Correlations between MOVPE process recipes, material properties, and performances of blue and green LED structures

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III-nitride electronic and optical devices (LEDs, lasers, transistors) are being actively developed these days in order to achieve higher performance and lower cost that would enable their wider adoption for different applications. Aside from the device design, much effort is focused on tuning and refining the conditions and recipes used to grow epitaxial structures with desired properties. Optimization of growth conditions and choice of the best epi procedure for obtaining high quality materials with targeted composition and doping levels is rather non-trivial. Changing such parameters as the reactor pressure, carrier gas composition, precursor flow rates, and growth temperature, as well as the use of special procedures like growth interruptions and thermal ramping is known to impact strongly the performance of nominally the same device structure. Depending on particular recipe and structure design, modifications of the growth conditions may induce changes in compositional and structural properties of the grown materials, affecting distributions of strain, defect density, and dopant concentrations in the heterostructure. In turn, this may lead to dramatic changes in optical and electrical device characteristics. Detailed understanding and quantification of correlations between the growth recipes and device performances is a key factor providing successful optimization of epitaxial technology.

In this paper we analyze MOVPE of advanced LED structures by coupled *process-device modeling*. Different process recipes to grow active region of the device were studied. The major attention is paid to the effect of process recipe on indium composition distribution in the active region. A number of approaches like indium pre-deposition, growth interruption, and temperature ramping while growing the barriers are tested to reveal their effects on the active region composition profiles. Correlations between these profiles in blue and green LED structures and device characteristics are discussed in the paper. Special attention is paid to analysis of LED structures with short-period superlattice (SPSL) active regions that provide improved quantum efficiency, reduced efficiency droop, and high emission wavelength stability with current. Performances of the structures corresponding to various growth recipes are also compared to reveal the most promising ways for control of indium composition profile and its impact on operation of the grown LED structures.

Supplementary information

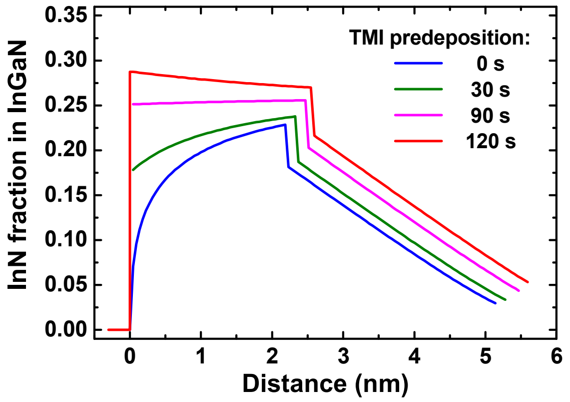


Fig.1 Effects of indium predeposition on the composition profiles of a single InGaN/GaN quantum well with 15 s growth interruption after InGaN well growth and temperature ramping for GaN cladding deposition.

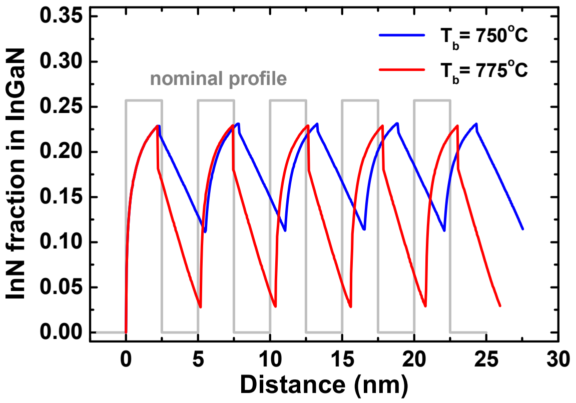
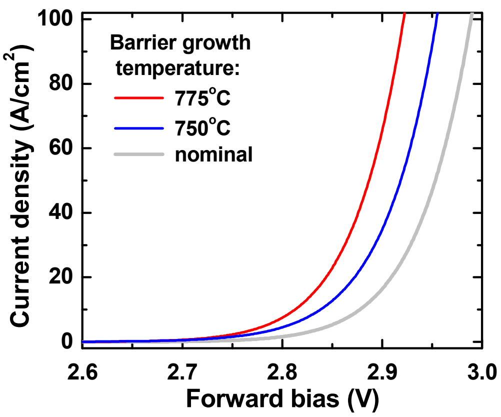
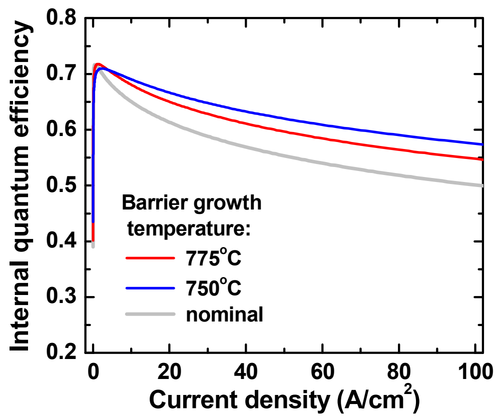


Fig.2 Simulated InGaN composition profiles in the SPSL active region with InGaN quantum well grown at 750°C and GaN barriers grown under different conditions: (i) 15 s interruption and growth at 750°C and (ii) 15 s interruption and growth at 775°C. Grey line shows the nominal composition profile.





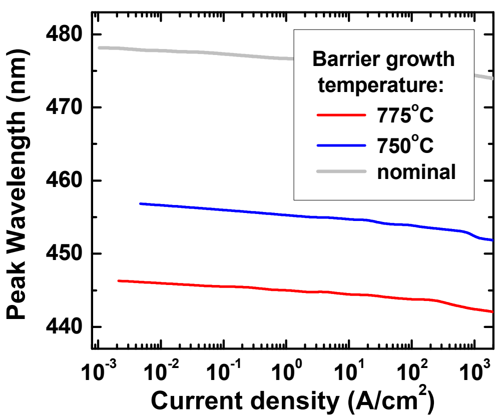


Fig.3 Current density-voltage characteristics of SPSL LED structures corresponding to different growth recipes, and their IQE and emission wavelength dependences on the current density computed with account of the realistic composition profiles obtained from modeling indium surface segregation.