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14. ABSTRACT We grew unintentionally doped n-type InGaN layers in the temperature range from 600 to 750°C; using GaCl ₃ , InCl ₃ , and NH ₃ as gas sources; and argon as carrier gas. The InN content in the layers varied from 5 to 50 mole % depending on the growth conditions. Growth was performed on undoped n-GaN/sapphire films with a thickness of 2 to 20 μm, and on Mg-doped p-GaN/sapphire template with a thickness of 3-5 μm grown separately by HVPE. The thickness of the InGaN layers ranged from 20 to 300 nm. Device challenges for making a p-side down					
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ABSTRACT

We grew unintentionally doped n-type InGaN layers in the temperature range from 600 to 750°C; using GaCl₃, InCl₃, and NH₃ as gas sources; and argon as carrier gas. The InN content in the layers varied from 5 to 50 mole % depending on the growth conditions. Growth was performed on undoped n-GaN/sapphire films with a thickness of 2 to 20 μm, and on Mg-doped p-GaN/sapphire template with a thickness of 3-5 μm grown separately by HVPE. The thickness of the InGaN layers ranged from 20 to 300 nm. Device challenges for making a p-side down HVPE-grown n-InGaN/p-GaN single heterostructure LED have been previously discussed. The simplicity in the device structure is the attractive feature of these devices. We used this type of device structure for demonstration of a simple InGaN-based LED in current work. The structures were not optimized for performance.

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We will discuss results of InGaN material and device growth by HVPE. Application of new device concepts for LEDs arising from new HVPE capabilities will be discussed, including all-HVPE InGaN based LEDs for SSL.

Green-blue-violet light emitters based on III-nitride compounds are typically fabricated utilizing InGaN alloys in active region of the optoelectronic devices. Most of these materials are grown by metalorganic chemical vapor deposition (MOCVD) and molecular beam epitaxy (MBE) [1-4]. Another technique that has found its application in the nitrides growth technology is hydride vapor phase epitaxy (HVPE) [5]. HVPE is considered the most promising way to provide high crystalline quality nitride substrate materials. Recently HVPE has proved to provide capability of growing device structures with nanoscale layer size and high quality InGaN materials [6, 7].

HVPE growth of indium containing group III nitride compounds is probably the most challenging area of this technology development. Despite significant effort both in theoretical and experimental research the achieved level of development is still limited. In this presentation, we review the results on growth and properties of InGaN layers by HVPE. Brief analysis of chemical and thermodynamic limitations for HVPE of indium containing nitride compounds will be given. Solutions to overcome the limitations will be discussed. Results of structural and optical characterization of the InGaN layers and structures are presented. We will present our view on all-HVPE LED concept and prospects of implementation.

We grew unintentionally doped n-type InGaN layers in the temperature range from 600 to 750°C; using GaCl₃, InCl₃, and NH₃ as gas sources; and argon as carrier gas. The InN content in the layers varied from 5 to 50 mole % depending on the growth conditions. Growth was performed on undoped n-GaN/sapphire films with a thickness of 2 to 20 μm, and on Mg-doped p-GaN/sapphire template with a thickness of 3-5 μm grown separately by HVPE. The thickness of the InGaN layers ranged from 20 to 300 nm. The growth rate of the InGaN layers was in the range from 0.1 to 3 μm/h, depending on the growth temperature, the V/III ratio in the gas phase, and active components flow rates. These parameters also affected the layer compositions, stress relaxation, and phase separation. We have investigated the effect of technological parameters on InGaN layers content and structural properties.

We also studied the influence of the quality of the substrate material on the structure of the InGaN layers. Simple n-InGaN/p-GaN hetero-junctions were grown forming all-HVPE upside down simple LED structures with thick emitting InGaN layer.

Optimization of the In_xGa_{1-x}N growth conditions resulted in controllable variation of the indium composition (x) in the range from 0.06 to 0.52, for HVPE grown layers without phase separation. Layers were grown with a full-width at half-maximum (FWHM) of the X-ray (00.2) ω-scan rocking curve in the range from 292 to 800 arc sec. Layers having higher indium content showed broader rocking curves.

