International Journal of Advances in Electronics Engineering– IJAEE
Volume 5 : Issue 1 [ISSN : 2278-215X]
Publication Date : 30 April, 2015

Light Emitting Capacitor for Lighting Application

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***Abstract*— Solid State Lighting (SSL) becomes one of the most important products due to their energy efficiency compared to conventional type lighting. Electroluminescence (EL) whether organic EL (also known as OLED) or inorganic EL are becoming increasingly important technology because of their potential applications for display and domestic lighting. Inorganic EL lamp is a capacitor-based electronic device technically known as Light Emitting Capacitor (LEC), while currently well-known LED lamp is a diode-based, where both of them have their own advantages. The advantages of SSL compared to conventional gas discharge lighting are they are very low power consumption, safe (non-toxic material used) and flexible design. The research is focused on development of LEC for domestic lighting purpose, and as an alternative for energy saving solid state lighting. One of its advantage is it can be generated using bi-directional current path such as from AC supply while LED and OLED only have one or unidirectional current path. The characteristics LEC, based on the type phosphor and lamp dimension in terms of electrical and optical properties were studied. Electrical properties is dealing with the measurement and calculation of current, voltage and power consumption whereas optical properties is dealing with the measurement and observation of emission spectra, brightness and color output. From the results, the intensity of emitted light (brightness of the EL lamp) depends on the driving parameters (voltage), which regulate all other operating characteristics. The electrical and optical properties also strongly influenced by the size (lamp dimension), type of phosphor (red, green, blue) and the thickness of the phosphor layer.**

Keywords—electroluminescent, solid state lighting, light emitting capacitor, phosphor

I. Introduction

The future global economy is likely and certainly to consume ever more energy, especially with the rising energy demand of developing countries in Africa and Asia including Malaysia. One of the most energy consumed product is the light source. Light sources play an important role in daily life and the present world cannot be imagined without the uses of many types of lamps today. This electrical lighting started more than a century ago. After Thomas Alva Edison invented the first practical electric lamp in 1879 [1] using a carbon filament, electric lamp technology developed rapidly. Edison's lamp, the so-called incandescent lamp work using the electric energy and a filament, where the filament inside the light bulb is heated and exhibits resistance that results in high temperatures that causes the filament to glow and emit light.

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In the 1850s, Heinrich Geissler discovered a low-pressure discharge and in 1901 Peter Cooper-Hewit developed the first low pressure mercury vapor lamp [2-3]. In this lamp the light is created from chemical reactions that occur when electricity is applied to the gases enclosed in vacuum chamber. This lamp is the very direct parent of today's modern fluorescent lamp.

Recently, the solid state light sources (SSL) i.e. Light Emitting Diode (LED) and OLED (organic LED) are under the spotlight instead of the older technology of the gas discharge light sources [4]. These types of light sources have advantages of very low power consumption, safety (non-toxic material used) and flexible design. LED which was introduced as an electronic component in 1960s where the early LEDs emitted low intensity of red light suitable to be used as an indicator in electrical devices. Modern version of LEDs can be obtained in ultra-violet, visible and infra-red wavelength with high intensity. While OLEDs is a LED in which the emissive electroluminescent layer is a film of organic compounds which emit light in response to an electric current. OLED also have made great progress since the first presentation of thin film based on small molecule organic materials by Tang and VanSlyke in 1987 [5-6]. Some of them (LED and O-LED) are already used in domestic lighting and also for some specific purposes such as LCD backlights, traffic light and portable player display panel. However these type of diode based semiconductor lamps still need a lot of improvement in order to reduce the price (LED) and increase the lifetime (OLED). Beside of its high cost of installation, LEDs also have a major obstacle, the so-callled "droop" the way that efficiency falls at high drive current. The problem universally exhibited by GaInN material system [7]. Due to this droop, the system lose a significant fraction of that efficiency at the high current levels required for typical domestic lighting.

Other type of SSL is phosphor based electroluminescence. The initial concept of phosphor based inorganic electroluminescence (EL) also known as Light Emitting Capacitor (LEC) was discovered and patented by George E. L. Mager in 1949 [8]. EL is a unique form of light source which unlike most other lamps can be shaped into many sizes (flexible design) and flat surfaces. The construction is similar to capacitors except the emission layer and it is different from LEDs/OLEDs in that they use a p/n junction which two semiconductive materials where electrons and holes combine on the boundary. The phosphor that commonly used for this purpose is the one that comprised of zinc sulfide (ZnS) which is mainly used in cathode ray tube (CRT). LEC technologies have low power consumption compared to competing lighting technologies, such as gas discharge based lamps of neon or fluorescent lamps, and traditional incandescent lamp, and even lower or competitive to commercially available SSL of LED lamps.

