IWN 2014: Conference Report

UKNC conference report

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Introduction

The 8th International Workshop on Nitride semiconductors (IWN 2014) was held in Wroclaw, Poland, in the Wroclaw centennial hall (Hala Stulecia) from the 24-29th of August 2014. IWN is run biennially with the previous edition of the conference held in Sapporo, Japan in October 2012. Over 700 contributions were made with participants from Japan, Germany, China, USA, South Korea, UK, France, and Poland to name several. There were 7 plenary speakers and 71 invited speakers.

Sessions were divided into 4 categories including Basic Physics and characterization, Optoelectronic devices, Growth, and Electronic devices. These were further split into technical sessions covering topics such as Ammonothermal growth, Quantum dots, LEDs, Power GaN HEMTs, to name a few.

Plenary Talks

The plenary talks were given by Shuji Nakamura from University of California Santa Barbara (UCSB), Armin Dadgar from the University of Magdeburg, Pallab Bhattacharya from the University of Michigan, Daisuke Ueda from Panasonic Corporation Kyotot institute of technology, Eva Monroy from CEA Grenoble, Claude Weisbusch from UCSB, and Akinori Koukitu from the Tokyo University of Agriculture and Technology.

The opening plenary talk was given by Shuji Nakamura titled “40 years of nitride optoelectronics”. This was very exciting as Prof Nakamura is one of the primary scientists responsible for the creation of GaN based blue LEDs and laser diodes. He started with the history of the creation of GaN based devices and described the japan society of applied Physics (JSAP) 1991 conference which had approx. 500 people studying ZnSe based blue lighting, contrasted with approx. 10 studying GaN as an alternative. The history of polar (c-plane) GaN, the creation of InGaN LEDs and their efficiency droop at high current densities, and the potential cause of droop being Auger recombination were also presented. The talk highlighted Prof Nakamura’s interest in growing GaN on different crystal planes due to the difference in the EQE against current density curves between polar and semipolar GaN, as well as his interest in GaN grown on a GaN substrate as opposed to the traditional sapphire substrate or alternatively a Si substrate. The talk closed with future applications and interesting directions which are being researched such as laser based lighting, bulk GaN crystal growth, and ammonothermal growth.

Armin Dadgar's presentation focussed on GaN grown on Si substrates. The potential advantages of this were highlighted such as cost reduction, larger wafer sizes, and the potential of GaN/Si devices to utilise high powers. Multiple challenges were shown, such as wafer cracking, and plastic deformation and how these can be overcome. For example to combat plastic deformation a scheme was presented for intentionally doping the substrates with oxygen. This stiffens the substrates and acts in opposition to the deformation.

One of the closing plenary talks was presented by Claude Weisbusch titled "Challenges of GaN LEDs". This primarily highlighted the current challenges of GaN based LEDs such as the gap in suitable materials for efficient green LEDs, efficiency droop at high current densities, and improving extraction efficiency. If LEDs can achieve a 5% increase in efficiency it was highlighted that the reduction in CO_2 emissions would be in the order of 150 million tonnes per year. And if 200lm/W LED light sources are created by 2025 (as predicted) LED energy savings would be largest when compared with the savings achieved using solar cells, wind energy etc. Other issues were considered such as the need for light sources which interact with our bodies natural 'circadian' rhythms to improve the quality of our light sources and not just their total efficiency. I felt this talk was useful for reminding me of the importance and magnitude of the applications of nitrides research, specifically with regards to lighting.

Contributed talks

As my work falls into the purview of material characterization I primarily went to talks in the basic physics and characterization and optical devices sessions. The wide array of talks allowed me to gain further insight into the work of others in the nitrides community.

One of the talks that I found interesting was given by Mohamed Ebaid from Chonnam National University, Korea, titled "GaN/InGaN multi-quantum well coaxial nanowires as efficient heterojunction photoanodes for the direct generation of Hydrogen via solar photoelectrochemical water splitting". This topic partially intersects with my own and so I found it rather motivating for my own work. The talk began by emphasising the need for sources of sustainable and clean fuels, a potential solution of which is given by the photoelectrochemical cell to generate Hydrogen. This then moved to the possible benefits of using GaN based alloys, specifically InGaN. His results showed a comparison between the current density against applied voltage for GaN nanowires and GaN/InGaN multi-quantum well coaxial nanowires (MWQ-CNWs), and showed higher current densities at an applied voltage for the latter samples. There was also an increase in the current density with increasing InN content in the QWs, therefore showing that to generate sufficient photo current for PEC applications the MQW-CNW samples were preferable to the GaN nanowires, and that the MQW-CNW samples should be grown with a high InN fraction. However there was a potential degradation of the crystal quality of the samples which contained the largest InN fractions, which is an open problem with this material system.

