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Theoretical investigation of multi-quantum well LED

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Dedication

Praise be to God, who has guided us to this, and we would not have reached it if God had given us grace

I dedicate this humble work to my dear mother and my dear father, may God protect them

It is to me who remained standing and worked hard for my education to complete this work near or far and to my family members, I am my support in the world and I can do them a favor

To all my relatives and all my friends and relatives without exception

To my dear teachers and to all my classmates

Finally, I ask Almighty God to make this work a benefit for all the stuck students who are about to graduate.

Abstract

LED has several characteristics that make it the most widely used in electronics, and its high efficiency compared to traditional lamps, its long life, and its small size enables us to use it in electronic devices such as calculators, remote control, and electrical signal in radio, television, traffic lights, and cars, where it can be considered environmentally friendly. Different types and structures have been previously studied in literature. In our work, multi quantum well (MQW) LED based on AlGaN using Silvaco-Atlas software has been simulated and studied.

The simulation results demonstrate that the device performance is considerably enhanced by the use of MQW LED. It provides high anode current (4.75A) at value 6V of anode voltage, and the luminous intensity reaches its maximum value of 0.14W at 4.75A. Therefore, the effect of quantum well number on the device was modeled and studied. The results indicate that the value of the maximum current density is obtained in case of low number of wells and it reaches 5.48A. In addition, the influence of well-width on MQW design has been examined. It is evident that the well-width of 2nm provides better performance based on its high anode current compared to that of 3nm.Through these results, we note that the high performance of the studied MQW LED structure can be found by the use of two quantum wells and 2nm of well-width conception.

Keywords: LED, multi quantum well, IV characteristics, Silvaco-Atlas software.

ملخص

يتميز LED بعدة خصائص تجعله الأكثر استخدامًا في الإلكترونيات ، وكفاءته العالية مقارنة بالمصابيح التقليدية ، وعمره الطويل ، وصغر حجمه يمكننا من استخدامه في الأجهزة الإلكترونية مثل الآلات الحاسبة ، والتحكم عن بعد ، والإشارة الكهربائية في الراديو والتلفزيون وإشارات المرور والسيارات ، حيث يمكن اعتبارها صديقة للبيئة. تمت دراسة أنواع وتركيبات مختلفة مسبقًا في الأدب. في عملنا ، تمت محاكاة ودراسة LED متعدد الآبار (MQW) استنادًا إلى AlGaN باستخدام برنامج Silvaco-Atlas.

تظهر نتائج المحاكاة أن أداء الجهاز تم تحسينه بشكل كبير باستخدام MQW LED. إنه يوفر تيار أنود عالي (A4.75) بقيمة V6 لجهد الأنود ، وتصل شدة الإنارة إلى قيمتها القصوى W0.14 عند A4.75. لذلك تم نمذجة ودراسة تأثير رقم البئر الكمي على الجهاز. تشير النتائج إلى الحصول على قيمة أقصى كثافة للتيار في حالة قلة عدد الآبار وتصل إلى A5.48 . بالإضافة إلى ذلك ، تم فحص تأثير عرض البئر على تصميم MQW. من الواضح أن العرض الجيد الذي يبلغ 2 نانومتر يوفر أداءً أفضل بناءً على تيار الأنود العالي الخاص به مقارنةً بتيار 3 نانومتر ، ومن خلال هذه النتائج ، نلاحظ أن الأداء العالي لهيكل MQW LED المدروس يمكن العثور عليه من خلال استخدام اثنين من الكم. الآبار و 2 نانومتر للتصور الجيد العرض.

الكلمات الرئيسية: LED ، بئر كم متعدد ، خصائص IV ، برنامج Silvaco-Atlas.

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List of symbols and abreviations

LED	light-emitting diode
OLED	Organic light-emitting diode
MQW	multi-quantum well
SIC	Silicon carbide
TV	Televisions
UV	ultra violet
DVD	Digital Video Disc
CD	Compact Disc
HBT	heterojunction bipolar transistor
HEMT	high electron mobility transistors
ITO	Indium tin oxide
LCD	liquid crystal display
GaAs	gallium-arsenic
AlAs	aluminium-arsenic
InGaN	indium-gallium-nitride
GaN	gallium nitride
AlGaN	aluminium gallium nitride

General Introduction

In ancient times, humans got many different sources of light such as sunlight, candles, lamps, etc., the American Thomas Edison invented the light bulb in the year 1879.[1], and after completing the research to develop the lamp, Henry Joseph Round for the first time observed electrical luminescence during the Sic experiment [2]. (Silicon carbide or carbon) in the year 1907 and the light-emitting diode (LED) was born. Over the last 50 years, little progress was made until the research into diodes and semiconductors began in earnest. Years later, researchers in science and industry discovered many different ways of emitting light at an intersection. PN in diodes when using other materials and processes. Therefore, LED is used in many electronic fields and is involved in installing many modern devices, including computers, controllers, phones in cars and bicycles, street lights, home lighting, and office lighting.

The classic model used to demonstrate the existence of a quantum well is to confine particles, which were initially free to move in three dimensions, into two sizes, by forcing them to occupy a flat area. Quantum confinement effects occur when the thickness of the quantum well becomes similar to the De Broglie wavelength of carriers (generally electrons and holes), resulting in energy levels called “energy subbands,” that is, carriers can only have discrete energy values. A variety of electronic multi-quantum well devices have been developed based on the theory of multi-quantum well systems. These devices have found applications in, for example, LED, lasers, light detectors, modulators, and switches. Compared to traditional instruments, multi-quantum well devices are much faster and operate more economically, which is an incredible interest for the technology and communications industries. These multi-quantum well devices are currently replacing many, if not all, traditional electrical components in many electronic devices. The multi-quantum well concept was proposed in 1963 by Herbert Kromer, Zors Alferov, and R.F. Kazarinov [3].In this context, our work consists of three chapters.

In the first chapter, we will give a description of the light-emitting diode (LED), where we will focus on operation principle, characteristics and some application of LEDs. In the second chapter, different types of light-emitting diode (LED) designs are presented. In addition, structure, characteristics, and operation of the device of each one will be included. Then, the third chapter consists of modeling and simulation of multiple-quantum-well (MQW) LED using Silvaco Atlas simulator. Then, the obtained results are presented and discussed.

Chapter I General of LEDs

1. Introduction

The light-emitting diode is mainly used as an alternative to incandescent lights through many of the advantages it provides, and it is a PN junction that converts electrical energy into light energy by the transmission of electrons. In this chapter, we will study the generalities of the LED through its definition, working principle, characteristic and applications, etc.

2. History of LED

Despite considerable progress in LED technology, it is still in a stage of development. Today we already see devices where one tiny, high-power LED can produce a brighter and better-quality light output than the earlier and the massive arrays containing 96 or more through-the-hole LEDs. However, the electroluminescence was first observed in 1907 by the British experimenter Round of Marconi Labs, using a silicon carbide crystal and a cat's whisker detector.[4]

In 1927, Russian inventor Oleg Losev created the first LED independently.[5]

Braunstein of the RCA reported infrared emission from GaAs, GaSb, InP, SiGe, and other semiconductor alloys in 1955 at room temperature 77 K. [6]

In 1958, Rubin Braunstein and Egon Loebner patent a green LED made from a lead Antimonide/Germanium alloy. Still, the shift to the industrial application was made by Prof. Nick Holonyak in 1962 with the development of the first practical LED.[7]

The first practical visible-spectrum (red) LED was developed in 1962 by Nick Holonyak Jr.[8]

This last was red lighting and used only for display applications. The early 70s have seen the appearance of the yellow LED (George Craford, 1972).[9]

In the same year, 1972, the blue and violet valve was discovered (Herbert Paul Maruska).[10]

But the last big step to the worldwide revolution for LED lighting applications was Shuji Nakamura, Isamu Akasaki, and Hiroshi Amano in 1993 with a high-power blue light-emitting diode able to allow white lighting.[11]

3. Definition of LED (Light Emitting Diode)

It is a semiconductor source that, when current passes through it, light is emitted. When the electrons in the quasi-conductor meet the electron holes, they join with each other and thus release energy in the form of photons. We determine the colors by the energy required for the electrons to cross the bandgap in the semiconductor.[12]

It is a PN-type connection of semiconductor material because it converts electrical energy into optical energy. In the case of forwarding bias, it lights up and conducts current after it exceeds the forward voltage.[13]

The following figures also shows the practical and theoretical symbol in circulation:

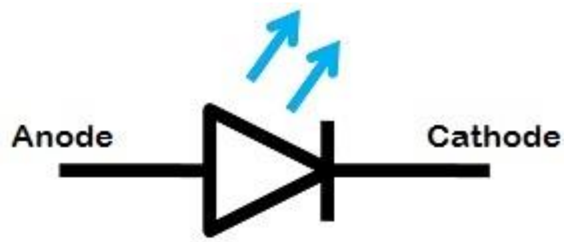


Figure 1: Practical form LED **Figure 2: Theoretical from LED**

4. Construction of LED

Light-emitting diodes use special semiconductors in the core. The majority of the products used are based on gallium. The material adopted must be a product of very high purity, but it has received "impurities" of two categories which will animate the generation of light. The first category of impurities leads to an excess of electrons (n-type material), while the second category leads to a lack of electrons (positive "holes": p-type material). Both are diffused in the same semiconductor, creating an interface between the n and p regions. If a direct voltage is applied such that the n zone is negative and the p zone is positive, the holes and electrons combine at the interface and then produce photons.[14]

