MATEC Web of Conferences **78**, 01110 (2016) DOI: 10.1051/matecconf/20167801110
IConGDM 2016

Development of ZnO Infrared LED and Its Emissivity

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Abstract. This paper provides an investigation of the design and characterization of zinc oxide (ZnO) in infrared light emitting diode (LED) application. Zinc oxide has been proved as one of the material that consists of wide range of electrical and optical properties [1,2]. A structure of ZnO infrared LED with pn junction is designed using a simulated environment. Layer of p-type doping is located at the top center of the LED while layer of n-type doping is at the bottom. This infrared LED is developed for its capability to emit electromagnetic spectrum. In order to obtain expected outputs, some parameters of the material have to be configured precisely. As a result, a current-voltage relationship and internal quantum efficiency is obtained. Besides that, emission rate and total emission rate of the design also has been successfully investigated. Finally, the properties of ZnO infrared LED are summarized and concluded.

1 Introduction

Light Emitting Diode (LED) is one of the extraordinary lighting technology that being invented to replace the traditional lighting system such as incandescent light bulb, high intensity discharge (HID) lamp and compact florescent (CFL). With the used of LED as our major lighting, greenhouse effect can be reduced and the economy growth can be sustained [3]. These benefits attract researchers to explore more regarding the characterization of LED. For your information, LED be able to produce a significantly higher light production and longer lifetime compare to a typical lighting systems. The typical light production of white LED is between 30-130 lm/W. Lifetime can be even 25 000 - 50 000 hours [3].

Unlike typical LED, infrared light emitting diode (IR LED) performing their function without emitting beautiful visible light. The IR LED emits in the infrared part of the electromagnetic spectrum and widely used in many optoelectronic applications, but perhaps the most familiar in a household setting is for used in remote controls. Although more efficient light production can be achieved using complicated design structures, simple p-n junction are still used for many IR emitters due to their low cost and ease of manufacture. As we know, p-n junctions are formed by joining n-type and p-type semiconductor material. Since the n-type region has a high electron concentration and the p-type a high holes concentration, electrons diffuse from the n-type side to the p-type side. Similarly,

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holes flow by diffusion from the p-type side to the n-type side. However, in the p-n junction, when the electrons and holes move to the other side of the junction, they leave behind exposed charges on dopant atom sites, which are fixed in the crystal lattice and are unable to move. As a result an electric field is formed between the positive ion cores in the n-type material and negative ion cores in the p-type material. This region is called the "depletion region" since the electric field quickly sweeps free carriers out, hence the region is depleted of free carriers.

Zinc Oxide (ZnO) is the major element in this research which exhibits the characteristic of semiconductor and piezoelectric properties. Lack in the symmetry of wurtzite combined with strong electromechanical coupling, help to produce strong piezoelectric in ZnO [4]. ZnO has a stable wurtize structure with lattice spacing a=0.325 nm and c=0.521 nm. Besides, ZnO is a polar group of 11-V1 semiconductor material with a direct wide bandgap of 3.37 eV which is suitable for short wavelength optoelectronic application [5,6]. High electron mobility, high thermal conductivity and high exciton binding energy make ZnO suitable for wide range devices [6]. ZnO is transparent to visible light and can be made highly conductive by doping.

2 Design of infrared LED

Infrared light emitting diode (IR LED) has been designed to have cylindrically symmetric geometry that made 3D visualization with a much shorter computation time in Comsol. The upper side of the p-n junction of IR LED has 50 um diameter of zinc oxide (ZnO), while the bottom side has 60 um diameter. However, due to r=0 axis is an axis of symmetry, the device geometry is represent by half of the diameter wide rectangle. The overall thickness of the LED geometry is 10 um. Since this research is investigated using p-n junction, p-type contact is designated at the center top of the IR LED while n-type contact at the bottom outside of the cylinder. The top 2.5 um of the IR LED thickness is dominated by p-doped while the bottom 7.5 um of the device is n-doped. Figs. 1 & 2 show 2D and 3D structure respectively.

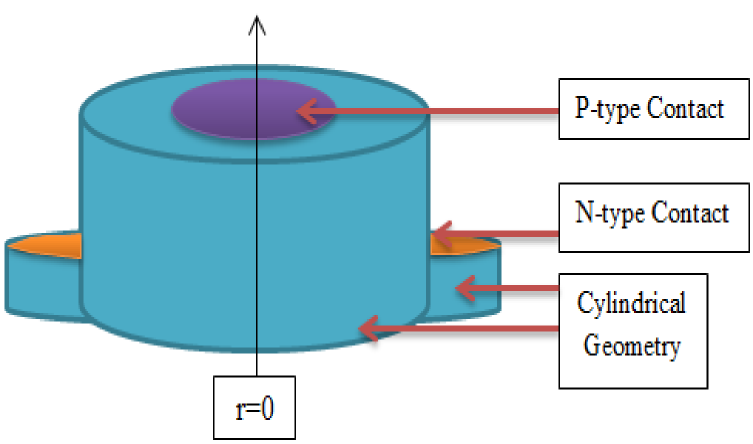

Fig. 1. Show 3D view of model.

