International Conference on Nitride Semiconductors 10 (2013) Report

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1. Introduction

The Gaylord National Resort and Convention Center in Washington DC, USA played host to the 10th International Conference on Nitride Semiconductors (ICNS 10) held between the 24th and the 30th of August 2013. The successful conference was attended by around 950 delegates from around the world. In addition there were exhibits from over 30 industrial organisations. The aim of the conference was to present advancements in research in the field of nitride semiconductors.

2. Plenary Speakers

The first plenary talk was given by Mike Krames of Soraa Inc. and was an overview of the development of solid state lighting moving towards GaN based LEDs on native substrates. The talk first outlined the development of conventional LED structures consisting of 2-3nm InGaN quantum wells with GaN barriers. White light is produced from such blue emitting structures through the use of phosphors.

The variation in brightness per area relative to the cost year on year was shown and this indicated that improvement is slowing. As the forward carrier density is increased, the quantum efficiency is reduced, an effect known as droop. The conventional LEDs make it difficult to achieve high light extraction efficiencies due to the high refractive index of nitrides. This makes it necessary for light to exit at a small angle to not be lost.

Native substrate based devices, where the GaN LED is grown on a GaN substrate, offer advantages over the old conventional structures. Lattice matching at the substrate interface leads to a reduction in dislocations and allows for simpler architecture and processing with no substrate removal. With only a single optical refractive index involved, high light extraction efficiency can be achieved. The LEDs are more reliable at higher current density with uniform power density and reduced droop. High quality commercial LEDs based on this concept were demonstrated.

The second talk by Miroslav Micovic from HRL Laboratories presented the development history of GaN transistors for sub-millimetre wave and high frequency applications. The T-gate GaN device developed had shown significant improvement in the highest frequencies at which electric current and RF power could be amplified. The GaN device also offered advantages over other materials.

Chris Van de Walle from the University of California discussed how loss mechanisms in nitride based LEDs can be identified and overcome. This talk described the origin of the droop process, a topic that had been widely debated throughout the conference. The internal quantum efficiency of an LED can be described by the following model:

$$\eta = \frac{Bn^2}{An + Bn^2 + Cn^3} \tag{1}$$

where, n – carrier density

A – parameter related to amount of non-radiative recombination at defects
B – parameter related to radiative recombination
C – parameter related to Auger recombination.

In the Auger recombination, the energy emitted as a photon in a radiative process is instead transferred to an electron that is excited to a high energy level and then losses energy through the emission of phonons. Energy can be conserved through an indirect Auger process that allows more energy levels to be accessed via phonons.

This process was identified as the primary cause of droop by referencing work presented by James Speck earlier in the conference. In this work, Auger excited hot electrons had been observed directly at the surface and a linear correlation was found between the Auger peak intensity and the degree of droop in an LED device.

Caution is required when considering the ABC model. The parameters A, B, and C are not necessarily constant but are proportional to the square of the electron and hole wavefunction overlap. A low quality device with many defects will have a large A and hence may appear ‘droopless’ despite poor performance elsewhere.

When it comes to reducing the Auger effect and its related losses, changing the temperature and strain engineering have little effect. It can be seen that Auger processes are related to the third power of carrier density. Reduction in carrier density is hence an important way of achieving better efficiency. This can be achieved by using wider quantum wells or more numerous quantum wells in the LED heterostructures.

The fourth plenary talk was delivered by Hiroshi Amano of Nagoya University who talked about the development of a new growth technique for high indium content InGaN multiple quantum well structures intended for full colour LED display applications. The alternative gas source supply method (ALE) minimises parasitic reaction between ammonia and the metalorganics and allows quantum wells with uniform thickness and high quality interfaces to be grown. All layers of blue LEDs were grown at the same temperature, simplifying the growth process.

The final plenary talk concerned an advanced luminescence nano-characterisation technique and was given by Jurgen Christen from Mageburg, Germany. The technique involves the simultaneous collection of a scanning transmission electron microscopy (STEM) signal and the cathodluminescence (CL) intensity or spectrum on a pixel by pixel basis (STEM-CL). This allows the optical properties to be imposed on to real structure images with direct nanometre scale correlation.

