ICNS 10 – Washington D.C.

UKNC Bursary Report :

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Background

The 10th edition of ICNS was held in Washington D.C. at the Gaylord national resort hotel from 24th to 30th of August 2013. This was the 10th edition of the conference, following on from the previous edition in Glasgow in 2011. A total of 893 people attended the conference, with 320 from the Americas, 297 from Asia, 6 from Australia and 235 from Europe, in total delegates came from 31 countries.

Plenary Talks

The first of the plenary talks was delivered by Mike Krames of SORRA inc. The talk focused on the progress made in homoepitaxial Nitride LEDs by the company SORRA and started with a very general introduction to solid state lighting. The potential for solid state lighting to reduce energy demand was covered with a prediction that a global move to LED based lighting could save 10% of worldwide electricity usage. Following this a history of LEDs was presented, from the first visible (red) LED in 1962 to the development of InGaN based LEDs and white LEDs through phosphor conversion. The limitations of current phosphor converted LEDs were discussed with luminous efficacies of 400lm/W for phosphor converted white and ~300lm/W for high quality (CRI) white. Recombination mechanisms were briefly discussed including mention of efficiency droop being caused by in-direct Auger recombination (this topic became a theme through the conference and specifically in the rump session). The current LED manufacturing steps were presented to frame the work carried out by SORRA. The basis of the work is on the use of bulk GaN subtrates, with the argument that due to the proliferation of III-nitride laser technology using GaN substrates has made GaN substrates available at a lower cost. The LEDs produced by SORRA are formed into triangular device structures allowing a high yield and increased light extraction efficiency. The emphasis of this talk was that the significantly increased performance of LEDs using GaN substrates had a cost benefit compared to using cheaper, lower performance LEDs. Performance data of SORRA LEDs were presented (identical EQE at 5 times higher drive currents than competitors e.g. 60% EQE at 600mA compared to 150mA for Nichia) but no prices were mentioned in the talk.

The second plenary talk was presented by Miroslav Micovic from HRL Laboratories focused on the use of III-Nitride materials in for transistor applications. The potential applications of GaN based electronics was presented with an emphasis on high speed applications such a millimetre and sub millimetre wave applications (30-300GHz and 300+GHz). The ability of GaN transistors to switch significantly higher power than competing materials was raised as one of the significant benefits allowing monolithic microwave integrated circuits using GaN to currently perform 7 times better than conventional devices. DARPA targets for the next generation of technologies stated that Fmax (the maximum frequency at which RF power can still be amplified) needs to reach 400GHz.

Contributed Talks

A selection of the contributed talks will be summarized here, with a focus on the optical devices: visible session.

The first of the visible optical devices sessions focused on the use of silicon substrates for the growth of nitride LEDs. Youngjo Tak et al of Samsung Advanced Institute of Technology presented details of LEDs grown on 8” Silicon (111) substrates. The cost benefit of using low cost/large area substrates was made with 8” Si(111) substrates costing $47. One of the key issues in the growth of GaN on Si was stated to be due to the sensitivity to the native oxide layer on silicon that leads to the growth of polycrystalline GaN. This s addressed by thermal annealing in a hydrogen atmosphere. It was also mentioned that a pre-treatment of aluminium in needed before the flow of ammonia to stop the formation of silicon nitride. Following this talk Martin Albrecht et al of Elektronenmikroskopie, Leibniz-Institut fur kristallzuechtung focussed on structural studies of GaN based LEDs grown of silicon highlighting that the reduction of threading dislocation densities is significantly more important for device performance (IQE) when reducing from 10^9 to 10^8 than 10^7 to 10^6.