II. Experimental Setup

The setup is divided in three phases, i.e. sample preparation including light ignition setup, electrical setup and optical setup for each properties evaluation.

A. *Sample Preparation*

Xenon lamp based phosphors were used in the experiment. It is the one that used for PDP, in three types of colors, red (Y_2O_3:Eu), green (Zn_2SiO_4:Mn) and blue ($BaMgAl_{10}O_{17}$). These three types of phosphor powders were dissolved using butyl-acetate to make it into slurry state. This slurry was manually coated to dielectric or glass layer for approximately 0.5~1mm thick and baked to remove water vapor or other impurities. LEC material must be enclosed between two electrodes and at least one electrode must be transparent to allow the escape of the produced light. Glass coated with indium tin oxide (ITO) was used as the front (transparent) electrode while aluminum was used as the back electrode. It produces light when phosphor crystals are excited by being exposed to electric current. The structure composes with two layer of electrodes, dielectric layer and emission layer. ITO will be used as an transparent electrode and phosphor will be used as an emission substrate. The lamp will be ignited using few hundred volts AC supply. The commercially available AC ballast was used for this purpose. The construction of LEC is shown in the Fig.1 below. Two types of dimension is used, i.e. 25 mm × 25 mm and 50 mm × 50 mm.

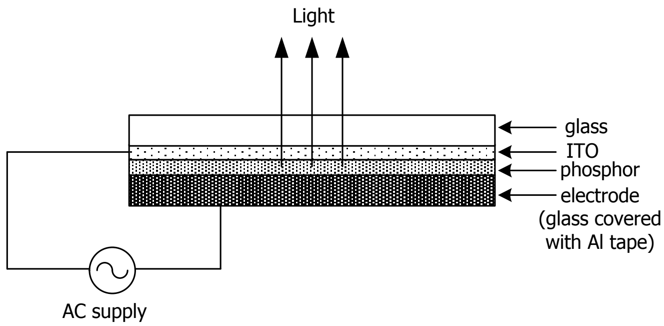

Figure 1. The construction of LEC

B. *Electrical and Optical Setup*

Electrical energy (AC supply) is induced to the electrodes, generated the electric field which causes a current flow, and when this current flow through the emission layer, due to the energy difference of the electron a photon is produced. Input voltage was varied from 200 V to 400 V using electronics ballast. This ballast can convert DC (10 to 20 V) to AC and amplified the voltage up to 800 V. Connection diagram is shown in Fig. 2 below. The input current and power consumption were calculated using Ohm's law. Input current was measure using the value of voltage drop across the resistor as shown in Fig. 3. Phosphors that have been used already made to have their own color of excitation. Each sample was made for each color of the phosphors which are blue, green and red. In order to have a white color output, these three phosphors need to be mixed together with a same ratio. Emission spectra from each sample were measured using Ocean Optics Spectrometer placed just in front of the sample. Their color output and brightness were observed and compared.

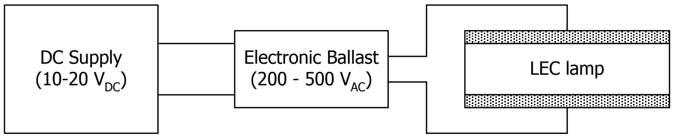

Figure 2. Diagram of electrical connection

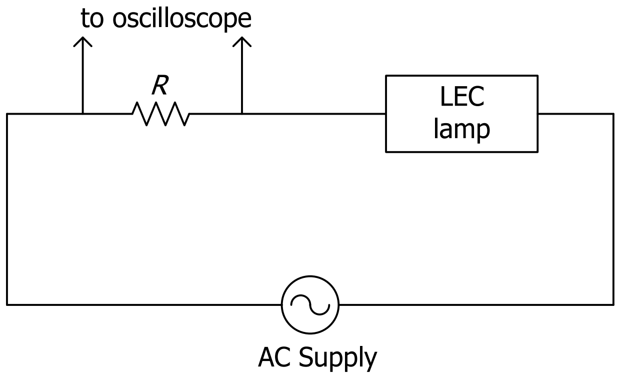

Figure 3. Equivalent circuit of the system

III. Results and Discussion

Data that have been taken were analysed and evaluate in terms of difficulties of light ignition, and their electrical and optical characteristics.

