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Design And Simulation Of Multiple Quantum Well Based White Led

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Abstract: ***This paper presents a review of design and simulation of multiple quantum well based white LED. The commonly used material for white led is InGaN, which is highly efficient. However, the development of high-brightness GaN based LEDs is handicapped by a significant factor named 'efficiency droop'. This efficiency droop is mainly due to leakage current and less recombination. In order to reduce leakage current, multiple quantum wells and Electron Blocking Layer are used and recombination rate is increased by adding proper indium composition. So, GaN based light-emitting diodes are currently of immense interest for applications in lighting, displays, sensing, biotechnology, medical instrumentation, and other areas due to its energy saving nature.***

Index terms: White LED, Multiple Quantum Well, Efficiency droop, Leakage current, Electron Blocking Layer.

I. INTRODUCTION

The major backlight units in display screen have changed into the lighting emitting diode to reduce the energy consumption and increase the luminous efficacy. The transparent flexible paper-based display serves as an active device to achieve less energy consumption in display for lighting in handheld consumer electronics[8-9]. There are many different materials that can be used for electroluminescence (EL) emission. In this paper, we focus on the group III-V semiconductor alloys. This high-brightness blue LED is later combined with the yellow emission phosphor Y3Al5O12:C to generate the white light LED[1-4].We have fabricated InAlGaN based MQW UV-LEDs fabricated on GaN substrates and achieved an UV output power of 7.4 mW at 352 nm [11]. An external quantum efficiency (EQE) of 1.1% has also been obtained from the quaternary InAlGaN based UV-LED fabricated on GaN substrate, which is the highest EQE ever obtained for 350 nm band UV-LEDs with top-emission geometry[11,12]. The invention of white light LED has opened up the field of solid state lighting. With its low energy consumption, extensively long lifetime, and potential for visible light communication, high-brightness LEDs have drawn huge attention in the past ten years. Early LEDs emitted low-intensity infrared light whereas modern LEDs are available across the visible, ultraviolet, and infrared wavelengths, with very high brightness.

II. LED STRUCTURE

The table shows the different grading profiles simulated in this work. It can be noticed that grading of the In content generally requires slightly higher maximum In concentrations compared to the square well.

Layers	Materials used
Substrate layer	Sapphire
Buffer layer	u-GaN
Electron layer	n-GaN
Active layer	InGaN/GaN

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Electronblocking layer	AlGaN
Hole layer	p-GaN

Table 1: Materials used in different Layers

The device is designed with the sapphire substrate as the first layer and followed with the buffer layer as undoped GaN which will give proper lattice match. Then n-GaN layer is placed, which will produce electrons. Electrons has the high mobility and moves towards the holes region through active region. The active region is made up of 6 periods of multiple quantum wells with the material InGaN/GaN layers. After MQW layer, Electron barrier layer is introduced, it will reduce the electron leakage from the barrier.

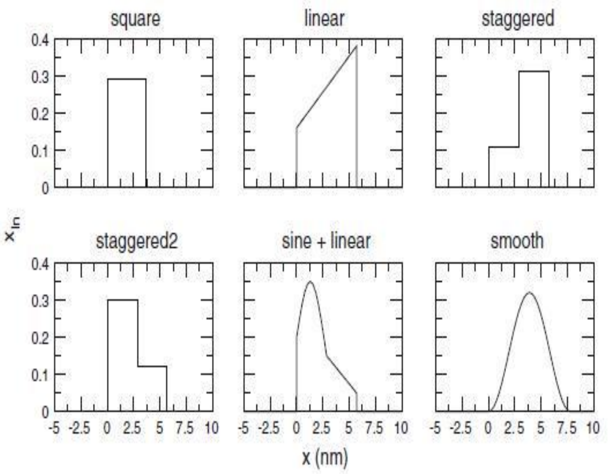

Figure 1: Grading profiles

The flow of energetic electrons flying over the active region (without being captured) to recombine with holes in p-type GaN or at the p-type contact electrode, i.e. *electron leakage*, is known as a common problem in GaN-based LEDs and it is the reason why an AlGaN electron-blocking layer (EBL) is implemented on the p-side of the active region. However, the EBL in GaN-based LEDs is often unable to completely block election leakage; for this reason, electron leakage has been suggested as an explanation for efficiency droop. Electron leakage over the EBL can cause the droop only when the leakage current rises stronger with the carrier density than the radiative recombination current. The p-type layer generate the holes and the electrons from n-type region recombine with holes and produce photons in the active region. The contact layer is fixed on the above layer.