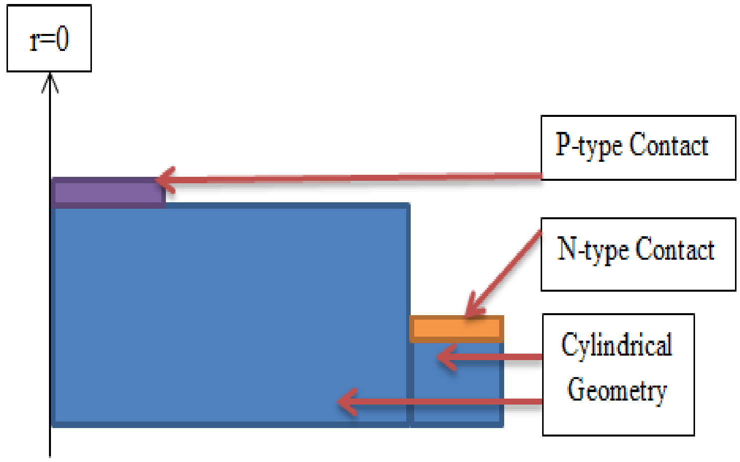

Fig. 2. Show 2D view of model.

As being explain in the introduction section earlier, the p-n junction method is used in the research due to low cost and ease of manufacturing. Hence, semiconductor (Semi) module is choosen in designing and interfacing the IR LED. The initialization study is used to refine the mesh based upon the gradient of impurity doping concentration whereas stationary study is adopted to sweep the bias applied to the device from 0 V to 1.5 V, allowing the current-voltage curve and optical emission characteristics to be calculated. The device geometry is represented by two rectangular structure represents n and p with different dimension in microns. Optical transition and Auger recombination segments are utilized for electroluminescence calculation and efficiency of the radiative emission measurement.

3 Results and discussion

Figs. 3 & 4 depict the function of mesh 1 and mesh 2. The mesh represents partition of the geometry model into small unit of simple shape. Thus, the function of mesh 1 is to increase the success rate of geometry functionality. Besides that, there are two part of the result that shows higher concentration of mesh which is at the p-type and n-type metal contact. This is because in the dark region, the mesh curvature factor is the parameter that provides the active constraint due to a circular shape that will be formed at both of the area in 3D geometry.

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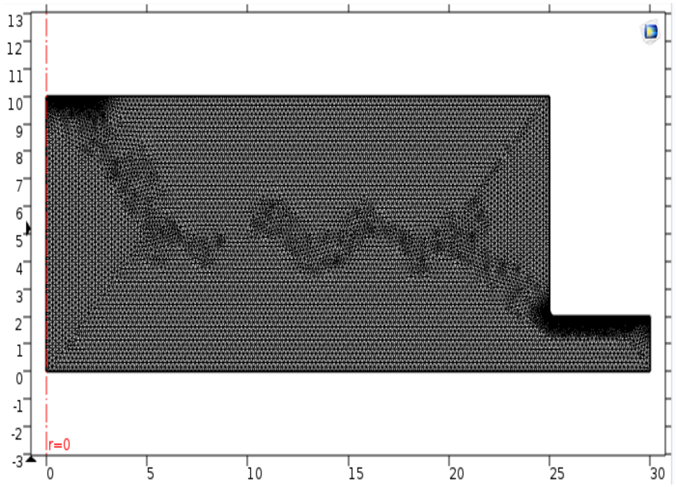

Fig. 3. Default mesh 1.

However, different things happen in mesh 2 which is the result of refined mesh output by the first study. The higher mesh densities that take place at the top of the figure show the p-n junction region. Therefore, it has being proved that p-n junction can be used in order to make Infrared LED.