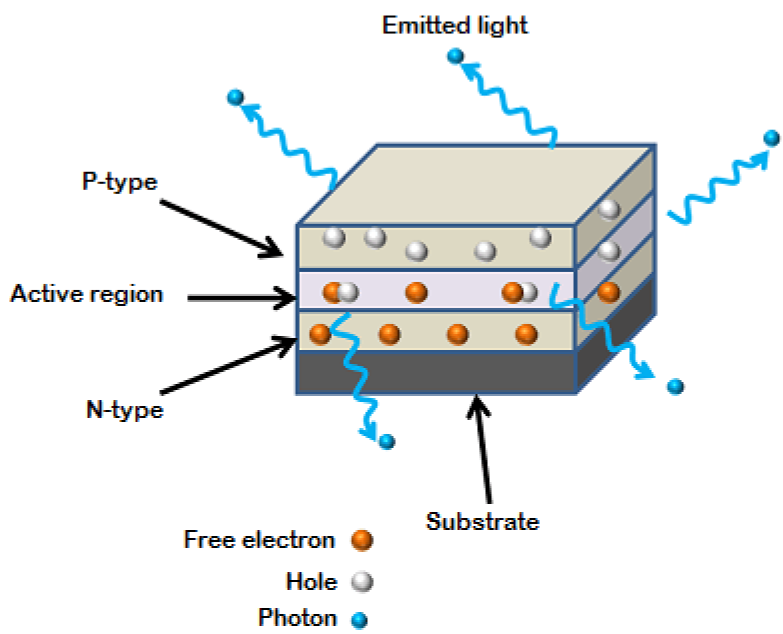
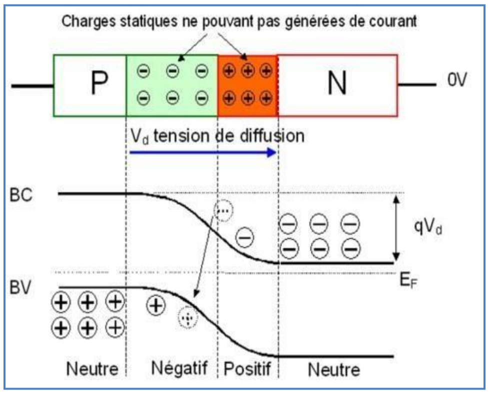


Figure 3:Construction of LED

5. Working Principle of LED

An LED can be defined as an optoelectronic component that emits light when an electric current pass through it. The first peculiarity of an LED is its ability to emit light from one or more solid-state semiconductor materials.

LED is close to components designed for the use of electronic functions. Thus, it uses technological design techniques and identical semiconductor materials. Its behavior as an insulator or an electrical conductor can also be explained by the theory of energy bands [15]. Also, the latter will depend on its topology, the doping rate, and the dimensions used. However, as a first approach, we can define an LED as an electronic component made from the juxtaposition of two semiconductor materials. The implementation is carried out like that of a PN junction for a diode. Thus, for LEDs, as for diodes having to perform electronic functions, one of the materials must be heavily doped with positive carriers (zone p) and the other with negative carriers (zone n),



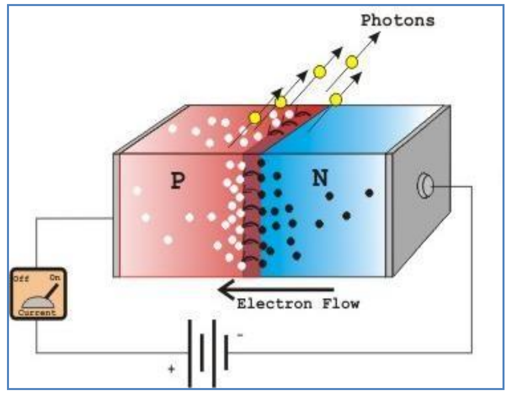


Figure 4:A PN junction for a diode

Figure 5:A PN junction for an LED

According to the theory of the energy bands of material, we can see that an electron in a material can only take energy values included in certain intervals called "permissible energy bands." These bands are themselves separated by others, called forbidden bands. One of the graphical representations allowing easy understanding of this physical phenomenon is given in figure 06 according to the intrinsic electrical properties of the material, which may be insulating, conducting, or else semiconducting as described in several references works. [15] [16] [17].

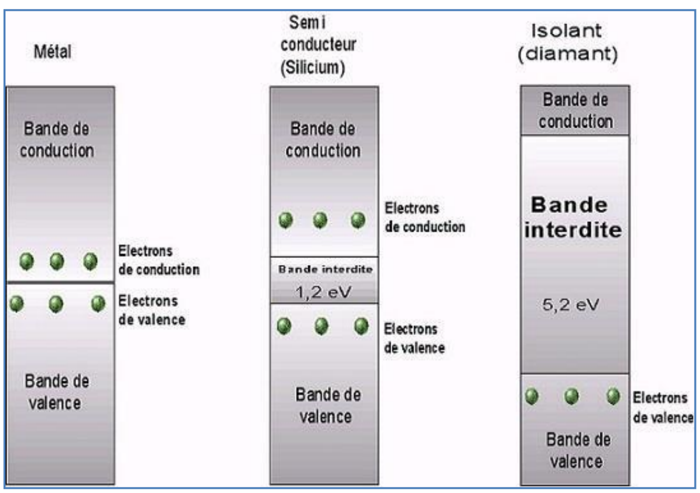


Figure 6:The nature of the materials

Whatever the type of material, two permitted energy bands to play a particular role in cloth: the " conduction band," which corresponds to the last energy band saturated with changes in the material, and the permitted energy band—next called "conduction band."

The conduction tape is rich in charges but does not participate in the electrical conduction phenomenon. Conductive tape, on its part, can be free of charges, regardless of materials operating at temperatures close to absolute zero. This energy range allows electrons to move tasks in the material, creating an electric current in the solid. By representing the energy in Fig.06, we can see those conductive materials such as metals have overlapping bands of conduction and valence, which makes it easy for electrons to pass directly from the valence band to the conduction band, thus flowing current throughout the material.

Moreover, in a semiconductor material, just as in an insulating material, these two bands are separated by a band. The only difference between a semiconductor and an insulator is the width of this separation, which gives each its respective properties.

When the semiconductor is forward biased, electrons move from the Parity band to "go up" in the conduction band, and others "go down" in the opposite direction. Each exchange from the Parity band to the conduction band is called recombination. This phenomenon of recombination of electron-hole carriers is at the origin of the LED light emission. The energy of the generated photon and the resulting properties depend on the energy threshold between the Parity band and the conduction band, and the type of semiconductor material.

To create as much light as possible, it is possible to optimize the number of recombination by using "doping" techniques similar to those used in the field of electronic components. Also, this process can have other effects such as decreasing the electrical resistance (related to losses), changing the emission wavelength, or even increasing the number of carriers in a material. As the research work carried out in this thesis does not aim to create an LED technologically, the links between the type of doping, its quantity, and the resulting physical effects, as well as the physical equations describing them.[15][18][19]

6. Biasing of LED

A sufficient amount of electrical current passes through to emit light in forward biasing, which is approximately 2v in a type made of gallium phosphate.

The intensity of illumination (Iv) changes directly with the forward current of the diode (Id) according to the following relationship:

$$Iv = 40Id$$

And because the LED operates on a small front voltage that does not exceed a few volts, the resistance is connected to it in series, limiting the current. The value of the current limit resistance is calculated according to the following relationship:

$$\mathbf{R = (Vs - Vd) / Id}$$

Whereas:

R = Resistance or current limiting resistance.

Vs = source voltage or supply voltage

Vd = The front voltage difference in the LED

Id = Diode forward current intensity

In reverse bias, a feeble current pass through the LED that does not produce light.[13] [20]

7. Characteristics of LED

LED lighting is Light-emitting diodes (LEDs). They are solid-state semiconductor devices. This has advanced from numeric displays and indicator lights to a range of novel applications like exit signs, traffic lights, signage, outdoor lighting, accent lighting, downlighting, etc. LED illumination is achieved when a semiconductor crystal is excited to produce visible light in the desired wavelength range directly.

It is a fact that LEDs offer many benefits like small size, long lamp life, energy-saving, and durability, etc. It is available in desired shapes, colors, sizes and

lumen-it can be designed in color changing, dimming, etc.

Following are significant characteristics of LED:

1. When a LED is activated power supply converts AC voltage into sufficient DC voltage, which is applied across the diode semiconductor crystal. Excess energy is converted into light

2. The use of indium gallium nitride (InGaN) as semiconductor material has resulted in the brightest LEDs and developed a white LED.

3. LEDs produce efficacies lumen/what greater than incandescent lamps and they are low voltage low current devices and

4. Color with LED is possible based on the chemical composition of the material that is excited. It can produce white, deep blue, yellow, green, orange, red, bright red, and deep red. [21]

8. Applications of LED

LEDs are now widely used from house to laboratory, from industry to military, from lighting to entertainment, and from environmental cleaning to medical surgery. These are brilliant candidates for displays in sexy mobile phones, laptops, and high-definition TVs. They are rapidly replacing their liquid crystal and cathode ray-based display counterparts. High brightness LEDs offer many potential advantages over traditional incandescent bulbs and fluorescent tubes. They are highly reliable with long service life. They consume relatively little energy, and lower operating voltage means that they are safer to handle, a particular concern in external applications where moisture has to be taken into account; and the project less heat into the illuminated field is another important consideration. An area where LEDs show their great promise is in architectural applications. The highly directional nature of LED illumination, alongside the saturated color output they offer, provides architects with lighting options, both internal and external, that are not possible using conventional lighting. This also makes LEDs particularly suitable for so-called task lighting, highlighting particular architectural or decorative features, or provides local spotlighting. Followings are some recent applications of LEDs:

8.1 Applications of LEDs in Display and Televisions (TVs)

Light-emitting diodes (LEDs) are widely used in televisions and monitors. For example, LED TV is a modern entertainment technology device that often uses a series of light-emitting diodes to represent a clear backlight display of a TV. True LED TV is one of those gigantic screens you usually see in outdoor stadiums, Grand Prix events, and rock music venues. LED TVs are powerful kits for delivering high-definition images; they are large screens made up of thousands of super bright LEDs.