Examples of the technique in use included the imaging of MQW structures where individual wells were identifiable with information about their widths. With an InGaN/GaN nanorod, the indium content of different facets could be shown on the structural image. The technique is useful for the characterisation of many other nanoscale structures.

3. Parallel Sessions

3.1 Overview

The parallel sessions were divided in to four main topics, each subdivided into specific areas of interest. The bulk and film growth topic included studies of the growth and characterisation of bulk material and nanostructures, studies of doping, defects, strain and structure as well as polar and semi-polar materials.

In the visible optical devices category, much attention was given to the fabrication, physics and characterisation of visible LEDs as well as lasers and solar cells. The optical properties of nanostructures, quantum wells and quantum dots were also presented. For the topic of UV optical devices, mid UV LEDs, lasers and photodetectors were featured along with the properties of UV related defects and nanostructures.

The sessions on electrical devices included numerous works on nitride HEMTs plus growth considerations and characterisation of electronic devices, GaN on silicon and novel concepts.

Due to the large number of parallel talks, I focussed on talks that were of personal interest or that were relevant to my own work on the characterisation of cubic nitrides. Highlights of these are presented below.

3.2 Nanocolumn Structure and Devices

There was much interest shown in growing nitrides in the nanocolumn structure. An example of this was Ishizawa and Kishino’s talk on GaN nanocolumn arrays grown on a Si (111) substrate. The growth of high quality GaN layers on Si is difficult due to lattice mismatch, the presence of dislocations and thermal expansion coefficients. High quality GaN can be achieved in nanocolumns.

A selective area growth (SAG) method was used, where a Ti nanohole mask led to the formation of nanocolumns during deposition by rf-plasma assisted molecular beam epitaxy (rf-MBE). The smaller diameter (125nm) columns were found to have much higher PL intensity compared to filling factor than the larger columns (430nm). They were also free of threading dislocations.

Shao et al. demonstrated double barrier resonant tunnelling (RT) Schottky diodes based on nanocolumns. By making using of tunnelling current, the RT diodes display negative differential resistance (NDR), where current peaks and falls briefly as the voltage is increased. They offer potential application in high resolution radar, THz devices and multiple valued logic circuits.

NDR is difficult to reproduce in film structures, so nanocolumns are used due to their reduced dislocations. Their structure consisted of a 2.5nm GaN well with 1.5/2.5nm AlN barriers. A Ni/Au Schottky contact was used to improve the peak to valley current ratio of the NDR. The contact reduces thermionic emission current before NDR and allows the effect of tunnelling to be seen. A peak to valley ratio of 41 was reported. Other groups such as Gardner et al. presented LEDs on nanocolumns, whilst nanocolumn lasers were discussed by Xu et al.

3.3 Solar Cells

In the session dedicated to solar cells, Iwaya et al. gave an overview of how nitrides are being used to achieve high conversion efficiency cells. The wide bandgap range of the InGaN system allows it to cover the majority of the solar spectrum. Nitrides with wide bandgaps are highly suitable for use as the top layer of a four junction cell and such set ups have led to maximum conversion efficiencies of 44% so far.

The top layer requires an InN molar fraction of greater than 25%, but increasing the fraction leads to indium segregation, which lowers open circuit voltage (OCV). This voltage is also reduced by the presence of growth pits. These factors are dependent on the growth conditions and the number of periods in the superlattice. Hironori et al. were able to improve OCV by using thick barrier layers to decrease pit density and a higher growth temperature to suppress indium segregation.

Fabien et al. discussed developments in growth technology for solar cells. They did not believe that further improvement of the InGaN/GaN heterojunction with 11% conversion efficiency was possible. Instead, an InGaN homojunction was used, which offers efficiencies of up to 17% but is more difficult to fabricate. Along with its tuneable bandgap, InGaN offers the advantages of a high absorption coefficient and radiation resistance. The potential problems included phase separation, difficult p-doping and current leakage.