Along similar lines I enjoyed the talk by Jonas Lahneman from the Paul-Drude-Institut fur Festkorperelektronik in Berlin, titled “Discrepancy between composition and emission energy for (In,Ga)N nanowires”. This talk showed the characterization of self-induced InGaN nanowires which had been grown on Si substrates using molecular beam epitaxy (MBE). The main feature of the talk was the surprisingly low emission energy observed using CL and absorption measurements for the InN fraction determined by XRD. Although they perform EDX to confirm the XRD composition results, it’s noted that this will not be accurate given EDX assumes a bulk single layer approximation which the NW geometry doesn’t fulfil. There was also a degree of InN inhomogeneity determined using the XRD. Two sets of sample grown at different growth temperatures were presented, one at 640°C, the other at 590°C. The XRD showed that the samples had In compositions of 6 and 16% respectively, which was confirmed by EDX. The band edge peaks measured using CL showed that with increasing In fraction there is a red shift in the centre energy of the spectra (≈2eV and ≈2.4eV for 640°C and 590°C respectively), but to a greater degree than one would expect for the InN contents (≈2.8 and ≈3.2eV for 640°C and 590°C respectively). The measured spectra were broad with line widths of ≈400meV. The speaker related the broad line widths of the spectra to the InN inhomogeneity measured, however this is not enough to explain centre energy of the peaks for this given structure. A potential suggestion is given where differences in the InN content within the NWs leads to carrier confinement at different energy levels, which in turn leads to the radial stark effect, and could explain the difference in expected and observed emission energies, as well as the broad absorption spectra measured. The speaker noted that it is the broad absorption spectrum which gives these samples potential for use in PEC cells, as the samples could potentially absorb a greater range of the solar spectrum.

The invited presentation by Stefan Schulz titled “Impact of alloy fluctuations on the electronic and optical properties of InAlN and InGaN systems: Insights from atomistic calculations” described the modelling of InAlN and InGaN using density functional theory and the tight binding model in order to see the somewhat neglected effect of random alloy fluctuations on the electronic and optical properties of these systems. The talk first discussed the large range of bowing parameters used to describe the change in the band gap with composition for InAlN. Recent literature indicates that this material has a very strong compositionally dependent bowing parameter. Here they showed that this behaviour can be described by In-related localized states, at low values of In, which lead to a breakdown of the virtual crystal approximation. These form in the conduction band and the valence band, and interact with these band edges altering the band gap. The speaker described how similar behaviour has been observed in other systems, such as GaNAs, but that this is the first example of a cation related localized state rather than the anion related localized state described in those systems. The model set up large scale super cells, where one In atom exists in a large AlN super cell of 1600 atoms. This shows the localized state to be above the CBE, which then modifies the wave function and the band gap energy. Similarly at the VBE their model shows how a pair of In atoms can have a shared N atom, leading to localization effects with the VBE. The speaker then described how they employed a tight binding model which they combined with a local polarization theory to describe these local fluctuations' effects. As these systems have large ionic bonds they employed an atomistic valence force field approach. This allows them to achieve an atomistic description of the electronic properties of these alloys. The theoretical results are in good agreement with recent experimental and theoretical data on the energy gaps' composition dependence, and suggest these systems have a compositionally dependent band bowing parameter. For the InAlN alloys there is also described an optical polarization switching effect at expected compositions of In (approx. 15-18%) which is related to localization effects. This model was also applied to InGaN QW systems and showed random alloy fluctuations can have a very strong impact on the strain fields and fluctuations in the potential energy of the system. The localization effect was found to be stronger for the hole, than the electron wavefunctions. These theoretical predictions have been experimentally observed using low temperature PL, where broad PL linewidths were observed, and which the speaker related to variations in the energy of localized hole states.

Another interesting talk was presented by Aurelian David, in place of Rafael Aldaz, on "High efficiency GaN-on-GaN violet and white LED sources" from Soraa Inc. This began by demonstrating the advantages of growing GaN-on-GaN substrates to reduce dislocation densities and droop while increasing wall plug efficiency and internal quantum efficiency (IQE). This allowed a 'volumetric' chip design which increased electrical efficiency. There devices displayed very high peak IQEs of 89%. There commercially available white LEDs showed high luminous efficiency (>100lm/W), which I think is interesting as this falls in line with the efficiencies Claude Weisbusch would later state in one of the closing plenary talks. Their CRI values were 95 and so were very good as a value of 80 or higher is commonly accepted to be good quality. However the speaker emphasised the potential inadequacy of this measurement in determining colour rendering quality as perceived by people, as by modelling various random spectra it is possible to that one can achieve high CRI values but when tested these do not render well as perceived by people. So they concluded that a wide spectrum approach to white lighting is a necessity for high quality LED lighting. This conclusion was based on results achieved when LEDs were tested in conjunction with human tests of perceived colour rendering. In these tests peoples' perception of colours, when illuminated by LED sources with different CRIs, showed a preference for high CRI and warm colour temperature lighting.

