperature method', which involves InGaN growth at 765 °C, then a temperature ramp during growth of GaN up to 860 °C. EBIC and CL were used to correlate dark spots, which indicated regions on non-radiative recombination. This was used to infer that these were point defects undergoing charging.

Concluding Remarks

I would like to thank the UKNC for providing me with the opportunity to attend the conference. As my first experience at a conference of this size, I found it very useful to be exposed to such a range of research in the field of nitrides. Furthermore, I found the opportunity to discuss current research very enlightening.

Next year IWN will be held in Orlando, Florida, and in 2017 ICNS-12 will be held in Strasbourg, France.