

# Enhancement in Indium Incorporation for InGaN Grown on InN Intermediate Layer

H. HARTONO<sup>1</sup>, P. CHEN<sup>2</sup>, E.A. FITZGERALD<sup>1,3</sup>, and S.J. CHUA<sup>1,2</sup>

<sup>1</sup> Singapore-MIT Alliance, National University of Singapore, Singapore 117576

<sup>2</sup> Institute of Materials Research and Engineering, Singapore 117602

<sup>3</sup> Dept. of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139

*Abstract* InN has been grown on GaN with a thin intermediate layer of InGaN by metalorganic chemical vapor deposition (MOCVD) to further enhance indium incorporation in subsequent InGaN layer. Trimethylindium (TMI) and ammonia (NH<sub>3</sub>) were used as the source for InN growth and transmission electron microscopy (TEM) confirmed the presence of pyramid-like structure of InN. A layer of InGaN subsequently grown on top of these InN pyramids shows a red-shift of ~20 nm relative to InGaN layer grown directly on GaN using the same growth condition. However, there is no significant pits reduction. An alternative method to enhance indium incorporation is to grow the InN by adding a small amount of trimethylgallium (TMG) into the TMI and NH<sub>3</sub> flow. This method provides a seed layer for the InN growth and it gives a higher density of InN pyramids. X-ray diffraction (XRD) measurement of this sample shows a high indium incorporation to give InGaN with  $x \sim 0.26$  as compared to  $x \sim 0.22$  for sample grown without TMG flow in the InN layer.

*Keywords* InN growth, InGaN growth, Indium enhancement.

## I. INTRODUCTION

In the recent years, group III-nitrides semiconductors and their alloys have gained

recognition as being among the most important materials for optoelectronic and electronic applications. Developments in the field of GaN, InN, and AlN have been spectacular due to their highly attractive inherent properties. However, there is still much that is not understood in the growth and properties of these compounds. This lack of understanding is most apparent in the In-rich-based nitrides. The problems impeding the progress in the growth of In-rich InGaN include poor optical properties, low percentage of indium incorporation, and the formation of In-droplets on the surface.

Considering this, a high quality InGaN film with high indium content might be realized on the basis of improvement of the quality of binary InN epitaxial. A lot of methods have been tried to grow good quality InN. Hovel and Cuomo in 1972 [1] were among the first groups to successfully grow InN with good electrical properties. Polycrystalline InN film with highly preferred orientation was grown on sapphire and silicon substrates by reactive RF-sputtering. Matsuoka et al. [2] and Wakahara et al. [3-4] reported the beginning of the single crystalline InN film by MOVPE in 1989. InN films were grown on sapphire substrate by reacting TMI with NH<sub>3</sub> and microwave activated N<sub>2</sub>, respectively. In the 1990s, epitaxial growth of single crystalline and good quality InN films was widely studied by MOCVD as well as

MBE on different substrates and underlying layers over a wide range of growth conditions.

InN growth by MOCVD is the most difficult among the III-N because the equilibrium vapor pressure of nitrogen over the InN is several orders higher than AlN and GaN [5]. Preparation of InN requires a low growth temperature because of the low InN dissociation temperature [6]. However, low growth temperature ( $\sim 500$  °C) restricts the decomposition rate of  $\text{NH}_3$  and is dominated by the formation of In-droplets due to the shortage of reactive nitrogen. On the contrary, a higher growth temperature brings about thermal decomposition or thermal etching of the grown InN.

In this letter, we report two methods of growing InN and TEM confirmed the presence of pyramid-like structure of InN. InN was grown by MOCVD to further enhance indium incorporation in subsequent InGaN layer.

## II. EXPERIMENTAL DETAILS

The deposition of a low temperature GaN buffer layer ( $\sim 25$  nm) was followed by a 1.5- $\mu\text{m}$ -thick GaN layer grown at 1000 °C on (001) sapphire by MOCVD. Trimethylgallium (TMG), Trimethylindium (TMI) and ammonia ( $\text{NH}_3$ ) were used as precursors for Ga, In, and N, respectively, with a mixed of  $\text{N}_2$  and  $\text{H}_2$  carrier gas. Four different samples were grown. In Sample A, a 140-nm-thick  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  was grown on the GaN layer. This sample is used to compare the optical and structural effect of InN on the subsequent  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  layer grown in Sample C. In Sample B, InN layer was grown at 580 °C on GaN with a thin intermediate layer of  $\text{In}_{0.22}\text{Ga}_{0.78}\text{N}$  and the same sample was capped with a 140-nm-thick  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  layer for Sample C. For InN growth, the flow rate of TMI and  $\text{NH}_3$  were 45 sccm and 18 slm, respectively. Sample D was grown with a different method, where a small amount of TMG was added into the flow of TMI and  $\text{NH}_3$

to grow InN, under otherwise unaltered condition from Sample B.

