Simulation of Full-Color III-Nitride RGB LED

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Abstract—**Full-color III-nitride light-emitting diode (LED) with complete covering of standard red-green-blue (RGB) optical emission spectrum is demonstrated. Intermediate carrier blocking layers (ICBLs) are introduced into multi-quantum well (MQW) active region of III-nitride multi-color LED to control the carrier injection distribution among the optically active quantum wells (QWs) with different emission wavelengths. Strong interdependence between ICBL parameters and active QW characteristics represents the main challenge for the full-color LED design and implementation. We show that ICBLs are essential elements of full-color RGB LED design requiring optimization both in material composition and doping level. Prototype ICBL-LED structure has been grown at Ostendo Technologies Inc. demonstrating tunable full-color operation.**

Keywords—light emitting diodes; multiple quantum wells; carrier injection; optoelectronic device modeling; numerical simulations.

I. INTRODUCTION

Multiple-wavelength emission from a monolithic LED structure is highly desirable for variety of applications. However, in commonly used MQW LED structures, the distribution of electrons and holes injected from opposite sides of the active region is hard to control, so that the output color spectrum coverage in multi-color LEDs remains limited. Intermediate carrier blocking layers (ICBLs) adjacent to optically active QWs have been recently proposed for tailoring the output color spectra in multi-color LEDs [1]. In this work, using numerical simulation, we show that ICBLs with optimized compositions and doping levels can provide necessary balance between electron and hole supply to optically active QWs and ensure full RGB spectrum coverage within practically important injection range up to 50 A/cm^2.

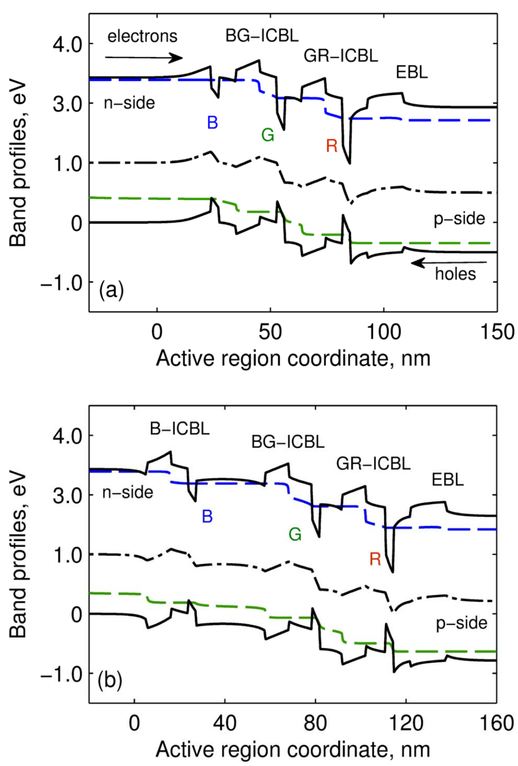

Fig. 1. Band-edge profiles of RGB LED active regions at nominal injection 20 A/cm^2. (a) two-ICBL layout. (b) three-ICBL layout with extra B-ICBL on the n-side of the structure.

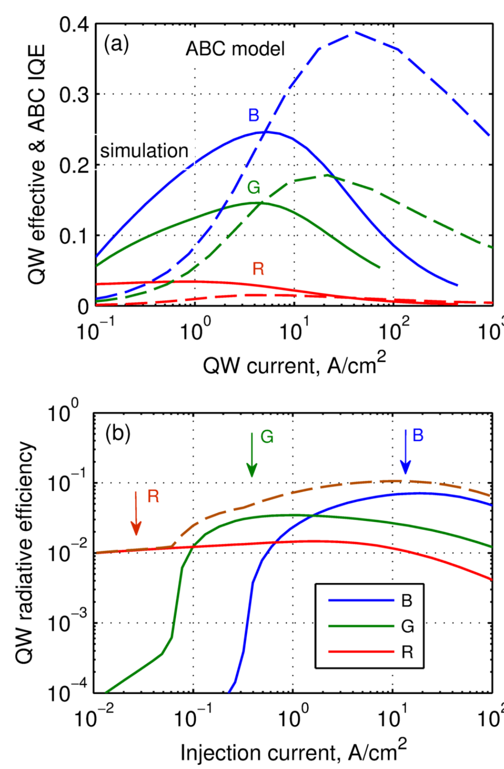

Fig. 2. Active QW emission characteristics: (a) IQE of different QWs in full simulation (solid) and calculated in ABC model (dashed). (b) QW radiative efficiencies vs total LED injection current.