8.2 Applications of LEDs in General Lightening

Light-emitting diodes are widely used in general, decorative as well as architectural lighting. This is more expensive per lumen compared to an incandescent bulb but is more durable and long-lasting. LED grow lamps are more efficient because LEDs produce more lumens per watt compared to other alternatives, and also because they can be tuned with specific wavelengths that can make the most of lamps, lanterns, street lighting, and video display screens at a wide range Wide, architectural lighting, and light source for machine vision systems, which require bright, focused, homogeneous and possibly intermittent lighting; motorcycle and bicycle lights, spotlights, including some models powered by mechanical emergency lighting, backlights of TVs and LCD screens. Available in RGB (RGB) lights, a full-spectrum light source extends the color gamut by 45%. Stage lights using banks of LED as an alternative to incandescent lamps.[22]

a b c

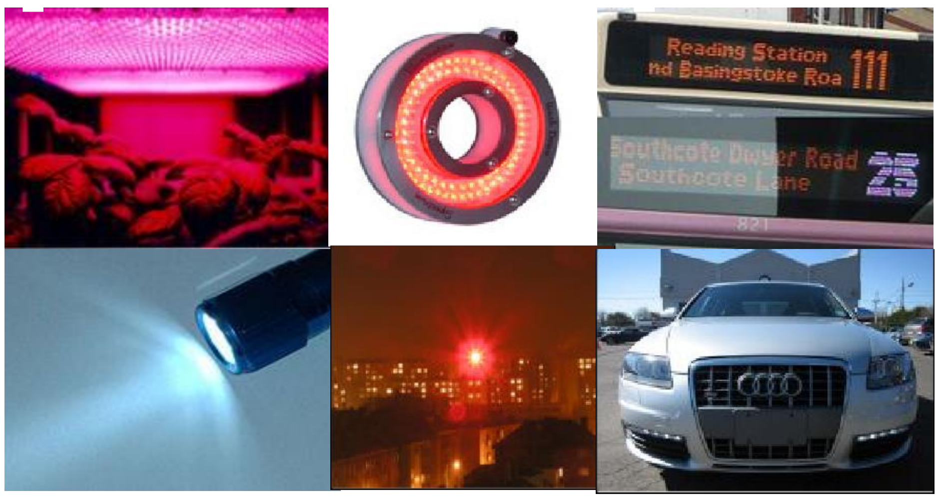


Figure 7:Applications of LEDs in general lightening

a) LED panel light source used in an experiment on plant growth. The findings of such experiments may be used to grow food in space on long duration missions.
b) Light sources for machine vision systems.
c) LED destination displays on buses, one with a colored route number.
d) Flashlights and lanterns that utilize white LEDs are becoming increasingly popular due to their durability and longer battery life.
e) A single high-intensity LED with a glass lens creates a bright carrier beam that can stream DVD-quality video over considerable distances.
f) LED lights on an Audi S6 car.

8.3 Laboratory and Medical Applications of LEDs

Light-emitting diodes have become critical components in research and development nowadays. They are widely used in displays in multimeters, indicators in power supplies, water purification, sterilization, diode lasers, and several medical applications. There are several applications of LEDs of different wavelength ranges, which are illustrated in the following table 1:

S.No.	Applications	Wavelength required (nm)
1	Detection of micro contamination	225nm/ 365nm
2	Water purification	225 – 280 nm
3	UV curing	365-375 nm
4	Scientific analysis	265-415nm
5	Bank note verification	365-385 nm
6	Phototherapy	310 – 420 nm
7	Crime Scene inspection	340 – 420 nm
8	UV dental whitening	345 – 420 nm

Table 1: Applications of LEDs of different wavelength ranges

LED phototherapy for acne using blue or red LEDs has been proven to reduce acne over three months significantly. Sterilization of water and other substances using UV light is frequently used for biological experiments.

8.4 Applications in Information and Telecommunication

LEDs have shown their potential applications in the field of information broadcasting and telecommunications. They are widely used in computer mice, scanners, sensors, etc. IR LEDs are the most critical components in the remote controls system, which are the main components of the current era of modern technology. IR LEDs are also used in optical fiber and free-space optical communication. Some flatbed scanners use an array of red, green, and blue LEDs rather than the typical cold-cathode fluorescent lamp as the light source. Having independent control of three bright colors allows the scanner to calibrate itself for more accurate color balance, and there is no need for warm-up. LEDs are also used in computers for challenging drive activity and power on. Some custom computers feature LED accent lighting to draw attention to a given component. Many computer manufacturers use LEDs to tell the user its current state.

9. Advantages and disadvantages of LED

9.1 Advantages of LED

1. LEDs can emit light of an intended color without using color filters that traditional lighting methods require. This is more efficient and can lower initial costs.
2. LEDs can be tiny (smaller than two mm2 [23]) and easily attached to printed circuit boards.
3. LEDs, being solid-state components, are difficult to damage with external shock. Fluorescent and incandescent bulbs are easily broken if dropped on the ground.
4. LEDs can have a relatively long useful life. One report estimates 35,000 to 50,000 hours of useful life, though time to complete failure may be longer [24]. Fluorescent tubes typically are rated at about 30,000 hours, and incandescent light bulbs at 1,000–2,000 hours.
5. LED lights to light up very quickly. The typical red LED achieves full brightness in less than a microsecond. [25] LEDs used in communication devices can have faster response times.

9.2 Disadvantages of LED

1. LEDs must be supplied with the correct current. This can involve series resistors or current-regulated power supplies.
2. Winter use: Since they do not emit more heat than incandescent lights, the LED lights used to control traffic can be blocked by snow, leading to accidents. [26] [27].

10. Conclusion

The discovery of the light-emitting diode (LED) imposed itself in many scientific and practical applications. LED is a light source in electronics and optical communications. It is made of semiconductors and lights up when an electric current pass through it in the forward bias mode. The light emitted principle of action depends on the electrical energy given to it that moves the charge carriers, which leads to the generation of free photons in all directions producing a spectrum of several colors, including orange, yellow, green, and red. LED has several characteristics that make it the most widely used in electronics, its high efficiency compared to traditional lamps, its long life span does not produce thermal energy, and its small size enables it to be used in electronic devices such as calculators, remote control devices, and the electrical signal in the radio and television ... as it can be considered environmentally friendly.

Chapter II Different types of LEDs

1. Introduction

In this chapter, we present different types of light-emitting diode designs. In each of these structures, the design, characteristics, operation of the device will be described. Then, will be mentioned some applications of these devices

2. Different types of LEDs

2.1 Heterojunction

A semiconductor heterojunction is a particular PN junction formed by depositing more than two different thin films of semiconductor materials on the same substrate in sequence. These materials have other band gaps. They can be compounds such as gallium arsenide. They can also be a semiconductor alloy such as silicon-germanium.

2.1.1 Design of Heterojunction

In general, the heterojunction systems can be divided into two different types:
p–n semiconductor heterojunction (Figure 8) and non -p–n heterojunction systems. The semiconductor p–n junction is an effective architecture for the highly efficient charge collection and separation. In general, when the p- and n-type semiconductors are in contact, they form a p–n junction with a space-charge region at the interfaces due to the diffusion of electrons and holes and thus create a built-in electrical potential that can direct the electrons and holes to travel in the opposite direction (Figure 8). When photons irradiate the p–n heterojunction with energy higher or equal to the bandgaps of the photocatalysts, the photo-generated electron-hole pairs can be quickly separated by the built-in electric field within the space charge region. Driven by the electric field, the electrons are transferred to the CB of the n-type semiconductors and the holes to the VB of the p-type semiconductors.[28]
In this p–n type heterostructure, can be obtained several advantages: (1) a more effective charge separation; (2) a rapid charge transfer to the catalyst; (3) a longer lifetime of the charge carriers; and (4) a separation of locally incompatible reduction and oxidation reactions in nano space.

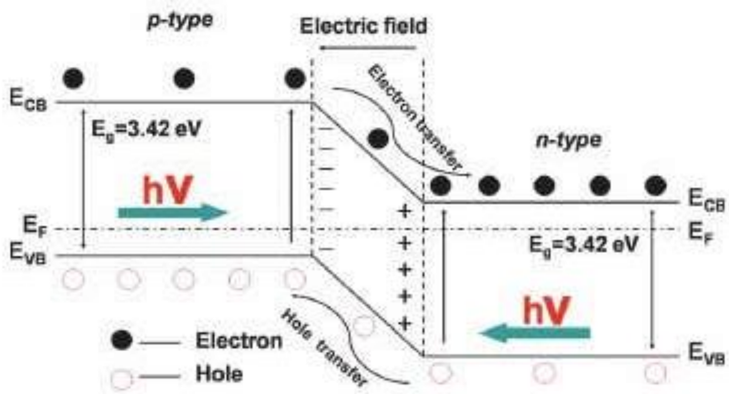


Figure 8: Schematic diagram showing the energy band structure and electron–hole pair separation in the p-n heterojunction

2.1.2 Working principal of Heterojunction

When the PN junction is forward biased, the electrons and holes are injected into the junction region. The region around the intersection contains many electrons in the conduction band and holes in the valence band. Thus, population inversion is achieved. At this stage, some of the injected charge carriers recombine and produce radiation in the form of light.