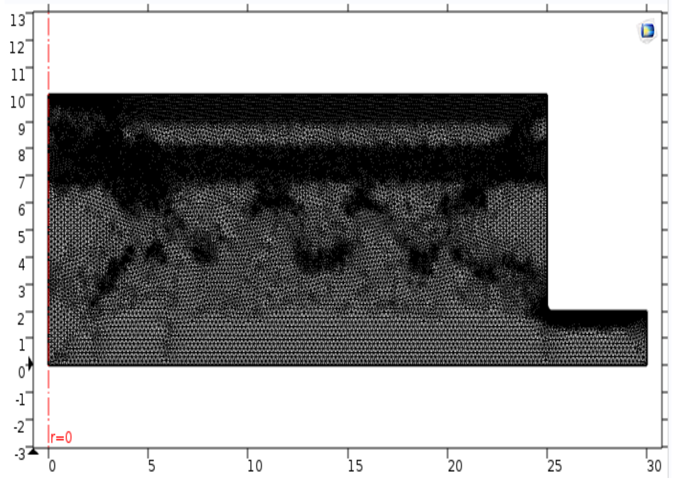

Fig. 4. Semiconductor initialization with mesh 2.

Figure 5 shows the result of doping that occur in the stimulation process. There are two kinds of doping which is p-type doping, where a regions that has extra holes and n-type doping, where a region that has extra electron. Based on the figure, the p-type surface layer is represented in blue while n-type region is represented in red. The doping gradually transitions from n-type to p-type over a range of a few micrometers (more than 4 um) to create a wide region in which light emission can occur. The variety colour plot is represented as threshold voltage and at the same time allows us to see the p-n junction. With the used of legend, the voltage range of each colour can be estimated. Based on the observation, the threshold voltage of n-type increases with doping while p-type decreases with doping.

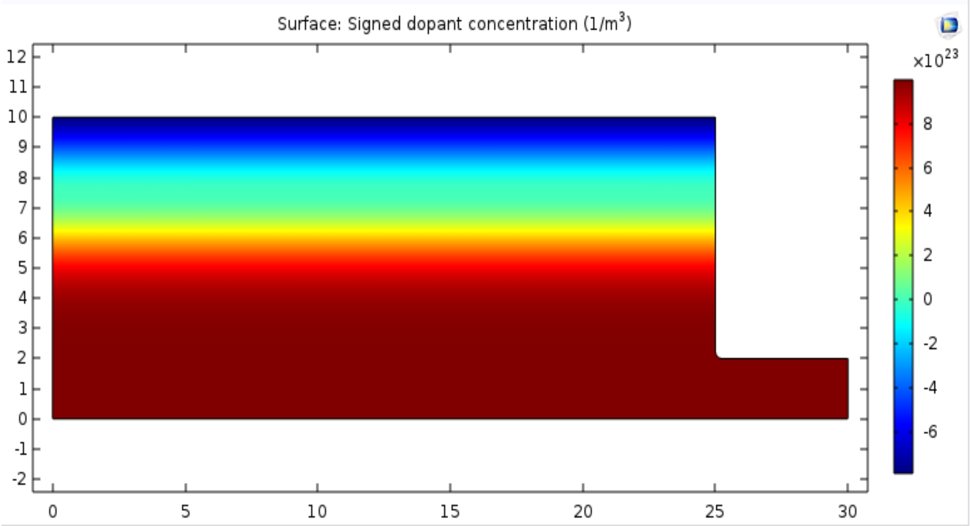

Fig. 5. Dopant Concentration.

Stationary study which is the sweeps of the biased voltage across the device from 0 V to 1.5 V is performed to prove that the device is clearly a diode. Fig. 6 illustrates the diode behavior with a turn-on voltage just around 1.1 V. After the turn-on voltage is achieved, even a small amount of voltage will give a great increase in current. It is also shown that the current is zero at any voltage below turn-on voltage whereby the diode can be viewed as a switch.

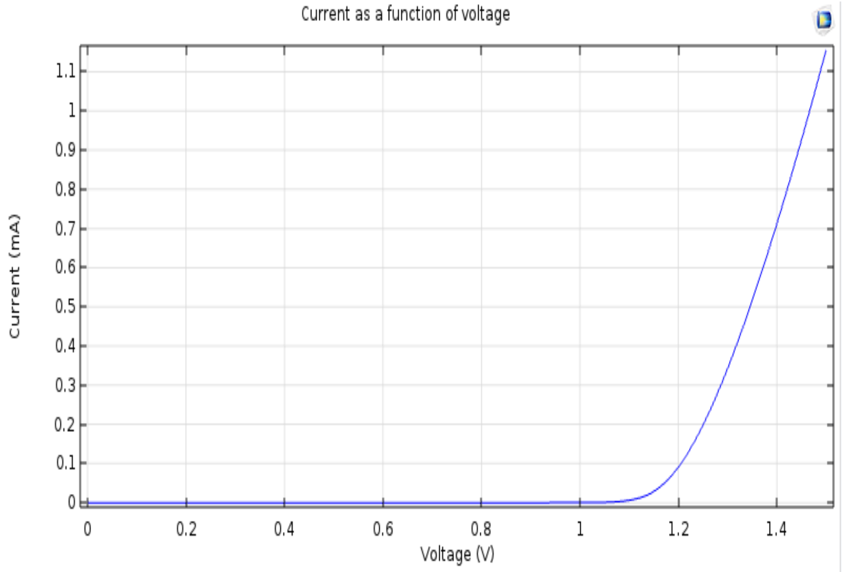

Fig. 6. Current versus applied voltage.

