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Studies on Low Cost LED Based Solar Cell for Emergency Lighting

Dr. N. Pal[*1], Nibedita Das[2], Prof. P. K. Sadhu[2]

[*1,2]Department of Electrical Engineering, Indian School of Mines (Under MHRD, Govt. of India)

Dhanbad – 826004, Jharkhand, India

nitai_pal@rediffmail.com

Abstract

This paper describes some studies on low cost solar cell for generation of electrical power from solar energy using common red coloured LED. The cost of LED based solar cell is relatively much lower as compare to commercially available photo-voltaic solar cell for small stand alone application become economically feasible. LED based solar cell can also help the environment by cutting electricity power generation and its associated greenhouse gas emission. Due to small size, durability, long operating lifetime, wavelength specificity, relatively cool emitting surfaces, and linear photon output with electrical input current waveband of LEDs (single color, nonphosphor-coated) over solid-state light sources is much narrower used for generating electricity. Therefore, a LED based solar cell is proposed which is recent progress toward realizing future low-cost, high-efficiency, and scalable nano-wire based LED. Solid-state lighting using LEDs need drivers integrated in the design to convert existing voltages into the voltages necessary to control the LEDs. An overall discussion is focused in key areas, such as, renewable energy with nano-scale devices such as nano-particles (0D), nano-wires (1D) or thin films (2D) of LED based solar cell are used to increase efficiency of over solid state lighting and open the door for tremendous progress to control the morphological features of the semiconductor at the nano-scale.

Keywords: LED, OLED, Incandescent bulb, CFL, Halogen Lamp, HID lamp and nano-wire.

Introduction

Solid-state lighting (SSL) system is an evolving technology [1] now virtually certain to display all traditional lighting technologies, including incandescent, fluorescent, and high-intensity discharge lighting in the developed world on grid electricity . The replacement lamp market is a huge one, and SSL products have the potential to yield significant energy savings compared with traditional replacement lamps. But SSL differs from traditional lighting in fundamental ways, and thus works best with fixtures that are specifically designed for SSL sources. That means LED, replacement lamps for conventional sockets can never take full advantage of SSL's considerable potential when they are used in fixtures that were designed for other lighting technologies [2]. Due to various complications, conventional LEDs and lighting system made from different materials are inherently inefficient. Moreover, the planar morphology also results in low light extraction efficiency whereas nano-wire arrays based LEDs have greatly improved light extraction efficiency due to use of group III-V semiconductors (GaN, AlGaN, InGaN, PbS etc.), which is poised to significantly reduce energy demand for 21st century. These findings, conclusions, and motivations aimed at developing nano-wires for LED illumination technology have been independently arrive at by competing research groups around the world [3].

Therefore, for avoiding electric shortage and environmental problems, this paper discussed LED based Solar cell with respect to other solid state lighting technology [4]. The SSL creates visible light with reduced heat generation or parasitic energy dissipation. Most common white LEDs convert blue light from a solid state device to an approximate white light spectrum using photoluminescence. The SSL provides illumination that is more energy-efficient, longer-lasting and more sustainable. But the concept of LED based solar cells with nano-wire has attracted significant attention because of their potential benefits in carrier transport, charge separation, and light absorption.

Overview of Solid State Lightning System

The SSL is a new lighting technology based on high brightness of light emitting diodes. This technology because of being much more energy efficient, having longer lifetime and design flexibility has attracted the attention of both manufactures and consumers. The reliability and performance of these lighting systems in different environment has been discussed here.

The enhanced efficiency and versatility associated with SSL-LEDs over traditional vacuum or gas tubes will enable:

- Substantial reductions in electrical energy consumption
- Substantial reductions in carbon-related pollution
- Substantial improvement in the overall human visual experience
- Creation of new semiconductor technologies with spin-off benefit for national security and economic competitiveness
- Creation of a new optoelectronics-based lighting industry, with many new, high-quality Substantial savings for the consumer.

Until the advent of SSL LED, lighting calculations evolved with the presumption that components can vary within the luminaire, that is Luminaries' photometric testing is performed in a laboratory using a reference lamp and ballast, and light loss factors (LLF)which are applied to compensate for the actual lamps, ballasts and physical conditions of the design [5], as a results the maintenance cycle of the compact fluorescent lamp can be as short as 10,000 hours, compared to 40,000 hours or more with the solid state lighting.