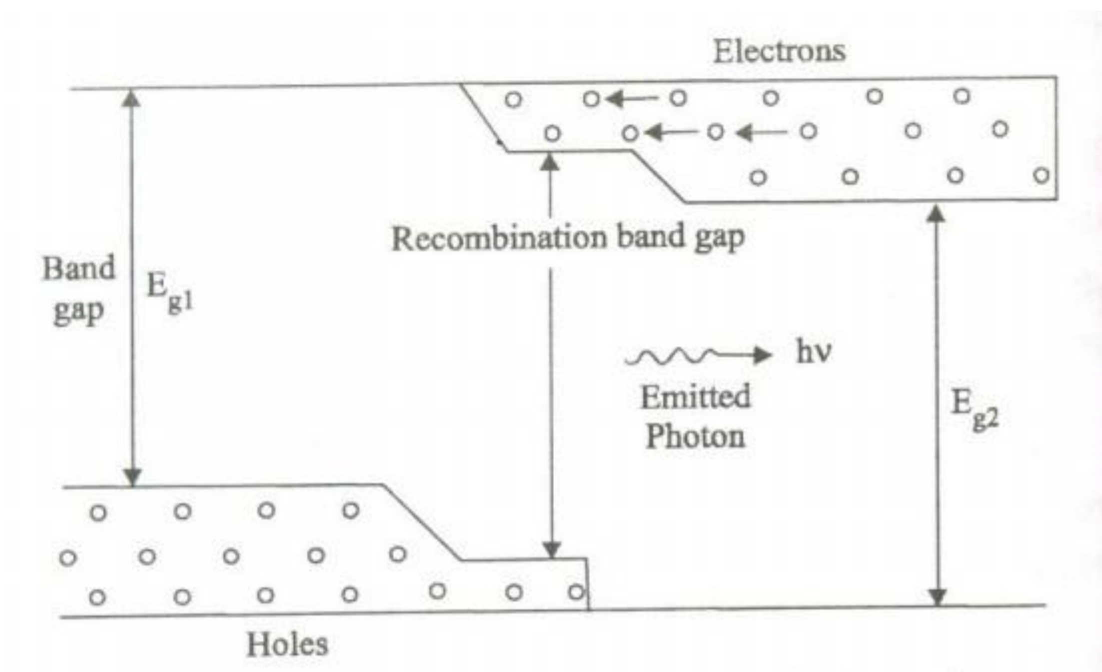


Figure 9:Working principal of Heterojunction

When the forward-biased voltage is increased, more and more light photons are emitted, and the light intensity is more. These photons can trigger a chain of stimulated recombination's resulting in the release of photons in phase.

The photons moving at the junction plane travels back and forth by reflection between two sides and grow their strength. A coherent beam of the laser having a wavelength of nearly 8000 A emerges from the junction region.[29]

2.1.3 Application of Heterojunction

There are many applications of Heterojunction in many fields, including:

2.1.3.1 Solar cells:

Heterojunctions are commonly formed through a crystalline silicon substrate interface and an amorphous Silicon passivation layer in solar cells. The Heterojunction with Intrinsic Thin-Layer (HIT) solar cell structure was first developed in 1983 [30] and commercialized by Sanyo/Panasonic. HIT solar cells now hold the record for the most efficient single-junction silicon solar cell, with a conversion efficiency of 26.7%. [31]

2.1.3.2 Lasers:

Using heterojunctions in lasers was first proposed [32] in 1963 when Herbert Kroemer, a prominent scientist in this field, suggested that heterostructures could greatly enhance population inversion. By incorporating a smaller direct bandgap material like GaAs between two more extensive bandgap layers like AlAs, carriers can be confined so that lasing can occur at room temperature with low threshold currents. It took many years for the material science of heterostructure fabrication to catch up with Kroemer's ideas, but now it is the industry standard. Later, it was discovered that it could control the bandgap by taking advantage of the quantum size effects in quantum well heterostructures. Furthermore, heterostructures can be used as waveguides to the index step, which occurs at the interface, another significant advantage to their use in semiconductor lasers. Semiconductor diode lasers used in CD and DVD players and fiber optic transceivers are manufactured using alternating layers of various III-V and II-VI compound semiconductors to form lasing heterostructures.

2.1.3.3 Bipolar transistors:

A heterojunction is used as the base-emitter junction of a bipolar junction transistor, with a higher high forward gain and low reverse gain result. This translates into perfect high-frequency operation (values in tens to hundreds of GHz) and low leakage currents. This device is called a heterojunction bipolar transistor (HBT).

2.1.3.4 Field-effect transistors:

Heterojunctions are used in high electron mobility transistors (HEMT), operating at significantly higher frequencies (over 500 GHz). The proper doping profile and band alignment give rise to highly high electron mobilities by creating a two-dimensional electron gas within a dopant-free region where minimal scattering can occur.

2.2 Organic LEDs

It is a light-emitting diode (LED) in which the electrical emission layer consists of a film or layer of organic compounds that emit light in response to electric current. This layer of organic semiconductor materials lies between two electrodes. Generally, at least one of these electrodes is transparent. There are two main types of OLEDs: those that use small molecules and those that use polymers.[33]

2.2.1 Architecture of Organic LEDs

OLED structure has many thin layers of organic material. These OLEDs compose of aggregates of Amorphous and crystalline molecules arranged in an irregular pattern. When current passes through these thin layers, the light gets emitted from their surface by the process of electro phosphorescence. OLEDs work on the principle of electroluminescence, and this can be achieved by using multi-layered devices. In between these multi-layered devices, several thin and functional layers are sandwiched between the electrodes.

When Direct Current is applied, charge carriers from the anode and cathode are injected into organic layers; due to electroluminescence, visible light gets emitted.

The architecture of OLED display comprises several layers: two or three organic layers like conducting layer, an emissive layer, and other layers such as substrate, anode, and cathode layers that are explained below in detail.[34]

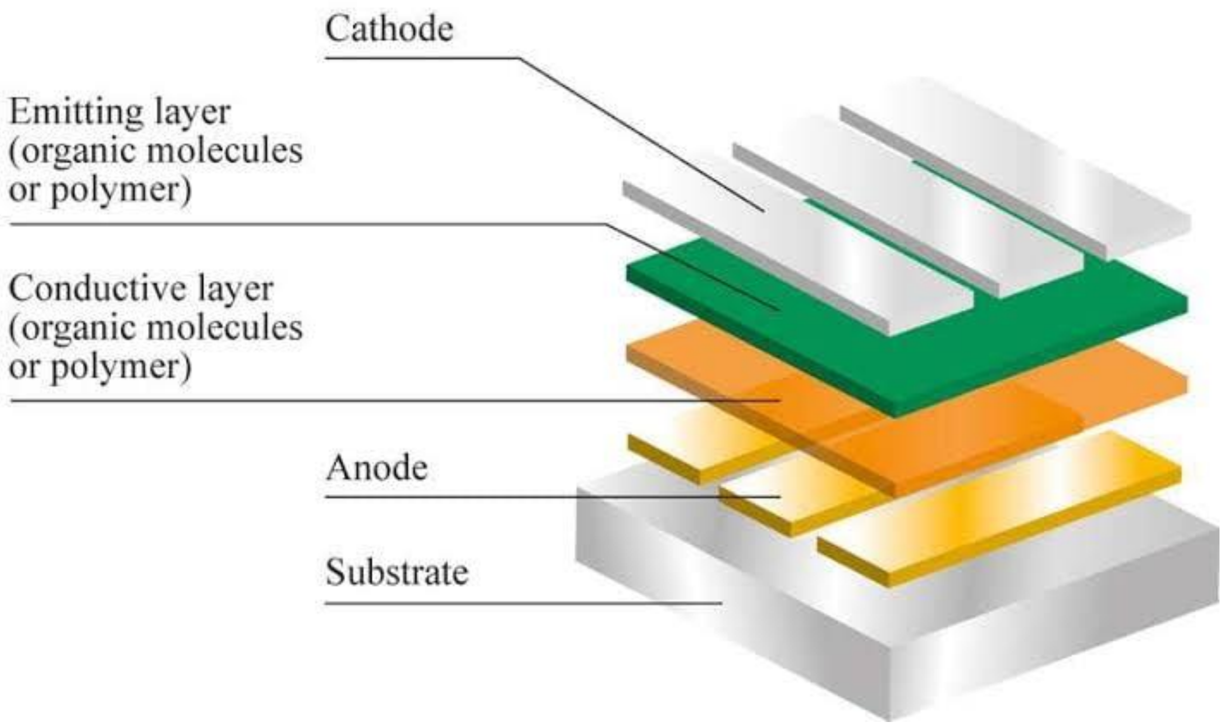


Figure 10:Architecture of OLED

- **Substrate Layer:** This layer is a thin sheet of glass with a transparent conductive layer, which a transparent plastic layer or foil can also make. This substrate supports the OLED structure.
- **Anode Layer:** This layer is active and removes electrons. When current flows through this device, electrons are replaced by electron holes. Thin layers are deposited onto an anode surface, and therefore, it is also known as a transparent layer. Indium tin oxide is the best example of this layer that serves as the bottom of the electrode or anode.
- **Conductive Layer:** Conductive layer is an integral part of this structure that transports the holes from the anode layer. This layer is made up of organic plastic, and the polymers used include light-emitting polymers, polymer light-emitting diodes, etc. The conductive polymer used in OLED is polyaniline, polyethylene dioxythiophene. This layer is an electroluminescent layer and uses the derivatives of p-phenylene vinylene and polystyrene.
- **Emissive layer:** This layer transports electrons from anode layers, and it is made of organic plastic molecules that are different from the conducting layers. There are multiple choices of materials and processing variables such that a wide range of wavelengths can be emitted

during emission. In this layer, two polymers are used for casting, such as polyfluorene, poly para phenylene, which usually emits green and blue lights. This layer is made of particular organic molecules that conduct electricity.

- **Cathode Layer:** The cathode layer is responsible for injecting electrons when current flows through the device. Making of this layer is done by using calcium, barium, aluminum, and magnesium. It may be either transparent or opaque, depending on the type of OLED.

2.2.2 Working principle of Organic LEDs

As depicted above, a typical OLED is composed of an emissive layer, a conductive layer, a substrate, an anode, and cathode terminals. The layers are made of particular organic molecules that conduct electricity. Their levels of conductivity range from those of insulators to those of conductors, so they are called organic semiconductors. The first, most basic OLEDs consisted of a single organic layer of poly (p-phenylene vinylene, synthesized by Burroughs et al. Multilayer OLEDs can have more than two layers to improve device efficiency. As well as conductive properties are concerned, some organic layers may be chosen to aid charge injection at electrodes by providing a more gradual electronic profile or to block a charge from reaching the opposite electrode and being wasted [35]. The combination of electron and hole for the generation of a photon in the OLED is illustrated in Figure 11.