Figs. 7 and 8 depicts the emission rate throughout the device for a voltage of 1.5 V and 1.2 V. At the larger bias the emission has become concentrated towards the center of the devices which show the spacial distribution of the radiative emission.

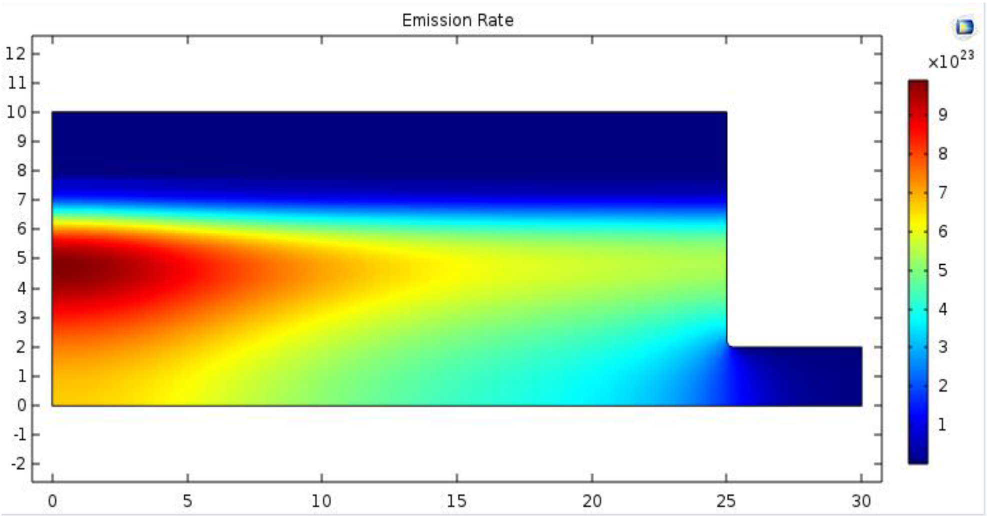

Fig. 7. Emission Rate throughout the device at 1.5 V.

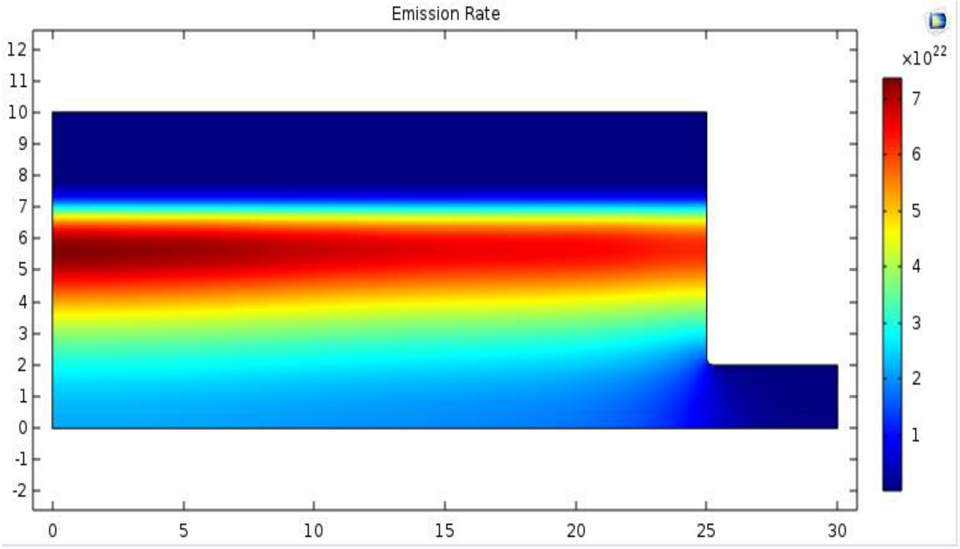

Fig. 8. Emission Rate throughout the device at 1.2 V.

