

Conference Report: IWN 2008

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This year's International Workshop on Nitride Semiconductors was held in Montreux, Switzerland from the 6th-10th October 2008. The format of the meeting was quite different to that of other conferences; the first two days were made up of plenary lectures while the next two days saw nine parallel sessions of contributed talks. In the final day more plenary talks were followed by a wrap-up session, summarising the highlights of the meeting.

Overall, 653 people attended the workshop, 194 of which were students. Of the 498 abstracts accepted, 14 were plenary speakers, 21 were invited talks in the workshops and 5 were contributed talks in the plenary sessions. The rest were either oral contributions in the parallel sessions or posters presented in one of the three poster sessions.

The themes of the nine parallel sessions were:

- Substrates for nitride epitaxy
- Challenging materials issues: InN and high In content alloys
- Challenging materials issues: AlN and high Al content alloys
- Challenging materials issues: Non-polar epitaxy
- Nanostructures
- Novel physical concepts and devices
- Optoelectronics: Materials and physics
- Optoelectronics: Technology and devices
- Electronic devices

The themes of most interest to me were non-polar epitaxy, substrates for nitride epitaxy and optoelectronics: Materials and physics, and after some highlights from the plenary talks, some highlights from these sessions will be given.

Plenary sessions

The first talk was from the Mitsubishi Chemical company¹; the main supplier of "bulk" GaN substrates for homoepitaxial growth of non-polar and semi-polar GaN. Currently, the 52 mm diameter substrates are grown by HVPE with typical growth rates of 105 $\mu\text{m}/\text{hour}$. Using this method, m-plane substrates measuring 4 mm x 20 mm can be routinely produced as slices from these c-plane "boules". The c-plane substrates have a high crystalline quality i.e. they are crack-free, $\omega(0001)$ FWHM as low as 35 arcsecs, dislocation density as low as $1 \times 10^6 \text{ cm}^{-2}$ and a low impurity concentration. The data presented did however show that the defect density was not constant through the film thickness (it was a factor of 5 higher near the MOVPE GaN template). In addition, wafer curvature was quite high. The main drawback of producing substrates in this way is that non- or semi-polar substrate size is limited by the thickness of the c-plane film (which in turn is limited by the amount of space in the HVPE reactor). On top of this, the substrates are very expensive. To address these problems, they are developing two new approaches for bulk substrate growth. The first is an ammonothermal method; growth on wafers of 3" or larger diameter is possible, but at present the films have a high oxygen and iron impurity content and are expensive to produce. The second method is growth by a "solvo-thermal" chemical reaction (they didn't give any further details). They have so far grown a 100 μm thick film on a seed crystal with good crystal quality ($\omega(0001)$ FWHM = 106 arcsecs). The main benefit of the solvo-

thermal method is that, once the growth parameters have been optimised, it should be a cheap way of producing bulk crystals.

Alternative substrates were also addressed by Alois Krost who described growth of crack free GaN on Si(111), Si(100) and Si(110)². In the past, large stresses in the films that have caused cracking, were reduced by including an AlN layer. They found that they needed to use a 4° substrate miscut to grow on Si(100) to avoid producing GaN grains with different orientations. Using this miscut, (0001)GaN and (10-12)GaN films were reported.

A novel way around the quantum confined Stark effect was presented by Akihiko Yoshikawa³, who reported single monolayer InN quantum wells in a GaN matrix. LEDs fabricated from such quantum wells showed only a small blue shift with increasing drive current, indicating that there is minimal internal electric field across the QWs.

Steve DenBaars⁴ described the recent achievements made at UCSB on non- and semi-polar devices achieved by growing on bulk GaN substrates from the Mitsubishi Chemical Company. They found that due to the lack of an internal electric field, non-polar wells could still function efficiently when they were much wider than c-plane ones; the most efficient m-plane wells were 15 nm thick. (11-22) semi-polar planes were reported to have a higher In incorporation rate than the c-plane, and this was attributed to a higher step density and therefore a higher density of dangling bonds on these planes. This higher In content makes semi-polar GaN useful for green emission and a green semi-polar LED with 19% EQE was reported. DenBaars also noted that the output power of the semi-polar LEDs decreased as the current increased, in the same way as for c-plane controls, indicating that the cause of this “efficiency droop” is not plane-specific. UCSB have also fabricated a number of m-plane lasers emitting at violet, blue, green and yellow wavelengths.

