Influence of the thick GaN buffer growth conditions on the electroluminescence properties of GaN/InGaN multilayer heterostructures.

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Progress in III-nitrides technology on sapphire substrates results in commercialization of blue, green light emitting diodes (LEDs) and CW blue laser diodes (LDs). Single- and multi-quantum wells of InGaN/GaN structures are typically used as active region in these optoelectronic devices. There are some factors that influence In incorporation in InGaN layers. These are growth temperature, cell pressure, carrier gas, buffer layer (AlGaN or InGaN) composition. In addition, it is clear that peculiarities of InGaN growth depends also on growth conditions of underlying layers.
Here we report on the influence of GaN buffer growth conditions on the In incorporation during InGaN growth of InGaN/GaN heterostructures fixing all other parameters.
The samples were grown by low pressure metalorganic chemical vapor deposition (MOCVD) employing an AlGaN nucleation layer deposited at 570°C on (0001)-oriented sapphire substrates. 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 under investigation consist of 1.5-3 μm thick GaN:Si n-type buffer layer grown at 1050°C in a hydrogen ambient, 5 period InGaN/GaN SL grown in argon ambient, and 0.5 μm GaN:Mg p-type contact layer grown at 1050°C in a hydrogen ambient. During InGaN/GaN superlattice growth the temperature was cycled between 790^{o}C and 900^{o}C. TMG flow was constant while TMI was supplied only during InGaN growth at low temperature.
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 colorless and mirror like.
The structures were characterized by EL measurements using In contacts.
*In-sit*u optical reflectance monitoring allows us to observe the transition from 3-dimensional growth mode at the beginning of the high-temperature epigrowth to 2-dimensional growth mode and to measure the growth rate (Fig 1).

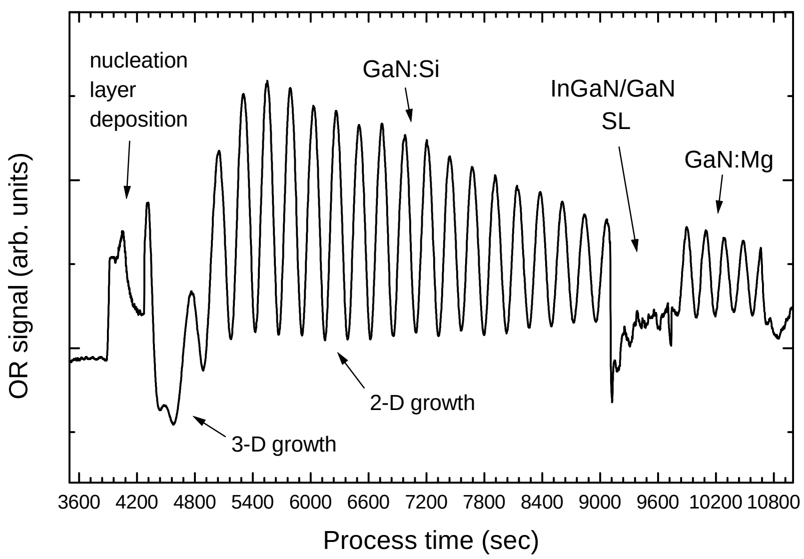

Fig. 1. Typical *in-situ* optical reflectance monitoring curve of GaN/InGaN heterostructure

It was observed that increase of the nucleation layer annealing time and temperature leads to the decrease of the high-temperature GaN growth rate. Even stronger decrease of the growth rate was observed when at the initial stages of the high temperature GaN epigrowth we increase the reactor pressure or reduce the ammonia flow. This changes of the growth regimes also leads to the significant increase of the duration of 3-dimesional growth mode. It is important to note 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.

During the EL study of the structures it was observed that the changes of GaN growth rate described above are accompanied with the significant changes in the EL peak position. 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. 2). 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.

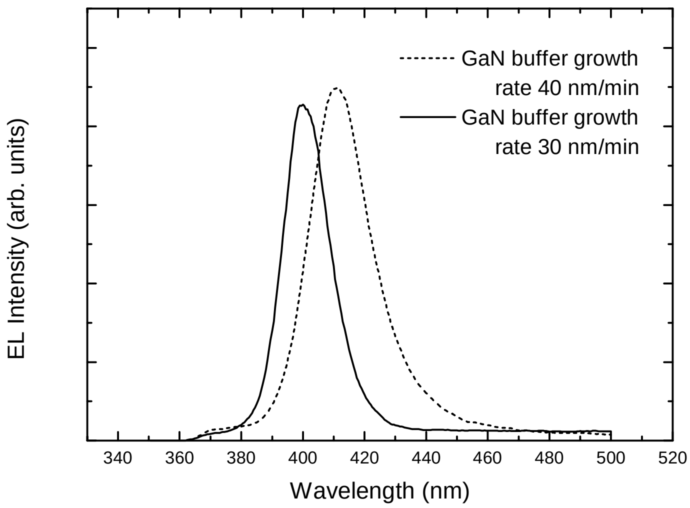

Fig.2 EL spectra of two InGaN/GaN LED structures grown with different nucleation layer annealing time resulting in different GaN buffer growth rate.

To explain the observed results we can use the follows model: various defects in GaN layer such as grain boundaries and/or penetrated dislocations may act as the growth initiation centers during high-temperature epigrowth. Thus, the higher is the growth rate at the given reactor conditions, the higher is the epilayer defect density (at present we are not sure, what type of defects plays role here, but in accordance with our understanding of GaN growth on sapphire the increase of the nucleation layer annealing time, the increase of the reactor pressure and the reduction of the ammonia flow during the initial stage of GaN epigrowth leads to the increase of domains size and, thus, leads to the decrease of the domain boundaries density.). It is well known that In incorporation in GaN/InGaN heterostructures is significantly reduced by high level of lattice mismatch in this system (pulling effect).

The GaN epilayers with higher defect density are “softer” and allow higher level of In incorporation. The same effect was observed during InGaAs growth on porus GaAs substrates.

It would be mentioned that in the EL spectra of the samples with the lowest growth rate, new long wavelength (490-510 nm) EL line is observed in addition to the main EL peak placed at 378-413 nm. The origin of this line is unknown jet. It may be a manifestation of the fundamental change of InGaN growth mode.

Thus, we have observed the complex influence of the epilayer defect structure on the EL spectra of InGaN/GaN heterostructures.