57th Electronic Materials Conference (EMC) Report

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Introduction

The 57th Electronic Materials Conference was held at The Ohio State University in Columbus, Ohio this year from the 24th – 26th of June. The conference had an attendance of over 500 delegates. Of the 40 sessions at the conference, 7 sessions were dedicated to nitrides (a full list of all the sessions is provided at the end of the report). Across these sessions, there were approximately 300 presentations, 60% of which were delivered by students. The first session was the awards ceremony and plenary session. During the awards ceremony awards are given for the best student presentation from the previous conference, the best paper published in the Journal of Electronic Materials, and the 2014 NIST uncertainty analysis award. The next EMC will be held from June 24th – 26th 2016 at the University of Delaware, in Newark, Delaware.

Plenary Session

The plenary talk was delivered by the 2014 Nobel Prize winner for physics Prof. Shuji Nakamura. His talk, titled "*The History and Developments of InGaN-Based LEDs and Laser Diodes*", was focussed on the importance of GaN and the discovery of a p-type doping method. In the first part of his talk, Prof. Nakamura discussed his Nobel Prize win 'for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources', and the media reaction, specifically the Japanese media, to this award. He said that one report in the Japanese media stated that he won the Nobel Prize for the development of a manufacturing method for blue LEDs, and that this report was then used as the source for the rest of the media. Because of this, almost all of the media in Japan, including the science council, reported his contribution incorrectly.

Prof. Nakamura then moved on to discussing the importance of the discovery of p-type doping in GaN and how this led to the development of blue, green and white LEDs. He then gave a brief history of the development of LED device structures and how the growth of high quality InGaN films allowed for the creation of blue double heterostructure light emitting devices. The work done by Nakamura (and his fellow Nobel Prize winners Isamu Akasaki and Hiroshi Amano) has resulted in many beneficial applications including energy efficient solid state lighting, display screens, medical devices, and optical storage.

Presentations

Session C: III-Nitride – Nanowires
Chairs: Kris Bertness and Zetian Mi

This session was focussed on the growth and characterisation of III-nitride nanowires. Two of the six presentations were delivered by students. The first presentation (student) discussed the formation of quantum dots in the InGaN disk regions of molecular beam epitaxy (MBE) grown GaN nanowires. The nanowires were characterised using time resolved photoluminescence (TRPL) and transmission electron microscopy (TEM). The TRPL measurements showed a quantum efficiency of over 40% for $In_{0.5}Ga_{0.5}N$/GaN nanowires. TEM was used to confirm the presence of self-organised islands in the nanowires, as well as the observation of single photon emission. These results are in contrast to AlGaN/GaN nanowires which have lower quantum efficiencies and show no signs of island formation.

The fourth presentation in this session was concerned with how the carrier concentration varies along the length of n-type (Si-doped) GaN nanowires grown by catalyst free MBE. Raman spectroscopy was performed using a 633 nm laser in a back scatter geometry. The carrier concentration was estimated by analysing the shift of the longitudinal optical phonon peak near 739 cm^{-1} due to coupling with plasmon modes of the free carriers. The results show that the carrier concentration is nearly constant as a function of length, with an increase in carrier concentration from the base to the tip of the nanowires of approximately 20%. This change in carrier concentration is attributed to a decrease in growing temperature at the tip of the nanowires.

Session I: III-Nitride – Characterization of Materials and Devices
Chair: Christian Wetzel

This session was focussed on the characterisation of III-nitride materials and devices. I delivered the eighth presentation in this session on electron channelling contrast imaging of AlGaN/GaN high electron mobility transistors grown on Si substrates. Seven of the ten presentations in this session, including mine, were delivered by students.

