Proc. Int. Workshop on Nitride Semiconductors
IPAP Conf. Series 1 pp. 875-877

Influence of the Thick GaN Buffer Growth Conditions on the Electroluminescence Properties of GaN/InGaN Multilayer Heterostructures

A.S. Usikov[1*], W.V. Lundin[1], D.A. Bedarev[1], E.E. Zavarin[1], A.V. Sakharov[1], A.F.Tsatsul'nikov[1], Zh.I. Alferov[1], N.N. Ledentsov[1,2], A. Hoffmann[2], D. Bimberg[2]

A.F. Ioffe Physico-Technical Institute of Russian Academy of Sciences, 194021,Poltekhnicheskaya 26, St Petersburg Russia
[1] *Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, 10623, Berlin, Germany*
**e-mail: usikov.vpegroup@pop.ioffe.rssi.ru*

The details of InGaN/GaN structures growth on sapphire by MOCVD were studied using *in-situ* optical reflectance monitoring. It was observed that GaN growth rate at the same growth conditions as well as InGaN luminescence properties are dependent on the growth conditions of underlying parts of epilayer. The complex influence of the GaN buffer layer growth conditions on the electroluminescence spectra of InGaN/GaN heterostructures was observed.

KEYWORDS: InGaN, MOCVD, electroluminiscence

1. Introduction

Progress in III-nitrides technology on sapphire substrates results in commercialization of blue and green light emitting diodes (LEDs) and CW blue laser diodes (LDs).[1,2] InGaN/GaN single and multiple quantum wells are typically used as active region in these optoelectronic devices. The emitting wavelength and luminescence efficiency are known to depend on In content as well as on InGaN composition fluctuations in the active region which are influenced by growth temperature, cell pressure, type of carrier gas, [In]/([In] +[Ga]) gas phase ratio.

Moreover , strains induced by large III-N layer-to-substrate and layer-to-layer lattice mismatch also affect In incorporation. This is so called pulling effect.[3] It means that InGaN properties must depend not only on InGaN growth conditions but also on growth conditions of underlying layers. In this work, the influence of the GaN buffer layer growth conditions on the luminescence properties of InGaN/GaN hetrostructures was studied.

2. Growth and Characterization

The samples under investigations were grown by low pressure metalorganic chemical vapor deposition (MOCVD) on (0001) sapphire substrates utilizing an AlGaN nucleation layer deposited at a low temperature of 570°C. Ammonia, trimethylindium (TMI), trimethylgallium (TMG) and thrimethylaluminum (TMA) were applied as component precursors. Purified hydrogen and/or argon were used as carrier gases.

The structures consisted of a 1.5-3μm thick GaN:Si buffer layer grown at a high temperature of 1050°C in hydrogen ambient at 200 mBar, five period of a InGaN/GaN superlattice (SL) grown in argon ambient, and a 0.5 μm-thick GaN:Mg p-type contact layer grown at 1050°C in hydrogen ambient. During InGaN/GaN SL growth the temperature was cycled between 790°C and 900°C, TMG flow was kept constant while TMI was supplied only during InGaN layer growth at low temperature of 790°C.

The structures differ by the nucleation layer annealing conditions and/or the initial stages of high temperature GaN buffer epigrowth. The growth conditions of the rest parts of the structure (main part of GaN buffer, InGaN/GaN SL and GaN:Mg p-type contact layer) were identical. All structures were of good crystalline quality with smooth surface morphology.

The structures were characterized by electroluminescence (EL) on-wafer measurements using In contacts. *In-situ* real-time optical reflectance monitoring (ORM) was employed to control the layer thickness and surface roughness during growth.

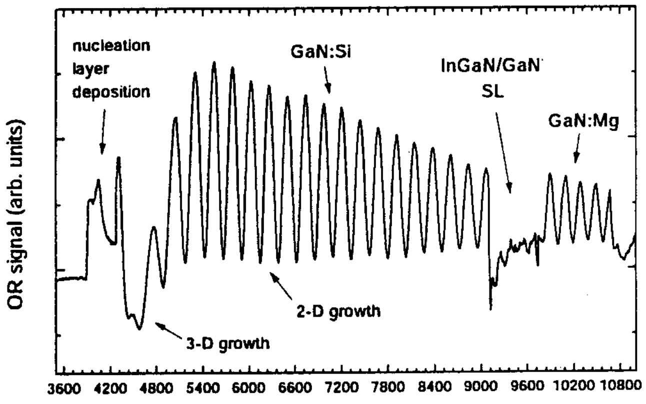

Fig. 1. Typical *in-situ* optical reflectance monitoring curve of GaN/InGaN heterostructure

3. Results and discussion

The nucleation layer deposition at a low temperature followed by its annealing is known to form the nucleation sites for epilayer growth. After the coalescence of initial islands during the GaN buffer growth under proper growth conditions, smoothing of the layer surface takes place. It leads to increase of the surface reflectivity and observation of ORM oscillations (see Fig.1.). The duration of the high-temperature growth before the surface smoothing as well as the growth rate after smoothing may be easily evaluated from the ORM curve. One oscillation correlates to GaN layer thickness of about 130 nm.