The metal-modulated epitaxy (MME) method was used for junction growth, where alternating shutters are used switch Ga and In flux on and switch between nitrogen and metal rich regimes. The conversion efficiency was found to be optimal for 55% indium content.

3.4 Photoluminescence

Reschikov et al. presented a talk on tuneable thermal quenching of PL in GaN. They had previously observed the effect in Zn and Mg-doped GaN, where the intensity of blue and ultraviolet PL bands rapidly decreased over the range of a few Kelvin. By adjusting the excitation intensity, the characteristic temperature of this rapid quench could be tuned over the range 130-230K.

The effect was also seen in the ultraviolet PL emission band of undoped, high resistivity GaN. The phenomenon was explained using a phenomenological model of a pool with drains, where the flow into the pool represented laser excitation and the drains represented radiative and non-radiative recombination channels. One can adjust the temperature or excitation power to close off the radiative drain, leading to the quench in PL emission. Thermal emission of holes from acceptor sites could be causing the switch off of the radiative channel.

3.5 Cubic Nitrides

Landmann et al. presented a theoretical study of the crossing point between direct and indirect bandgaps in cubic $Al_xGa_{1-x}N$ alloys. A hybrid density functional theory (DFT) approach was used to find the cross over point at which the energies of the direct ($\Gamma_v \rightarrow \Gamma_{c1}$) and indirect ($\Gamma_v \rightarrow X_{c1}$) transitons matched. The predicted bandgap crossing was at $x = 0.64$.

Buerger et al. demonstrated a novel use for cubic nitrides with their talk on non-polar GaN quantum dots integrated into cubic AlN microdisks. Microdisks offer strong confinement due to total internal reflection off their rounded walls. This leads to applications in photonics and quantum technology such as single photon sources. Hexagonal GaN QW dots are affected by reduced recombination probability due to the Quantum Confined Stark Effect brought about by spontaneous polarization and piezoelectric fields. The cubic phase has the advantage of lacking these fields.

The c-GaN quantum dots were grown between 30nm layers of cubic AlN using plasma assisted MBE on a 3C-SiC substrate. A chemical undercut and photoresist etch was used to create disks of ~2µm standing on a narrow post.

Micro-PL measurements carried out on the disks revealed narrow peaks on the spectrum's main feature. At high excitation power, laser emission from the quantum dots was seen, with whispering gallery modes (WGM) observed. WGMs are resonances of electromagnetic waves that constructively interfere with each other due to being internally reflected into themselves.

My own talk concerned the characterisation of cubic GaN layers doped with either magnesium (Mg) or silicon (Si). The photoluminescence (PL) spectra of the Mg doped material featured a dominant blue emission band whose origin is not well established. Transport measurements performed on the samples indicated reasonable conductivity for the Si doped cubic GaN but strong self-compensation in the Mg doped layers leading to very low conductivity.

Our time resolved PL results suggested that the origin of the cubic GaN:Mg blue band emission was a transition between shallow Mg acceptors and a deep donor believed to be the compensating complex. The talk was complemented by several attendees whilst the questions raised important considerations that were useful to consider in future work.

4. Rump Session

The session that I attended was focussed on methods of reducing LED costs. Although changes such as larger growth substrates offer cost reductions, the session was dominated by the much debated issue of the origin of droop. This is relevant to the issue of cost as reduced droop allows smaller devices to produce the same amount of light, and smaller devices which are cheaper to produce. The role of the Auger process in causing droop was presented, whilst the alternative view of high onset injection causing a voltage drop over the p-doped layer was also discussed.

5. Conclusion

Attending ICNS 10 was extremely valuable to me as it provided useful feedback about my research and possible avenues for progression. In addition I was able to gain an overview of research in the wider field and learn about the main areas of interest for other groups. The presentations by industry experts underlined the commercial importance of nitride research. The conference also gave me the opportunity to have useful discussions with other people who were involved in my area of research. I would recommend attending the conference to other PhD students working on nitride semiconductors.

6. Acknowledgement

The author would like to thank the UK Nitrides Consortium for financial assistance in attendance of the conference.