An interesting perspective on bulk substrates was given by Chichibu⁵. He pointed out that the high degree of bow in the thick c-plane films grown by HVPE manifested as tilt in the m-plane substrates sliced from them. This tilt was also found to be present in the m-plane films grown on these substrates by MOVPE, which resulted in different values of the $\omega(1-100)$ FWHM along [0001] and [11-20]. He reported that m-plane InGaN grown on of GaN on these m-plane substrates (in contrast to the semi-polar films reported by DenBaars) had a lower In content than the c-plane equivalent. In the workshop sessions, In incorporation in m-plane films was addressed in theoretical work presented by J. Northrup⁶, who calculated that there would only be efficient In incorporation in m-plane films at low hydrogen concentration and high In concentration, which may explain Chichibu’s result.

P. King gave an interesting theoretical talk explaining the so-called “anomalous” properties of InN⁷. He explained how a multitude of observations (such as the inversion to n-type at the surface of p-type material) occurred because the conduction band extends to very low energies at the Γ point in InN. This means that the charge neutrality level in this material lies well within the conduction band. The consequences for band pinning and electron accumulation at surfaces were explained for various situations. The conclusion of the talk was that InN is not unusual, but is just an extreme case of the other III-nitrides.

Another noteworthy talk was given by Susumo Noda who addressed the theory behind photonic crystals⁸. He explained how the photonic band gap could be varied by changing the periodicity of the photonic crystal and how very small disruptions in this periodicity could increase light extraction efficiency significantly. Most of the reported results were for the arsenides but he did

show that it was possible to produce cavities in GaN, via a technique similar to pendeo-epitaxy, which could be used as a method of producing photonic crystals in the nitrides.

There were relatively few talks from industry at the workshop. One of the few was given by Cree who described their current bests in terms of their phosphor-coated LEDs⁹ including a cool-white LED which emits 105 lm/W at 350 mA and a warm-white LED with an output power, of 67 lm.

To end the first set of plenary lectures, an informative demonstration about stage lighting was given by the stage manager of the conference centre: Conventional stage lighting utilises white halogen lights (or “projectors”). Different colours are obtained by covering these projectors with transparent, coloured “gels”. Since the gels filter the light in order to produce the correct colour, the method is inefficient. He described the evolution of commercial LED projectors and how the first LED projectors had excellent energy efficiency compared to conventional ones (operating at only 20 W) but brightness was poor and since it used separate red, green and blue LEDs to produce white light, shadows were tri-chromic. The current generation of LED projectors is much improved as each bulb comprises a red, green and blue LED chip. This has eliminated the tri-chromic shadow, and due to improvements in LED performance, the brightness is now comparable to conventional projectors. The principle benefit of LED projectors is that obtaining a bright, white light requires only 58 W compared to 575 W for the equivalent beam from a conventional projector. LED projectors have the potential to greatly reduce the energy demands of stage lighting.

Workshops: Non-polar epitaxy

Many topics were addressed in this session so only a few will be mentioned. Most of the non-polar and semi-polar devices reported were grown on bulk substrates, since this produces stacking fault free devices.

Since light emitted from non-polar devices is polarized, due to the valence band splitting present in this material, several of the talks focused on ways of controlling this polarization direction by controlling the strain of the template onto which the quantum wells are grown by varying the composition of the alloy substrates^{10,11,12}. The talks were a mixture of experimental¹⁰ and theoretical^{11,12}.

Asakai Hirai from UCSB combined a theoretical approach (using Wulff's theorem) with experiment to predict and confirm the equilibrium shape of GaN crystals grown in different orientations¹³. Using selective area growth on bulk, m-plane GaN substrates, she showed experimentally that the resulting crystals were bound by (10-10), {10-11}, {11-20} and (000-1) facets, and this corresponded to those predicted by the theory.

Workshops: Substrates for nitride epitaxy

Novel methods of bulk growth were discussed in this session. Derrick Kamber addressed the ammonothermal method¹⁴. The seed crystals used had different orientations and he found that the growth rate depended on orientation (between 11 and 90 $\mu\text{m}/\text{day}$). The slowest growing and therefore most stable facet was found to be the m-plane. m-plane and semi-polar (11-22) crystals had similar values of FWHM of the symmetric reflection to HVPE grown crystals so had good crystal quality.

Liquid phase epitaxy was addressed in a number of talks eg. ^{15,16}. The LPE grown crystals had a low dislocation density ($\sim 10^4 - 10^7 \text{ cm}^{-2}$) due to a 3D islanding step resulting in much dislocation bending at the early stages of LPE growth.

