Wavelength Tune Of InGaN Based Blue LEDs By Changing Indium Percentage And Operational Voltage Variables

Bekir Gecer and Ismail Kiyak

***Abstract*—Blue light-emitting-diodes (LEDs) are special and different than the other LEDs due to their high-efficient lighting. They have large badgap energy. So gallium nitrides are mostly used during designing blue light. This application focus on the emission properties of a InGaN LED. The emission intensity, energy diagram, spectrum, and efficiency are calculated for an applied voltage. The indium and GaN composition in the blue LED can be varied to control the emission wavelength. In here, composition of InGaN and operational voltage values were varied to control wavelength. Effects of the different InGaN composition and different voltage values were given in results as comprehensively for 5 different simulations. This study is dissimilar than other wavelength studies due to used original parameter values and wavelength compared methods for many situations about InGaN percentage and voltage values. As a result of simulations, we can infer that the high In_x percentage in composition and high voltage makes wavelength gap of an blue LED larger.**

Index Terms—**Comsol, InGaN, LED, Voltage, Wavelengths.**

I. Introduction

BLUE LEDs are so popular and different than other LEDs due to their use in modern high-efficiency lighting. Because of the large bandgap energy of blue LEDs, gallium nitrides are mostly used for designing blue light [1]. In the first yers of LED technology, blue devices were lacking. The firstly, red LED was generated in the 1950s and by the 1960s the pursuit of shorter emission wavelengths had already yielded green LEDs. The GaN-based blue LED researchs were started by Akasaki in 1973. In there, The MBE and HVPE methods were used for growth [2].The solid-satate lighting performs such as reality thanks to improvements in high power light emitting diode technology. It is 100 + lumens per LED chip. The sensor position, driver of LED, design, control and stability with temperature are practical ussues for implementation of combining red, green and blue (RGB) LEDs. [3]. In another paper, the structure optimization of the multi-quantum well based Light Emitting Diode (LED) was presented. In there, the electrical and optical properties of the device on several factors such as well width, barrier width, the number of quantum wells were investigated by authors [4]. Room-temperature photoluminescence (PL) measurements are performed on the GaInN/GaN multiple-quantum-well hetero-structures grown on GaN-on-sapphire templates with different threading-dislocation densities in [5]. A photoluminescence technique measures the Auger recombination coefficient in quasi-bulk InxGa1−xNInxGa1−xN (x∼9%–15%)(x∼9%–5%) layers grown on GaN (0001). The samples vary in InN composition, thickness, and threading dislocation density in [6]. In [7], a blue-red LED wavelength-shifting system (B-R system) was studied to improve the photosynthetic betacarotene productivity of Dunaliella salina. The characteristics of the GaN-based blue LED on Si substrate is studied in [8]. In [9], effect of the different wavelength Blue LED on human optical biorhythm was given with used methods. The performance of 2QWs LED is studied by comparing device behavior according to available one quantum well (1QW) light emitting diode model in Comsol simulation program in[10]. In another comsol work, to design high bandwith GaN-based blue LEDs, Ag-grating and diamond heat sink were used [11]. In reference [12], the performance improvement of GaN-based LEDs using different methods. In another study, InGaN based blue LEDS are worked to enhance their efficiency in bottom tunnel junction [13]. The optical model of red, green and yellow phosphors with a Blue LED is constructed using the optical simulation sofware LightTools in[14].

In this study, 5 different InGaN-based blue LED designed and simulated using Comsol programs. Effects of the different input voltages of different In_x percentages on the wavelength were compared after simulations. There is no another study that compare wavelength of blue LED at different voltage and In_x percentages for 5 simulations in the literature. Here, many applications were studied at varied In_x percentages and voltage parameters. Also, optimizations were worked for maximum LED performance about wavelength. So, this paper is novel and original. Section II is about LED

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design and simulation parameters, III is about results and conclusion is in stage IV.

II. LED Design And Simulation Parameters

The Comsol software program offers many facilities in simulation-LED design. Here, you can control and test designs in the virtual environment and determine the optimal configuration. The Fig.1 shows basic geometry of AlGaN based LED device with layers. In this stage, we focus on the InGaN based blue LED, its design and simulation parameters were given for the simulation programs in tables.

The following input parameters were used to specify the composition of the optically active InGaN material and device lateral dimensions. There are 5 different LEDs design and simulation parameters for comparison of wavelength.