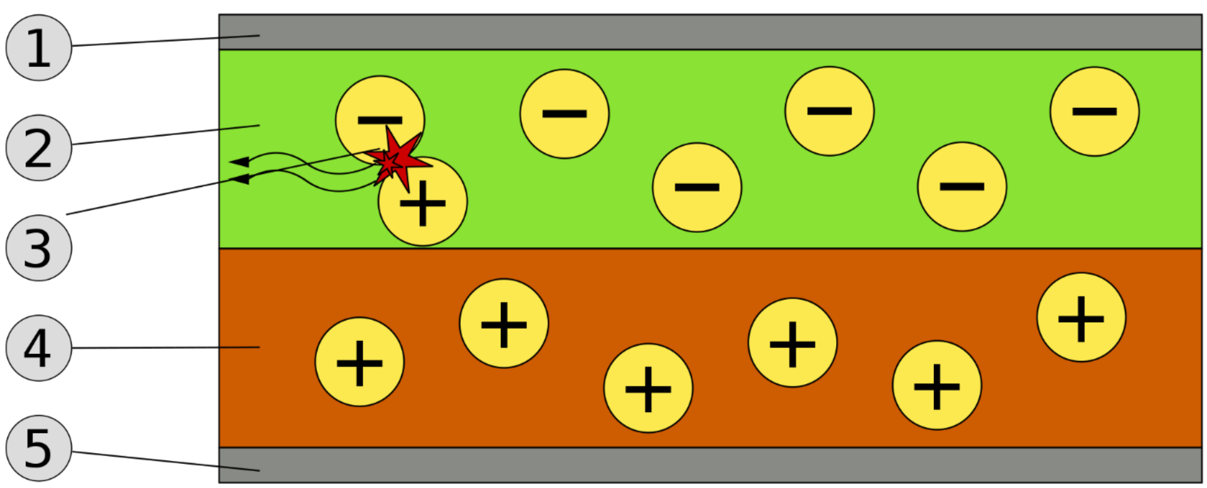


Figure 11: Schematic of a 2-layer OLED: 1. Cathode (−), 2. Emissive Layer, 3. Emission of radiation, 4. Conductive Layer, 5. Anode (+)

A voltage is applied across the OLED such that the anode is optimistic concerning the cathode. This causes a current of electrons to flow through the device from cathode to anode. Thus, the cathode gives electrons to the emissive layer, and the anode withdraws electrons from the conductive layer; in other words, the anode gives electron holes to the conductive layer. Soon, the emissive layer becomes negatively charged, while the conductive layer becomes rich in positively charged holes. Electrostatic forces bring the electrons and the holes towards each other, and they recombine. This happens closer to the emissive layer because, inorganic semiconductors, cavities are more mobile than electrons (unlike in inorganic semiconductors). The recombination causes a drop in the energy levels of electrons, accompanied by an emission of radiation whose frequency is in the visible region. That is why this layer is called emissive. The device does not work when the anode is put at a negative potential concerning the cathode. In this condition, holes move to the anode and electrons to the cathode, so they are moving away from each other and do not recombine. Indium tin oxide (ITO) is commonly used as the anode material. It is transparent to visible light and has a high work function which promotes the injection of holes into the polymer layer. Metals such as aluminum or calcium are often used for the cathode as they have low work functions, which promote the injection of electrons into the polymer layer [36]. Molecules commonly used in OLEDs include organometallic chelates (for example, Alq3, used in the first organic light-emitting device) [37] and conjugated dendrimers. Recently a hybrid light-emitting layer has been developed that uses nonconductive polymers doped with light-emitting, conductive molecules. The polymer is used for its production and mechanical advantages without worrying about optical properties. The small molecules then emit light and have the same longevity as the small molecule OLEDs.

2.2.3 Application of Organic LEDs

- **Readily achieved by OLEDs (2002 – 2005)**

• **Monochrome applications:** small monochrome displays for handheld electronic devices (cell phones, PDAs, digital cameras, GPS devices, etc.).

• **Two or multicolor applications**: Car electronics (radios, GPS displays, maps, warning lights, etc.), instrument electronics, heads-up instrumentation for aircraft and automobiles, and rugged PDAs.

• **Full-color application:** LCD backlights, small full-color displays such as high-resolution personal communicators.

- ❖ **Nearly-readily achieved by OLEDs (2005 -2010)**

• **Large Displays:** Wall-hanging TV monitors, large-screen computer monitors.

Applications Convertible to OLEDs

- General White light applications (to replace incandescent/halogen, fluorescent)
- Lighting panels for illumination of residential and commercial buildings.
- Lighting panels for advertising boards, large signs, etc.
- Ultra-lightweight, wall-size television monitors.
- Office windows, walls, and partitions.
- Color-changing lighting panels and light walls for home and office, etc.
- Large displays, "smart panels."

New Applications that OLEDs could enable

- Applications benefiting from programmable performance (intensity, color, direction)
- Applications are capitalizing on integration with displays, vehicles, architecture, military equipment, etc.
- Smart lights. [38]

2.3 Nanowire LEDs

A nanowire is a nanostructure with a diameter of 9 to 10 nanometers and an unrestricted length. It is on these scales that the effects of quantum mechanics are essential.

Various types of nanowires exist, including superconducting (as YBCO), metallic (as Ni), semiconductors (such as silicon nanowires (SiNWs), InP, and GaN), and insulation (such as SiO2 and TiO2).

Molecular nanowires consist of repeating molecular units that are either organic (for example, DNA) or inorganic (for example, Mo6S9 - xIx).

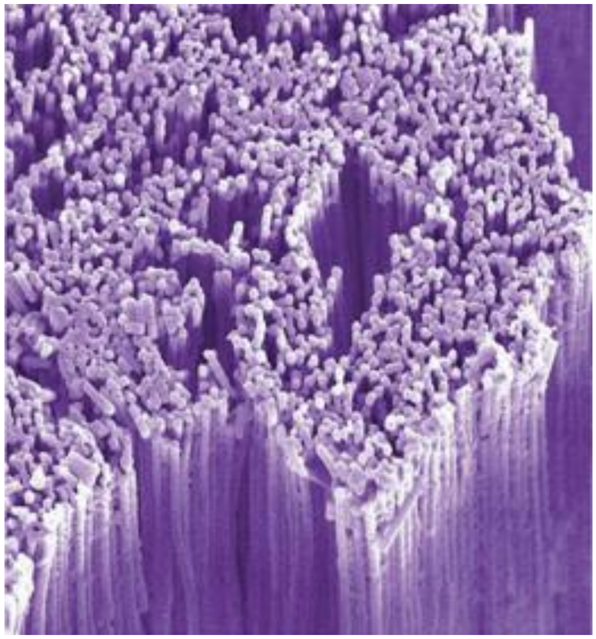


Figure 12:Image by scanning electron microscopy of nanowires

The III-Nitride semiconductor family has a wide range of technologically critical applications, especially in visible and ultraviolet light-emitting diodes (LEDs) [39][40] and lasers.

III-nitride-based nanowires and quantum-confined heterostructures have emerged as promising nanostructured technology for the development of visible light-emitting diodes (LEDs) and lasers [41] [42]. Ga (In)N nanowires grown on (001) silicon by molecular beam epitaxy (MBE) are relatively free of extended defects compared to planar GaN grown on foreign substrates [43] [44].

2.3.1 Design of Nanowire LEDs

It is a set of the plurality of devices arranged side by side on a support layer, wherein each device comprises a first conductivity type semiconductor nanowire core and an enclosing second conductivity type semiconductor shell for forming a pn or pin junction that in operation provides an active region for light generation and a first electrode layer that extends over the plurality of devices and is in electrical contact with at least a top portion of the devices to connect to the shell, wherein the first electrode layer is at least partly air-bridged between the devices [45].

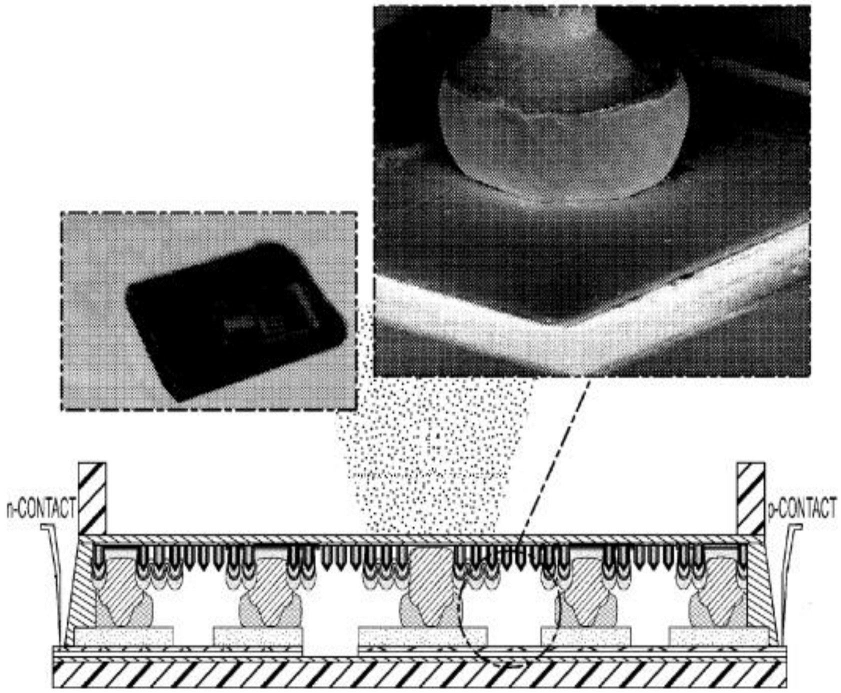


Figure 13:The light emitting diode (LED) structure

2.3.2 Working principal of Nanowire LEDs

The working principle of n-type silicon nanowire biosensors. (a) Positive charges accumulate on the surface. The electrostatic attraction force to electron carriers results in higher conductance. (b) The original state of SiNW. (c) Negative charges accumulate on the surface. The electrostatic repulsion force to electron carriers results in lower conductance [46].

