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A.F. Tsatsulnikov, W.V. Lundin, A.V. Sakharov, E.E. Zavarin, S.O. Usov, et al.. Deep green and monolithic white LEDs based on combination of short-period InGaN/GaN superlattice and InGaN QWs. PHYSICS OF SEMICONDUCTORS: 30th International Conference on the Physics of Semiconductors, 2011, Seoul, France. pp.253-254, 10.1063/1.3666350 . hal-01736043

HAL Id: hal-01736043

<https://hal.science/hal-01736043>

Submitted on 23 Mar 2018

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Citation: [AIP Conference Proceedings](#) **1399**, 253 (2011); doi: 10.1063/1.3666350

View online: <https://doi.org/10.1063/1.3666350>

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Deep Green And Monolithic White LEDs Based On Combination Of Short-Period InGaN/GaN Superlattice And InGaN QWs

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Abstract. This work presents the results of the investigation of approaches to the synthesis of the active region of LED with extended optical range. Combination of short-period InGaN/GaN superlattice and InGaN quantum well was applied to extend optical range of emission up to 560 nm. Monolithic white LED structures containing two blue and one green QWs separated by the short-period InGaN/GaN superlattice were grown with external quantum efficiency up to 5-6%.

Keywords: LED, superlattice, quantum well, MOCVD.

PACS: 81.07.Ta, 81.05.Ea, 85.60.Jb, 81.15.Gh

INTRODUCTION

LEDs with emission wavelength >530 nm have poor efficiency due to many problems such as quality of the InGaN layers with high In content, quantum confined Stark effect and Auger processes which also becomes stronger with InGaN composition increase. But development of such LEDs is very important for new generation of multi-color light emitters including smart-white RGB light sources for SSL [1]. In this paper we report significant improvement of deep-green LED properties by modifications of structure design and development of monolithic white LEDs.

EXPERIMENT

The investigated LED structures were grown in AIX2000HT system with 6 x 2" planetary reactor on (0001) sapphire substrates. Active region of deep green LEDs contains single 3 nm thick InGaN layer deposited on InGaN/GaN short-period superlattice (SPSL). The SPSL contains 12 periods and was formed by InGaN-conversion technique [2-4]. InGaN QW and SPSL were separated by GaN barrier grown at the same temperature as SPSL. Monolithic white

LED contains in active region one green InGaN QW and two blue QWs separated by the same SPSL. Grown structures were investigated using spectroscopy of photo- and electroluminescence, high-resolution transmission electron microscopy.

RESULTS AND DISCUSSION

Because recombination of carriers occurs in the last QW, conventional design of the LEDs active region includes top InGaN QW deposited on set of bottom QWs having lower In content or thick low content InGaN layer. To improve structural properties of the active region of deep green LEDs we proposed to replace such structure with the single InGaN QW deposited on top of short-period 1 nm InGaN / 1 nm GaN SPSL. It was shown that using of this design of active region leads to the increase of the maximal emission efficiency up to 16% at 540 nm and up to ~8% at 560 nm (Fig. 1).

For growth of the short period InGaN/GaN superlattice method of cycle conversion of the InGaN layer to GaN by applying of growth interruptions in hydrogen atmosphere was used.

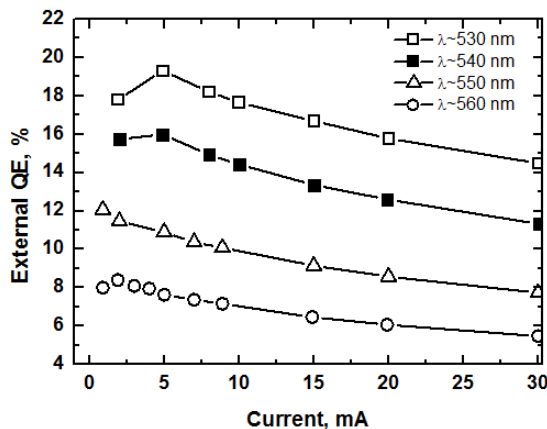


FIGURE 1. Quantum efficiencies of the green LEDs..

Detail investigations of the properties of these SPSL by high resolution transmission electron microscopy (HRTEM), XRD and photoluminescence revealed formation of periodical InGaN/GaN structures with rough interfaces and regions with coalescence of neighboring InGaN layers (Fig. 2). These regions are non-correlated in the vertical direction. The coalescence of neighboring InGaN layers results in the dependence of a PL line shape of the SPSL on the number of periods in the 400–470 nm spectral range. It was shown that such SPSL allows to improve structural properties and carrier transport in the InGaN active region [2, 3].

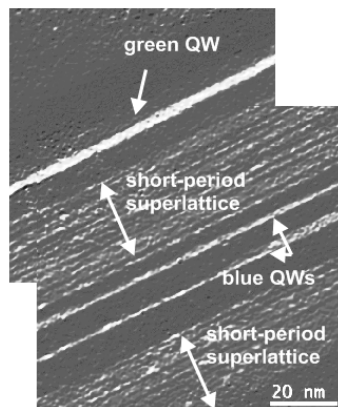


FIGURE 2. HRTEM image of the active region of the monolithic white LED.

The approach based on combination of the SPSL with InGaN QWs was applied for development of effective monolithic white light emitters [5]. This LED contains short period InGaN/GaN superlattice as barrier layer between InGaN QWs emitting in blue and yellow—green ranges (HRTEM image of the active

region of the monolithic white LED is shown in the Fig. 2). Optical properties of such structures were studied and it was shown that using of this SPSL allows realization of effective emission from the all active InGaN layers despite on significant (24 nm) distance between blue and green QWs. White light emission with maximal external quantum efficiency of ~5-6% and CCT in the range of 6000 - 7600 K was demonstrated from these LEDs (Fig. 3).

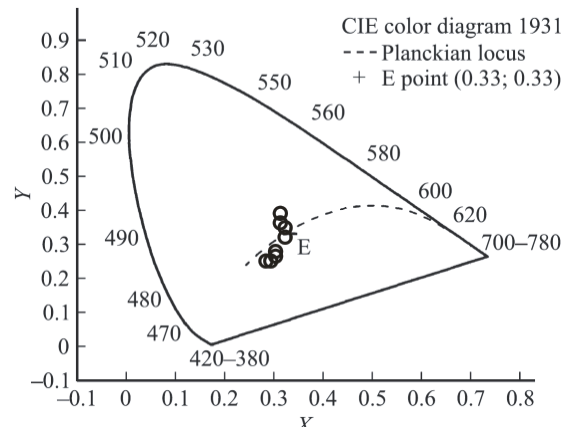


FIGURE 3. CIE color diagram of the monolithic white LED.

ACKNOWLEDGMENTS

This work was supported by RFBR grants 09-02-12449 and 10-02-01044-a.

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