III. FABRICATION OF LED

InGaN blue-violet laser diodes have numerous applications, in particular high-density optical storage systems such as Blue-ray. Since the first demonstration of blue-violet laser diodes in 1995, the epitaxial growth of InGaN based Opto electronic devices has been dominated by the metal organic chemical vapour deposition (MOCVD) technique. Molecular beam epitaxy (MBE) with its fine control of growth parameters and capability for in situ growth monitoring is a well-established technique for depositing III–V optoelectronic devices. However, until recently, MBE had not been successful in producing high-quality InGaN based light emitting diodes (LEDs) and lasers. In January 2004, the authors reported the first InGaN laser diodes grown by MBE, operating under pulsed current conditions at 0.01% duty cycle, with a room-temperature threshold current density of 30 kA cm_2 and a threshold voltage of 35V. Subsequently, the authors reported high power InGaN LEDs grown by MBE, with 3.75 mW optical output power at 20 mA current. Low duty-cycle pulsed operation was also shown on InGaN laser diodes grown by plasma-assisted MBE on low dislocation density (<100 cm_2) GaN substrates. These results demonstrated the potential of MBE growth for nitride optoelectronic devices. But they left open the question whether MBE can produce material of high enough quality for room temperature continuous-wave (CW) laser diodes, which would be of fundamental interest as well as of commercial significance.

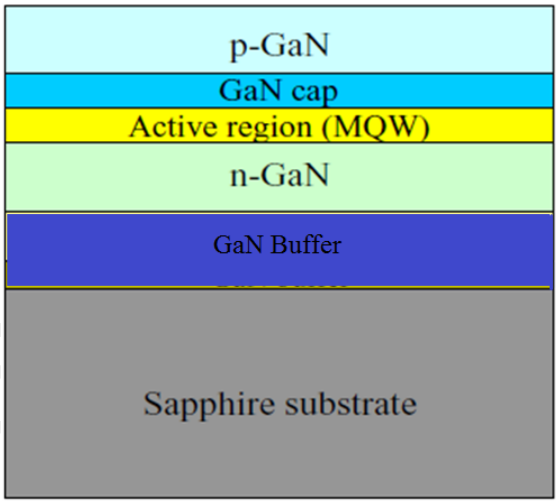

Figure 2: Structure of the fabricated white LED

Subsequently, the blue LED chips were fabricated on quarters of 2-inch diameter sapphire substrate. These LED chips were then further coated with suitable chemicals to produce white LED lamps. To convert the blue light emitting LED chips into white light emitting ones, a solution of yellow phosphor ($Y_3Al_5O_{12}$:Ce) and epoxy resin was prepared, then coated on the surface of the blue LED chip. Depending on the concentration of the powder phosphor in prepared coated solution, a cool white or warm white lighting from the LED lamps was obtained.

IV. SIMULATION AND DESIGN PROCESS

- ✓ *STRUCTURE DEFINITION:* A device structure can be defined in three different ways for use in ATLAS. The first way is to read an existing structure from a file. The second way is to use the Automatic Interface feature of Deckbuild. [13]The third way is to create a structure by using ATLAS command language.
- ✓ *SPECIFYING THE INITIAL MESH:* Specifying a good grid is a crucial issue in device simulation. To prepare this structure for ATLAS simulation, we used the AUTO parameter on the MESH statement. This will allow the user to build the structure layer by layer so that the input deck syntax will appear similar to the structure grown by MOVPE technique used to create these LEDs.[13] Once the x.mesh statements were defined the user can then

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select the material, molar fraction, number of y mesh points and doping on each REGION statement.

- ✓ *MATERIAL AND MODEL SPECIFICATION:* Once the mesh is specified, every part of it must be assigned to the material type. ATLAS has a library of reference materials and models that can be assigned to different regions in the semiconductor device.[13] Physical models implemented in ATLAS can be grouped into five categories mobility, recombination, carrier concentration, impact ionization, tunneling.
- ✓ *RESULTS ANALYSIS:* The basic types of analysis can be carried out with the use of ATLAS software package.[13]The simulation results can be presented in the output and transfer characteristics, in the form of carrier concentration, electro luminescence, etc. The contents of the output files are presented in graphical form.
- ✓ *MODEL VALIDATION:* The comparing measurement data for example current-voltage voltage-current density, current density-luminescence with the simulation results are used to check the model validity. [11-13]The purpose is to identify and simulate the design of the InGaN and to improve the performance of final device in terms of efficiency etc.