No metallic indium or phase separation was observed by XRD analysis. X-ray 2θ/ω diffraction scans measured for various In_xGa_{1-x}N layers grown on GaN/sapphire templates showed only one single (00.2) peak corresponding to the In_xGa_{1-x}N layer for each sample.

Both pseudomorphic (fully strained) and fully relaxed layers were observed for In_xGa_{1-x}N layers grown on GaN templates. The nature of relaxation will be discussed. The rocking curves tend to be broader for layers having higher indium composition. The crystalline quality of InGaN layers tends to improve with crystalline quality of template substrate.

Room temperature PL measurements revealed InGaN related peaks in the visible range of the spectrum. The peak position for InGaN layers with various content shifts from the GaN PL peak position towards the InN PL peak position with increasing indium content as shown in Fig. 1(a). The dependence of the PL peak positions on indium content is in good agreement with data reported on InGaN grown by other methods [8].

Device challenges for making a p-side down HVPE-grown n-InGaN/p-GaN single heterostructure LED have been previously discussed [9, 10]. The simplicity in the device structure is the attractive feature of these devices. We used this type of device structure for demonstration of a simple InGaN-based LED in current work. The structures were not optimized for performance. Fig. 1 (b) presents EL spectra of LEDs based on a n-In_xGa_{1-x}N/p-GaN single heterostructures. Depending on the indium content, the EL peak position shifts from blue (450 nm) to Orange (590 nm).

We consider our results as a first step towards low cost all HVPE high brightness high efficiency LEDs for wide range of applications including SSL.

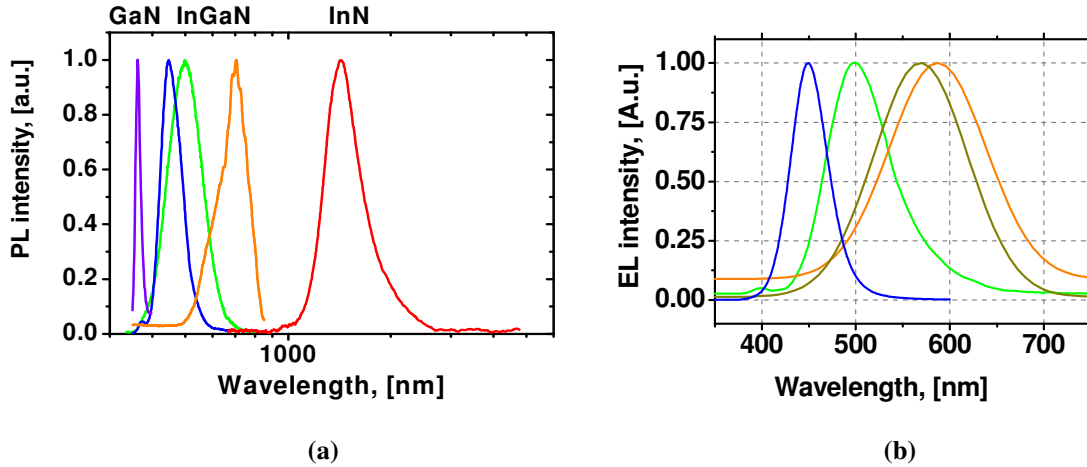


Figure 1. (a)- Normalized room temperature PL spectra of HVPE grown InGaN layers with different InN content together with reference spectra of HVPE grown GaN and InN. InGaN related lines at 445, 500 and 710 nm are indicated and (b) - Normalized EL spectra of n- $\text{In}_x\text{Ga}_{1-x}\text{N}$ /p-GaN LEDs. Lines at 450, 500, 570 and 590 nm are indicated

This work was initiated by Dr. Vladimir A. Dmitriev in 2005. Author shares his belief that HVPE is capable to advance to produce the whole LED structures. I acknowledge continuous support from DARPA and DOE in frame of numerous projects. I express my special gratitude to my colleagues at TDI who made possible the presented results. I also grateful to Professor Fernando A. Ponce ASU, Dr. Noble Johnson of PARC, Dr. Zuzanna Liliental-Weber of LBNL, Dr. Michael Wraback and many others for fruitful collaboration in development of this technology

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