LEDs offer advantages over traditional incandescent type lighting, including:

● Faster turn-on time, increasing the time and distance available to the motorist resulting in fewer rear-end collisions.
● Increased efficiency and lower power consumption.
● Vibration and shock resistance.
● Longer operating life.

During reviewing [6], Hunter Lab researchers have represented "difference between a light source and CIE illuminations", where the light is only a fraction of the total energy emitted in form of "electromagnetic radiation" and the visible light comes to earth as a spectral wavelength. But CIE (Commission International de L'Eclariage) has modified the spectral power distributions of different type of white light sources and called them "illumination." White light is composed of various colors of the whole range of visible spectrum. The first commercial WLED based on Phosphors was produced by Nichia in Japan [8] and material of white LED was Gallium Indium Nitride and coated the chip with yellow fluorescent phosphor. Various colors of visible spectrum of white light is shown in Fig. 1 where, typical spectrum of ''white'' light created by mixing the output of red, green, and blue monochromatic LEDs [9-10] and the relative intensity is represented in arbitrary units.

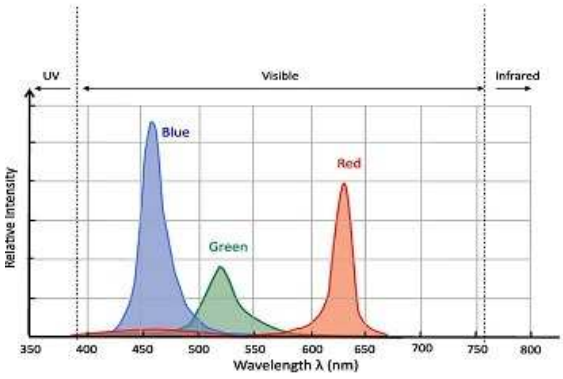


Fig. 1 : Spectrum characteristic of white LED [8 & 10]

There is a wide range of illuminants available, most industrial users will be using one of four CIE illuminants representing the general types of white illumination found in the home, office and exterior conditions. These illuminations are Incandescent or tungsten lamp, fluorescent lamp, LEDs, OLEDs and high-efficiency solar cells. But many of lightning system due to incorporate structures with a high degree of strain, in recent years around 2009, semiconductor nano-wires have increased attention for their unique properties and complex structures [18-19]. In 1990, scintist William Buhro's had proposed III-V nano- whiskers using a solution-liquid-solid process at Washington University, where they synthesized III-V nano-whiskers using a solution-liquid-solid process [20]. After onwards, researchers are working in the nano-wire field are constantly pushing the envelope to develop new fundamental of LED based solar cell. This graph.2 from [21] shows from 1990 to2009, nano-wire based dozen of papers are published, still researchers are trying to develop new technology by using nano-wire, nano-quantum rod etc.

Advantages of Nano-wire LED based Solar Cell over Conventional LED

There are certain advantages of nano-wire LED based solar cell over conventional LED. These are as under:

- Due to unique characteristics and the vast array of applications, Nano wires have nanometer-scale of 1-dimensions approx. 1-100 nm in diameter as compared to bulk semiconductor material LED.
- It has a relatively low absorption coefficient of visible light and near-infrared rays of the electromagnetic spectrum [18] as compared to conventional LED.
- It produces large illumination in terms of brightness and color rendering index with self assembly technology provided complex

structure but low cost as compared SSL system. So “glo” research centre and other R&D are tried to develop one-dimensional crystalline semiconductor structure (nano-wires) with direct control of morphology and chemical composition [22].

- This is a non polluting source of electricity.
- LED based solar lights are independent of the utility grid. Because, since LED signals require very low power to operate, it is feasible to run the signals with battery back-up during power failures. Hence, the operation costs are minimized.

