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Yellow Luminescence Imaging Of Epitaxial Lateral Overgrown GaN Using Ionoluminescence

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ABSTRACT

Luminescence imaging techniques such as Photoluminescence (PL) and Cathodoluminescence (CL) have been extensively used to characterize the optical properties of GaN. However, analysis using these techniques is limited to near surface regions and may not represent bulk material properties. This restricts the understanding of the defect-related yellow luminescence in GaN, which tends to originate at the interface region. In this work, we propose the use of MeV protons to probe several microns into a Epitaxial Lateral Overgrown GaN layer. Monte Carlo simulations of the ionization profile show that MeV ions have a much higher penetration depth than the keV electrons used in CL. The well-defined electronic energy loss peak or 'Bragg peak' at the end of range for MeV ions enables us to perform depth resolved imaging of the yellow luminescence distribution. Another advantage of using a MeV ion beam over keV electrons is the relatively small lateral spreading of ions in a material, making it a more suitable technique for providing high-resolution images of any buried defects in GaN.

INTRODUCTION

The luminescence properties of GaN have been studied extensively due to its application in optoelectronic devices. In addition to the near band edge emission, a defect-related yellow band is often observed in as-grown GaN deposited by various methods. Many groups have performed CL measurements to investigate the correlation of yellow luminescence (YL) with extended defects [1,2]. However, these studies are limited to near surface regions due to the relatively small probing depth of the keV electrons used in CL, and do not necessarily represent bulk properties. The yellow intensity and distribution is expected to be vastly different with depth since the dislocations and extended defects are generated as a consequence of the lattice mismatch between the layer and the substrate. There have also been some studies using cross sectional CL to reveal features not detectable in the planar view [3]. In order to study the effects of defects on luminescence at various depths in GaN, we introduce a new technique called Ionoluminescence (IL) to characterize GaN. In this work, energetic MeV H^+ ions are employed to investigate several microns into epitaxial lateral overgrown (ELO) GaN layer. The spatial distribution of the threading dislocations in ELO GaN also allows for the investigation of the correlation of threading dislocations with YL. Different depths are probed by varying the incident ion energies. Due to the well-defined electronic energy loss peak at the end of range, depth resolved information of the YL distribution can be extracted.

EXPERIMENTAL DETAILS

Lateral overgrown GaN stripes, patterned by the underlying Si_3N_4 mask, were deposited on GaN buffer layer/ [0001] Al_2O_3 substrate. Initially, a 2 µm thick GaN seed layer was grown by MOCVD (40 mins) on a c-plane sapphire substrate. A 100 nm SiN mask layer was deposited on GaN by plasma enhanced chemical vapor deposition (PECVD) and then patterned into $[1\bar{1}00]_{GaN}$ oriented stripes, which define a 3 µm opening (window) at a periodicity of 13 µm. The lateral overgrowth GaN layer was achieved at a pressure of 100 Torr, with trimethlygallium (TMG) and NH_3 at a flow rate of 123 µmol/min and 10000 sccm respectively in combination with 6000 sccm of H_2 diluent. After regrowth of the GaN, stripes of 8 µm thickness propagated vertically through the window, with a width of 12.8 µm over the mask so that the stripes are close to coalescence.

Various depths of the ELO GaN are probed using H^+ ions with energies of 1.0 MeV and 0.5 MeV at the Singletron accelerator facility at the National University of Singapore [4]. The ion beam is focused to a sub-micron spot size with three magnetic quadruple lens and scanned across the sample. Light emission induced by the ions is then detected by a Hamamatsu H7421-40 Single Photon Counting Head via a Perspex light pipe. For YL monochromatic imaging, an interference notch filter with a transmission wavelength of 550nm is placed in front of the PMT. The high sensitivity of the PMT enables the collection of the IL image with a typical beam current of less than 1 pA. This helps to limit the ion beam damage on the sample.

For comparison, CL measurements using 25 keV electrons are also performed on the same sample using an SEM system. The CL signals are collected with a semi-ellipsoidal mirror and coupled into the Hamamatsu R928 PMT via a bundle of optical fibers. A JOBIN YVON model H10-IR monochromator is used for monochromatic imaging and spectral analysis. The CL spectra have not been corrected for system response. Monte Carlo simulations of the electronic energy loss profile of electrons and ions have also been carried out using the software packages CASINO [5] and SRIM 2000[6] respectively. All IL and CL measurements are collected at room temperature.