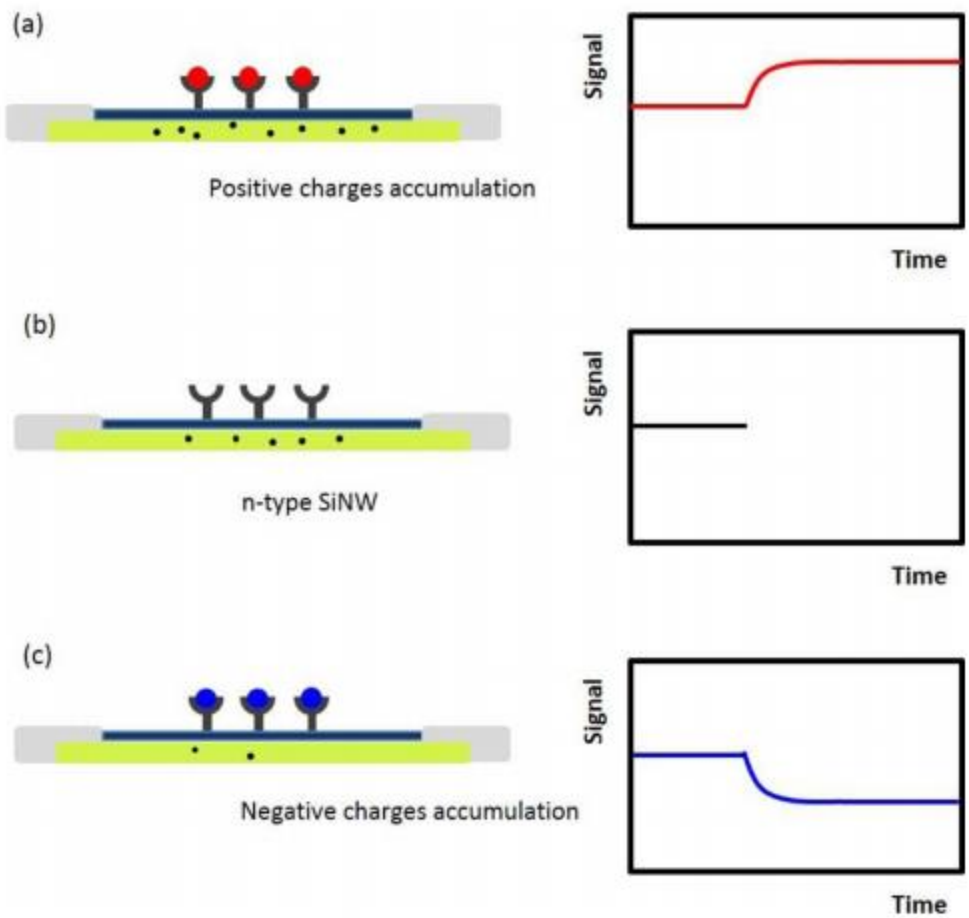


Figure 14:Working principal of Nanowire LEDs

2.3.3 Application of Nanowire LEDs

The resulting nanowires are used to fabricate light-emitting diodes (LEDs), lasers, solar cells, and sensors [47][48][49]. However, expensive single crystalline substrates are commonly used as substrates for nanowire heterostructures and epitaxial devices, limiting the manufacturability of nanowire devices.

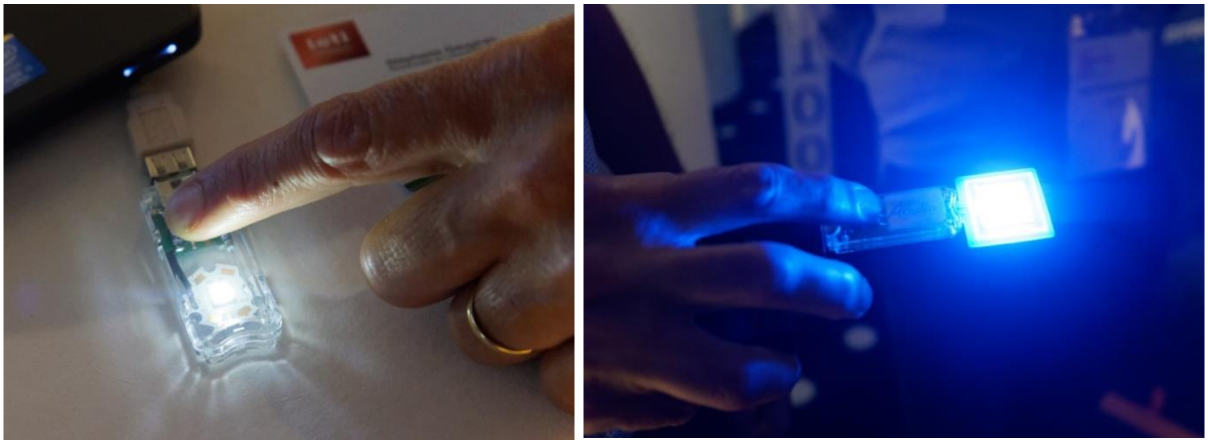


Figure 15:Nanowire LEDs Example Applications

3. Conclusion

In this chapter, we have introduced different types of LED designs. We have studied some of its structures by describing the device's design, characteristics, and operation. We have mentioned some of the applications of these devices.

Chapter III Study and Simulation of MQW LED

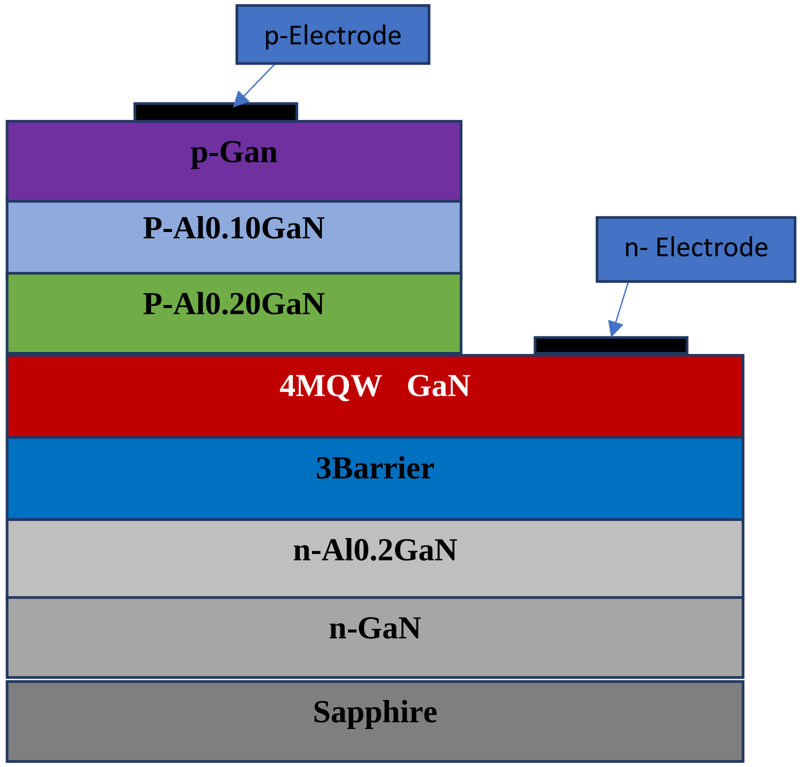
1. Introduction

Simulation software Silvaco Atlas is a software that allows the design, modeling, and simulation of semiconductor devices. Using this program, multiple quantum well (MQW) LED will be simulated and studied in this chapter. The effect of quantum well number on performance of the device is presented. Therefore, the influence of quantum well thickness will be discussed and the results are illustrated.

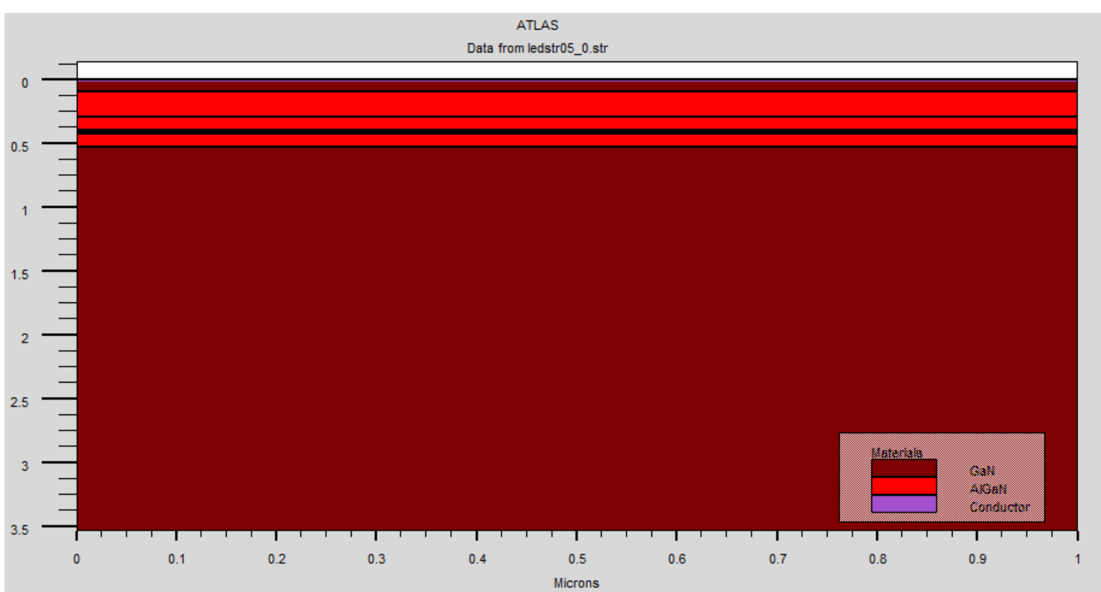
2. Structure description

Optical gain and spontaneous recombination models implemented in ATLAS are used to account for the effects of quantum mechanical confinement of carriers and strain effects in Multiple Quantum Wells (MQW). To enable these models, use the MQW statement. The MQW statement has parameters describing the locations and compositions of the wells, the effects of strain on the band edges, parameters relating to the gain and recombination models, and parameters relating to how the models interact with other electrical and optical simulations models.