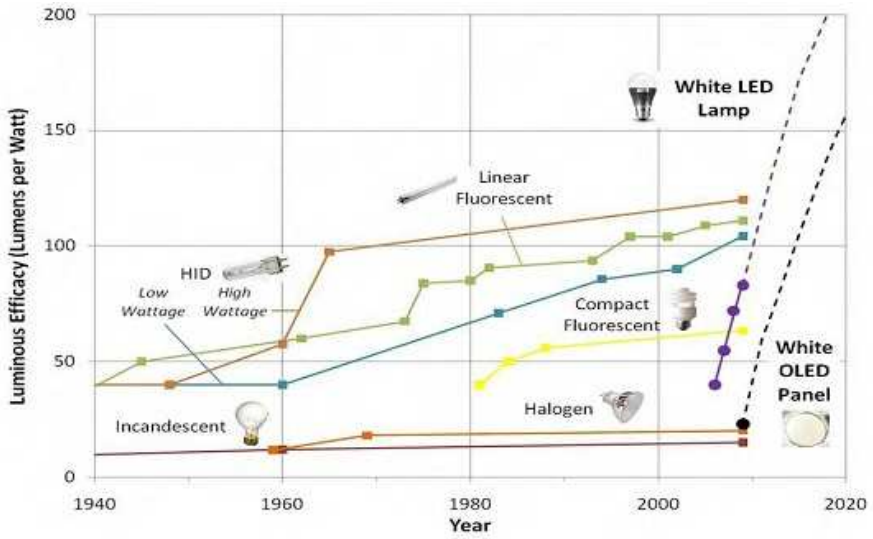
Even LED light sources producing up to 200 lumens per watt (lm/W),but decrease worldwide electricity consumption for lighting by more than 50%, So to overcome these limitations Scientist Leti had developed first nano-wire based LED as well as grow of nano-wires on silicon substrates using metal-organic vapor phase epitaxial.

System Description

During reviewing lighting researchers observed that LEDs with a visible spectrum from 400 to 700 nm wavelength contains can enable shorter wavelength for significant improvement in peripheral visual performance at mesopic conditions for automotive and mining applications [12]. With compare to other slighting devices of characteristics like CFL, Hallogen, Incandesce bulb, HID, OLED etc. intensity of LED have 4000 to 5600 micro candle (mcd) [9] which is shown bellow in Table 1. The Graph 1 shows plot of luminious efficieny verses years of research.

Table 1: Comparison features of SSL energy system

Name	Features	Luminous flux emission (Lumen/W)	Luminous output (lm)	Wattage (W)	Life time (khrs.)
Incandescent lamp	Weak durability so glass envelop can be broken, no inert gas, heating loss more	15	900	60	1
HID	Weak durability so glass envelop can be broken, heating loss more, no inert gas	111-120	37800	315-341	12
Halogen	Weak durability so glass envelop can be broken, heating loss more, Inert gas present	20	970	48	4
CFL	Weak durability so glass envelop can be broken, heating loss is less as compared IB,HID, inert gas contained	97-111	950	15	12
LED	Strong durable as compared to others, reflective lens envelop cannot be broken easily, heating loss is very less, no inert gas	621-132	139	1.05	50
OLED	Durability, less heating loss, no inert gas	23	15	0.65	5



Graph. 1 : Plot of luminious efficieny verses years of research

So, like LED, OLEDs have attracted much attention because of their potential applications in full-color flat-panel displays and high-efficiency lightings [13]. But Like the conventional light sources such as bulbs, fluorescent lamps, and inorganic LEDs, flat panel OLED lighting cannot be free from thermal-related issues [13-16]. Other than LEDs, however, OLEDs have a very short heat transfer pathway between the internal heat source (i.e. light-emitting active area) and the outer device surface. Nevertheless, the Joule heating is also parasitic on the OLED devices. The heat flow in OLEDs is governed by the following equation expressed as

$$C\frac{\partial T(x,t)}{\partial t}=\frac{\partial}{\partial x}\left(k(x,t)\frac{\partial T(x,t)}{\partial t}\right)+\left[\frac{J_n(x,t)^2}{q\mu_n(x,t)n(x,t)}+\frac{J_p(x,t)^2}{q\mu_p(x,t)p(x,t)}\right]$$

Where, T indicates the temperature, k the thermal conductivity, C the volumetric heat capacitance, J the current density, μ the carrier mobility, n the electron density, and p the hole density. Due to the Joule heating, there arise a reduction of luminance, short lifetime and large spectral shift of OLEDs.

