International Conference on Nitride Semiconductors 2011, Glasgow, Scotland: Conference Report

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Introduction

The 9th International Conference on Nitride Semiconductors (ICNS-9) was held in Glasgow, Scotland. It is a biennial conference which ran from 10th -15th July 2011. In total, it was attended by approximately 1000 participants from around 50 different countries. There were 24 invited speakers, 271 contributed talks held in parallel sessions over the 5 days and 537 posters presented in 3 sessions.

The ICNS conference series is used to present research results from the area of group III-nitride semiconductors and is the perfect place to learn about the state of the art so far.

The themes of the parallel sessions were:

- Light Emitting Diodes and Improving Efficiency
- Epitaxial Growth and Structural Properties
- Bulk and Template Growth
- Nanostructures and Novel Nitride Alloys
- Lasing and Laser Diodes
- Power and High Frequency Devices
- Optical and Magnetic Properties
- Solar Cells and Energy Harvesting
- Device Fabrication and Reliability
- InN and Related Materials
- Theory and Modelling of Materials and Devices
- Sensors and Photodetectors
- Late News

I attended talks in quite a few of the above areas. However, I was particularly keen to listen to the talks about epitaxial growth as well as how we can exploit these materials to harvest more renewable energy through solar cells.

Plenary Sessions

The first plenary talk was given by Professor Umesh K Mishra from the University of California, Santa Barbara entitled "III-nitrides for high power, high frequency electronic devices". This started by giving a brief overview of what characteristics we desire from a material and how that led us to the use of GaN and other nitride alloys.

Most of the devices presented were N-polar AlGaN/GaN HEMT's grown by both MBE and MOCVD. The MBE samples are essentially made of two parts, everything below the 2DEG gives charge, and everything on top reduces the leakage of the device. A trap also has to be introduced to keep the Fermi level below the conduction band for enhancement mode devices. These samples have shown a good performance at 400GHz.

The MOCVD samples were grown on sapphire which was giving them extremely rough surfaces. After much experimentation, it was found that they needed to grow on 4° miscut sapphire in order to achieve smooth, step-flow, n-face growth.

Some work was also carried out on Ga-polar AlGaN/GaN but this did not work well at high frequencies.

Parallel Sessions

The sessions that were mainly of interest to me were the "Epitaxial Growth and Structural Properties" and the "Solar Cells and Energy Harvesting". I did however attend some on improving the efficiency of LED's and how to address the phenomena of "droop" to improve my knowledge of other areas.

One of the highlights of these sessions was the invited talk given by Professor W Alan Doolittle on the technique he has pioneered called Metal Modulation Epitaxy (MME) and how he uses this to grow InGaN alloys. His technique uses shutters to open and close the metal cell fluxes that are incident on the substrate and leaves the Nitrogen plasma on the surface at all times. Once a certain amount has been put down on the surface, the metal shutters are closed so the plasma can use up the excess. For this technique to succeed, metal fluxes of two or three times greater than stoichiometry are used.

He uses different variations of the technique depending on what the desired growth outcome is (be that high structural quality or high p-type material). With both methods the growth always continues whilst the shutters are closed. The major difference is that for high structural material, fluxes of 2-3 times stoichiometry are used but for high p-type material, metal fluxes between 1-2 times stoichiometry are used. These high fluxes of metal ensure that growth never occurs within the intermediate regime as this can lead to pitting on the surface.

They have also found that MME can be used to grow single-phase InGaN alloys throughout the miscibility gap with rms roughness's below 1nm.

Also the invited talk entitled "Nitride based solar cells" by Dr Wladek Walukiewicz gave an accurate insight into the complexities of being able to produce high efficiency solar cells. The two main types of producible solar cells (multijunction and intermediate band) were presented. His group have concentrated on the intermediate band cell as the multijunction type can become a very complex structure to create. For instance, a three junction solar cell needs control of six different elements and three dopants. The latter cell uses an intermediate band that is created between the valence and conduction bands and acts as a "stepping stone". This allows photons to be absorbed at three different energy levels which correspond to the three different energy levels as shown in figure 1. This allows the absorption of photons with a range of energies.

