Conference Report: International Conference on Nitride Semiconductors (ICNS – 13)

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Introduction

The 13th International Conference on Nitride Semiconductors (ICNS-13) was held at the Hyatt Regency Bellevue in Bellevue, Washington, USA, from the 8th to the 12th July 2019. Plenary talks were given on Monday and Friday, while more detailed oral presentations held during the day in between were divided into thirteen different topics. Apart from talks, there were poster sessions and a rump session, where people talked about their research and discussed together. Below I have summarized some talks and posters at the conference that I am interested in.

Developments of Nonpolar/Semipolar Edge Emitting Laser Diodes and VCSELs

Shuji Nakamura, UCSB, USA

This plenary talk gave an overview of III-nitride emitting laser diode with the wavelength from 250nm to 1.7μm. InGaN-based semipolar blue-emitting laser diodes were developed for the next generation of lighting. In the study of blue LEDs, when increasing the LED current density, internal quantum efficiency decreases. It is called efficiency droop, of which origins are Auger recombination, electron leakage and carrier dislocations. It is proved that the carrier wavefunction is affected by the direction and magnitude of the polarization-related electrical field. For semipolar (20-2-1) and nonpolar (10-10) quantum well (QW) orientations, wavefunctions of electron and hole have a large overlap, indicating a high-efficiency and low-droop performance. Besides, semipolar and nonpolar QWs have shown almost no wavelength shift and small full width at half maximum (FWHM). Other advantages of semipolar and nonpolar QW orientation include smaller hole mass, larger moment-index element and an increase of the confinement factor. Compared to LEDs, laser diodes can offer higher power, higher spatial brightness and no efficiency droop above threshold. III-nitride continuous wave (CW) laser diode operates under high voltage, leading to wall-plug efficiency that is much lower than LEDs. High voltage operation also leads to temperature increases, which results in carrier outflow from QWs and hence increases the internal loss. To reduce the LDs operating voltage, Indium Tin Oxide (ITO) is used due to its low refractive index, and it can improve the confinement of optical mode in the active region and reduce the optical loss from metal contacts. The speaker also introduced the nonpolar buried tunnel-junction blue vertical cavity surface-emitting laser diodes (VCSELs) they developed.

Efficiency of Nitride LEDs – Impact of Point and Extended Defects

Nicolas Grandjean, EPFL, Switzerland

Blue light-emitting diodes (LEDs) with active region consists of InGaN/GaN quantum wells (QWs) have attracted research interests because of their remarkably high internal quantum efficiency, despite the high dislocations. It is because of a dislocation self-screening mechanism – the formation of V-pits builds up an energy barrier for carriers. However, apart from dislocations, other defects such as impurities and point defects that can act as a non-radiative recombination centers (NRCs) can reduce the III-nitride efficiency significantly. In the presentation, the speaker introduced an InGaN containing layer underneath the QW active region that can strongly improve the external quantum efficiency. The InGaN underlayer has Indium concentration lower than 5% to limit the internal absorption, and it can reduce the internal electrical field due to band bending and bury impurities or point defects. Without this underlayer, defects will segregate at the surface and incorporate with InGaN QWs where creates NRCs. The origin of surface defects was discussed. When growth temperature is larger than 870 °C, defect concentration is proportional to temperature, as well as the growth thickness. The defect creation rate is steady when temperature above 950 °C and thickness larger than 100 nm. In GaN, two dominate defects are V_{Ga} and V_N, the former is inefficient in InGaN/GaN QWs with 10-15% Indium concentration, while the latter has large formation energy. The formation of V_N-V_{Ga} complex is detrimental for LEDs since it is a major NRC in n-type GaN.

Impact of Mg Doping of the Electron Blocking Layer on the Reliability of UVC Light Emitting Diodes

Jan Ruschel, Technische Universität Berlin, Germany

In this talk, the impact of the Mg-doping concentration in the AlGaN electron blocking layer (EBL) on the performance of AlGaN-based UVC LEDs emitting at 265 nm was presented. The Mg concentration in the EBL was varied from 0.15-1.5%. They found that less Mg doping leads to faster degradation in optical power. Optical power reduction is also more significant at low measuring current levels, especially for LEDs with lower Mg doping. As a result, the degradation is more likely related to the Shockley-Read-Hall (SRH) recombination effect which is stronger under lower measuring current. Increasing the Mg doping concentration in the EBL is an effective method to increase device lifetime and suppress degradation.

Role of Exciton Recombination Process on Internal Quantum Efficiency in AlGaN-Based UV-B Multiple Quantum Wells

Hideaki Murotani, Tokuyama College, Japan

For AlGaN-based UV LEDs, the evaluation of internal quantum efficiency (IQE) plays an important role in performance improvement. In AlGaN-based multiple quantum wells (MQW), the exciton emitting process is essential due to the large binding energy. IQE was studied by measuring the photoluminescence (PL) and time-resolved PL (TRPL). The study revealed that IQE depends on temperature and excitation power. The maximum value of IQE decreases with increasing temperature. It is because the non-radiative recombination rate of excitons increased with increasing temperature. At low temperature (below 100K), radiative recombination process of exciton dominates, whereas at high temperature (above 100K), radiative recombination rate decreases rapidly and the emission is dominated by non-radiative recombination. The temperature-dependent TRPL shows that the radiative recombination rate is independent of the temperature below 100 K, and then increases linearly with further increasing temperature. The study of IQE indicates that exciton recombination process is essential in AlGaN MQW emission, even at room temperature.