For avoiding all these, LED based solar cell is used. Due to intrinsic characteristics device (Fig. 2, [6]) having core/shell structures p/n, p/in, p/pn and p/pin (where p, i and n represent p-type, intrinsic and n-type respectively), in which an applied voltage produces a current flow in forward direction, which generates light with angle when charge carriers injected across the junction recombine. In forward bias, recombination charges occur between p/n, p/in, p/pn, p/pin layers. Forward current and junction temperature determine the light intensity output from a LED and the energy band of semiconductor is shown below in Figs. 3 shows depletion region between p-n structures. In Fig. 4, the photon energy emitted from p/n LED based solar cell is shown.

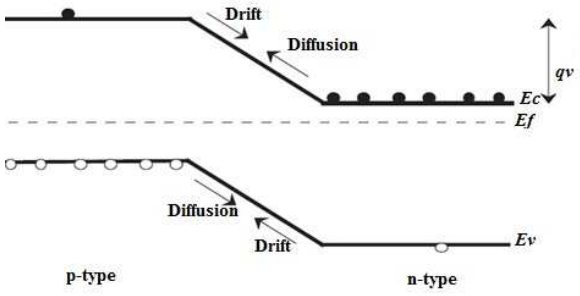


Fig. 2 : Schematic structures of energy band diagram of LED [6]

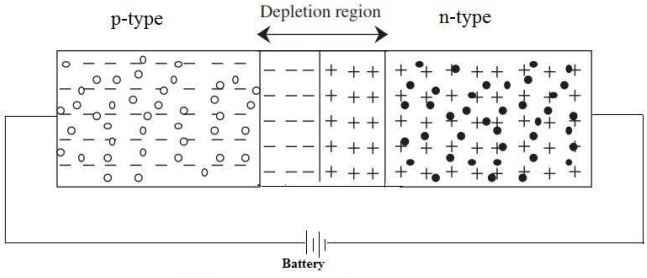


Fig. 3 : Schematic diagram of depletion region of p-n structure.

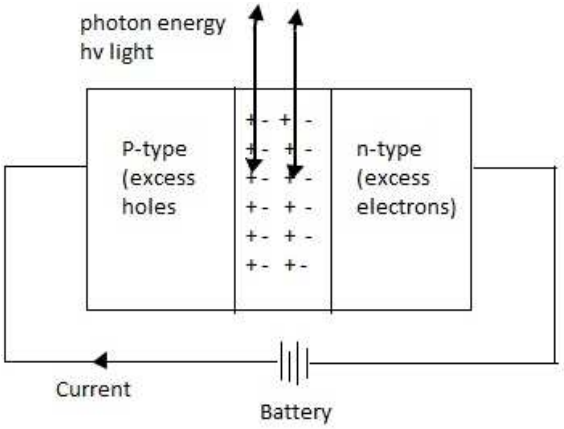


Fig. 4 : Photon energy emitted from p/n LED based solar cell

By using Moore's Law [7], if LED junction temperature increases, the light output decreases and the forward voltage drop decreases and wavelength of light increases which shows in Fig.2, [6]. The LED produces narrow band radiation, with wavelength determined by the energy band of the semiconductor. White Light Emitting Diode (WLED) is a device that emits white light when an electrical current passes through it in forward direction. The interest of WLED for lighting applications has been growing over the past few years and will replace the incandescent, fluorescent systems in the next few years due to their very long life, low voltage operation needs and high efficiency. This WLED based solar cells system for lighting application aims to provide solar energy for operating WLED lights for maximum hours of operation.

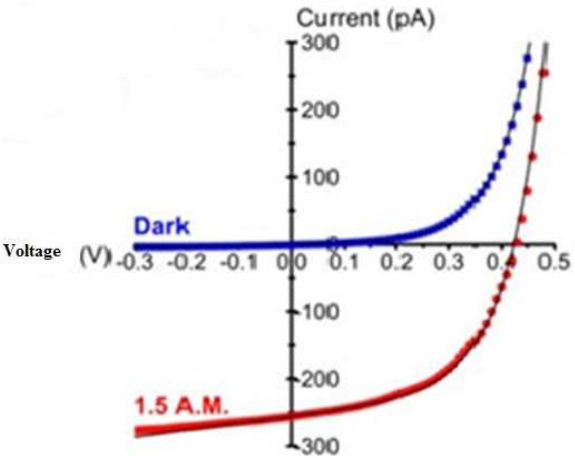


Fig. 5 : V_{oc}-I_{sc} Characteristics during Dark region.