The second presentation (student) of the session reported on how to control the free carrier concentration and mobility in GaN by controlling the carbon impurities. It is difficult to achieve high mobility n-type GaN grown my metal-organic chemical vapour deposition (MOCVD) due to carbon impurities which act as a compensating acceptor. In order to reduce the carbon impurities, low Si-doped GaN layers were grown using a V/III ratio of 4000, a Ga (TEG) partial pressure of 4 mTorr, and a growth temperature of $1000^{o}C$ in order to achieve Ga supersaturation . Using this growth method, the carbon impurities were reduced to a level below the detection limit of secondary ion mass spectroscopy (SIMS). A maximum hall mobility of 820 $cm^2\ V^{-1}$ was measured for a carrier concentration of $5 \times 10^{16}\ cm^{-3}$, down to a mobility of 700 $cm^2\ V^{-1}$ for a carrier concentration of $1 \times 10^{16}\ cm^{-3}$. For carrier concentrations below this level, a sharp decrease in mobility was observed.

The fifth presentation in this session discusses the importance of the thermal conductivity of GaN to device performance and reliability. The thermal conductivity is often reported as being greater than 200 W mK^{-1}, however mean free path spectroscopy has shown that this can be highly dependent on the thickness of the GaN layer. For thicknesses less than 1 mm in undoped GaN films can be less than half of the reported 200 W mK^{-1}. Further investigation, using time domain thermoreflectance, has shown that the thermal conductivity of GaN is not a single discrete value, but is dependent on film thickness and doping levels.

Session Q: III-Nitride – Light Emitting Diodes
Chair: Robert Kaplar

This session was focussed on the design and characterisation of III-nitride LEDs. Seven of the ten presentations in this session were delivers by students. The first presentation (student) of the session reported on a 3 junction GaN bipolar cascade LED design for low on-resistance and reduced efficiency droop. By using an active region cascade design, a multiple radiative recombination process can be generated from one injected electron-hole pair. This cascade structure allows for low current density operation with a maximum peak efficiency. The device structure was grown using plasma assisted molecular beam epitaxy (PAMBE). The results presented represent the lowest reported series resistance for cascade LEDs.

The seventh presentation reported on the possibility of using flexible ceramic substrates for GaN based LEDs. The LED structures are typically epitaxially grown on sapphire substrates before being transferred on to a flexible substrate. Common flexible substrate materials are polymers, on to which GaN LEDs have been transferred, and plastic substrates which have had GaN an GaAs transistors transferred on to. However, due to the poor thermal conductivity of these materials the LEDs cannot be operated in high power conditions. By using ceramics as flexible substrates, GaN LEDs can be operated at high driving currents. The flexible ceramic used in this case was a thin film of yittria-stabilised zirconia. Due to the good thermal conductivity and stability of the ceramic substrates, solid state lighting applications can be produced with fewer package processes.

Session X: III-Nitride – Novel Devices
Chairs: Andrew Allerman and Siddharth Rajan

This session was focussed on the design and characterisation of novel III-nitride devices, and again seven of the ten presentations were delivered by students. The first presentation (student) in this session reported on the use of nanporous GaN distributed Bragg reflectors with near unity reflectance. GaN based vertical cavity surface emitting lasers (VECSELS) are challenging to fabricate due to the difficulty of forming planar distributed Bragg reflectors (DBRs). By using a conductivity selective electrochemical etching process for doped GaN, a porous structure of parallel columns can be formed. Using reflectance spectrum measurements the GaN DBRs were found to have a peak reflectance of 99.5%, and the beam angle divergence by the DBR mirror was measured to be less than 0.1^{o}. The parallel arrays of nanpores creates an optical birefringence for incident light polarised perpendicular and parallel to the pores which provides polarisation stability of the lasing mode.

The third presentation (student) reported on the use of a III-nitride based microcantilever heater for the detection of organic vapours at low temperatures. Volatile organic compounds (VOCs) pose significant health hazards in both industrial and home environments, and as such the detection of these compounds is important. There are several detrimental issues with the common methods for detecting these VOCs including high power consumption, limited selectivity, and expensive characterisation tools. These issues can be nullified by using an AlGaN/GaN heterostructure triangular microcantilever heater (TMH) sensor. This TMH design can detect a wide range of diluted VOCs below their auto-ignition temperatures based on the TMH response to their latent heat and dipole moment.