RESULTS

Comparison of IL and CL techniques

IL is an analogous imaging technique to CL where the light generation mechanism is governed by the electronic energy loss of the ions or electrons in the material. The main difference between the two techniques lies in the generation volume, which is basically determined by the range and lateral spreading of the beam. Figure 1 shows the SRIM simulation for the ionization profile of 0.5 MeV and 1.0 MeV H^+ in GaN. The electronic energy loss profile of 25 keV electrons is plotted on the same graph for comparison, using the CASINO software. The ionization profile is proportional to the number of e-h pairs created as the beam traverses into the material. It can be seen that the electronic energy loss for 25 keV incident electrons is about 2 orders of magnitude smaller than that for MeV H^+ ions. Therefore, for 1.0 MeV H^+, the total number of e-h pairs created is 40 times larger than that produced by a 25 keV electron.

Most of the ionization for 25 keV electrons occurs in the first 0.5 μm below the surface, while MeV H^+ ions suffer most electronic energy loss at the end of range and at a much longer penetration depth. This well-defined peak known as the 'Bragg' peak allows us to measure depth resolved information of the YL in the sample, provided that the absorption of the light is negligible in the material [7]. Since GaN is transparent to yellow light, we have assumed that the absorption of YL in GaN is negligible. By increasing the H^+ energy from 0.5 MeV to 1.0 MeV, the penetration depth is increased from 3.4 μm to 8.6 μm. This depth range probes the interface region between the GaN overgrown and seed layer.

Figure 2 shows the lateral spreading of keV electron and MeV ion in GaN. It can be seen that keV electrons spreads out spherically while the energetic ion has a more well-defined path and range in the material. Since the diffusion length of the e-h pairs in GaN is only about 50-100 nm [8,9], the spatial resolution is mainly determined by the lateral spreading of the beam. Simulations show that 1.0 MeV H^+ ions shows a comparable lateral spread to 25 keV electrons. This indicates that MeV H^+ ions are suitable for depth profiling of buried defects, without suffering significant loss of spatial resolution with depth. The corresponding regions of interest probed by the beam in the ELO GaN sample are shown.

Figure 3 shows the CL spectra of the just-coalesced ELO GaN collected from the wing and window regions. It can be seen that the UV intensity is approximately 3 times higher in the wing regions as compared to the window regions. This shows that the threading dislocations in the window region act to quench the UV luminescence. The yellow bands in the wing and window regions do not show any difference in intensity at this depth.

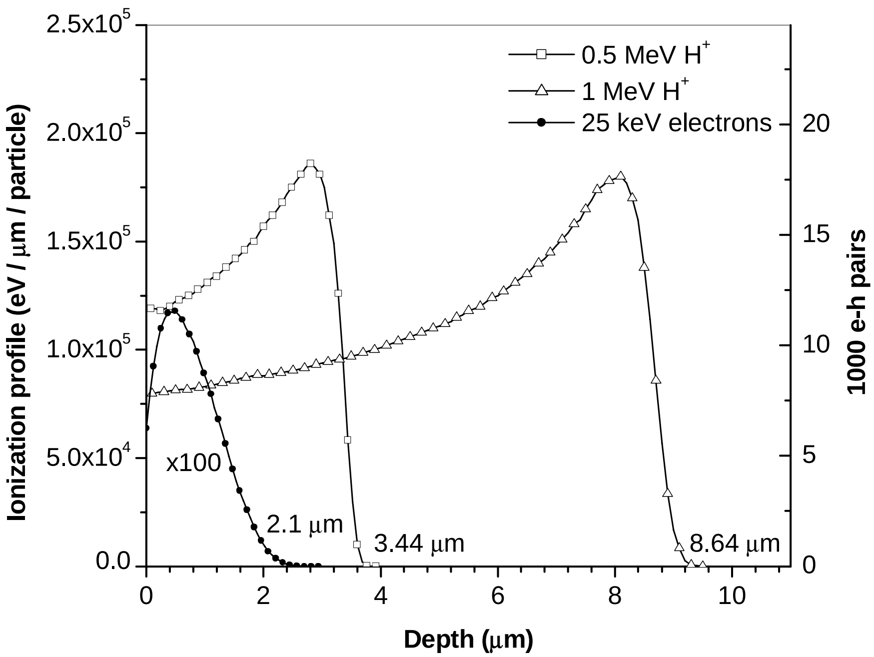

Figure 1: Ionization profile of 1.0 MeV and 0.5 MeV H^+ ions simulated using SRIM2000. This is compared with that of 25 keV electrons simulated using CASINO software. The number of e-h pairs created is proportional to the ionization profile.