The nano-wires have a built-in core-shell p-n junction and can be grown on inexpensive silicon substrates [23] such as an array of silicon layer composed of core and shell regions of opposite carrier polarity. Charges generated in p/pin structure could be extracted from both quasi-neutral regions by contacting separately the substrate, connected to the core, and the top surface of the posts, connected to the shell. The diameter of nano-wire is about twice the minority carrier diffusion length, which is hundreds of nanometers to several micrometers even at high carrier densities $10^{18}cm^{-3}$ [21 & 24]. By using TEM technology and X-ray spectroscopy, characterization and properties of the phosphorous dopant and oxygen profile of p/pin core/shell based nano-wire was studied in [11].

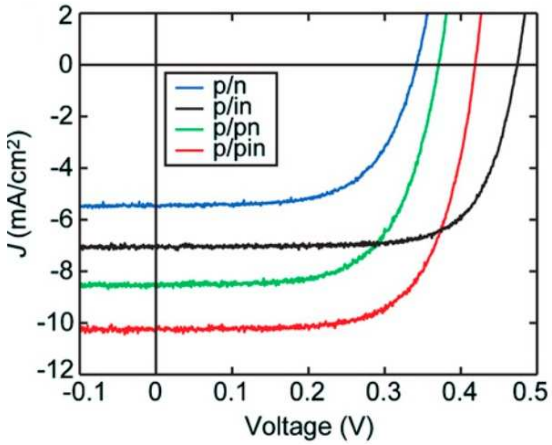


Fig. 6 : Current density versus voltage (J-V) characteristics of single-NW solar cell

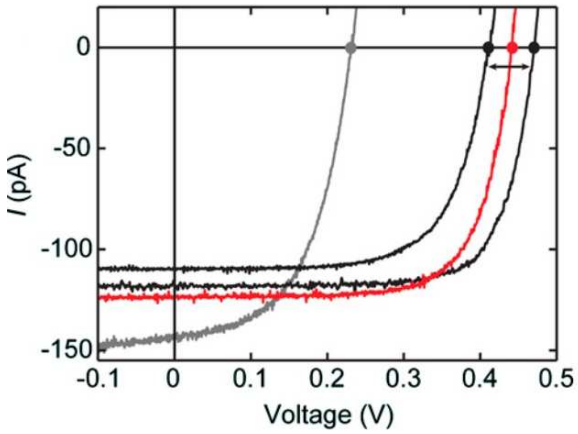


Fig. 7 : Current-Voltage (I-V) characteristics of single NW solar cell

All current density versus voltage (J-V) characteristics and current – voltage (I-V), of Figs. 6 & 7 have measured under air mass 1.5 global (AM 1.5 G) 1-sun (100mW/cm^2) illumination with current density (J) is calculated in [10].The illuminated J-V curve shows progressive changes of Voc and other features like

- For highest value of Voc >0.47, width of nano-wire approx 200nm gives information that much larger micron-scale diameters [22] are not necessary to achieve good performance.
- The p/in device exhibits a high fill factor (FF) of 73%, which is higher than previous obtained [24].
- The high FF combined with the steep slope of the J - V curve at Voc are clear signatures of negligible series resistance in the devices. So, ohmic losses are negligible.
- For similar crystalline quality coaxial nanowire, the insertion of an approximately 30 nm intrinsic layer causes 140 mV (p/n to p/in) and 40 mV (p/pn to p/pin) improvements in Voc.

Discussions

During reviewing, in solid-state lighting technology, performance of LED based solar cell over solid state lighting technology