The final visible optical devices session of the day was centred around the use of nanostructures for LEDs and Lasers. In this session I presented work based on that which was previously presented at the UKNC meeting in Cardiff on hybrid organic/inorganic white light emitters based on InGaN/GaN MQW nanorods and a light emitting polyfluorene co-polymer. In this session various approaches to using nitride nanorods were presented including top down and bottom up. Joannes Ledig of TU Braunschweig presented characterization of core-shell InGaN/GaN nanorods including EBIC using in-situ SEM nano-manipulators. This technique was used to show that it is possible to form a p-doped shell entirely surrounding the nanowire forming a p-n junction and depletion region. George T. Wang of Sandia National Laboratories presented data on a different approach to core shell nanorods fabricated first by a top down etch process followed by regrowth of InGaN quantum wells on the m-plane side facets of GaN nanorods on c-plane GaN. A doped p-GaN layer was grown and coalesced over the core shell nanorod structures to form a continuous film allowing contact and fabrication of LED structures. CC Yang of National Taiwan University also talked about core-shell structures and reported the use of nano-imprint lithography to pattern the selective area growth of n-GaN nanorods with pulsed growth conditions allowing the control of the overgrowth shape and allowing staged nanorod shapes with graded diameters. After the growth of a thin p-GaN shell layer the wafer was placed in an MBE reactor and GaZnO was deposited to form a transparent conducting oxide layer for p-contact to from devices. It was shown that the electroluminescence wavelength was weakly dependent on injection current, indicating that the emission is from a mixture of polar and non-polar quantum well facets but dominated by emission from non-polar facets. Lasing was demonstrated by Jeremy B. Wright in GaN nanowires prepared by silicon dioxide nanosphere lithography using dry and wet etching. Low diameter nanorods were used in order to reduce the number of lasing modes in the nanorods, with the cut-off for single transverse mode being ~120nm. Different methods of reducing the number of longitudinal modes were presented including removing the nanords from the sapphire substrates and placing two nanords close enough for coupling of the evanescent fields creating a coupled cavity with wider mode spacing. Another technique involved placing nanorods on a gold pad to act as a loss mechanism, quenching many of the modes with differing severity, leading to single longitudinal mode lasing.

Hua-Shuang Kong of Cree presented the GaN on silicon carbide approach to LEDs currently marketed by Cree. The approach to complete system in house manufacturing was discussed in relation to producing substrates, wafers and finished devices. This was presented as an important advantage for full system optimization for example control of the device architecture to tailor the properties of devices by the use of conducting SiC to form vertical LED structures. The performance of Cree's commercially available devices was reported as extraction efficiencies up to 88% and efficacies of 200lm/W at 1W. Rei Hashimoto of Toshiba Corporation presented a paper on high efficiency yellow InGaN LEDs grown on c-plane sapphire. It was stated that their work had found that of the two problems associated with high indium content InGaN, strong QCSE and significantly reduced crystal quality, the reduction in crystal quality was the most significant factor in reducing performance. The approach used to combat this was the use of low indium incorporation InGaN barriers with a thin (1nm) AlGaN interlayer and a high indium content quantum well in their multiple quantum well devices. This allowed improved crystal quality leading to 19.3% EQE at 20mA injection current in the yellow spectral region.

The advantages of nitrogen polar GaN were discussed by Eiji Kishikawa of the University of Tokyo, specifically, higher indium incorporation than gallium polar GaN. The issues of MOCVD and MBE grown nitrogen polar films were covered with MOCVD grown films having rough surface morphology and MBE grown films having high dislocation density. In the work presented by the author the pulsed sputtering deposition technique was used to deposit nitrogen polar GaN films and LED structures on sapphire with similar XRD rocking curve values to films grown by MOCVD with indium incorporation from 10-46%. The films had atomically flat surfaces good optical qualities with an absence of yellow band emission. Danti Chen of Yale University discussed techniques using GaN membranes fabricated using conductivity selective electrochemical wet etching. Using this technique, high quality GaN/Air DBRs were fabricated with high reflectivity with only 4 pairs. The technique was also applied to the transfer of LEDs from the growth substrate to other foreign substrates, allowing applications in flexible electronics. This topic was continued by C.C. Yang of National Taiwan University who presented work on lift off processes utilizing photo-electrochemical etching. A patterned sapphire substrate was used to create an air void groove structure between sapphire and GaN. After masking the device structure a dry etch to the sapphire allowed the grooves to be exposed to solution for photo-electrochemical etch of the GaN at interface between GaN and sapphire. The process has been demonstrated at the full wafer scale with 95% yield. It was also demonstrated that the UV illumination required for photo-electrochemical etching can be supplied by an array of GaN LEDs.