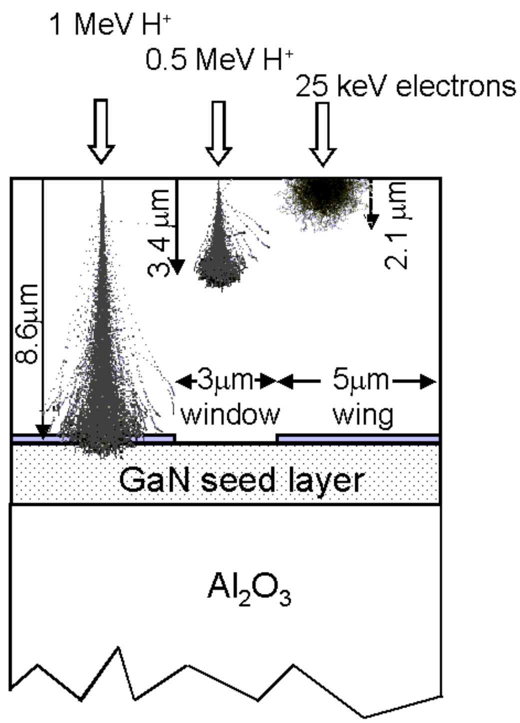

Figure 2: Simulations of the generation volume of 1.0 MeV H^+, 0.5 MeV H^+ and 25 keV electrons in GaN. The corresponding depths of interest in ELO GaN probed by the different beams is also shown.

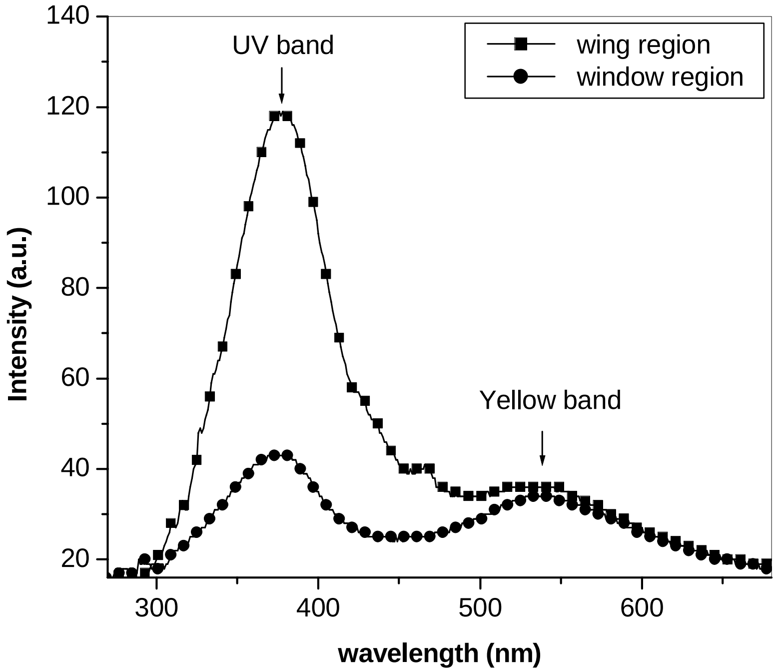

Figure 3: Individual point CL spectra collected from the wing and window region (Not corrected for spectral response).