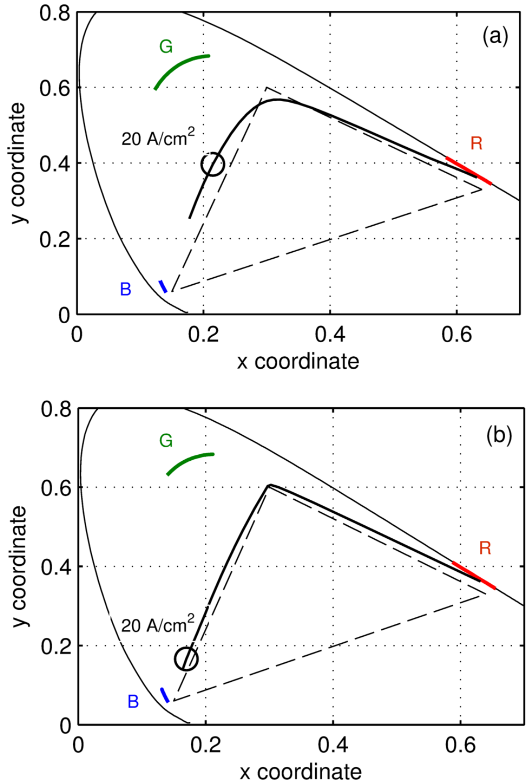

Fig. 3. RGB color gamut coverage: (a) two-ICBL layout; (b) three-ICBL layout with extra B-ICBL on the n-side of the structure. Circle marker indicates nominal injection current of 20 A/cm^2

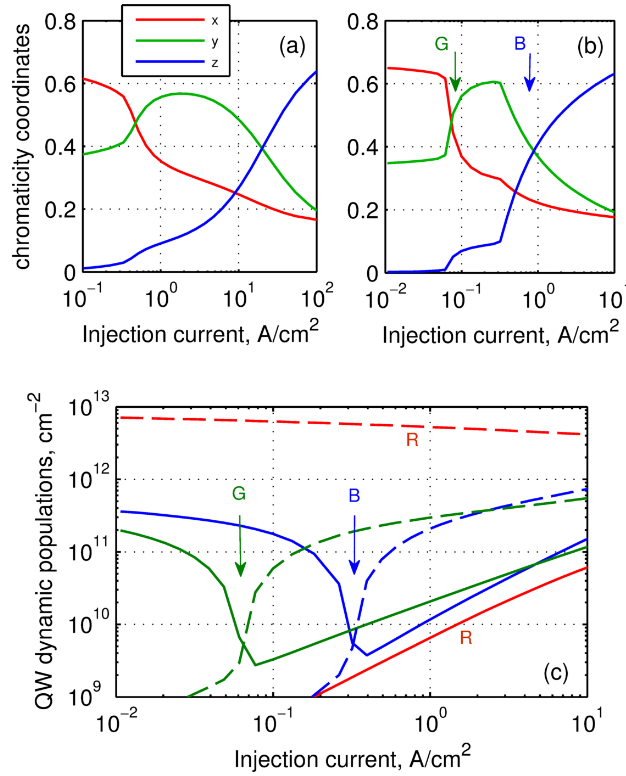

Fig. 4. Top: injection dependence of CIE chromaticity coordinates x, y, and z; (a) two-ICBL layout, (b) three-ICBL layout. Bottom: (c) electron-hole population swap in blue- and green-emitting QWs (3-ICBL layout).

II. Simulation Results

Figure 1 shows active region band profiles in three-color RGB ICBL-LEDs with basic two-ICBL and optimized three-ICBL active regions.

Figure 2 shows emission characteristics of active QWs in simulated structures: Subplot (a) compares IQE of different QWs obtained by full simulation (solid lines) and calculated in ABC model (dashed lines). Subplot (b) presents QW injection dependence of QW radiative efficiencies in three-ICBL RGB LED. Optimized structure demonstrates well-defined regions of RGB color succession, i.e. red, green, and blue color dominance at successively higher injection current.

Figure 3 compares CIE chromaticity diagrams for both simulated structures and illustrates the main effect of ICBL design optimization. Optimized three-ICBL LED demonstrates full coverage of RGB color spectrum. Lower and upper limits of injection current used in CIE diagrams are, respectively, 50 mA/cm^2 and 50 A/cm^2 Colored lines around the corners of standard RGB gamut (dashed-line triangle) show the evolution of individual QW emissions (QW emission blue-shift).

Figure 4 presents corresponding injection dependencies of CIE chromaticity coordinates (upper subplots). Lower subplot (c) illustrates the physics behind the operation of the optimized device. The process of QW electron-hole population swap [2] indicated in subplot (c) by arrows is accompanied by a sharp increase of corresponding QW emission illustrated by subplot (b). Non-equilibrium dynamic populations of RGB QWs are affected by difference in QW confinements [3] and strongly depend on MQW injection conditions [4]. As a result, MQW injection distribution engineered by ICBL active region design provides for three strictly separated regions of dominating colors presented in Figure 2(b).

Prototype monolithic ICBL-LED has been grown recently at Ostendo Technologies Inc. [1]. For simulations we use COMSOL-based software package developed at Ostendo Technologies Inc. [2]

References

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