Temperature dependence of Sub-220nm Emission from GaN/AlN Quantum Structures by Plasma Assisted Molecular Beam Epitaxy

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Abstract: GaN/AlN structures are utilized to achieve deep-UV emission. By reducing thickenss of GaN QW to 1 ML, 224nm emission is achieved. A further shift to 219 nm is gettable as GaN islands are introduced.

OCIS codes: (250.5590) Quantum-well,-wire and –dot devices, (260.7190) Ultraviolet, (300.2140) Emission

1. Introduction

The AlInGaN compound semiconductor system spans over the wavelength range: 200 nm - 400 nm in the UV regime. But as shorter wavelength is approached by increasing Al composition in these AlGaN compounds, several issues in the form of threading dislocations, alloy fluctuations, quantum confined stark effect (QCSE), edge emission limit the overall efficiency. Recently a new approach incorporating 2 monolayer (ML) thick GaN quantum dots (QDs) was used to demonstrate deep UV emission [1]. QDs improve radiative recombination efficiency over quantum wells (QWs) by confining from all directions and thus keeping the carriers away from dislocations. Using different growth strategies emission has been achieved from 274 nm – 224 nm from GaN/AlN structures [2]. Using GaN as the active region in place of AlGaN has the advantage of getting brighter emission from the surface as polarization property of AlGaN changes from $E \perp C$ for GaN to $E \| C$ for AlN [3,4].

2. Experimental

In this work, we show that sub-220nm emission can be obtained using GaN/AlN quantum structures grown with less than 1 ML average coverage of GaN layer by plasma assisted molecular beam epitaxy (PAMBE). Fig 1 shows the schematic of the GaN/AlN structures explored in this work. A thermocouple temperature of 730^{o}C and RF plasma power of 275 W corresponding to growth rate of 0.29 ML/s is utilized for the growth of GaN/AlN structures. AlN is grown close to stoichiometry with Al beam equivalent pressure (BEP) of 1×10^{-7} Torr. Fig 2 shows the photoluminescence (PL) spectra indicating the shift in wavelength from 260 nm to 224 nm as the GaN QW thickness is reduced from 2 ML (7 secs GaN growth) to 1 ML (3.5 secs GaN growth), respectively. The Ga BEP was kept constant at 2.15×10^{-7} Torr. The STEM scans confirmed the growth of 2 ML (Fig 3a) and 1 ML (Fig 3b) thick GaN. Reduction of Ga BEP while keeping the RF plasma power constant would result in formation of 2D GaN islands (GaN Quantum Dots) which would also reduce the emission wavelength. Fig 4 shows the change in peak PL wavelength from 232 nm through 220 nm to 219 nm as the Ga BEP is reduced from 1.9×10^{-7} Torr through 1.6×10^{-7} Torr to 1.3×10^{-7} Torr, respectively at 77K. Fig 5 shows the STEM scan for sample emitting at 232 nm peak wavelength. The GaN layers can be seen to be discontinuous with lateral dimensions varying between 15-25 nm. The presence of high energy peak in PL spectrum can be attributed to bi-modal size distribution of GaN islands with respect to the thickness. The 219 nm emission is lower than the predicted wavelength emission at 224 nm from 1 ML thick GaN layers in AlN matrix [5].

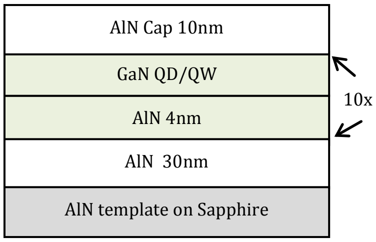

Fig. 1. Schematic of the structure

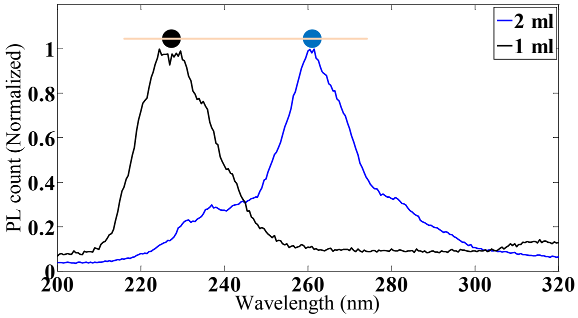

Fig. 2. Normalized PL spectra (using 157nm laser) for 2 ml and 1 ml GaN QW at room temperature. Peaks are 260nm and 224nm respectively.