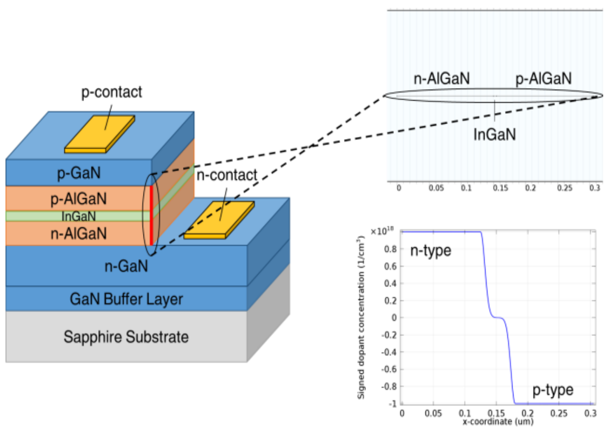

Fig.1. Geometry of LED device.

First simulation parameters were given in Table I. Here, In_x percentage is %12. The operational voltage value is 3.2 V and efficiency is 18.03 for simulation 1.

TABLE I
REFERENCE PARAMETERS 1

Name	Expression	Value	Description
In_x	0.127	0.127	Indium fraction
InGaN_bg	In_x*InN_bg + (1 - In_x)*GaN_bg - b*In_x*(1 - In_x)	2.753 V	Bandgap energy of InGaN layer
A_cross	200[um]*200[um]	4E−8 m²	Cross sectional area

Second simulation parameters were given in Table II. Here, In_x percentage is %9. The operational voltage value is 3.2 V and efficiency is 18.78 for simulation 2.

TABLE II
REFERENCE PARAMETERS 2
(LOWER IN_X PERCENTAGE THAN REFERENCE)

Name	Expression	Value	Description
In_x	0.09	0.09	Indium fraction
InGaN_bg	In_x*InN_bg + (1 - In_x)*GaN_bg - b*In_x*(1 - In_x)	2.9322 V	Bandgap energy of InGaN layer
A_cross	200[um]*200[um]	4E−8 m²	Cross sectional area

TABLE III
REFERENCE PARAMETERS 3
(HIGHER IN_X PERCENTAGE THAN REFERENCE)

Name	Expression	Value	Description
In_x	0.134	0.134	Indium fraction
InGaN_bg	In_x*InN_bg + (1 - In_x)*GaN_bg - b*In_x*(1 - In_x)	2.72 V	Bandgap energy of InGaN layer
A_cross	200[um]*200[um]	4E−8 m²	Cross sectional area

Third simulation parameters were given in Table III. Here, In_x percentage is 13.4 %. The operational voltage value is 3.2 V and efficiency is 18.04 for simulation 3.

TABLE IV
REFERENCE PARAMETERS 4 (SAME VALUES AS REFERENCE)

Name	Expression	Value	Description
In_x	0.127	0.127	Indium fraction
InGaN_bg	In_x*InN_bg + (1 - In_x)*GaN_bg - b*In_x*(1 - In_x)	2.753 V	Bandgap energy of InGaN layer
A_cross	200[um]*200[um]	4E−8 m²	Cross sectional area

Fourth simulation parameters were given in Table IV. Here, In_x percentage is 12 %. The operational voltage value is 3.1 V and efficiency is 25.46 for simulation 4.

TABLE IV
REFERENCE PARAMETERS 4 (SAME VALUES AS REFERENCE)

Name	Expression	Value	Description
In_x	0.127	0.127	Indium fraction
InGaN_bg	In_x*InN_bg + (1 - In_x)*GaN_bg - b*In_x*(1 - In_x)	2.753 V	Bandgap energy of InGaN layer
A_cross	200[um]*200[um]	4E−8 m²	Cross sectional area

Fifth simulation parameters were given in Table V. Here, In_x percentage is 12 %. The operational voltage value is 3.3 V and efficiency is 9.073 for simulation 5.

TABLE V
REFERENCE PARAMETERS 5 (SAME VALUES AS REFERENCE)

Name	Expression	Value	Description
In_x	0.127	0.127	Indium fraction
InGaN_bg	In_x*InN_bg + (1 - In_x)*GaN_bg - b*In_x*(1 - In_x)	2.753 V	Bandgap energy of InGaN layer
A_cross	200[um]*200[um]	4E−8 m²	Cross sectional area

According to tables, the efficiency was found depend on voltage and percentages of materials.

III. Simulation Results

In this section, results of 5 different LED design simulations which input parameters were given in section II, were shown in figures as below. The electroluminescence spectrum is shown below for simulation 1. Effects of wavelength gap and arc length on the realtive intensity were seen in Fig 2 and Fig 3.