- In case of lighting system only needs to operate for a few hours per night where as LED based solar cell is more intense point source with the proper optics, can be focused to provide high intensity beam distributions with less per unit area and is more suited as a diffuse source.
- The current cost of solid-state sources is approximately 2 orders of magnitude higher than the sources being replaced, when measured in the cost per lumen. This currently limits their general application; however, as improvements in materials, processing, and efficiency are realized in the development of new products this cost differential will disappear [17].
- Small-scale luminaries are desirable for the application.
- Solar irradiance is abundant throughout the year at the site, especially, during power shortage period.
- The electric power grid is not readily accessible and/or it would be costly to bring power to the site.
- Financial subsidies are available through an electric utility, state energy office, or other entity, which would offset a significant portion of the capital costs for the PV lighting system.
- Higher surface brightness will require diffusive elements. So luminaires can be located in an area that receives direct sunlight for a majority of daylight hours, and in which dirt is not likely to accumulate quickly on the PV panels
- Materials, like GaAsP, GaP, CIGS, Cu_2S, Cu_2O etc. are used in LED, OLED based Solar cell to improve efficiency (lumens/W) which produce white light can be produced at an efficiency of about 30 lumens/W [1].

While selecting a solar cell material, one has to satisfy certain requirements. First of all, it should be a good absorber of the incident light with the optical absorption coefficient as high as possible. It should have a favorable band gap for maximum efficiency, i.e. near 1.55-1.6 eV. The material must have direct band gap.

Therefore, for low cost nano-wire material based LED solar cell, coaxial silicon nano-wire (p-type/intrinsic/n-type (p-i-n)) have achieved an apparent energy conversion efficiency of up to 3.4% under AM 1.5 illumination and are able to drive functional nano-electronic sensors and logic devices [21] and more recently, strong light-trapping effects were observed in high-density silicon core-shell nano-wire array solar cells with efficiencies up to 6% [21]. However, scientists are tanking challenge to design and synthesize nanowires and their heterostructures with performances exceeding that of the existing silicon photovoltaic technology, which has a commercial efficiency larger than 20% and is being pushed to it, is theoretical limiting efficiency of 29% [21].

Conclusions

Today, people are more concerned about fossil fuel exhaustion and environmental problems caused by conventional power generation and renewable energy sources than ever before. So, now day's instead of only LED,LED based Solar cell are widely used due to high efficiency, long operating life and low voltage operation which ideal for solar. As LED efficacy and light output have improved, they are becoming main stream. Expectations are increasing for solar powered LED lighting to become the environmentally friendly outdoor lighting solution for the 21st century. Due to the recent advancement in the light emitting diode (LED) technology, high brightness white LED based solar cell becomes feasible in residential, industry and commercial applications to replace the incandescent bulbs, halogen bulbs, and even compact fluorescent light bulbs. During the day, solar power is converted to electricity with photovoltaic (PV) cells and battery charger replenishes a lead-acid battery for energy use during the night so that LEDs are used to provide light during the evening. Solid state lighting system is not a new concept, but the efficiency of lighting system can be improved by searching the

different modification of lighting materials or reflecting materials or by changing clustering of LEDs. Hence, ample opportunity of research work is till now waiting to develop the high efficient solid state lighting system. Additional benefit of the reduction of carbon dioxide emission can be extracted by implementing the concept of solid state lighting system design in the field of pollution of environment. In future, solid-state lighting can be regarded as the most energy efficient lighting system. Solid-state lighting shows great potential in automotive applications. Solid-state lighting has been long regarded as the future king of efficient lighting. This paper indicates that that foretold future is now here for one of the harder applications of nano wire based solid state lighting, the general lighting of common commercial spaces.

Future Work

The upfront cost of solid-state lighting is the main barrier to high market penetration. So, future research work can be done on SSL lighting systems with different new functionalities through heterogeneous nano-structures for improving and enhancing luminescence efficiency of LED and OLED using solar systems.

Acknowledgment

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References

[1] Jeffrey Y. Tsao, Michael E. Coltrin, Mary H. Crawford, and Jerry A. Simmons "Solid-State Lighting: An Integrated Human Factors, Technology, and Economic Perspective", J.IEEE, Vol.98 (7), pp. 1-18,2010.

[2] By James Brodrick, "LED and OLED Solid State Lighting", Multi-Year Program Plan-US. Department of Energy, April 2012.

[3] http://www.nist.gov/pml/div686/manufacturing/energy.cfm.

[4] Hyunjae Kim, Byunghun Lee, and Chun-Taek Rim, "Passive LED Driver Compatible with Rapid-Start Ballast",8th International Conference on Power Electronics - ECCE Asia, The Shilla Jeju, Korea, May 30-June 3, 2011.

