Optical Materials 82 (2018) 71–74

Contents lists available at ScienceDirect

Optical Materials

journal homepage: www.elsevier.com/locate/optmat

Optimization of growing green-emitting InGaN/GaN multiple quantum wells on stress-relieving superlattices

J. Mickevičius*, T. Grinys, A. Kadys, G. Tamulaitis

Institute of Photonics and Nanotechnology, Vilnius University, Saulėtekio al. 3, LT-10257, Vilnius, Lithuania

ARTICLE INFO

Keywords:
III-Nitrides
InGaN
MOCVD
SPSL
Photoluminescence
Carrier localization

ABSTRACT

Optimization of photoluminescence intensity of green-emitting InGaN/GaN multiple quantum wells deposited on a template consisting of low-indium-content short-period superlattice was studied by growing the structures at different temperatures for active layer and template. The importance of carrier localization is revealed. The temperatures for growing the template and the active layer predominantly influence large-scale and small-scale potential fluctuations experienced by nonequilibrium carriers, respectively, while the difference between the temperatures impacts the formation of nonradiative recombination centers, and has to be maintained small to ensure high photoluminescence intensity.

1. Introduction

InGaN-based emitters in deep green region are sought for light-emitting diodes (LEDs) and especially for laser diodes, which are in demand for color picoprojectors [1]. However, the incorporation of a higher In content to shift the emission into the longer wavelengths encounters substantial difficulties due to low quantum efficiency caused by structural quality in general and strain at the interfaces between buffer and active layer and quantum well and barrier in particular. The low-indium-content short-period superlattice (SPSL) has been widely used as a strain-relief layer between GaN buffer and InGaN/GaN multiple quantum well (MQW) active region in InGaN-based light-emitting structures [2–8]. The improvement of optical and electrical properties [3,5–7] as well as a smaller blue shift of the emission band with increasing carrier injection, which was attributed to the decrease of internal polarization field [2,4–6], have been demonstrated in the structures containing SPSL. On the other hand, a stronger localization effect and a larger depth of the localized states have also been reported [2,3].

The SPSL on top of a thick GaN buffer can be prepared as an effective template used for the further growth of an InGaN/GaN MQW active region. Variation of the SPSL growth conditions as well as the structure of the SPSL might be used to purposefully modify the properties of the active region, and several approaches have been reported: using SPSLs with different In content [4] or different well and barrier thickness ratio [3,5], gradually changing In content within the same SPSL [6,7], growing SPSLs at different temperatures [8] or gradually varying the growth temperature [7]. In most cases, however, the effect of the SPSL template on the active region has been straightforwardly attributed to strain relaxation.

Recently, we have shown that decreasing the growth temperature of SPSL allows for varying the emission band of InGaN/GaN MQWs in a wide spectral range by just a small change in the growth temperature of the active region [9]. However, a strong red shift of the emission band was shown to be caused by increasing tail in the energy distribution of localized states [9], while the carrier recombination peculiarities were affected by the significant transformation of the localizing potential landscape [10]. In this work, we continue our previous study and discriminate the impact of the SPSL and MQW growth conditions on the optical properties of InGaN/GaN MQWs with a focus on the energy distribution of localized states.

2. Experimental

Fig. 1(a) shows a schematic view of the InGaN/GaN MQWs structures studied. Each epitaxial layer was grown on a c-plane (0001) sapphire substrate using metalorganic chemical vapor deposition (MOCVD) in a close-coupled showerhead 3 × 2″ reactor (AIXTRON). Trimethylgallium (TMGa), trimethylindium (TMIn), and ammonia (NH_3) were used as Ga, In, and N precursors, respectively. N_2 was used as ambient and carrier gas. Initially, a 1.7-μm thick undoped GaN layer followed by a 2-μm thick n-type GaN layer with a doping concentration of 3×10^{18} cm^{-3} were grown at 1080 °C. On top of the GaN buffer, the strain-relieving SPSL templates consisting of 8–15 periods of alternating low-In-content $In_xGa_{1-x}N$ (x = 4–7%) and GaN layers were grown by modulating the flow of In precursor, as shown in Fig. 1(b). The

* Corresponding author.
E-mail address: juras.mickevicius@ff.vu.lt (J. Mickevičius).

https://doi.org/10.1016/j.optmat.2018.05.047
Received 30 March 2018; Received in revised form 3 May 2018; Accepted 16 May 2018