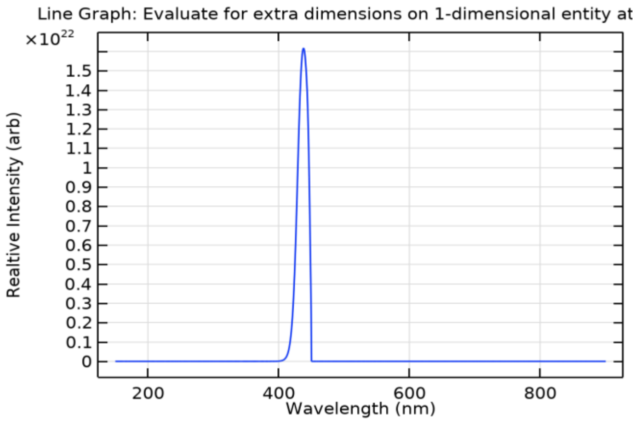

Fig.2. Line Graph: Evaluate for extra dimensions on 1-dimensional entity at coordinates in Geometry 1 (kg/(m2*s3))(371-449nm)

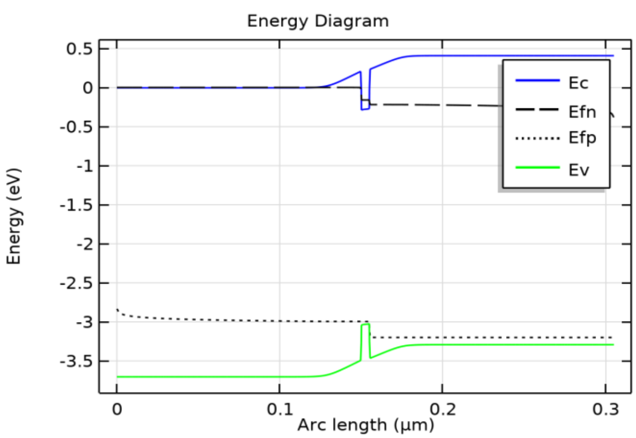

Fig.3. Energy Diagram

The electroluminescence spectrum is shown below for simulation 2. Effects of wavelength gap and arc length on the realtive intensity were seen in Fig 4 and Fig 5.

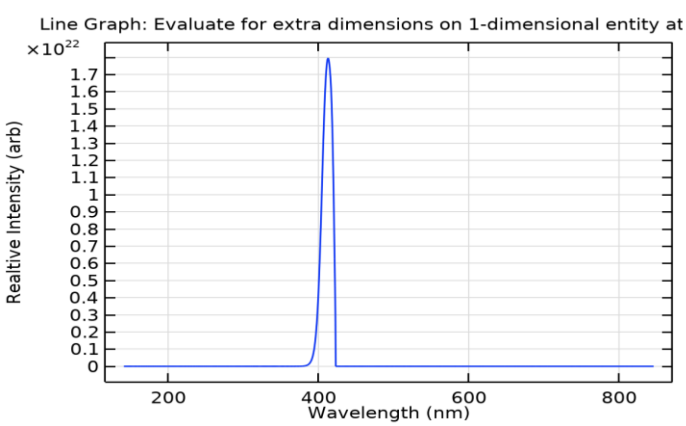

Fig.4. Line Graph: Evaluate for extra dimensions on 1-dimensional entity at coordinates in Geometry 1 (kg/(m2*s3))(380-423nm)

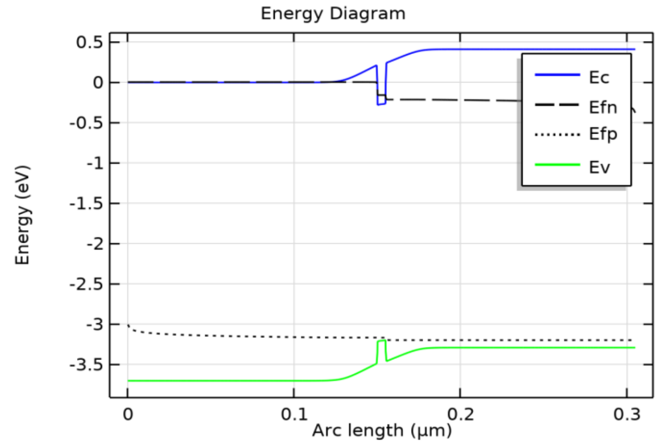

Fig.5. Energy Diagram

The electroluminescence spectrum is shown below for simulation 3. Effects of wavelength gap and arc length on the realtive intensity were seen in Fig 6 and Fig 7.

