Report from ICNS-07

Carol Johnston, University of Cambridge, Pembroke Street, Cambridge, CB2 3QZ. cfj21@cam.ac.uk

Introduction

International Conference of Nitride Semiconductors (ICNS)-07 was held in Las Vegas, USA from the 16-21st September 2007. It was the largest ICNS since it began in 1995, with just under 900 delegates. There were 27 invited speakers, 220 oral presentations and 471 posters. Talks were held in three parallel sessions and divided into categories, including Nonpolar and Semipolar Materials and Devices, LEDs for Lighting, and Nanostructures. These are the themes that will be discussed in this report.

Nonpolar and Semipolar Materials and Devices

There were four sessions devoted to non- and semipolar material and several other sessions included work done on these materials.

When m-plane, a-plane or semi-polar GaN is grown heteroepitaxially, the resulting thin film is typically rough with a "slate-like" morphology and contains a high density of defects. One method to try to reduce the high defect density in these materials is epitaxial lateral overgrowth (ELO). Vennéguès and co-workers [2] used ELO on semipolar (11-22) material. When the mask stripes were oriented along <10-10>, TEM studies showed that the partial dislocation density in the wing regions was drastically reduced. Basal plane stacking faults were still present throughout, which implies that the BSFs in this region are much longer than those in the as-grown material and ELO window regions.

Hirai and co-workers[12] performed ELO on nonpolar, m-plane material and found that step flow growth occurred in the wing regions, whereas the rough surface was present in the window regions. The +c wing regions were found to be stacking fault free. From this, they conclude that the slate-like morphology was caused by the stacking faults. They also tested the effect of miscutting substrates and found that the LED structures with the smoothest surface could be grown when the substrate was miscut by 9.7° towards the c-axis.

For nonpolar, a-plane material, Lida and co-workers[3] used sidewall epitaxial lateral overgrowth (SELO). In this case, the lateral overgrowth is initiated at inclined facets. By using a very low V-III ratio (of 13) growth of the +c wing was favoured during coalescence and this lead to films in which the stacking fault emission in the CL spectrum was reduced (implying a reduced stacking fault density) compared to SELO material grown at less extreme V-III ratios.

A very different approach was used by many of the groups growing nonpolar material: the use of homoepitaxial m-plane GaN substrates. These were slices of HVPE-grown, low dislocation density c-plane GaN and most groups were supplied by the Mitsubishi chemical company. This method avoids the stacking faults associated with heteroepitaxially-grown non-polar material. In particular, Chichibu and co-workers[4] grew m-plane GaN in this way and achieved nonpolar LEDs with monolayer steps on the surface. There was no CL emission associated with stacking faults and no V-pits in the InGaN layers. The nonpolar films were grown at a very high V-III ratio (i.e. 3000-10000 for GaN and $4x10^4$ – $1x10^6$ for InGaN). This was found to increase the PL lifetime in the devices due to a decrease in the concentration of Ga vacancies. The films were coalesced at a low V-III ratio but this was problematic since it lead to oxygen incorporation and therefore an increased number of donor states.
Hence, although the problem of defects has been circumvented in this type of material and nonpolar LEDs with good external efficiencies (eg. 38.9% at 400 nm[5]) have been achieved, there is still work to be done to fully understand and perfect these structures.

Another interesting aspect of the non- and semipolar material that was highlighted was their anisotropy, both in terms of their optical and electrical properties. McLaurin[6] pointed out that since the a- and m-planes have only 2-fold symmetry, the effective hole mass and therefore the hole mobility, μ, in these structures, is expected to be anisotropic. They found this to be the case in nonpolar films with a high density of stacking faults. μ was larger along [11-20] than [0001] in m-plane films. However, m-plane films with a low stacking fault density demonstrated no difference in μ in these two directions and the μ was found to be the same as that in c-plane material. The difference in the faulted films was therefore attributed to the presence of stacking faults, which can be thought of as strips of Zinc Blende material running parallel to [11-20] within the Wurtzite matrix. Associated with the heterointerfaces are potential steps in the band structure, so in the direction perpendicular to the faults, i.e. along [0001], these steps act as scattering centres. This can explain the reduced μ in this direction.

Stacking faults are also responsible for broadening reciprocal lattice points due to the reduction in lateral coherence length perpendicular to the faults. McLaurin[7] used Williamson Hall analysis[8] to separate the broadening due to stacking faults from that due to other sources (eg. mosaicity in the films) of X-ray rocking curves. Since the broadening due to stacking faults is the same for all reciprocal lattice points, it is a measure of the stacking fault density in the film. They performed this analysis on several m-plane films and the stacking fault densities obtained were in good agreement with those found from TEM analysis of the same films.