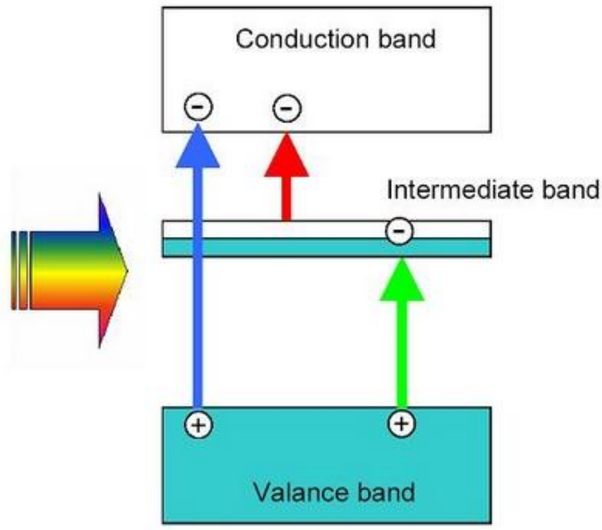

Figure 1: Schematic diagram of an intermediate band solar cell [1].

InGaN is deemed to be the perfect semiconductor for this as it has a "tuneable" energy gap from around 0.7-3.4eV. It also has superior radiation resistance properties and is much less complex to grow. Strangely, one of their more successful solar cells consisting of an InGaN p-n junction grown on p-type silicon exhibits LED properties and emits green light! This has been attributed to a large Stokes shift within the material causing fluorescence.

I was also lucky enough to be chosen to give a presentation at the conference. It attracted quite a lot of attention due to the similarity to Professor Doolittle's MME method. My talk focussed on a growth method we have developed known as Anion Modulation Epitaxy (AME). This has enabled us to produce better structural quality material for GaN down to temperatures of 500˚C compared with an MBE grown sample. We also have managed to reduce the rms roughness of the surface from 16nm to approximately 1nm. Finally we have also managed to p-dope GaN at a temperature of 550˚C using AME. Previously, this is normally done using MBE at temperatures of 650 - 680˚C with the specific conditions of growing on the very edge of stoichiometry.

One of the posters that caught my attention was investigating the growth of InN nanocolumns on GaN templates by RF-MBE. The obvious motivation for this is that InN could be exploited for infrared optical devices, high-speed electronic devices and of course solar cell applications. The one thing that seems to be stopping all researchers in this area is the presence of the surface electron accumulation layer. InN nanocolumns however can contain non-polar sidewalls and these are likely to be free of electron accumulation [2, 3].

Both In-polar and N-polar nanocolumns were grown and characterised by SEM, CL, PL, XRD and TEM. The In-polar columns were grown on GaN templates whilst the N-polar columns were grown on sapphire. The growth temperature, Indium nucleation time and V/III ratio dependence were all investigated.

The results of the samples grown on GaN templates are as follows.

A series of growths were carried out between 430˚C and 510˚C using the same fluxes and V/III ratios (~28) and SEM images were taken to look at the effect of the temperature. Lower growth temperatures were found to form pyramids while high growth temperatures enhance the lateral growth rate. The V/III ratio was also investigated and the substrate temperature was kept at 485˚C. The density of the nanocolumns was found to be mainly determined by the In flux when the V/III ratio ≥9. In this region the nanocolumn diameter was not affected. If the Indium beam flux was too high, the nanocolumns start to be influenced by each other and coalescence occurs. Increasing the Indium flux further towards stoichiometry (V/III ≤2.5) results in almost full coalescence. The resulting film is similar to samples grown in the N-rich growth region.

The effect of an Indium nucleation layer was also investigated. This is important to obtain relative uniform distribution of the nucleation site. Nucleation times of 0, 10 and 25s were investigated. It was found that no initial Indium nucleation resulted in clustering of the nanocolumns which in some cases led to coalescence of the adjacent columns. Too long a nucleation time (25s) causes dense and tapered nanocolumns which are bulbous on top and held up by a thread-like structure.

The TEM data revealed that there were very few dislocations within the nanocolumns which is why there was a significant increase in the luminescence when compared with InN films.

Nucleation time and V/III ratio was investigated for nanocolumns grown on sapphire. The diameters of the nanocolumns range from 30nm to 70nm. This is approximately 10 times smaller than the columns on the GaN template. Also, there are 100 times more nanocolumns grown on sapphire compared with GaN. The affects of nucleation time and V/III ratio are the same as the GaN substrate nanocolumns, however sapphire gives a non-uniform diameter. It is also unclear whether the sidewalls are non-polar which is why their work concentrated on the In-polar nanocolumns.

Two of the thirteen sessions were based around crystal growth. The talks within each session are listed below.

