IWN 2018 International Workshop on Nitride Semiconductors: Conference Report

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The International Workshop on Nitride Semiconductors 2018 (IWN 2018) was held in Kanazawa, ANA Crowne Plaza Kanazawa Hotel in Japan, from November 11 to 17, 2018. The conference consisted of two short courses, five plenary talks and lectures that were categorised in four different sections: Growth, Characterization, Optical Devices, Electronic Devices featuring both invited and contributed talks. The conference featured poster sessions divided in the same categories as for the talks, where we had a chance to talk with different researchers and discuss their findings. I was given the opportunity to present my research in the oral session AlGaN-based Materials on 15th of November, in the form of a contributed talk titled "*Correlation of composition and luminescence in AlGaN epilayers*". I mainly attended the sessions on AlGaN and/or characterisation (more specifically doping and point defects, optical and electrical properties, structural analysis; defect characterisation, UV LEDs).

I will summarize five of the talks I found particularly interesting, including two of the plenary talks. I also attended one of the short courses, which I will describe first:

Short course- Prof. Debdeep Jena *"Nitride Electron Devices".*

In this course Debdeep Jena explained the main working principles for the Nitride Schottky and p-n diodes, Nitride High Electron Mobility Transistors, Nitride Vertical Transistors. In the end, he introduced the future generation of Nitride Electronic Devices and some surprises, challenges and future directions. He described that GaN is already the preferred platform for the microwave electronics today and in the future can go on to enable a new platform for integrated quantum communications and quantum computation. Some of the challenges regarding contacts and carrier injection in ultra wide band gap nitrides were explained, e.g. the problem in finding metals that can efficiently connect to CB (conduction band) or VB (valence band) for some UWBGs, difficulties in doping of Schottky-tunnel contacts etc. He explained the behaviour of the field effect transistor, properties of III-V semiconductors, origin of polarization in the nitrides and the consequences of the polarization. The polarization engineering in III-Nitride heterostructures was also one of the topics. He explained the difference between vertical and lateral power devices and what the challenges associated with high performance HEMTs are. He pointed out the basic material requirements for the transistor, GaN electronics, RF electronics and semiconductors for photonics. I have enjoyed his lecture because he gave us a good overview of the devices and at the same time we could revise our general knowledge.

AlGaN session - Matthias Bickermann "On the preparation of AlN single crystals and substrates for AlGaN devices"

Dr. Bickerman spoke about the usage of AlN single crystal substrates, their growth and dislocation effects. AlN substrates are employed in the deep-UV devices to provide pseudomorphically strained AlGaN layers with low defect density. We learned that bulk AlN grown by physical vapor transport

(PVT) has a threading dislocation density (TDD) well below 10^5 cm^{-2} when grown in N-polar (000-1) direction on AlN seed wafers. He wanted to point out that the distribution of dislocations will have a large impact on macroscopic defect formation when seeds including such areas are used for subsequent growth runs. Dislocation distribution and evolution are particularly influenced by growth on prismatic facets during the diameter increase. If the growth process is not optimized prismatic facets may contribute to lattice plane bending in subsequently grown crystals. In polished substrates, such curvature leads to a varying off-orientation on the substrate surface that may hamper homogeneous step flow in subsequent epitaxy. Concentration of the impurities in AlN should satisfy the following term $3[C] < ([O] + [Si])$ and $([O] + [Si] + [C]) < 10^{19}$ cm^{-3} to get the optimum values for the of α(265nm). Desirable characteristics for the AlN substrates are deep-UV transparency and control of the deep-UV absorption affects. During the lecture he also presented a novel approach to prepare substrates that are lattice matched to high AlN-content AlGaN by alloying AlN with ScN of up to 1.0 at%.

Doping session - Ramon Collazo "High conductivity in Si implanted AlN"

During this lecture, I have learned that the defect incorporation in AlGaN is dependent on the defect formation energy and in turn the defect formation energy depends on the chemical potentials. Dr. Collazo explained how they employ a systematic point defect control by using the defect formation energy. He showed an example of chemical potential control of C incorporation in MOCVD GaN. They managed to quantitatively predict the C incorporation as a function of growth conditions in GaN using growth parameters, metal supersaturation, chemical potentials of III/N and impurity atoms etc. With it, they can specify the necessary growth environment for minimal C incorporation below ~1E15 cm^{-3}. Another interesting fact he showed is how the Fermi level can be modified, in terms of probability of the defect level being occupied/unoccupied and in turn how it is possible to reduce the point defects. The defect quasi Fermi level was modified by introducing excess minority carriers (by above bandgap illumination). Finally, they have achieved significant reduction in the point defects (C_N, H, V_N) in Si and Mg doped AlGaN and confirmed the results with experimental measurements including PL, SIMS and electrical measurements.