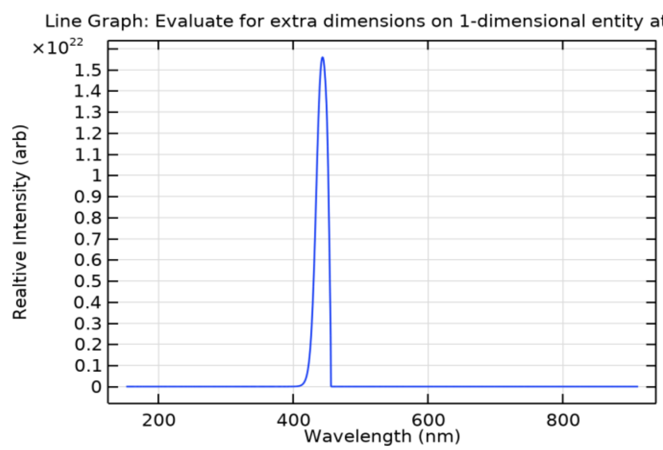

Fig.6. Line Graph: Evaluate for extra dimensions on 1-dimensional entity at coordinates in Geometry 1 (kg/(m2*s3))(374-456nm)

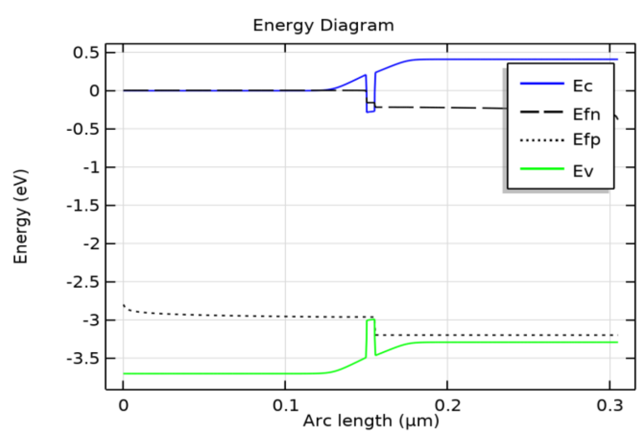

Fig.7. Energy Diagram

The electroluminescence spectrum is shown below for simulation 4. Effects of wavelength gap and arc length on the realtive intensity were seen in Fig 8 and Fig 9.

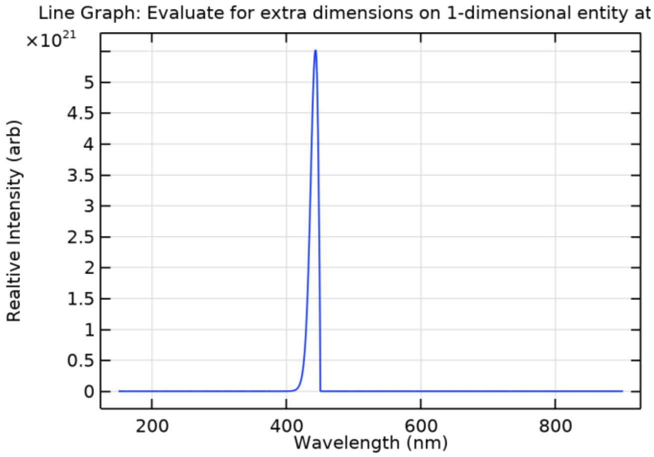

Fig.8. Line Graph: Evaluate for extra dimensions on 1-dimensional entity at coordinates in Geometry 1 (kg/(m2*s3))(374-451nm)

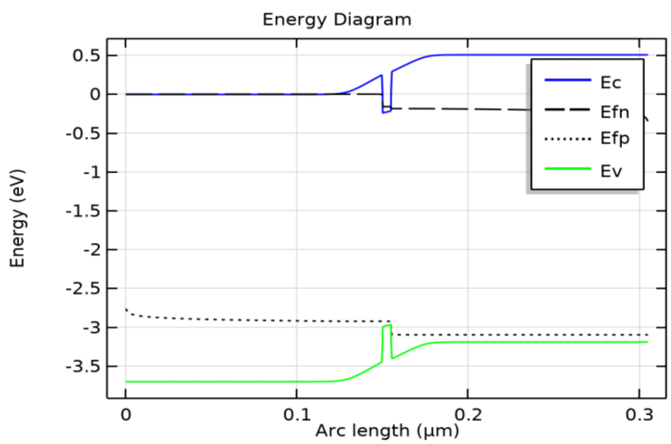

Fig.9. Energy Diagram

The electroluminescence spectrum is shown below for simulation 5. Effects of wavelength gap and arc length on the realtive intensity were seen in Fig 10 and Fig 11.