## III. RESULTS AND DISCUSSION

Photoluminescence (PL) at room temperature shows a red-shift of  $\sim 20$  nm for Sample C as shown in Fig. 1 relative to Sample A. The main peak position of InGaN is  $\sim 490$  nm and  $\sim 510$  nm for Sample A and C, respectively. This red-shift is believed to be due to the emersion of InN in the InGaN layer subsequently grown on it. However, this optical effect is not accompanied by the structural improvement in the InGaN layer. Scanning electron microscopy (SEM) in Fig. 2(a) and 2(b) show the pits formation for both Sample A and C and there is no significant pits reduction in Sample C. In Sample A, the size of the pits varies from  $\sim 35$  to  $\sim 70$  nm with a total density of  $\sim 6.0 \times 10^9/\text{cm}^2$ , while the pits in Sample C are relatively more uniform with a larger diameter of  $\sim 100$  nm and density of  $\sim 4.8 \times 10^9/\text{cm}^2$ . This larger diameter (also confirmed by cross-section TEM – not shown here) is believed to be contributed by the higher indium incorporation from the InN layer as the thickness of InGaN layers in both Sample A and C are the same ( $\sim 140$  nm).

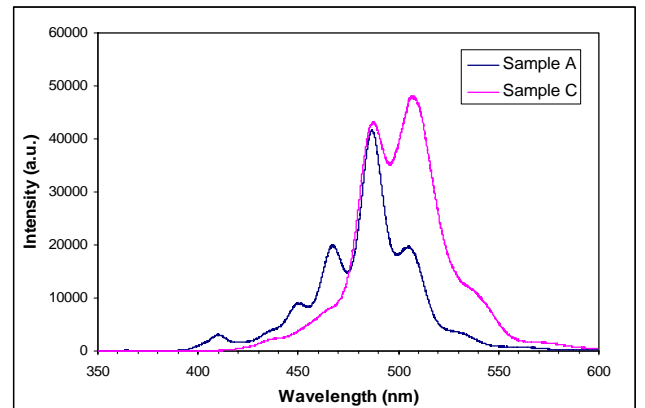
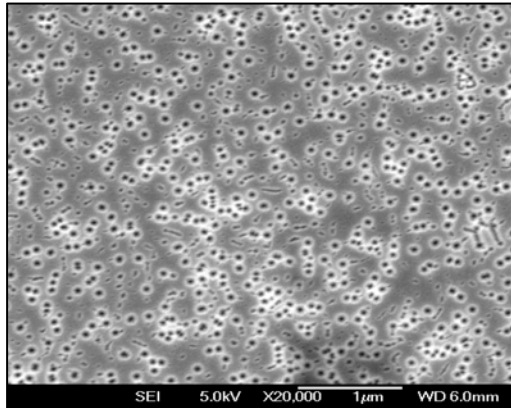
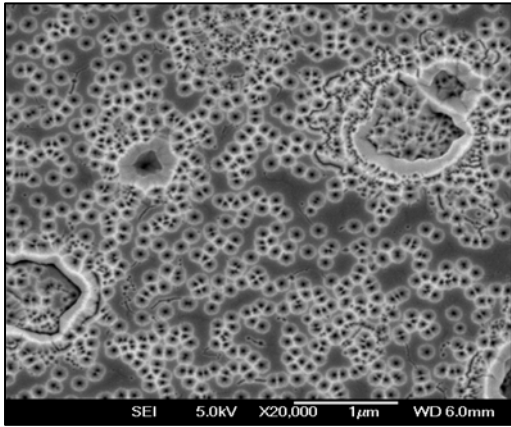


Fig. 1. PL spectra of Sample A and C at room temperature. The main peak position of InGaN in Sample A is  $\sim 490$  nm and Sample C is  $\sim 510$  nm. There is a red-shift of  $\sim 20$  nm for InGaN in Sample C relative to Sample B.



(a) Sample A



(b) Sample C

Fig. 2. (a) The SEM image of Sample A shows the pits variation from  $\sim 35$  to  $\sim 70$  nm with a total density of  $\sim 6.0 \times 10^9/\text{cm}^2$ , (b) in Sample C, pits are relatively more uniform with a larger diameter of  $\sim 103$  nm and density of  $\sim 4.8 \times 10^9/\text{cm}^2$ .

Sample B has the same structure as Sample C but without the top  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  layer. Sample D was grown with a different method, where a small amount of TMG was added into the flow of TMI and  $\text{NH}_3$  to grow InN, under otherwise unaltered condition from Sample B. The flow of TMG over the sample induced the formation of a seed layer for the InN growth and it gave a higher density of pyramid-like structure than the method used in Sample B, as shown by the cross-section TEM of Sample B and D in Fig. 3 and 4, respectively. This structure is believed to be InN layer. It should neither be pits-defect as

it is not originated from the threading dislocation (TD) underneath nor In-droplets as the samples were etched with HCl to remove the droplets before the TEM preparation. However, XRD spectrum of Sample D in Fig. 5 does not capture the InN peak, whereas, it does for Sample B. The InN layer might be covered up by the InGaN layer and results in higher overall composition,  $\sim 26\%$  for InGaN in Sample D (as compared to  $\sim 22\%$  in Sample B).