Figures 4a,b show the YL maps collected with 0.5 MeV and 1.0 MeV H^+ ions respectively. This corresponds to a depth of 3.4 and 8.6 μm below the surface. At a depth of 3.4 μm, the YL intensity is relatively low and it is homogeneously distributed across the GaN stripes. Near the interface region at a depth of 8.6 μm, the window regions appear distinctively higher in yellow intensity when compared to the wing regions. The coalescent fronts can also be seen clearly from the high-resolution IL map. The line profile of the YL intensity in figure 4c shows that the intensity in the window is about four times higher than that observed in the wing regions. Although the threading dislocations propagate to the surface (as seen in the TEM map of similar ELO GaN sample published previously in [10]), the yellow luminescence does not seem to concentrate at the window regions for the first 3 μm below the surface. This indicates that threading dislocations are not the origin of the YL and point defects are more likely candidate for the mid-band gap transition. The higher yellow luminescence observed at the window regions with depth suggest that it could be due to the diffusion of the point defects from the seed layer to the overgrown layer [11].

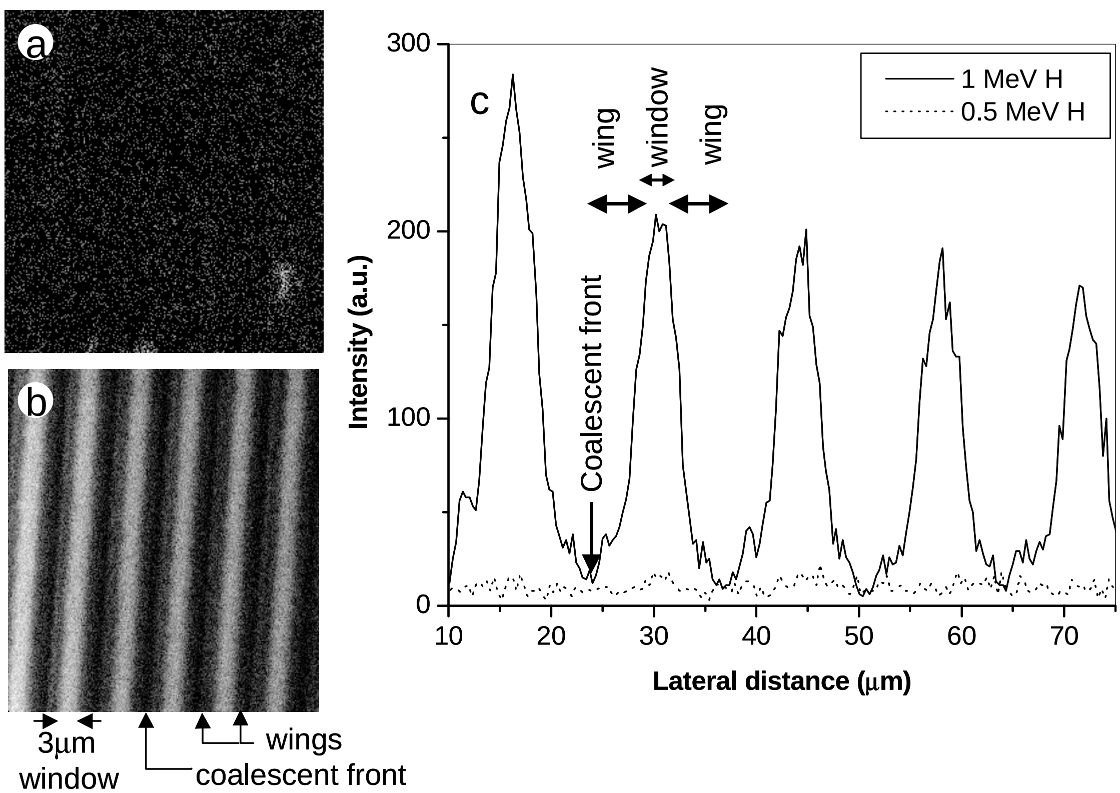

Figure 4: Yellow luminescence map collected at a depth of a) 3.4μm and b) 8.6μm using 0.5 MeV and 1 MeV H^+ respectively. c) Line profile of the yellow intensity across the GaN stripes at different depths.

CONCLUSION

The CL and IL results show that the YL distribution varies vastly with depth. Within the first 3.4 μm of the ELO GaN layer, the yellow luminescence is low in intensity and homogeneously distributed throughout the stripes. This suggests the good crystallinity for regions near the surface. As the depth increases to the interface regions, higher yellow emission is observed from the window regions while the wings remain low in intensity. We have therefore demonstrated that IL is a suitable technique for imaging luminescence properties of GaN several microns below the surface, which is not possible using CL.

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