[5] James R Benya, PE, FIES, FIALD, "Lighting Calculations in the LED Era" Design Calculations with Solid State Lighting, June 30, 2011.

[6] Hunter Lab, "Equivalent White Light Sources and CIE Illuminants", Insight on Color, Application Notes, 17 (5), PP.1-5, 2008.

[7] T. Soga,"Nanostructured Materials for Solar Energy Conversion", Nanostructure Materials for Solar Energy Conversion, Elsevier B.V,pp-614, 2006.

[8] By Paul Greenland, "Powering Next-Generation Solid-State Lighting National Semiconductor Corp", Santa Clara, Calif. Power Electronics Technology May 2004.

[9] F. J. Lopez Hernandez, E. Poves, R. Perez-Jimenez and J. Rabadan, "Low-Cost Diffuse Wireless Optical Communication System based on White LED, J.IEEE Tenth International Symposium on Consumer Electronics, June, 2006 .

[10] By Ine-ˆs Lima Azevedo, M. Granger Morgan, and Fritz Morgan, "The Transition to Solid-State Lighting", J. IEEE, March, Vol. 97, 3, 2009.

[11] Thomas J. Kempa, James F. Cahoona,, Sun-Kyung Kim, Robert W. Daya, David C. Bell[c], Hong-Gyu Park, and Charles M. Liebera, Coaxial multishell nanowires, Vol.109(5): PP1407-1412 , January 31,2012.

[12] John J. Sammarco, Senior Member, IEEE, Jean Paul Freyssinier, John D. Bullough, Xin Zhang and Miguel A. Reyes, "Solid-State and Incandescent Sources for Miner Cap Lamps", J.IEEE , 2009, 45, 5.

[13] J W Park, D C Shin and S H Park, "Large-area OLED lightings and their Applications", J. Semiconductor Science and Technology, February 2011, Semicond. Sci. Technol. Vol.26, No. 34, pp. 9, March 2011.

[14] Gary B. Levy, Member, IEEE, William Evans, Member, OLED-on-Silicon Color Microdisplay IEEE Journal of Solid-state Circuits, Vol. 37, no. 12, December, 2002.

[15] Jiaopin Wang, Kailin Pan, Jing liu, Weitao Zhu, "LED Lighting System by Using Ceramic Materials**",** 11th International Conference on Electronic Packaging Technology & High Density Packaging (ICEPT-HDP) 16-19 Aug, 2010, 1417 - 1421 .

[16] Bin-Juine Huang, Chun-Wen Tang and Jia-Hong Wu "Study of System Dynamics of High-Power LEDs", Electronic Materials and Packaging, International Conference on 11-14, pp.1-6, Dec.2006.

[17] S.G. Johnson and J. A. Simmons, "Materials for Solid State Lighting"**,** J. Materials Research Society Spring Meeting, April 1-5,

2002, in San Francisco, California, and published in the Proceedings.
[18] Allon I. Hochbaum and Peidong Yang, Semiconductor Nanowires for Energy Conversion, Chemical Reviews, 110, 527–546, Chem. Rev. 2010
[19] http://udini.proquest.com/view/semiconductor-nanowires-and-goid:859252336/.
[20] Trentler, T. J.; Hickman, K. M.; Goel, S. C.; Viano, A. M.; Gibbons, P. C.; Buhro, W. E. Science , Vol. 270, No. 5243, pp. 1791-1794, Dec. 15, 1995.
[21] Peidong Yang,* Ruoxue Yan, and Melissa Fardy, Semiconductor Nanowire: What's Next ? Nano Lett., Vol.10, pp.1529–1536, 2010.
[22] Xavier Hugon and Philippe Gilet of Helio Del and Patrick Mottier of Leti explain how nanowire-based LEDs can improve LED efficiency and cost reduction for solid-state lighting applications, NanoLEDs,Vol.6(3), April/May, 2011.
[23] http://qdev.nbi.ku.dk/research/novel_devices/.
[24] Tian, B. Z.; Zheng, X. L.; Kempa, T. J.; Fang, Y.; Yu, N. F.; Yu, G. H.; Huang, J. L.; Lieber, C. M. *Nature* Tian BZ, et al. (2007) Co-axial silicon nanowires as solar cells and nanoelectronic power sources. Nature, Vol.449, pp. 18, October 2007.