LEDs for Lighting

This was addressed in the special session entitled “High efficiency solid state lighting: Solutions for global warming”. All the talks in this session were from industry and most focussed on high power LEDs. The industry aim is to produce white LEDs that emit 150 lm/W at 2 A. There are obviously many issues to overcome in order to achieve this, which were outlined in Narendran’s talk[9]. He stressed that as well as concentrating on increasing the IQE of LED chips, industry must concentrate on the other aspects that strongly reduce the efficiency of the ready-to-use LED bulbs. These include secondary optics, thermal management, light absorption by phosphors and losses in the DC/AC conversion circuits.

Part of the problem with phosphor coatings is their non-uniformity. This can lead to differences in the “tone” of the white light produced. Phillips have addressed this part of the phosphor problem by using solid ceramic phosphor coatings, whose thickness can be tailored to compliment specific LED chips. This means that the tone of white light produced by different LED chips is indistinguishable to the human eye.

One of the barriers to wide-scale adoption of LEDs for lighting is their high cost. Cree[10] are addressing this problem by growing on 4” and 6” wafers to get the benefit of economy of scale. They also use large chips rather than several small ones and in this way have achieved an output of 1000 lm from a single chip.

Seoul semiconductor[11] claim to have circumvented the DC/AC issue by manufacturing an LED which runs directly from AC, but the details were not fully explained.

Nanostructures

Several groups are working on nanostructures. Han[12] described growth of <10-10> axis nanowires. Using selected area growth (i.e. the initial stages of ELO to form an uncoalesced film) they were able to control where the nanowires grew. Triangular stripes of material along <11-20> could be joined together with arrays of <10-10> nanowires. They also grew a hexagonal array of pyramids and joined them together with nanowires in this way. Han also described how altering the growth conditions changed the surface energy of the wires and therefore changed the crystallographic orientation that the wires grew in, resulting in bending of the nanowires.

Growth of quantum dots was addressed in several of the sessions. For example, Daudin and co-workers[13] gave a comparison between nonpolar and c-plane dots. In c-plane material, N-rich conditions are required to form GaN quantum dots on AlN buffer layers. In contrast, in the a-plane case, Ga rich conditions are required. The asymmetric strain leads to alignment of dots along

[1-100] and the dots have a truncated triangular-pyramidal shape. For the case of m-plane dots, both Ga and N rich conditions favour dot formation and in this case they align along [11-20]. The quantum confined stark effect (QCSE) present in c-plane material increases the emission wavelength of large dots, while the emission wavelength of sufficiently small dots depends on its size (and therefore the carrier confinement). In the nonpolar cases, the light emitted is anisotropically polarised and the absence of the QCSE means that the wavelength does not vary with increasing drive current, which is common to other types of nonpolar material. Interestingly, the PL decay time was found to be invariant to quantum dot size in nonpolar dots. This is not yet understood but Daudin suggests that there may be a common localisation mechanism in nonpolar dots on a nm length scale.

The poster sessions provided a useful networking opportunity. My poster (entitled “Morphological study of (11-20) a-plane GaN grown on (1-102) r-plane sapphire”) was very well received. After discussions with Ben Haskell and Philippe Vennégùes on the origin of stacking faults, I plan to do TEM studies of the first few monolayers of a-plane growth in order to try to determine where the stacking faults in these materials originate.

Overall, I’m glad I was able to attend ICNS-07. It was a very interesting and well organised conference. I have benefited from having the opportunity to present my work and talk to leading researchers in the field.

Thank you for awarding the travel grant to me.

---

[1]TEM study of semipolar GaN templates and ELO films deposited on m-plane sapphire by MOVPE. P. Vennéguès, CNRS-CRHEA, ICNS-07.
[2] Defect mediated surface morphology of nonpolar m-plane GaN. A. Hirai, UCSB, ICNS-07.
[3] Sidewall ELO in nonpolar a-plane GaN by MOVPE. D. Lida, Meijo University, ICNS-07.
[4] Homoepitaxial growth of nearly stacking fault free m-plane (In, Ga)N films by MOVPE using low defect density free standing substrates. S. Chichibu, Tohoku University, ICNS-07.
[5] Non-polar m-plane GaN LEDs: Growth and characterization. J. Zhongyuan, UCSB, ICNS-07.
[6] Isotropic p-type conduction in stacking fault free m-plane GaN. M. Mclaurin, UCSB, ICNS-07.
[7] Basal plane stacking fault contributions to x-ray rocking curve widths in m-plane GaN. M. McLaurin, UCSB, ICNS-07.
[8] Williamson and Hall, Acta metallurgica **1** (1953) p22.
[9] Crucial issues for LED lighting. N. Narendran, Rensselaer Polytechnic Institute Lighting Research Center, ICNS-07.
[10] High efficiency blue and white LEDs for illumination. J. Edmond, Cree, ICNS-07.
[11] Acriche: Innovation in solid state lighting. C. Lee, Seoul Semiconductor Company, ICNS-07
[12] Nitride nanowires and networks: Growth, heterostructures, epitaxial alignment and applications. J. Han, Yale University, ICNS-07.
[13] [0001] [11-20] and [1-100] GaN quantum dots: Growth and optical properties. B. Daudin, CEA/Grenoble, ICNS-07.