It was observed that increase of the annealing time and/or annealing temperature of nucleation layer leads to the decrease in the GaN buffer layer growth rate (see Fig.2.). Increase of the reactor pressure or reduction of the ammonia flow at the initial stages of the GaN buffer layer growth leads to the more pronounced reduction of the growth rate after the surface smoothing in addition to the very strong prolongation of the GaN growth before the surface smoothing (see Fig.3.). It should be noted that the observed changes in the growth rate were much higher than the ones due to the run-to-run irreproducibility in our growth machine. Thus, we have observed that the growth rate of GaN epitaxial layer is determined not only by TMG mass flow, but also by the growth conditions of underlying layer.

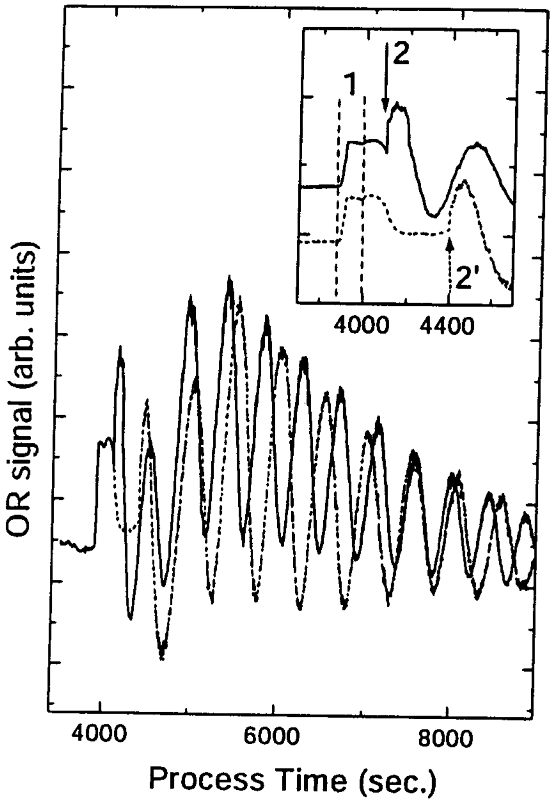

Fig.2 ORM curves for two layers with different duration of the nucleation layer annealing. 1-nucleation layer deposition; 2-start of high-temperature GaN growth after nucleation layer annealing.

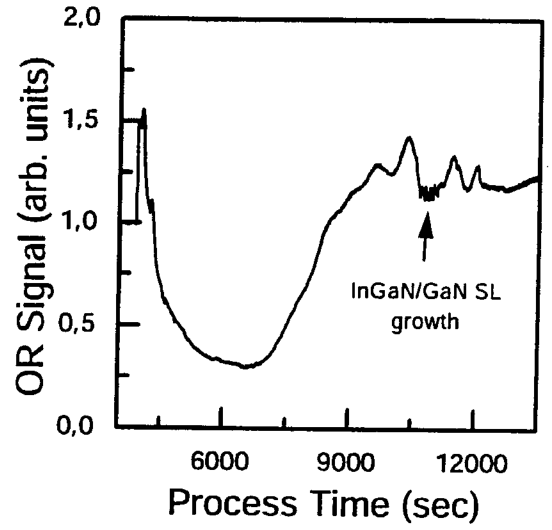

Fig.3 ORM curve for LED structure grown with increased pressure (400mBar) at first 15 min. of epigrowth.

These changes of GaN growth rate were found to be accompanied with the significant variation in the EL peak position of InGaN/GaN structures. In each set of samples differs by one parameter (nucleation layer annealing, reactor pressure or ammonia flow during the initial stage of the high-temperature GaN growth) the lower was the growth rate of GaN buffer layer the shorter was the EL wavelength. For the samples from different sets this dependence was not obligatory but the tendency was the same (Fig. 4, 5). This result can not be due to the possible simple decrease of InGaN layers thickness. It was proved by growth of structures with different thickness of InGaN layers.

To explain the obtained results, following model was proposed.