Epitaxial Growth and Structural Properties:

1. Towards high-temperature homoepitaxial growth of AlN using Hot-Wall MOCVD
2. Epitaxial lateral overgrown AlN templates for high efficiency UV LEDs
3. In situ void formation technique using AlN shell structure on GaN stripes grown on c-sapphire substrates
4. Extremely High Internal Quantum Efficiencies from AlGa_/Al_ Quantum Wells
5. Growth of high quality AlGaN layers for deep ultraviolet light emitting diodes using a hybrid MOCVD/HVPE growth system
6. Composition mapping in InGaN with quantitative and comparison with atom probe measurements
7. Analysis of In distribution in InGaN quantum wells on the atomic scale by HR-TEM
8. Dopant segregation at dislocations in Si- and Mg-doped GaN
9. On the origin of basal stacking faults in nonpolar wurzite films epitaxiallygrown on sapphire substrates
10. Revealing stacking faults in m-plane GaN using electron channelling contrast imaging in a scanning electron microscope
11. Defect reduction in semipolar (11-22) GaN grown on *m*-plane (1-100) sapphire using a direct growth technique
12. Analysis of Mg acceptors activation property in strain modulated AlGaN/GaN superlattices with AlN interlayer
13. Carbon-doped p-type (0001) plane AlGaN (Al= 0.06 to 0.50) with high hole density
14. 240-260nm light source tube using Si-doped AlGaN quantum wells upon excitation by electron beam
15. GaN/AlGaN p-n Heterostructures Grown by NH3 Molecular Beam Epitaxy for Determining the Polarization Charge through Capacitance-Voltage Measurements
16. Towards identification of the two main acceptors in c-plane Mg-doped GaN
17. Effect of carbon on carrier mobility in *n*-type GaN films
18. Hole traps in variously grown n-GaN
19. Growth and applications of AlInN
20. In Depth Investigation Of InGaN/GaN Multiple Quantum Wells Grown On III-Nitride Distributed Bragg Reflectors For Polariton Laser Diode Applications
21. Strain Relaxation Mechanisms in Green Emitting GaInN/GaN Laser Diode Structures
22. Development of the Multiwafer Production Epitaxial Growth Process in Prototype HVPE System for 100-350 μm thick GaN on Sapphire
23. Enhancement of Substrate Breakdown Voltage of GaN Buffer Layers Grown on n-type 4H – SiC

24. AlN/GaN Short-Period Superlattices Coherently Grown on 6H-SiC (0001) Substrates by Molecular-Beam Epitaxy
25. MME of InGaN alloys
26. Efficient Green Emission from InGaN Quantum Wells Coherently Grown on Semipolar (112_2) GaN Substrates
27. Semipolar GaInN quantum well structures on large area substrates
28. Enhancement of optical properties in nonpolar a-plane InGaN/GaN multiple quantum wells with step-stages QW structure
29. Optical polarization properties in *m*-plane InxGa1-xN pseudomorphically grown on ZnO
30. Nonradiative recombination in long-wavelength polar, nonpolar, and semipolar GaInN/GaN quantum wells
31. Strain Relaxation in Semipolar Nitrides for Optoelectronic Device Applications
32. Greatly improved crystal quality of non - polar GaN grown on a - plane GaN nano - rod template obtained using a self - organised nano - mask
33. Investigation of Atomically Flat M-plane GaN Areas Grown on □-LiAlO2(100)
34. High crystalline quality of a-plane GaN during one-sidewall-seeded epitaxial lateral overgrowth on r-sapphire
35. Growth and reduction of dislocation density of {11-22} GaN on shallow etched *r*-plane patterned sapphire substrates
36. Anisotropic optical and structural properties of semi-polar (11-22) AlN grown on (10-11) sapphire
37. Anisotropic optical properties of high-quality m-plane bulk AlN
38. Efficient InGaN/GaN based blue LEDs grown on 8-inch diameter Si(111) substrates by metal-organic vapor phase epitaxy
39. Improved Crystal Quality and Light Output Power of GaN-based Light-emitting Diodes Grown on Si Substrate by Buffer Optimization
40. Influence of Growth Temperature on Buffer Leakage Current of AlGaN/GaN/AlGaN DH-FET Grown on Silicon substrates
41. Ga-bilayer controlled AlGaN/GaN HEMT structure grown on Si by PA-MBE
42. Impact of buffer growth on crystalline quality of GaN grown on Si(111) substrate
43. Growth and relaxation mechanisms of AlN-interlayers for thermal mismatch accommodation in GaN on silicon substrates
44. Effect of Indium on the conductivity of poly-crystalline GaN grown on High Purity Fused Silica
45. Metalorganic Vapor Epitaxy growth of nitrides analyzed using a novel in situ X-ray diffraction system
46. Analysis of doping induced wafer bow during GaN:Si growth on sapphire
47. Fabrication of crack-free thick AlN film on a-plane sapphire by low-pressure HVPE
48. The Role of Liquid Phase Epitaxy during Growth of AlGaN by MBE
49. Schottky barrier height and interface chemistry for metals contacted to low dislocation density AlGaN grown on c-oriented AlN wafers
50. An original method to fabricate nitride-based photonic crystal membranes