I gave an oral presentation titled "Composition and Optical properties of $GaN_{1-x}Sb_x$ highly mismatched alloys grown by MBE". The talk was situated in the main auditorium during the basic physics and characterization session 'optical properties II' where a number of interesting talks were presented on a range of topics. As well as allowing me to present my work to the wider nitrides community, the conference allowed me to meet and discuss my research with collaborators from other institutions, in particular a co-author from Berkeley. This was very helpful as it allowed me to inform them of our most recent progress and gave me further insights into this work. It also acted as a source of continued motivation.

Poster session

The poster session provided a relaxed atmosphere to explore a wide array of work on nitrides and to speak with others on topics similar to my own. For example work was presented on the prospect and challenges of using a GaN based semiconductor for the electrode material in a photoelectrochemical (PEC) cell to use solar radiation to split water molecules and generate Hydrogen fuel. This poster titled "Photoelectrochemical water splitting on GaN and InGaN/GaN core/shell nanowires" illustrated many of the advantages of using a material system similar in many ways to the materials proposed in our work but with a more developed material. The NWs were grown on n-type Si substrates using plasma assisted molecular beam epitaxy (PA-MBE). The PEC cell properties were evaluated by using a 3 electrode configuration in 1mol/L HBr. For the GaN NW devices the current density against applied voltage was evaluated for samples which were undoped and samples which had been Si doped. The doping was found to affect the current density, with the Si doped samples exhibiting higher current densities at the same applied voltage. There were high conversion efficiencies observed for both the undoped and Si doped GaN NWs, of 15 and 18% respectively. They also observed H_2 generation. As well as the GaN NWs there were InGaN/GaN core/shell NWs grown. On these SEM images were taken which showed uniform sized nanowires, grown aligned with the growth direction. For these devices there was a reported behaviour of decreasing conversion efficiency with increasing excitation wavelength. However at the excitation wavelength mentioned above for the GaN NWs there was an increase in the InGaN/GaN NWs efficiency to 27.6%, suggesting this structure would be beneficial for the PEC cell application.

Work was presented by A. V. Luce from Lawrence Berkeley National Labs as part of the 'optical devices' section on the "Design of intermediate band solar cell using highly-mismatched dilute nitride GaAsPN". I have collaborated with this group on our own work and so it was interesting to see what other research they were tackling. The poster demonstrated the groups work on plans to build an intermediate band solar cell (IBSC) by exploiting a localized N induced level within the band gap that is separate from the conduction band to harvest solar photons of energies lower than the band gap of the host material. This scheme is similar to that used with a multi-junction photovoltaic cell where layers of semiconductors with different band gaps allow a greater proportion of the solar spectrum to be absorbed. The poster showed that by changing the ratio of As to P it was possible to tune the position of this intermediate band (localized level) and the conduction band position to anable a more efficient absorption of the solar spectrum. The work showed the fabrication of n and p-doped layers achieved using Si and Be respectively. Next full IBSC devices were grown using MBE on a GaP substrate, and with a GaAsP buffer layer. The devices had a multi-layered structure designed to optimise charge carrier extraction and demonstrate absorption from different energy band transitions (between the conduction band, the intermediate band level and valence band). Shown were the measured I-V characteristics of the device, and the EQE against energy plots.

Round table session

I went to the 'Optoelectronic devices' session and found this to be a stimulating discussion among some of the best and brightest in this field. The session had 7 speakers who spoke on a range of topics at the forefront of research. The session acted primarily as a summary of the advantages and challenges of working on a range of topics that had been presented during the week. Sir Colin Humphreys began by summarising some of the work at Cambridge and collaborating groups on growing and characterizing InGaN multiple quantum wells using different barrier growth temperatures. They have found that by growing there QW layers by increasing the temperature either directly after starting the InGaN growth, or by first having a lower temperature capping layer of InGaN, and then increasing the temperature, that they get increased IQE at low current densities. The samples that exhibit higher IQE show gaps in their QWs when imaged using TEM. It is thought that this increases the ease with which carriers can recombine. Despite these results the droop process appears to be unaffected with any of the growth modes mentioned. Other topics included the demonstration of the first GaN based terahertz quantum cascade laser, laser diodes, and UV laser diodes to name a few.

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