Figure 9 shows the total rate of emission, integrated over the entire domain of the device, as a function of the current. The sub-linear curve is characteristic of LED droop, a phenomenon where the efficiency of LEDs decreases with increased current density. This reduction is even more apparent in Figure 10, which shows the internal quantum eficiency (IQE) as a function of the current. The IQE is the ratio of the emission rate to the carrier injection rate, and gives the proportion of injected carriers which radiatively recombine to emit light. Initially the IQE is very low, as no current flows, however as soon as current begins to flow the IQE is quite high. As the current increases the IQE drops drastically to plateau at a value of 0.981.

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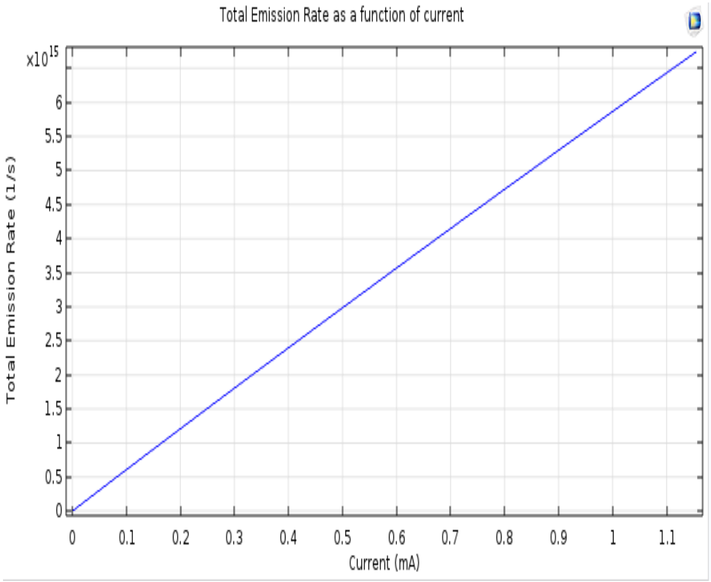

Fig. 9. Total emission rate as a function of current.

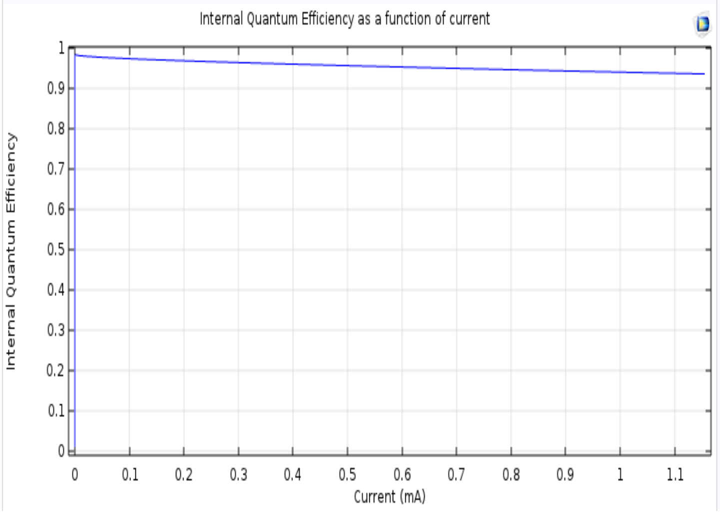

Fig. 10. Internal quantum efficiency(IQE).

In this work, Auger recombination has been included as non-radiative recombination mechanism. The rate of Auger recombination is proportional to the cube of the carrier density, whist the radiative emission rate is proportional to the square of the carrier density [7]. This means that as the carrier density is increased by the increasing current a larger proportion of the carrier recombine via the Auger mechanism, leading to the observed drastic reduction in IQE. The IQE is only a measure of the efficiency of the radiative recombination within the device. The IQE also indicates that efficient operation of LED would occur with low current below 5 mA. This would be the desirable range of operation current for a remote control device, where intensity of emission is not important compared to increased battery lifetime. This current corresponds to voltage between 1.2 V and 1.3 V and so the emission will be distributed similar to that shown in Fig. 8. However, if the LED is to be used in a situation where total brightness is more important than efficiency, it could be desirable to drive the device with a larger current. It would be advantageous to change the material, the thickness or the shape of the LED. For example, a ring shaped p-contact would produce the brightest emission on the central axis to leave the device .

4 Conclusions

As a conclusion, the infrared LED is successful developed and characterized. The result from I-V curve potrays that the p-n junction method can be used as one of the methods to build a quality and simple infrared LED. Besides that, IQE plot also indicates the efficiency of LED operation whether by using low or high current.

The authors would like to thank the School of Microelectronics Engineering, Universiti Malaysia Perlis (UniMAP) especially SPILS for their support in this work. Partial of this research is funded by FRGS 9003-00461 under Ministry of Higher Education, Malaysia.

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