Development of GaInN Heterostructures of High InN Fraction

After the development of red and blue LEDs, efficient emitters in the green spectral region are of prime relevance to energy-efficient solid-state lighting. Here GaInN layers of high InN-content are deemed key. Huge lattice-mismatch to GaN, however, likely renders such GaInN layers highly defective and strong piezoelectric fields reduce the radiative efficiency. Therefore, strategies are being devices that gradually reduce the mismatch between desired well-compositions and their embedding barrier layers.

First generation LED light sources rely on a blue emitting LED whose light is partially converted by a layer of phosphor to provide a broad spectrum akin to white light. For higher efficiency and better control of the spectrum, it should be better to combine the light of blue, green and red LEDs instead. Yet, there is a big variation of efficiency with wavelength. The concept of "green gap" nicely describes this shortcoming in the green and amber spectral regions. Here this is where we see tremendous improvement potential by advanced epitaxial processes for $Ga_{1-x}In_xN$ of high InN fractions *x*. We therefore work to improve the efficiency of such direct emitting LEDs in the longer wavelength green, amber and red spectral region.

One of the biggest challenges in this is the development GaInN epitaxial layers with low residual defect densities. So far it is commonly observed that the structural defect density of $Ga_{1-x}In_xN$ increases with InN fraction as needed for the longer wavelength emission.

LED devices grown on micro-patterned sapphire substrates have shown a 20% increase in light output power over unpatterned devices, and also showed a 20% increase in external quantum efficiency.[1] Moreover, even higher improvements were found when switching from patterning on the micrometer length scale to the patterning on the nanometer length scale, i.e. patterns sizes on the order of hundreds of nanometer.[2],[3],[4]

In this collaborative project we particularly explored the opportunity for fabrication of non-polar growth of a-plane GaInN/GaN heterostructures on r-plane sapphire substrates by MOVPE. An initial layer of a-plane GaN is grown on r-plane sapphire and demonstrates the usual high defect densities. After growth interruption, a 200 nm SiO_2 layer followed by a 10 – 40 nm layer of Ni was deposited. By rapid thermal annealing, Ni was transformed to self-assembled nano islands that then served as an etch mask for the underlying GaN. After RIE-ICP etching the template wafer is then regrown with $Ga_{1-x}In_xN$.

A scanning electron microscopy (SEM) image of the cross section and top surface of the resulting structure is shown in Figure 1. GaN pillars from the nano patterned template are seen in the highlighted area. The regrown material is visible above the pillars. This image

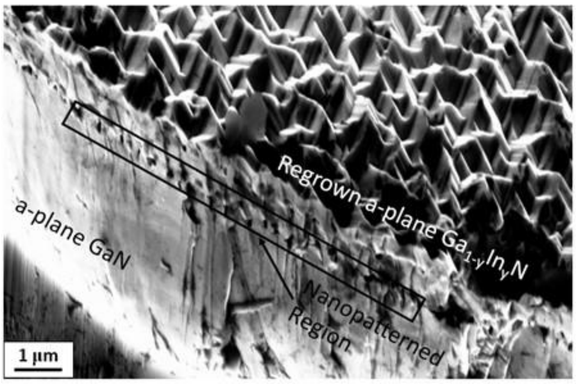

Figure 1 An SEM image showing the cleaved cross section and rough growth surface of this example of a-plane $Ga_{1-y}In_yN$ material grown on nano patterned a-plane GaN on sapphire.

reveals that a coalesced film was achieved, although the surface turns out to be quite rough. The roughness most likely is due to the low growth temperature as needed for high In-incorporation.[5]

Photoluminescence (PL) spectra were obtained before and after the $Ga_{1-x}In_xN$ regrowth as shown in Figure 2. The template shows the

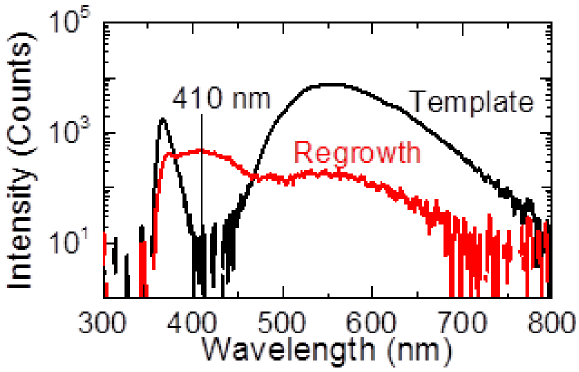

Figure 2 Photoluminescence spectra before and after a-plane $Ga_{1-x}In_xN$ regrowth.

near band-edge luminescence of GaN and the broad yellow luminescence. After regrowth of $Ga_{1-x}In_xN$, an additional contribution is seen near 410 nm, which should be attributed to the $Ga_{1-x}In_xN$ layers. Based on this peak wavelength, we estimate the InN content of some 3%. In x-ray diffraction, however, we have not been able to identify a separate relaxed layer of GaInN. This suggests that the regrown layer may have grown pseudomorphically and could be under compressive stress.

In next steps we are now exploring paths to achieve a smoother surface texture, preferably on the nanometer roughness scale, and how to increase the incorporated InN fraction to the reach of 20% to 30%. A likely approach is the use of epitaxial growth along the negative c-axis of GaN which has shown promising aspects in the literature.[6]

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