Consequences of lateral and horizontal point defects diffusion through interfaces in green semiconductor lasers based on InAlGaN grown on substrates with different dislocation density

E. Grzanka1,2, R. Hrytsak1, Sz. Grzanka1,2, A. Lachowski1, M. Grabowski1, L. Marona1,2, P. Michałowski3, R. Czernecki1,2, J. Smalc-Koziorowska1,2, M. Leszczyński1,2

1 Institute of High Pressure Physics, Polish Academy of Sciences, Sokolowska 29/37, 01-142 Warsaw, Poland
2 TopGaN LTD., Sokolowska 29/37, 01-142 Warsaw, Poland
3 Łukasiewicz Research Network - Institute of Microelectronics and Photonics, Wólczynska 133, 01-919 Warsaw, Poland

Email of communicating author: ewa.grzanka@unipress.waw.pl

Inside InGaN Quantum Wells (QW), 2.1nm thick, grown by MOCVD method and used in deep blue and green Light Emitting Diodes (LED) and Laser Diodes (LD) emitters as their active part, In concentration fluctuation are very often present. In fluctuation are associated with point defects presence, especially complex VIn–In. It is known that amount and size of In fluctuation increase with In content in QWs, being a big problem especially in green emitters. Presence of Indium fluctuation inside QWs can contribute to shortening of optical devices lifetime, decreasing of their efficiency and significantly reduce temperatures at which QWs get decomposed.

In semiconductor Laser Diodes, P-type layers are grown over the InGaN QWs, typically at temperatures much more higher (it can be even at 1000°C) than QWs growth temperatures (710°C – 780°C depending on desired In content). During LED and LD structure growth, it is extremely important to properly establish p-type growth temperature since too high temperature (>1000°C) leads to the decomposition of QWs due to diffusion of point defects from the substrates to QWs but too low temperature (<900°C) causes worsening of p-type conductivity. In this work we show that at medium growth temperatures range of p-type layers, i.e. around 900-940°C, homogenization process of QWs, grown on sapphire template, take place. It leads to improvement of the properties of the emitted light – full width of half maximum of the emitted spectra decrease and optical power increase. In case of the QWs grown on bulk GaN substrate (with the same In content and width as QWs grown on sapphire template) we don’t observe phenomenon of the homogenization of QWs. As consequence, process of decomposition of the QWs take place at little bit higher temperature – around 20°C more, however is much more violent - degree of decomposition in short time become huge and decomposition of the subsequent QWs occurs faster than in case of sapphire template. All described above phenomenon were investigated using a combination of High Resolution X-ray Diffraction (HR-XRD), Photoluminescence (PL), Electroluminescence (EL), Transmission Electron Microscopy (TEM) and Cathodoluminescence (CL). The experimental results were supported by theoretical calculations (first principles studies), especially concerning diffusion of point defects through the GaN/InGaN interfaces. Process of indium concentration homogenization in QWs is possible due to lateral diffusion mainly of In vacancies (VIn) but also Ga vacancies (VGa) during the p-type layers growth. Decomposition occurs when vertical diffusion of VGa take place from substrate towards the QWs, through up to 10 kinds of interfaces.

Explanation of the above mentioned differences in homogenization and decomposition process is fact the bulk GaN substrates had much lower dislocation density compare to sapphire template (10⁴ vs. 10⁸). It is known that close to dislocation can be much more point defects than in some distance away from them and also In distribution in QWs is disturbed by threading dislocation. This mean that in case of QWs grown on bulk substrate distribution of In atoms and diffusion of point defects is much more homogenous – hence lack of the homogenization process observed in EL measurement in case of bulk substrate as the evidence that In fluctuation are smaller. In this work we also show that close to threading dislocation QWs are much more decomposed that in larger distance from dislocation. However in case of bulk substrate, due to lower dislocation density they don’t constitute any border for decomposition and this process can occur without any disruptions or limitations. These results are very important for optimization of the MOVPE growth of deep blue and green emitters. Due to cost very often optimization is carried out on sapphire template and only devices growth take place on bulk substrate.


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