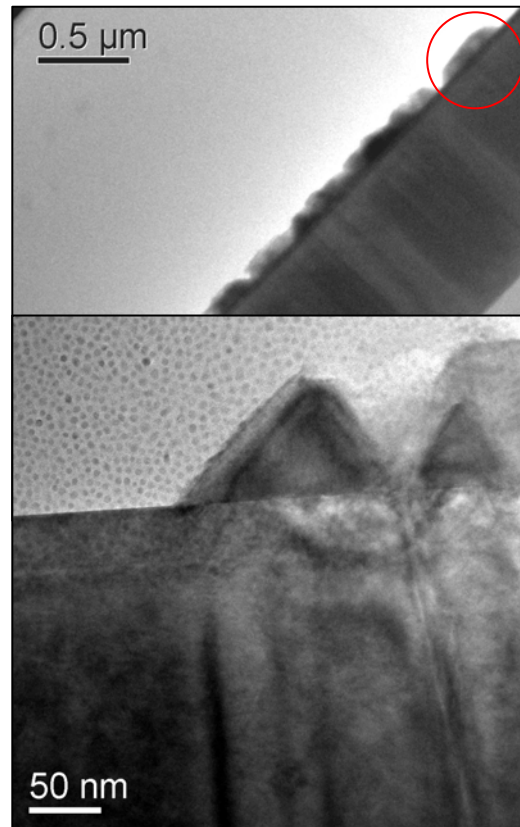


Fig. 3. Cross-section TEM of Sample B shows the pyramid-like structure of InN.

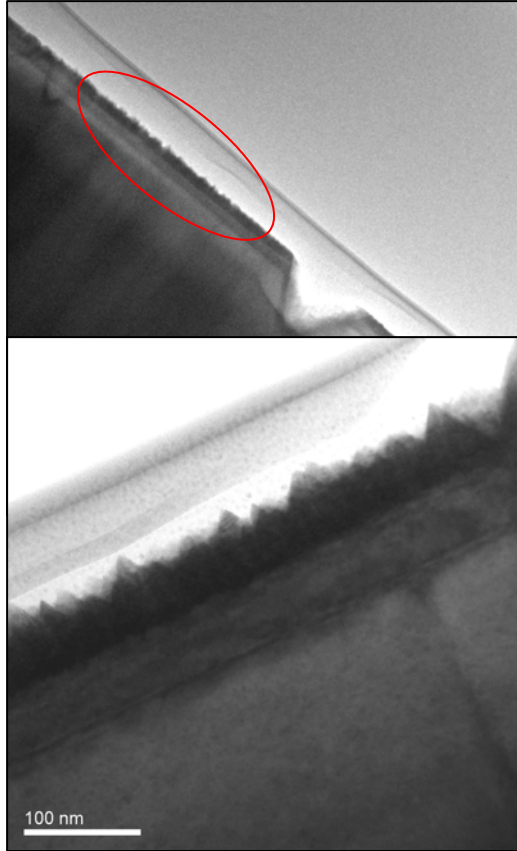


Fig. 4. Cross-section TEM of Sample D shows higher density of pyramid-like structure of InN.

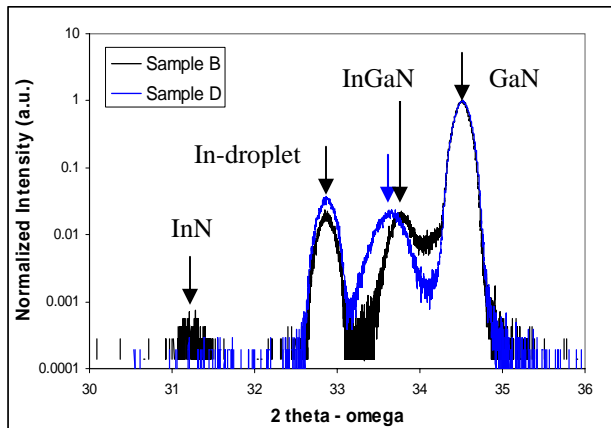


Fig. 5. XRD spectra show 22% and 26% InGaN for Sample B and D, respectively.

#### IV. CONCLUSION

A layer of InGaN grown on top of pyramid-like structure of InN shows a red-shift of  $\sim 20$  nm relative to InGaN layer grown directly on GaN using the same growth condition. However, this InN does not cause improvement structurally as there is no significant pits reduction on InGaN surfaces. Adding a small amount of trimethylgallium (TMG) into the TMI and  $\text{NH}_3$  flow gives a higher density of InN pyramids and results in higher incorporation InGaN with  $x \sim 0.26$  as compared to  $x \sim 0.22$  for sample without TMG flow in InN layer growth.

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