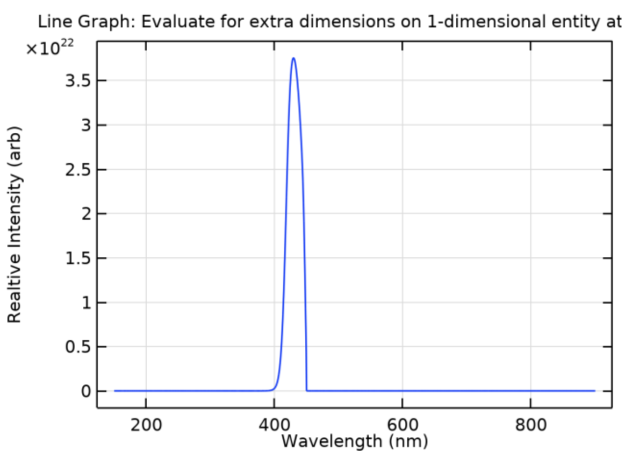

Fig.10. Line Graph: Evaluate for extra dimensions on 1-dimensional entity at coordinates in Geometry 1 (kg/(m2*s3))(367-452nm)

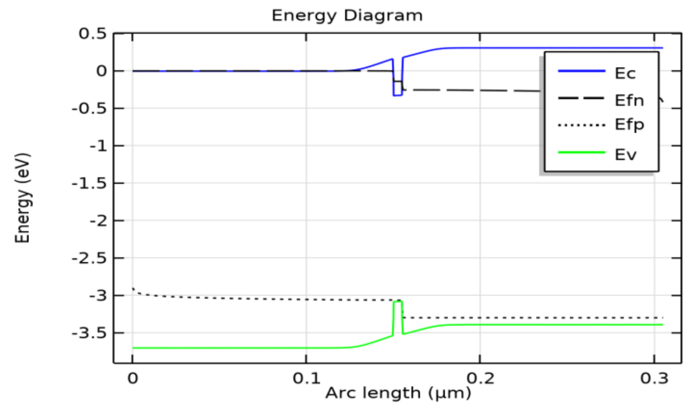

Fig.11. Energy Diagram

IV. Conclusion

The electroluminescence spectrum is calculated and plotted as a line graph for the case of a single input voltage, and as a height plot as a function of voltage and wavelength for the case of a voltage range input. The current that flows through the device is calculated for each applied voltage. High voltage input values show larger wavelength gap behaviour than low voltage input values. Also, effects of the different percentegas of InN and GaN on the wavelength were seen in the results. High In_x parcentaged LED gives larger wavelength gap behavior than low In_x parcentaged LED in the results.

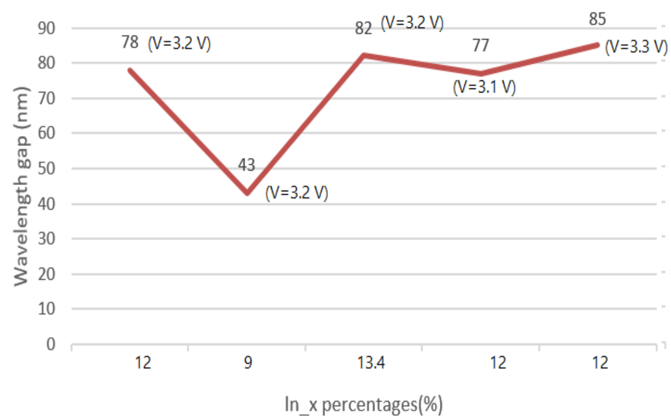

Fig.12. Relationship between In_x percentage and Wavelength gap.

Wavelength gap-In_x graph is seen in Fig.12 and simulation results are given in Table VI.

TABLE VI. SIMULATION RESULTS

Simulation No	Wavelength
Simulation 1	371-449 nm
Simulation 2	380-423 nm
Simulation 3	374-456 nm
Simulation 4	374-451 nm
Simulation 5	367-452 nm

According to Table VI, the maximum wavelength gap with 85 nm was obtained at V=3.3 V voltage value and %12 In composition percentage. The minimum wavelenth gap is 43 nm at V=3.2 V voltage and %9 percentage.

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