V. RESULT AND DISCUSSION

- ✓ The maximum UV output power was 4.1 mW for an injection current of 160 mA. The wave-length shift of the emission peak due to sample heating was 1.6 nm at a injection current of 160 mA, which was larger than that obtained for an InAlGaN based UV-LED fabricated on a GaN substrate. i.e. 0.5 nm at 400 mA [11] which is shown in the figure.3.

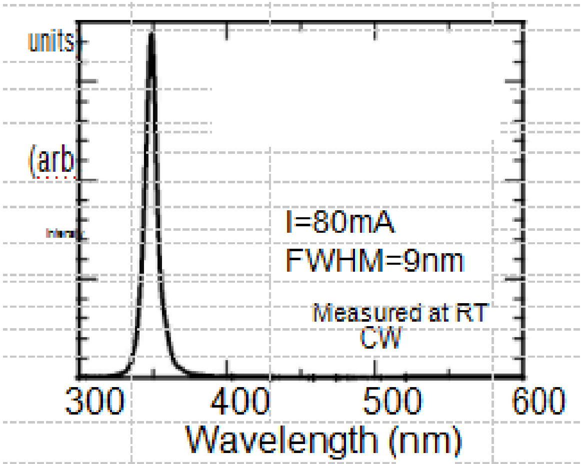

Figure 3: Electroluminescence (EL) spectrum of a quarternary InGaN based UV-LED fabricated on a GaN/sapphire template

- ✓ The maximum value of EQE was 1.02% with an injection current of 60 mA. This value is as high as that obtained for a 351 nm AlGaN-QW LED fabricated on GaN substrate [10-12]. Using high threading-dislocation-density (TDD) ($>10^9 cm^{-2}$) GaN or AlGaN template on sapphire or SiC substrate, the efficiency of the AlGaN-based LED is quite low be-cause the emission intensity of the AlGaN-QW is very sensitive to the TDD as shown in figure 4.

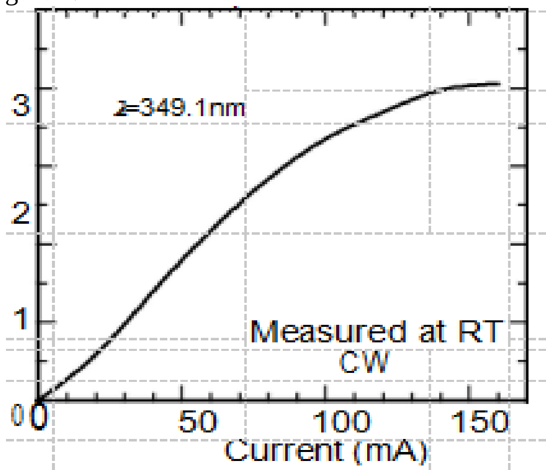

Figure 4: I-L characteristics of a quarternary InAlGaN based UV-LED fabricated on a GaN/sapphire template

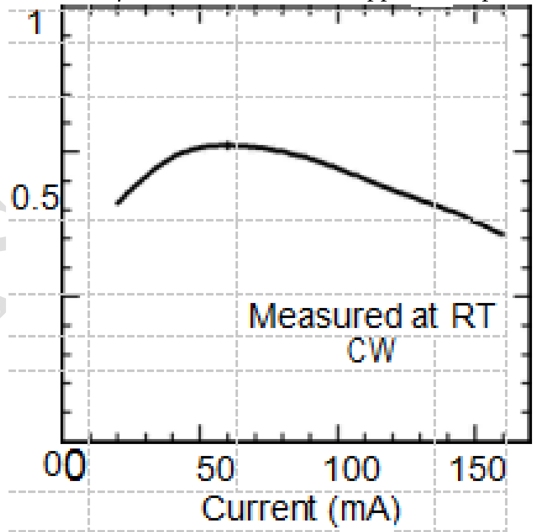

Figure 5: External quantum Efficiency of a quarternary InAlGaN based UV-LED fabricated on a GaN/sapphire template

VI. CONCLUSION

Under high-injection conditions, electron drift in the p-type layer of the diode causes a decrease of the injection efficiency. In order to reduce leakage current, multiple quantum wells and Electron Blocking Layer are used and recombination rate is increased by adding proper indium composition. The maximum external quantum efficiency (EQE) was 1.02% with an injection current of 60 mA , which is as high as the EQE obtained for a 350 nm band AlGaN-based QW LED fabricated on GaN substrate[10-12]. Moreover, the model is capable of providing new valuable information and putting forward new tasks for further research. Improving the quantum efficiency remains a continuing challenge for researchers in this field. Only a small percentage of the photons generated actually emitted from the device. The rest were internally reflected and absorbed by the crystal, generating unwanted heat.

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