Session Y: III-Nitride – Ultraviolet Emitters and Detectors
Chairs: Andrew Armstrong and Theeradetch Detchprohm

This session was focussed on the design and characterisation of III-nitride UV emitters and detectors. Four of the five presentations in this session were delivered by students. The first presentation in this session discussed the possibility of electrically injected AlGaN nanowire ultraviolet lasers. UV lasers have a wide range of applications including water purification, data storage, and biochemical sensors. Current semiconductor technology has only achieved a minimum wavelength of 336 nm. Some of the challenges involved in reducing the wavelengths of these lasers into the deep UV range include high threading dislocation densities and inefficient p-type doping of Al-rich AlGaN. MBE was used to grow nearly defect free AlGaN core-shell nanowires on Si. These nanowires were used to fabricate highly stable, electrically pumped lasers with wavelengths across the entire UV-AIII band (approximately 320 – 340 nm).

The fourth presentation (student) was reporting on the use of argon (Ar^+) ion implantation in III-nitride solar blind UV photodetectors as a means of edge termination. Due to their radiation hardness and wide tunable bandgap, the III-nitride materials are of great interest as a possible replacement for photomultiplier technology. However, these materials also suffer from large leakage currents and premature breakdown which leads to poor device performance. Electric field crowding is also a problem in GaN based devices operated under a large electric field. To reduce the effect of the electric field crowding, AlGaN p-i-n structures were grown on UV transparent sapphire substrates using MOCVD. Ar^+ ions were implanted to a depth of 50 nm which resulted in a quasi-amorphous GaN region by introducing trap states in the middle of the bandgap. These trap states help to distribute the electric field, which reduces the leakage current and field spiking at the contact edges. This method has led to a reduction in leakage current by two orders of magnitude and the elimination of premature breakdown.

Session List

Plenary Session
A: 2D Electronic Devices
B: Electronic Materials for Biological Sensing and Interfacing
C: III-Nitride – Nanowires
D: Solar Cells – Wide Bandgap and Tandem Cells
E: Gallium Oxide and Related Materials
F: Epitaxy if Narrow Gap Materials
G: Synthesis of 2D materials
H: Spintronics
I: III-Nitride – Characterization of Materials and Devices
J: Solar Cells – Materials, Devices, Defect and New Concepts
K: Materials for Memory and Computation
L: Narrow Bandgap Materials and Devices
M: Contacts to Compound and Low-Dimensional Semiconductor Materials
N: Nanowire Characterization and Growth
P: Metamaterials and Plasmonics
Q: III-Nitride – Light-Emitting Diodes
R: Organic and Hybrid Photovoltaics
S: Dielectrics for Metal Oxide Semiconductor Technology
T: Epitaxial Materials and Devices
U: SiC Materials Growth and Characterization
O: Materials Integration
V: Electronic Properties of 2d Materials
W: Low Dimensional Structures – Quantum Dots, Wires and Wells
X: III-Nitride – Novel Devices

Y: III-Nitride – Ultraviolet Emitters and Detectors
Z: Organic, Flexible and Printed Thin-Film Electronics
AA: Epitaxial Oxides and Multifunctional Oxides
BB: Point Defects, Doping and Extended Defect Characterization
CC: SiC Devices and Processing
DD: III-Nitride – Power Electronic
EE: Optical Properties of 2D Materials
GG: Embedded Nanoparticles and Rare-Earth Materials in Semiconductors
II: III-Nitride – Thin Film Growth
KK: Electrochemical Energy Storage, Conversion and Production
MM: ZnO and ZnO based Alloy Semiconductors
NN: Nanoscale Characterization and Microscopy
FF: Carbon Nanotubes
HH: Thermoelectronics
JJ: Compound Semiconductor Growth on Si Substrates and Si-Based Heterojunctions
LL: Molecular and Organic Materials for Sensors and Light Emitters

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