Control of properties of InGaN/GaN structures by growth sequence variation

Alexey V. Sakharov, Denis V Davydov, Wsevolod V. Lundin, Andrew E. Nikolaev, Oleg S. Usov, Maria A. Yagovkina, Eugeni E. Zavarin and Andrew F. Tsatsulnikov

Ioffe Physical-Technical Institute, Politekhnicheskaya 26, St.-Petersburg, Russia

Although high-efficiency LEDs have been created and a huge number of papers have been published on the stability and internal structure of InGaN layers, a clear picture has not yet evolved. Theoretical works are controversial: one claims that homogeneous alloy is unstable [1], another that growth of homogeneous thin films is possible for rather high In concentrations [2]. In many experimental works it was noted that InGaN have a tendency to phase separation, and this can be favorable or not depending of device application.

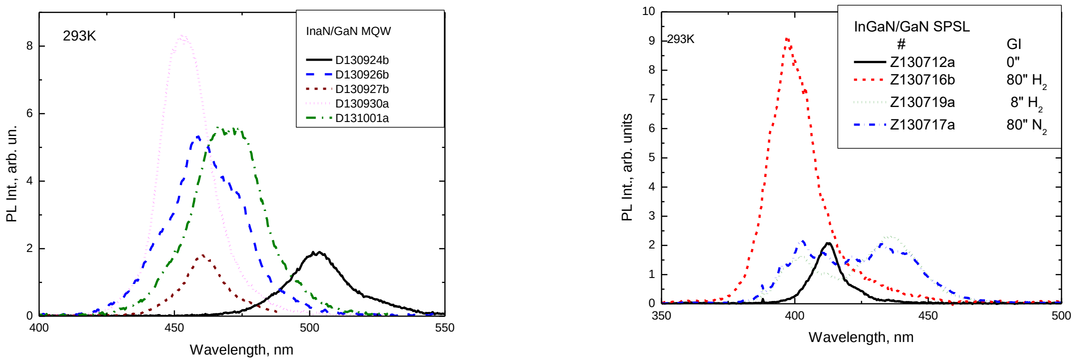
In this work, we report on an investigation of the effect of growth interruption time and ambient as well as other growth conditions on the optical properties of InGaN/GaN multilayer structures grown by MOVPE, including QWs and short-period superlattices (SPSLs).

Growth was performed on AIX2000HT and Dragon125 growth systems with rotating inductively heated graphite susceptor using GaN/sapphire templates and standard precursors. Details of growth can be found in [3]. Structures were characterized by X-ray diffractometry and photoluminescence (PL) using 325 nm line of CW He-Cd laser for excitation; LED testing (electroluminescence spectra and L-I-V curves) was performed on-wafer using indium contacts. Different kind of optical and LED structures emitting in the optical range of 400-560 nm were studied, with active region composed of SQW, MQW, SPSL or their combination. InGaN/GaN SPSLs were formed by specially developed growth sequence comprised of InGaN deposition and growth interruption (GI) [4].

Figure 1(a) shows room temperature PL spectra recorded for series of samples comprised of 5 InGaN QWs separated by 8 nm GaN barriers; sample parameters are summarized in a table below. Initial sample has 4 nm QW thickness and average In composition in active region ~5% (15% In composition in QW) and PL peak around 500 nm; we apply different approaches to shift emission to 460 nm by applying GI after QW growth, changing QW thickness and In composition. It can be seen that resulting structures have very different properties, though close emission range. Structures with GI have broad spectra (spectral width is higher than for initial sample) and relatively low average In composition in active region, structures without GI have narrow spectra. GI leads not only to InGaN decomposition with In evaporation, but to some redistribution of In atoms with formation of inhomogeneities. GI in H2-containing and H2-free ambient have nearly same effect, but process in the presence of hydrogen comes faster. Activation energy derived from temperature dependent PL study shows that maximal carrier localization and thermal stability have samples with GI, minimal – sample with thick QW. LED samples with QW active region formed with GI have 2-3 times higher efficiency for the same wavelength as compared with “plain” QW LEDs.

Figure 1(b) shows PL spectra for series of a 24-period SPSLs samples with total 60 nm thickness with different GI. Initial sample is “bulk” InGaN with 10% In composition. Introducing of long (80 secons) GI in H2-containing ambient results in short-wavelength shift and strong PL intensity increase with average In composition drop to 3.2%. It should be noted that PL peak of this sample is red shifted in respect to bulk InGaN of the same composition, so we can not say that GI results only in In evaporation. Much more interesting results were obtained for short GI in H2-containing and long GI in H2-free ambient: average

In composition was 5%, and besides short-wavelength shift of main PL peak a second peak arises with sufficiently *longer* wavelength, and again we have same effect of indium redistribution, but with shorter times in presence of hydrogen. Absolutely the same situation was observed for samples with initial 16% In composition, and even PL from second peak can be dominant with maximum at ~500 nm. LED samples with such SPSL active region have lower efficiency in comparison with MQW LEDs, but they were not optimized.



a

b

Fig.1 PL spectra of InGaN/GaN MQW (a) and SPSL (b) samples grown with different growth sequences

Table 1 Growth parameters and properties of InGaN/GaN MQW samples

##	nominal QW thickness, nm	QW growth T, ºC	GI time, sec	GI ambient	<In>, %	PL peak, nm	PL FWHM, nm	Ea, meV
D130924b	4	760	0	-	4.9	503	24	27
D130926b	4	760	18	H2	1.3	461	28	56
D130330a	4	782	0	-	3.6	454	18	16
D130927b	2.5	760	0	-	3.5	461	17	28
D131001a	4	760	256	N2	2.0	470	26	56

To conclude, it was demonstrated that growth interruptions after InGaN deposition can form localizing centers with high luminescence efficiency, possibly by mass processes in near surface region. Practical application of this effect will be further disussed.

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