51. Sequential Tunneling Transport in GaN/AlGaN Quantum Cascade Structures
52. Nondestructive Terahertz Measurement of Carrier Density of Thin GaN Semiconductor
53. Quantum Well Composition and Dopant Measurements using SIMS
54. Crystal phase-selective epitaxy of rutile and anatase Nb-doped TiO2 films on a GaN template by the helicon-wave-excited-plasma sputtering epitaxy
55. Anion Modulation Epitaxy (AME), an alternative growth strategy for group III-Nitrides
56. Controlling Polarity on GaN Substrates
57. Formation of step-free GaN surface at low temperature of 770 oC by controlling surface supersaturation
58. Role of Hydrogen for high quality GaN p-type doping
59. Removal of Interface Pollution at the Regrowth Interface of AlGaN/GaN Structures on GaN Templates Using Nitrogen Plasma Treatment
60. Investigation of MOCVD Growth Parameters on the Quality of High Growth Rate GaN, InGaN and AlGaN Epitaxial Layers
61. Growth, Doping, and Compositional Grading of In-Rich InGaN Thin Films Grown Using a High Flux Energetic N-atom Source
62. Elimination of Indium Surface Segregation in InGaN Grown Throughout the Miscibility Gap

Bulk and template growth:

1. Freestanding highly crystalline single crystal AlN substrates grown by a novel closed sublimation method
2. Faceting in AlN Bulk Crystal Growth and its Impact on Crystal Properties
3. Growth of AlN bulk single crystals on 4H-SiC substrates and analyses of their structural quality and growth mode evolution
4. Effect of Ammonia Cluster Energy on the Molecular Beam Epitaxial Growth of GaN and AlN on Al2O3
5. Structural Characterization of the Nonpolar Substrate Grown by Multistep Hydride Vapor Phase Epitaxy
6. Electron irradiation of bulk HVPE GaN: structural properties and photoluminescence
7. Raman analysis of HVPE-grown free-standing gallium nitride with various orientations
8. The growth of high-quality and self-separation GaN thick-films by HVPE
9. Properties of GaN from HVPE boule growth
10. Spatio-time-resolved cathodoluminescence study on a freestanding GaN substrate grown by halide vapour phase epitaxy
11. Characterization of GaN substrates made by Na flux method
12. Molecular beam epitaxy of zinc-blende and wurtzite AlGaN bulk crystals
13. Ammonothermal growth of GaN
14. Ammonothermal growth of low oxygen concentration GaN using a dry acidic mineralizer and fabrication of an Al0.2Ga0.8N/GaN heterostructure
15. High Nitrogen Pressure Solution growth of GaN by multi feed-seed configuration
16. Effect of additives on Liquid Phase Epitaxy growth of non-polar GaN single crystals using Na flux method

17. Plasma Vapor Deposited Nano-columnar AlN Nucleation Layers for High Performance GaN Devices
18. Novel Chemical lift-off Approach for (In)GaN Using Sacrificial ZnO Template Layers

All of the abstracts for these talks can be found at http://www.icns9.org/ and many of the papers are being published in the ICNS conference proceedings.

Conclusions

Attending this conference has allowed me to extend my knowledge in all areas related to III-nitride semiconductors and to also develop my knowledge of other growth methods. It also gave me the opportunity to have some in depth discussions with professors and students alike, in and around my area of research and from all over the world.

The conference has been invaluable in extending my knowledge in the up and coming areas of group III-nitride research. I would like to thank BACG and UKNC for the financial support. Without this I wouldn't have been able to go present my work at such an important event.

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References

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