Thomas Lehnhardt of Osram presented work using green emitting InGaN multiple quantum wells optically pumped by blue emitting LEDs as colour conversion in green emitting LEDs. In order to combat the difficulties of reduced crystal quality with high indium InGaN quantum wells, optically pumped quantum wells allows the better electrical performance of blue emitting quantum wells to be exploited with green emitting quantum wells optically pumped. The significant advantage is that the extremely high v-pit density present in longer wavelength emitting InGaN that poses significant current leakage issues in electrically injected devices do not strongly effect the optical performance of optically pumped devices. The v-pit density of the optically pumped quantum wells was found to be an advantage due to increased light extraction efficiency. Issues with carrier transport cause poor carrier distribution through electrically injected multiple quantum wells where as optically pumped quantum wells exhibit better distribution of carriers, leading to a reduced carrier density and a later onset of efficiency droop.

Rump Session

I attended the optoelectronic devices rump session with seven high profile panellists from several academic institutions and industry. The topics for discussion were varied, from UV and visible LEDs to Lasers and solar cells, one topic however dominated the debate; efficiency droop. Following on from the debate that had been taking place in the questions after contributed talks during the week, the debate focused on two separate positions, that droop is caused by indirect Auger recombination or by current leakage effects. This debate was extended from debate following work carried out by members of UCSB and CNRS Ecole Polytechnique (Phys. Rev. Lett. 110, 177406 (2013)) where direct evidence of high energy electrons associated with Auger recombination was linked to the onset of efficiency droop. This was countered mainly by F. Schubert with arguments based on current leakage.

Closing Plenary Talks

The first of the closing plenary talks was delivered by Chris van de Walle of UCSB and focussed on loss mechanisms in nitride materials. This followed on from the discussion in the rump session concerning the origins of efficiency droop. The conclusion of the analysis of the causes of efficiency droop was that it is intrinsic to the material and the only effective approach to engineer devices less susceptible was to reduce carrier densities. Specifically one prominent solution was to use InGaN quantum wells in non-polar directions to allow quantum well widths to be considerably wider, reducing the effective carrier density along with the reduced carrier density due to the intrinsically faster radiative lifetimes due to lack of QCSE. This Talk was followed by Hiroshi Amano of Nagoya University who discussed two non-standard growth techniques for nitride materials. The first of the techniques was increased pressure MOCVD, in this work InGaN quantum wells were grown at pressures of 4 atm. with good quality. The ability of computational fluid dynamics techniques to model the growth of InGaN in the increased pressure MOCVD was demonstrated. The second of the techniques discussed was atomic layer deposition based on very fast pulsing of grow sources of the order of 10ms. Low growth temperatures are possible with atomically sharp quantum well interfaces. High hole mobility p-GaN was demonstrated with a growth temperature o 670 degrees centigrade allowing improved performance if InGaN layers due to the lower growth temperature. The Final Plenary talk was delivered by Jurgen Chisten of Otto von Guericke University of Magdeburg. This plenary talk introduced the technique of STEM–CL for characterization of the optical properties of nitride materials on a sub nanometre scale. The properties of the measurement technique were introduced before practical examples of work carried out using this technique. This included a 62 period quantum well structure where luminescence from individual quantum wells was distinguishable showing increasing well width and red-shift with increasing well number.

Next conference and closing.

The venue for the next (11th) edition of ICNS was announced as Beijing, China, the first time the conference has visited China.

A short presentation was made by the organizers of the next International Workshop on Nitride semiconductors, introducing the arrangements for the seventh edition of IWN in Wroclaw, Poland 24th-29th of August.

Acknowledgments

I wish to thank the UK Nitrides Consortium for the financial support that helped allow me to travel to this edition of ICNS, present my work to the wider community and experience some of the interesting work being carried out by the international nitrides community.