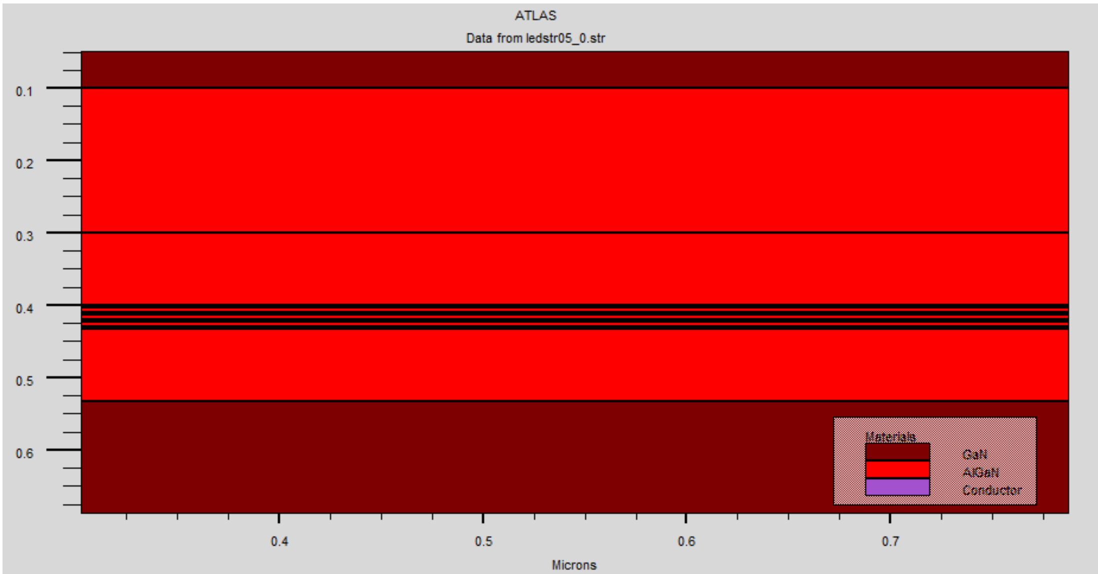
Figure 16 shows the studied structure of multiple quantum well LED. The structure consists of twelve regions (fig 16.a). First one, a 300 nm thick n-type GaN with a doping concentration of 2×10^{18} cm^{-3}. Followed by a 100 nm thick n-typeAlGaN with a same doping concentration. Three regions of undoped AlGaN which represents a quantum barrier with 7 nm thickness. Then, four regions of undoped GaN with 3 nm thickness. A p-$Al_{0.2}$GaN, p- $Al_{0.1}$GaN and p-GaN of doping concentration of 2×10^{20} cm^{-3} with 100nm, 200nm and 100nm, are deposed on quantum wells, respectively. In addition, tow electrodes, cathode and anode, are connected on top and bottom, respectively. Figure 16.b represents the structure design through the Silvaco Atlas simulator. To better indicate the quantum wells and quantum barrier layers, we have expanded the figure, and it is clear in figure 16.c.


p-Electrode
p-Gan
P-Al0.10GaN
n- Electrode
P-Al0.20GaN
4MQW GaN
3Barrier
n-Al0.2GaN
n-GaN
Sapphire

(a)


ATLAS
Data from ledstr05_0.str
0
0.5
1
1.5
2
2.5
3
3.5
Materials
GaN
AlGaN
Conductor
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Microns

(b)



(c)

Figure 16:Structure of the multiple quantum well LED

3. Simulation parameters of the LED

In order to simulate a device, it is necessary to determine the parameters of the materials used in the conception of the device, such as gap energy (eV), electron affinity (eV), electron and hole mobility (cm2/Vs), lifetime of electrons and holes τn_0 and τp_0 (ns) and auger recombination aug_nAnd aug_p of both materials AlGaN and GaN. These parameters are recorded in the following table 2.

Parameters	GaN	AlGaN
Bande gab Eg (eV)	3.42	3.77
Electronic affinity (eV)	4.23	3.98
Mobility (cm^2/Vs)	mun0=100 and mup0=10	mun0=100 and mup0=10
Life time of electrons and holes τn_0 and τp_0 (ns)	10^{-9} 10^{-9}	10^{-9} 10^{-9}

Auger Recombination aug_n and aug_p	10^{-34} 10^{-34}	10^{-34} 10^{-34}

Table 2: Parameters used in simulation of MQW LED

4. Mesh

Mesh has an important role in getting a good simulation. Therefore, the utmost care must be taken to ensure reliable and accurate results. The elements that define the unit cell that the emulator uses are posts. To get good and accurate results, so the network resolution must be determined according to the changes of physical quantities. The network must be dense in the AlGaN layers. It's also very good on top and bottom. Thus, the grid designed for our structure is shown in the figure below (figure 17).

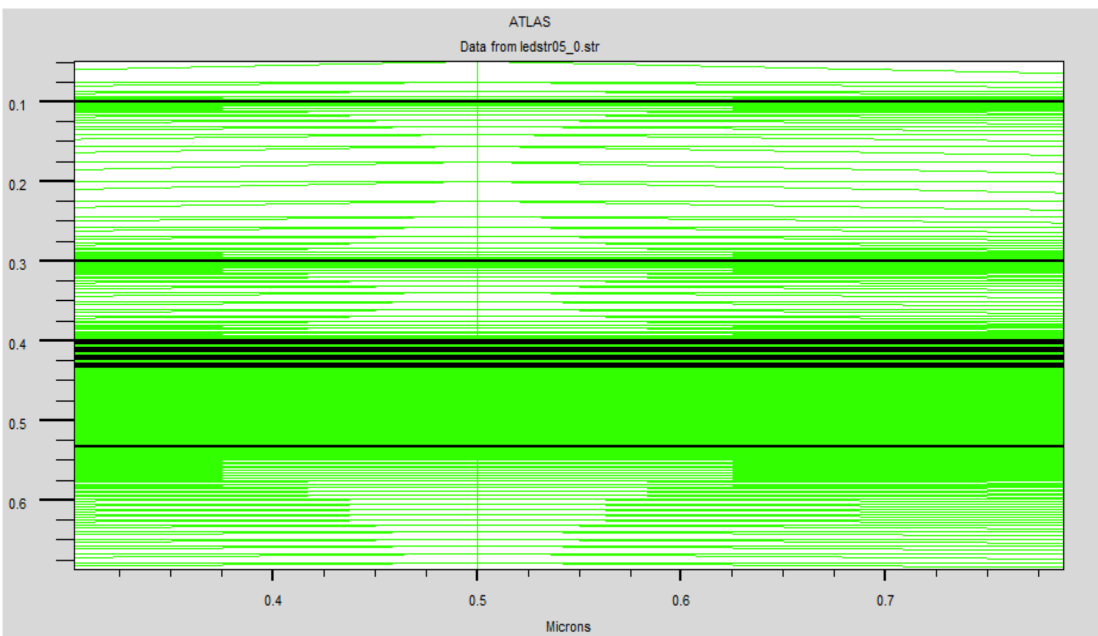


Figure 17: MQW mesh

5. Results and discussion

By implementing the simulation parameters mentioned in Table 2, the I-V characteristic of the analyzed structure can be given in Figure 18. It is to note that the well width is fixed at 3nm with four quantum well. From the figure, it can be seen that the structure provides high anode current (4.75A) at value 6V of anode voltage. Therefore, the threshold is about 2.9V which is less than other standard structures. The obtained results make the proposed structure very useful for future technology. Accordingly, the variation of luminous intensity versus the anode current is shown in figure 19. It is clear that as the anode current increases, more the luminous is increased and reaches its maximum value of 0.14W at 4.75A.

