(Practical side of LED) Pseudo Paper (II)

The Basic Principles of Light Emitting Diodes with an Analysis of their History and Future

**Section I: Basic Principles of LEDs**

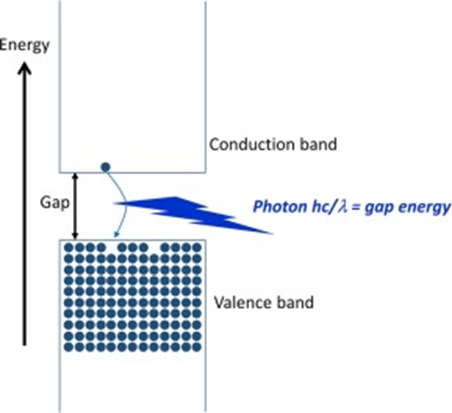
The light emitting diode (LED) is a Nobel Prize winning invention of the 20th century that has helped redefine energy efficient light emission. Utilizing the optical phenomena of electroluminescence, the LED produces light via a direct source of current, rather than a heated filament or gas. In its simplest form the LED is a pair of semiconductors that consist of conduction and valence bands which allow for free electrons to recombine and release photons. Although the first LEDs were created in the 1920’s, useful applications were not invented until the 60’s, and commercial applications were not available until as recently as the 1990s. [1][2]

The driving physical theory behind the LED is electroluminescence. Discovered in 1907, electroluminescence is the process of light emission through the recombination of electrons in an atomic lattice, typically semiconductors. When electrical current is passed through the material free electrons are forced into an excited state. With the right type of material, this process also creates a conduction band of electron holes. When a free electron transfers back to a lower energy state, the energy is typically released as a photon of light (although not always for larger systems). This is extremely useful for two reasons. Firstly, due to the quantized nature of energy, we know the energy applied to any electron will release that same energy when it recombines. Second, the energy of any photon is a well-known result (Equation 1) and is related to the wavelength of the photon. Thus, the color of light can be predicted simply from the energy of the excited electrons. [1][4]

1) E = hc/λ

The basic design of an LED is such that electron recombination can occur frequently and in large abundance. The structure of the LED typically consists of Gallium Nitride (GaN), or some other type of crystal structure, doped with impurities. The two most common type of semiconductor doping techniques are p-type and n-type. The p-type technique uses impurities to create electron holes in the valence material (typically Boron is the injected impurity), and n-type is when the impurities cause an excess of free electrons in the conduction band (typically Phosphorus is used). For LED’s, doping can be either n-type or p-type. The impurities added allow for more states closer the band gap on both bands, thus allowing for easier electron travel across the band gap. When an external voltage is applied to the semiconductors, an electric field is produced and current is formed from the electron recombination. The recombination emits energy as photons. If the semiconductors have an indirect band gap, the energy is released as vibrations, if the semiconductor has a direct band gap, then the energy released is light. GaN is a common semiconductor that can have a direct band gap, which is why they are heavily used in LEDs. See figure one. [1]

Figure 1



*Demonstration of the basic setup of an LED. The conduction band consists of free electrons while the valence band consists of the electron holes. Electrons jump the energy gap by releasing energy in the form of photons. The amount of energy needed to jump is proportional to the wavelength of the photon, thus the band gap can be used to set the color of the LED. [1]*

The basic LED structure described can produce the primary colors red, blue, and green, with only some technical modifications to the design. The red LED is the simplest to produce as it requires the least energy to emit red light, so the simple GaN semiconductor doped with Phosphorus. Along similar lines, a green LED can be created through GaN doped Indium, although this is slightly more difficult to do due to the higher energy gap and doping process. The most difficult primary color LED to create is Blue. This is partly due to blue having the shortest wavelength and the difficultly of creating materials with the proper band gap for blue light emission to occur. However, doping materials such as Silicon, Indium Tin Oxide, and Gallium Nitride have all been viable was of producing blue LEDs. Commercially, sapphire is the most commonly used as it resembles the structure of Gallium Nitride and has less of an economic impact. [1][3]

More complex LEDs can be created using more involved designs. For example, the white LED can be produced in many ways, each with their own advantages and disadvantages. The first way is to simply combine the red, blue, and green LEDs output to produce what humans perceive as white light. This method is the simplicity way to produce a white LED, however it is limited in two major ways. First is by the lowest optical power of the RGB system, that is, the total optical power has a limiting factor which is the lowest optical power of one of the three LEDs. Second by the discrete wavelengths emitted by each LED. This means the emission of white light is fixed by only three wavelengths, and thus doesn’t cover the spectrum of light that is typically white light. The second method for producing white LEDs is to produce monochromatic light from Phosphorus. In this method, Phosphorous materials are shined with low spectrum light (typically blue) which then produce yellow light. Most but not all of the blue and yellow light mix to form white. The downsides to this method are that not all of the white and blue light combine to form white, so you typically are left with residual blue and yellow light, as well as the more technical challenge of phosphorus shining rather than combing three separate LEDs. Besides the white LED, many different types are currently in development, from high power, alternating current, or even dual color. [3][5]

**Section II: History of LEDs**

The first known demonstration of electroluminescence occurred in 1907 by H.J. Round, who made a crude example of the phenomena by placing electrodes on different parts of silicon carbide. He saw different colors emit from his setup but made no attempt to describe the phenomena. It wasn’t until 1929 that an Oleg Losev managed to create the first light emitting diode. Using the same material as Round, he created a more refined version of the setup and was even able to patent his design. However, most scientists still did not understand luminesce and the study of semiconductors was still in its infancy. [1]

It wasn’t until a deeper understanding of semiconductive properties were obtained that progress on the LED would continue. With the invention of p-n junctions and transistors, this method of producing light was finally able to output reliable and more powerful signals, specifically the development of gallium semiconductors allowed for the red LED to be created. Invented in 1962 by Biard and Pittman, the first true LED was a GaAs based red LED. It was patented the same year and the parent company, Texas Instruments, began plans to commercially produce the product. The initial uses of the red LED were limited to mainly scientific laboratories and select industries due the high initial cost. [1][6]

After 1962, many other types of LEDs were quickly invented due to the similar structure for producing different colors of light. However, it was nearly a decade before the blue LED was finally shown to be possible. The trouble

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**Section III: Current Research and Future Potential of LEDs**

Sources:

[1] LEDs for lighting: Basic physics and prospects for energy savings - Bruno Gayral

[2] The role of ITO resistivity on current spreading and leakage in InGaN/GaN light emitting diodes - V.Sheremet M.Genç M.Elçi N.Sheremet A.Aydınlı I.Altuntaş K.Ding V.Avrutin Ü.Özgür H.Morkoç

[3] White light emitting diodes with super-high luminous efficacy -Yukio Narukawa, Masatsugu Ichikawa, Daisuke Sanga, Masahiko Sano and Takashi Mukai

[4] The Editors of Encyclopaedia. “Electroluminescence.” Encyclopædia Britannica, Encyclopædia Britannica, Inc., 2 June 2017, [www.britannica.com/science/electroluminescence](http://www.britannica.com/science/electroluminescence).

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[6] http://www.freepatentsonline.com/3293513.pdf