Workshops: Optoelectronics: Materials and physics

This session focussed on fundamental understanding of the nitrides. Shelly Moram gave an interesting talk on the distribution of threading dislocations in GaN films grown by a number of methods¹⁷. Her results disagree with the commonly used “mosaic tilt and twist” model and instead suggest that instead of forming low angle grain boundaries, TD distribution is actually random.

M. Albrecht addressed the issue of which types of dislocations are non-radiative¹⁸. His results suggest that **a** and **a+c**-type act as non-radiative recombination centres and he suggested that the $\sim 3.3 \text{ eV}$ emission widely reported in the literature (and particularly in non- and semi-polar CL and PL studies) is due to excitons bound to dislocations.

Philomela Komninou discussed partial dislocations¹⁹. From analysis of high resolution TEM images of non-polar material, three types of PD core structure were distinguished: 5/7, 8 and 12 atom rings. The configuration present in a particular film depends on the specific thermodynamics of the growth conditions. All of these configurations introduce states in the band gap (due to the presence of dangling or “wrong” bonds) and many of these states would produce an emission at $\sim 3.3 \text{ eV}$ so she attributes this 3.3 eV emission to partial dislocations.

This emission wavelength was mentioned again in the contribution by J. Christen²⁰. His PL studies of heteroepitaxially grown m-plane films contained a peak at $\sim 3.3 \text{ eV}$ which decreased in intensity as the thickness of the SiN_x mask layer used in the films increased. He assigned this peak to PSFs but no TEM was done on the material. In light of other talks, the result suggests that this peak is due partial dislocations, which decrease in density as SiN_x interlayer thickness increases.

In addition to the workshop sessions discusses, there were many other interesting contributions covering HEMTs, nanowires and quantum dots for example.

Thank you for awarding me the travel grant and enabling me to attend and present at such an interesting workshop.

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- ¹ T. Fujimori, Invited talk "HVPE and ammonothermal GaN substrates for high performance devices" IWN 2008
 - ² A. Krost, invited talk "Silicon as a substrate for III-nitride technology" IWN 2008
 - ³ A. Yoshikawa, invited talk "InN: State of the art- advances in epitaxy control, p-type doping and novel nanostructures" IWN 2008
 - ⁴ S. DenBaars, invited talk "Recent breakthroughs in nonpolar and semipolar GaN LEDs and laser diodes" IWN 2008
 - ⁵ S. Chichibu, plenary talk "Optical properties of nearly stacking-fault-free m-plane GaN and InGaN films grown by MOVPE on low defect density free-standing substrates" IWN 2008
 - ⁶ J. Northrup, Workshop talk "In incorporation on nonpolar facets" IWN 2008
 - ⁷ P. King, plenary talk "Understanding the extreme electronic properties of InN: Chemical trends and the charge neutrality level" IWN 2008
 - ⁸ S. Noda, invited talk "GaN photonic crystal surface emitting laser" IWN 2008
 - ⁹ J. Ibbetson, invited talk "Status of high power white LEDs: Beyond 100 LPW in volume production" IWN 2008
 - ¹⁰ K. Hazu, Workshop talk "Polarized and spatially resolved cathodoluminescence studies of nonpolar AlGaIn" IWN 2008
 - ¹¹ A. Yamaguchi, workshop talk "Polarization control of nonpolar InGaIn quantum well emission by using AlInGaIn alloy substrates" IWN 2008
 - ¹² K. Kojima, workshop talk "Control of optical anisotropy of semipolar and nonpolar quantum wells" IWN 2008
 - ¹³ A. Hirai, workshop talk "Quasi equilibrium crystal shapes of GaN under the VPE environment" IWN 2008
 - ¹⁴ D. Kamber, workshop talk "Plane dependant growth of GaN by the ammonothermal method" IWN 2008
 - ¹⁵ S. Katsuike, workshop talk "Growth of 2" GaN single crystals with the thickness of several mm using Na flux method" IWN 2008
 - ¹⁶ E. Meissner, workshop talk "Demonstration of ipscaling LPE at room temperature and pressure towards 3" diameter and multiwafer processing" IWN 2008
 - ¹⁷ M. Moram, workshop talk "Spatial analysis of threading dislocations in GaN" IWN 2008
 - ¹⁸ M. Albrect, workshop talk "Radiative and non-radiative recombination at threading dislocations in n-type and p-type GaN studied by CL and defect selective etching" IWN 2008
 - ¹⁹ P. Komninou, workshop talk "Electronic structure of 1/6[20-23] partial dislocations in Wurtzite GaN" IWN 2008
 - ²⁰ J. Christen, workshop talk "Micro-PL of defect reduced a-plane GaN grown by MOVPE using in situ SiN_x masks" IWN 2008