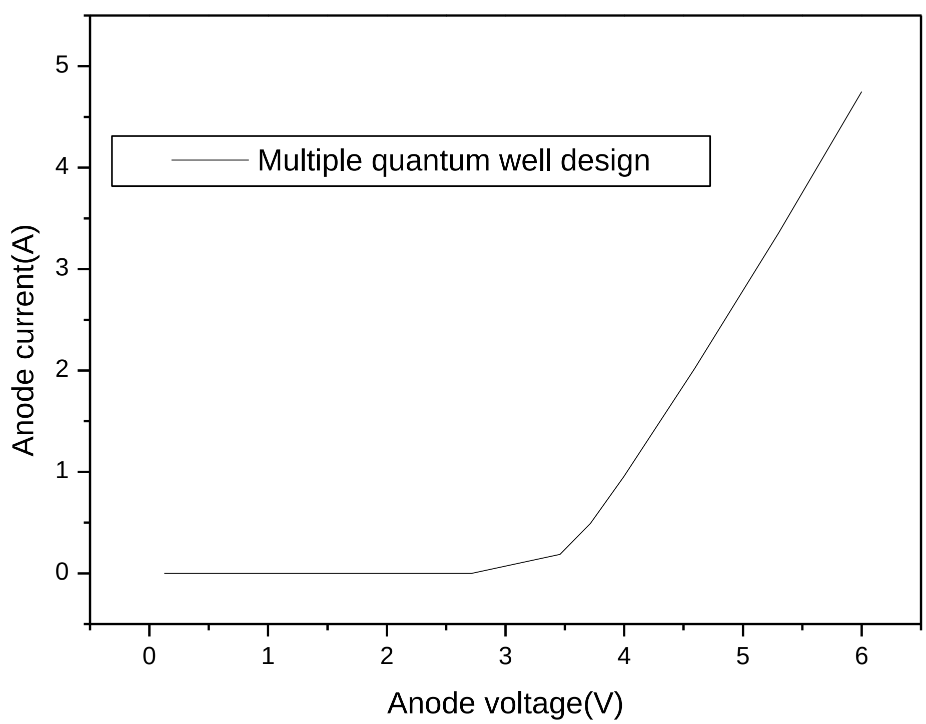


Figure 18: I-V characteristics of MQW LED structure

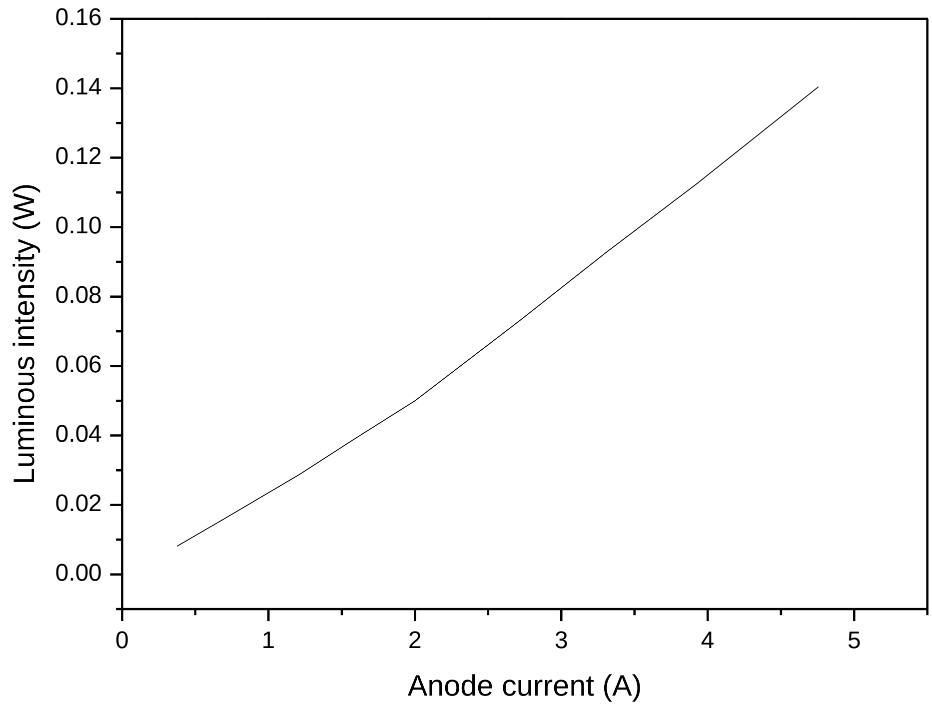


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Figure 19 : Variation of luminous intensity as function of anode current

Figure 20 plots the variation of the current density as a function of the voltage with varying number of quantum wells. It is noticeable that as number of quantum wells decreases, the current density is increased. The value of current density is 5.48A in case of 2 quantum wells which is greater than in cases 3 and 4 quantum wells. The reduced current in case of increased number of quantum wells can be attributed to the nonradiative recombination rate caused due to the lower mobility of carriers which are not able to reach wells present at both sides, n-GaN and p-GaN.

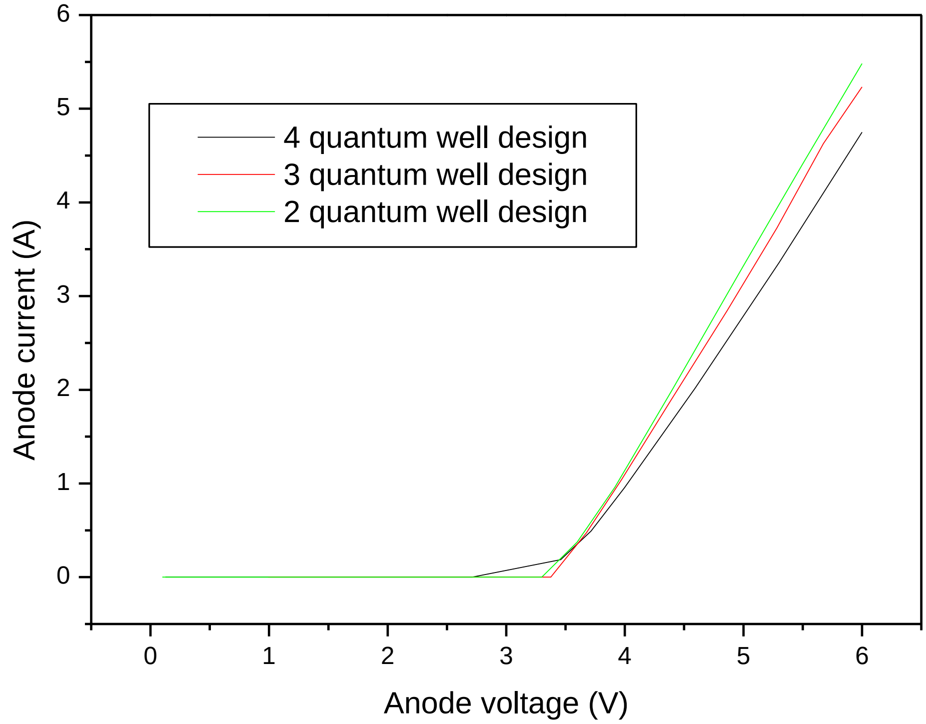

Figure 20 : I-V characteristics of different number of quantum well structures

To investigate the influence of well-width on MQW LED structure, figure 21 shows the I-V characteristics of the device with different well-thickness.it is evident that the well-width of 2nm provides better performance based on its high anode current compared to that of 3nm. This can be attributed to more separation of hole wave function and electron wave function in case of wider quantum well which leads to less electron and hole recombination.

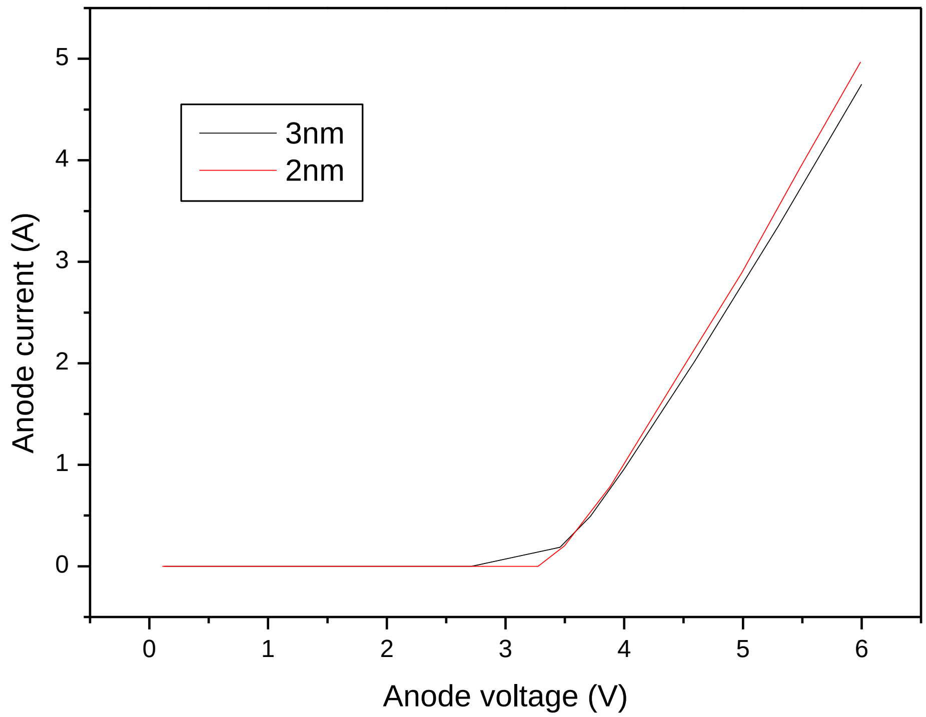

Figure 21 : Anode current versus anode voltage with varying well-thickness

6. Conclusion

In this chapter, we have used the Silvaco Atlas simulator to examine and study the multiple quantum well-LED (MQW) structure. The effect of quantum well number on LED structure has been analyzed. The obtained results demonstrate that the current density in case of 2 quantum wells is greater than that in cases 3 and 4 quantum wells. In addition, different quantum well-width has been investigated and studied. The simulation results indicated that the well-width of 2nm provides better performance compared to that of 3nm. It is noticeable that the MQW LED exhibits better performance with lower quantum well number and lower well-width.

General conclusion

LED has several characteristics that make it the most widely used in electronics, and its high efficiency compared to traditional lamps, its long life, and its small size enables us to use it in electronic devices such as calculators, remote control, and electrical signal in radio, television, traffic lights, and cars... Where It can be considered environmentally friendly. In this work, we have studied the generalities of LED by its definition, working principle, characteristics and some applications.

Different types of LED such as heterojunction LED , organic LED, Nanowire LEDs are presented. However, the structure that we have simulated is a Multi-quantum well (MQW) light-emitting diode based on AlGaN material; the well is placed between two layers of n-AlGaN and p-AlGaN. This sandwich traps both electrons and holes in the active region, thereby increasing the rate of radiative recombination. We extracted the main electrical characteristics such as IV and PV by Silvaco Atlas simulation software. The multi-quantum well diode has better performance causes the light emission of the LED diode to come only from the Quantum well.

The Multi Quantum well (MQW) LED structure has been simulated and studied in order to show the high performance offered by this device. The obtained results indicate that the multi-quantum LED structure exhibits a high current density of 4.75A, and the high strength luminescent reaches its maximum value of 0.14W at 4.75A. Therefore, the effect of quantum well number on the device was modeled and studied. The results indicate that the value of the maximum current density is obtained in case of low number of wells and it reaches 5.48A. In addition, the influence of well-width on MQW design has been examined and studied. It is evident that the well-width of 2nm provides better performance based on its high anode current compared to that of 3nm.Through these results, we note that the high performance of MQW LED structure studied in this work can be found by two quantum wells and 2nm of well-width conception.

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