Recent Advances of GaN Growth by Na-Flux Method

Yusuke Mori, Osaka University, Japan

In this invited talk, the speaker introduced Na-flux method to grow bulk GaN crystal with high purity, high thermal conductivity and low threading dislocation density (TDD). Using small GaN seed to prevent cracking, they successfully fabricated GaN wafer with large diameter on multi-point seeds (MPS). However, GaN lattice constant variation occurred during the MPS growth, and it depends on the growth mode. To produce uniform GaN crystal, they fabricated GaN in the vertical direction (c-plane growth). Before vertical growth, they performed lateral growth by dipping the pyramidal GaN crystal seeds into the fresh solution. Then the thin film is present only around the pyramidal GaN crystal, which restricted the growth in the lateral direction. Then take out the growth substrate and repeat the step over and over again until the surface become flat, high-uniformity GaN can be grown vertically on the flat surface. The technique combined MPS and flux film coated (FFC) technique and fabricated GaN with high transparency, low TDD (10^2~10^5 cm^{-2}), and large radius of lattice curvature.

Determination Methods of H1 Trap Concentration in N-Type GaN Schottky Barriers via Sub-Bandgap-Light Isothermal Capacitance Transient Spectroscopy

Kazutaka Kanegae, Nagoya University, Japan

In MOVPE-grown n-type GaN, carbon antisite C_N, acting as a compensating acceptor, is a dominate defect. Developing an effective method to measure the trap density is essential and will provide feedback to improve the growth condition. The speaker introduced a quick and easy method to determine the C_N density ($[C_N]$) using sub-bandgap-light-excited isothermal capacitance transient spectroscopy (ICTS) with high accuracy. The $[C_N]$ concentration is proportional to the ICTS peak, which is a product of $[C_N]$, hole occupation ratio and depletion-layer-edge correction factor. Hole occupation ratio is calculated using electron and hole photoexcitation rates and hole thermal emission rate. The measurement takes a long time in the conventional temperature sweeping method, since the depletion-layer-edge correction factor depends on temperature. In the isothermal method, depletion-layer-edge correction factor was determined by varying the reverse bias voltage, and hole occupation ratio was obtained by fitting the ICTS curve using rate equation. Therefore, $[C_N]$ can be calculated, and the result showed good agreement with the carbon concentration.

Density Control of GaN Quantum Dots on AlN Single Crystal

Nicolas Grandjean, EPFL, Switzerland

III-nitride quantum dots are promising single-photon source due to their high exciton binding energy, and they operate for single-photon emission (SPE) not only at cryogenic temperatures but at room temperature. For quantum dot SPE, it should be possible to excite a single quantum dot, which requires a low density quantum dot growth. The speaker introduced the growth of Stranski-Krastanov (SK) GaN quantum dots on AlN by MBE. To reduce the density of GaN quantum dots, they tried to enhance the diffusion length so that adatoms are more likely to nucleate at existing islands rather than creating new islands. However, GaN decomposition occurs at higher temperatures and hence the method of diffusion length enhancement with temperature has a limitation. An alternative approach to improve diffusion length is controlling the GaN growth rate, and the surface energy was minimized by reducing the pressure of NH_3. Using this technique, the density of quantum dot on AlN substrate was accessible to $8\times 10^{6} cm^{-2}$.

MOCVD Growth and Characterization of InN and InGaN Quantum Dots

Caroline Reilly, UCSB, USA

InGaN quantum dots are of interest for the study of long wavelength visible lasers, as well as InN quantum dot on c-plane GaN, where carriers are well-confined due to the large difference of bandgap. The speaker introduced the MOCVD growth of InN quantum dots and high-indium composition InGaN quantum dots. For the growth of InN QDs, when increasing the growth temperature, the dot density decreased dramatically and the shape changed from circular to hexagonal. Both width and height of quantum dots increase with increasing temperature when the temperature is larger than 565℃. For InGaN quantum dots, high indium composition quantum dots were found in large dots, while the indium composition for small dots is close to 50%. The speaker also introduced an InN/GaN cap layer grown at low temperature, to reduce the effect of growth temperature on quantum dots. The experiment revealed that the emission wavelength and strength were unchanged after capping. With a cap layer, InN quantum dots performed infrared emission at room temperature with density of $1\times 10^{10} cm^{-2}$.

Realization of Linewidth Narrowing in a Single Photon Emitting GaN Quantum Dot

Kang Gao, University of Tokyo, Japan

III-nitride quantum dots play an important role in single photon emitter (SPE) due to their wide emission wavelength range and the potential to operate at room temperature. However, compared to other SPEs, the emission linewidths of III-nitride quantum dots are over an order of magnitude larger because of spectral diffusion. The speaker investigated the impact of excitation energy on the linewidth of III-N quantum dots. GaN quantum dot is sandwiched by AlGaN layer, and the quantum dots were excited using a 266 nm continuous wave (CW) laser and a tunable UV pulsed laser respectively. Under CW excitation at 5 K, the second-order autocorrelation measurement showed a dip at 0 s, indicating a single photon emission. Next, the quantum dot was excited using a pulsed laser, with excitation wavelength from 270-310 nm (4.59-3.99 eV). From photoluminescence spectrum, the full width at half maximum (FWHM) of quantum dot emission decreases linearly with decreasing excitation energy. The linewidth reduction is due to the reduced spectral diffusion – when the excitation energy is close to the bandgap of GaN, much small than AlGaN, density of states reduces in the single photon emission. The suppression of emission linewidth is essential for developing indistinguishable single photon using III-nitride semiconductors.

Concluding remarks

I would like to thank the UKNC for providing me with the funding and supporting me to attend this conference, which is my first international conference. I would also like to thank my whole research group for the support, especially Prof. Matthew Halsall and Dr Simon Hammersley for all the help to my work. It is grateful to understand different research topic of nitride material and discuss my work with international nitride community.