Fig 6 compares the PL spectrum of QW and QD samples emitting around 221nm at 77K. It can be observed that QW sample is more prone to temperature variation than QD sample (Fig 6: Inset). This signifies higher carrier confinement in 1ML GaN 2D islands resulting in low carrier recombination at non-radiative recombination centers.

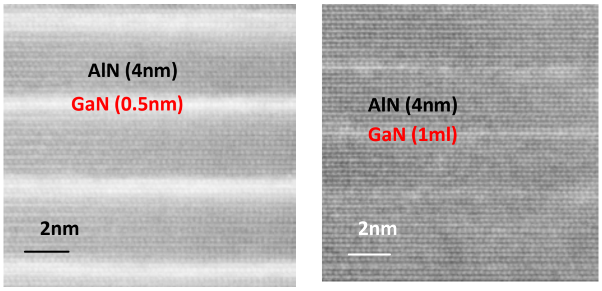

Fig. 3. STEM image for a) 2 monolayer b) 1 monolayer GaN QW in AlN matrix.

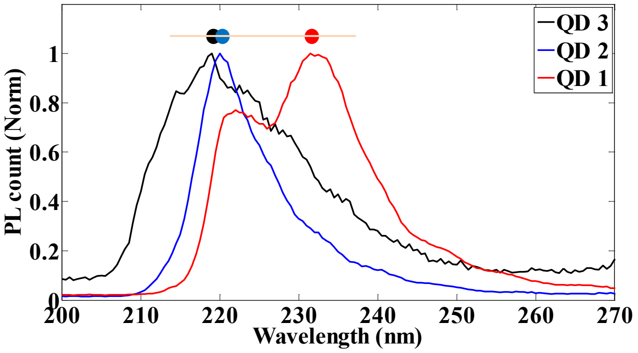

Fig. 4. Tuning emission wavelength with QDs starting from 232nm to 219 nm by gradually reducing Ga flux from stoichiometric value (at 77K)

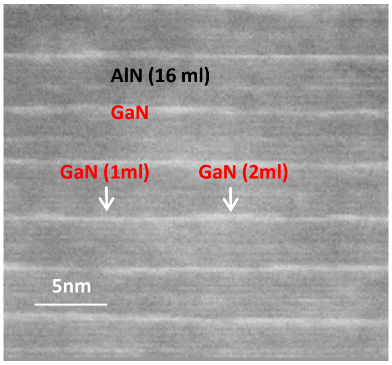

Fig. 5. STEM for QD sample emitting at 232nm at 77K. Segments of different GaN thickness are also shown.

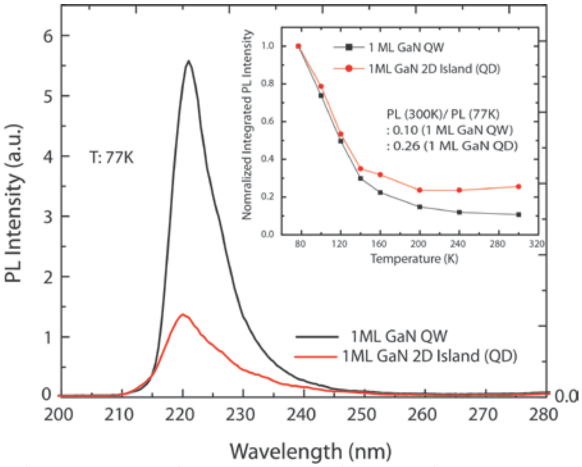

Fig. 6. PL Spectra from 1 ML QW and QD sample at 77K. Inset: PL Intensity variation for QW and QD sample with temperature

3. Conclusion

We could demonstrate sub-220 nm emission from GaN/AlN structures by forming 2D GaN islands. Incorporation of the high radiative recombination efficiency GaN/AlN active regions emitting at $\lambda < 230$ nm can lead to high efficiency UV LEDs and laser diodes emitting in the concerned deep-UV wavelength regime. Further utilization of tunnel injection of carriers and polarization induced doping can enhance the efficiency of the aforesaid deep-UV optical emitters. We are yet to characterize the GaN/AlN structures emitting below 220nm for the polarization of light. However, prior results [3,4] point towards light being dominantly TE polarized.

4. References

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