Various defects in GaN layer such as grain boundaries and/or penetrated dislocations may act as the growth initiation centers during high-temperature GaN buffer layer growth. Thus, the higher is the growth rate at the given reactor conditions, the higher was the epilayer defect density. At present we are not sure, what type of defects plays here, but the increase of the nucleation layer annealing time or temperature, the increase of the reactor pressure and the reduction of the ammonia flow during the initial stage of GaN epigrowth are thought to increase of domains size and to the decrease of the domain boundaries density.

As mentioned above, In incorporation in GaN/InGaN heterostructures significantly reduced by high level of lattice mismatch in this system (pulling effect). Therefore, GaN buffer layers with higher defect density that corresponds to higher growth rate are "softer" and allow higher level of In incorporation. The same effect was observed during InGaAs growth on porous GaAs substrates.[4]

It would be mentioned that in the EL spectra of the samples with the lowest growth rate, new long wavelength (440-510 nm) EL line is observed in addition to the main EL peak placed at 378-413 nm. The origin of this line is unknown yet. It may be a manifestation of the fundamental change of

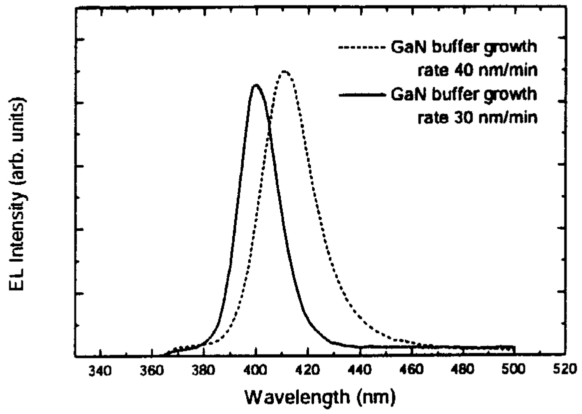

Fig.4 EL spectra of two InGaN/GaN LED structures grown with different nucleation layer annealing time resulting in different GaN buffer growth rate.

InGaN growth mode. It was published previously that growth of InGaN/GaN LED structures on low-dislocation-density GaN/SiC substrates also leads to the blue-shift of the main InGaN-related EL peak in comparison with growth on sapphire substrates and appearance of additional long-wavelength EL line.[5]

4. Conclusions

We observed that increase of the annealing time or temperature of nucleation layer annealing, increase of the reactor pressure or reduction of the ammonia flow at the initial stages of the GaN buffer layer growth leads to the decrease of the GaN buffer layer growth rate and the blue shift of EL peak position of InGaN/GaN structures.

Acknowledgements

This work was supported by the NATO SfP 972614 grant, NanOp program, Ministry of Science Project No 99-117 and RFBR

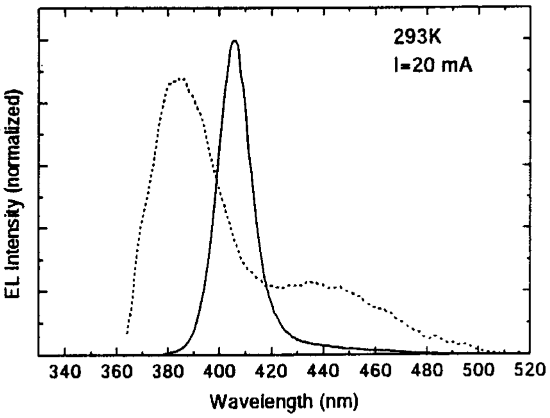

Fig.5 EL spectra of LED structures grown with (dashed line) and without (solid line) increas in pressure (400mBar) at first 15 min. of epigrowth

1) S.Nakamura, M. Senoh, N. Iwasa, S. Nagahama, T. Yamada and T. Mukai: Jpn.J.Appl. Phys., **34**, L1332 (1995)
2) S.Nakamura, M. Senoh, S. Nagahama, N. Iwasa, T. Matsushita, and T. Mukai: Appl. Phys. Lett., **76**, 22 (2000)
3) F. Scholz: EW MOVPE VII, workshop booklet, F0
4) F.Yu. Soldatenkov, V.P. Ulin, A. A. Yakovenko, O.M. Fedorova, S.G. Konnikov, and V.I. Korol'kov: Tech. Phys. Lett. **25(11)** 852 (1999)
5) V. Schwegler, C. Kirchner, M. Seyboth, M. Kamp, K.J. Ebeling, Yu.V. Melnik, A.E. Nikolaev, D. Tsvetkov, and V.A. Dmitriev: phys. Stat. Sol. (a) **176**, 99 (1999)