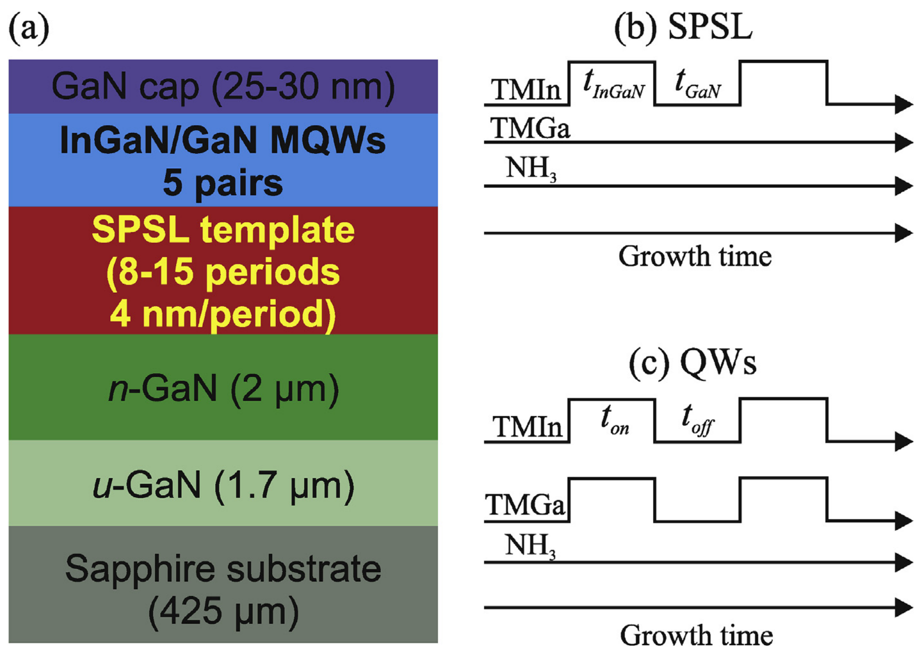

Fig. 1. Schematic diagram of InGaN/GaN MQWs structure with an InGaN/GaN SPSL template (a), flow charts of metalorganic precursors and ammonia used when growing SPSLs (b) and MQWs (c).

thickness of one superlattice period was 4 nm. The temperature of the SPSL growth was varied in the range from 880 to 800 °C, several of the structures were grown using gradually decreasing temperature (within 20 °C). The final layer of the SPSL was a 1–2-nm thick GaN layer. The active layer consisting of five InGaN/GaN MQWs was subsequently deposited. The quantum wells (QWs) were grown using a pulsed growth regime, which was accomplished by modulating the flow of In and Ga precursors into the reactor chamber, while maintaining the flow of NH_3 constant [see Fig. 1(c)]. Both metalorganic precursors have been delivered synchronously for the duration of 15 s (t_{on}) and the delivery pulses have been followed by 12 s long pauses (t_{off}). Several samples were grown using slightly longer pulses of 20 s. The NH_3 flow was kept at 0.268 mol/min, while TMIn and TMGa flows during t_{on} were 1.1×10^{-5} and 3.2×10^{-6} mol/min, respectively. The growth temperature of QWs was varied in the range from 820 to 770 °C. The GaN barriers were grown in the usual constant-flow regime at higher grown temperatures of 830–850 °C. A thin (25–30 nm) GaN capping layer was grown on top of active layer. A total of 28 samples were studied.

The structures were characterized using photoluminescence (PL) spectroscopy at room temperature. CW He-Cd laser (325 nm) and the 3rd harmonic (355 nm) of the Q-switched YAG laser radiation (pulse duration 4 ns) were used for low- and high-intensity excitation, respectively. The luminescence signal was analyzed by a double monochromator (Jobin Yvon HRD-1) and detected by a photomultiplier (Hamamatsu).

3. Results and discussion

The PL spectra for several InGaN/GaN MQW structures emitting at different wavelengths are presented in Fig. 2. As a result of the variation in temperatures for growing SPSLs and QWs, the PL band peak position varies from 2.0 to 2.8 eV with a general trend that the decrease of either of the temperatures results in a red shift of the PL band. On the other hand, the effect of the growth temperatures on the PL intensity is ambiguous: the PL intensity increases when using lower temperatures to grow the SPSL template or higher temperatures to grow the MQWs. Meanwhile, the full width at half maximum (FWHM) of the PL band increases when decreasing the SPSL growth temperature and shows no correlation with the MQW growth temperature.

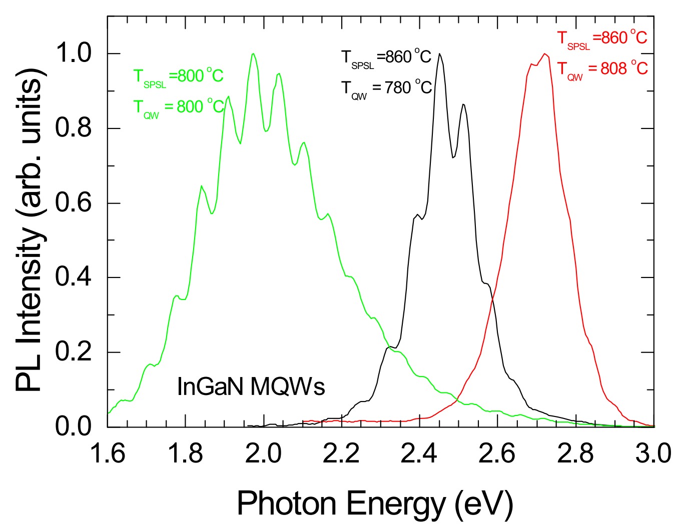

Fig. 2. Normalized PL spectra of three samples grown using different temperatures (indicated) for deposition of SPSL template and InGaN/GaN MQW active layer.

As discussed in our previous study of the samples selected from this large set, the red shift of the PL band is mainly due to the strongly increasing tail in the energy distribution of localized states with a small contribution due to a slight increase in the QW width [9]. The peculiarities of the localizing potential manifest themselves mostly through the peak position shift and inhomogeneous broadening of the PL band [14]. To discriminate the influences of the SPSL and MQWs growth conditions, we plot the data on peak position and FWHM as contour plots, shown in Fig. 3.

The role of the growth temperature of InGaN QWs is typically associated with the control of In content, and lower growth temperatures are favorable for higher In incorporation [11]. However, the structural analysis revealed very similar In content in the InGaN QWs grown at temperatures in the range 800–810 °C (see Ref. [9] for more details), which points to the mass transport limited growth regime [12], and implies that further decrease of growth temperature does not change