Plenary talk- Tomás Palacios "Gallium Nitride and the New Computer Revolution"

Prof. Palacios explained in his lecture why Gallium nitride (GaN) has tremendous potential to facilitate economic growth in a semiconductor industry that is silicon-based. Some of the advantages of GaN are high electric field strength and electron mobility, which can be exploited in high frequency communications and photonic applications. Due to advancements in growth technology, it is now possible to commercialise GaN power conversion applications. Nowadays, the first generation of devices are entering the market for applications that require higher speed, low specific resistivity and low saturation switching transistors. Industries are investing in different markets that will use GaN transistor technology in new circuit topologies, packaging solutions and system architectures. He was also talking about the processing-related advances, like techniques that enable epitaxial lift-off and substrate transfer which are extremely attractive for the optoelectronic applications. These kinds of novel techniques will enable improved light extraction, a smaller size devices and ultimately more flexible displays as well as sensors. The development of lift-off technology is important for the III-N based devices, and in particular to high-performance, cost-effective power electronics. In the lecture he was also comparing lateral and vertical GaN devices, and how both structures are considered for GaN power devices. The key message was that in order to improve the efficiency of power electronics, the availability of low-cost, efficient and reliable power switching devices is crucial and, the GaN-based devices are definitely exciting candidates. Vertical GaN power devices offers capability of achieving high breakdown voltage and current levels without enlarging the chip size, the superior reliability is gained by moving the peak electric field away from the surface into the bulk devices, and the easier thermal management is possible, compared to lateral devices. That is the reason why the field of vertical GaN power devices is growing exponentially.

DUV LD session - Zlatko Sitar "Development of Low Threshold UVC Laser Diodes"

Dr. Sitar's lecture gave us an overview of the challenges in production of UVC lasers and how AlGaN based technology developed on a single crystalline AlN substrate can account for some of it. In general, even though there has been a tremendous progress in III-nitride-based laser diodes, sub-300 nm UV semiconductor lasers have not been realized yet, mostly due to absence of proper crystalline substrates and modest understanding of defect control in the wide bandgap semiconductors. The dislocation density is not the only problem, it is also necessary to reduce the non-radiative centers and compensating point defect in order to achieve high internal quantum efficiency (IQE). He explained the influence of point defects on radiative lifetime, IQE and lasing thresholds. Dr. Sitar et al. have determined IQE using both RT/LT relative intensity measurements and integrated PL intensity as a function of excitation power using the Shockley-Read-Hall (SRH) model. In his research, they have performed an elaborate study of carbon contamination incorporation by supersaturation, and they have used Fermi level management to control the incorporation of the vacancies and carbon in different multi quantum well structures. With their developed technology they managed to get some impressive figures, e.g. IQE values in the UVC range >95% and lasing in the optically pumped structures at RT with thresholds as low as $3kW/cm^2$ and lasing wavelengths 237 to 280 nm. Up to this point, much effort has been focused on reducing the optical lasing threshold and improving the quality of the active region. Now, attention is being spent on waveguide design and current injection.

Plenary talk- Michael Kneissl "Exploring the Wavelength Limits of AlGaN-Based Deep UV LEDs"

Deep UV light emitting diodes (UV LEDs) in the wavelength range between 220 and 280 nm are of great interest for many applications like water purification, disinfection of surfaces, and gas sensing. In order to reach these short wavelengths AlGaN heterostructures with high Al mole fractions exceeding 80% are required. In this talk, the prospects of the AlGaN based deep ultraviolet light emitting diode (DUV-LED) were addressed. Prof. Kneissl gave an overview of the current technologies and how they are used nowdays. Different growth possibilities were explained, e.g. AlN/sapphire templates. In order to enable efficient light extraction through the sapphire substrate, the LED heterostructure was grown on UV-transparent AlN/sapphire templates. Some of the problems were mentioned, like limits of Si doping, steep drop of EQE below 250 nm, as well as the effects of the optical polarization of light emission on light extraction. Another challenge is the low extraction efficiency due to the very basic LED chip designs that are currently implemented. Most of the deep UV LED chip designs do not incorporate any advanced methods for light extraction, which results in poor light extraction efficiency. A number of factors contribute to this overall small EQE value. A significant portion can be attributed to the relatively high defect density in AlGaN materials leading to reduced radiative recombination efficiency. They managed to produce DUV-LEDs emitting at 265 nm using heterostructure with an n-AlGaN current spreading layer and a p-AlGaN electron blocking layer, and even a DUV-LED with peak emission at 217 nm. AlGaN heterostructures tunnel junctions were also presented.

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