A. *Light Ignition*

Table 1 and 2 show the input voltage needed to ignite the sample when using two different lamp dimensions. For dimension of 25 mm × 25 mm, the blue phosphor sample starts to ignite at 200 V and the green phosphor sample starts to produce light at 300 V. The red phosphor and white phosphor samples starts to ignite light at same input voltage 250 V. Table 2 shows the input voltage for lamp dimension of 50 mm × 50 mm, the blue phosphor sample starts to ignite at 250 V and the green phosphor starts to produce light at 300 V. Starting voltage for red phosphor and white phosphor samples are 350 V and 400 V respectively. All type of phosphor (except green) gives a different result for both types of lamp dimensions. Based on these two different type of lamp dimensions, all samples needs more voltage to produce light for the second dimension. From the results, it shows that the different type of dimension gives different starting ignition voltage for each sample.

TABLE 1. Type of phosphor-voltage characteristics of LEC with ITO and Al electrode (dimension: 25 × 25 mm)

Input Voltage (VAC_{p-p})	Types of phosphor			
	Red	Blue	Green	White
200	√	x	x	x
250	√	x	√	√
300	√	√	√	√
350	√	√	√	√
400	√	√	√	√

TABLE 2. Type of phosphor-voltage characteristics of LEC with ITO and Al electrode (dimension: 50 × 50 mm)

Input Voltage (VAC_{p-p})	Types of phosphor			
	Red	Blue	Green	White
200	x	x	x	x
250	√	x	x	x
300	√	√	x	x
350	√	√	√	x
400	√	√	√	√

B. Electrical Characteristics

Current properties are show in Tables 3 and 4 below. From Table 3, the blue phosphor sample needs the lowest current and the green phosphor sample need the highest current to produce light. The range of the current needed to produce light for this dimension is from 6.56 mA to 8.94 mA. From Table 4, the white phosphor sample needs the highest current and the blue phosphor sample needs the lowest current to ignite light. The range of the current needed to produce light for the second dimension is higher than the first dimension which is from 7.24 mA to 11.31 mA.

Power consumed by each samples were calculated and shown in Figs. 4 and 5. As shown in the figures, the power consumption of sample is linearly proportional to the input voltage. From Fig. 4, the range of the power consumption for the first dimension is between 1 W to 4 W, whereas for second dimension as shown in Fig. 5, the value of the power consumption is ranged between 1 W to 5 W. From both results, it can be said power consumption for this kind of LEC lamp is much lower than fluorescent lamps and comparable to LED lamps.

The input voltage and current need for each phosphor for the second dimension is slightly higher than the input voltage and current need for the first dimension. This is thought due to the dimension of the electrodes. The dimensions for the second electrode are 50 mm × 50 mm which it is wider than the first dimension 25 mm × 75 mm. As the surface of the electrode is bigger than the first one, there are more input voltage and current need to be supplied through whole the surface. It needs more electrons to excite the whole surface of the electrodes.

TABLE 3. Current value for LEC dimension 25 × 25 mm

Type of Phosphor	Current (mA)
Blue	6.56
Green	8.94
Red	7.24
White	7.24

TABLE 4. Current value for LEC dimension 50 × 50 mm

Type of Phosphor	Current (mA)
Blue	6.56
Green	8.94
Red	7.24
White	7.24

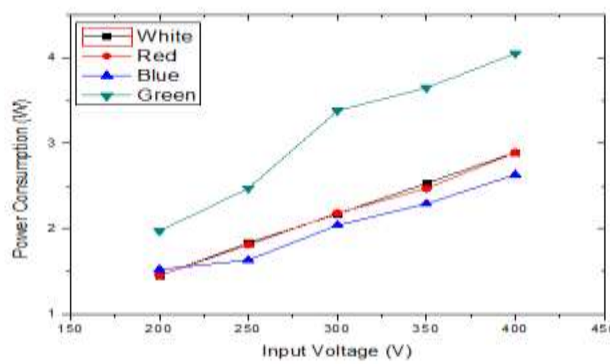

Figure 4. Power consumption vs. Input voltage for LEC dimension 25 × 25 mm

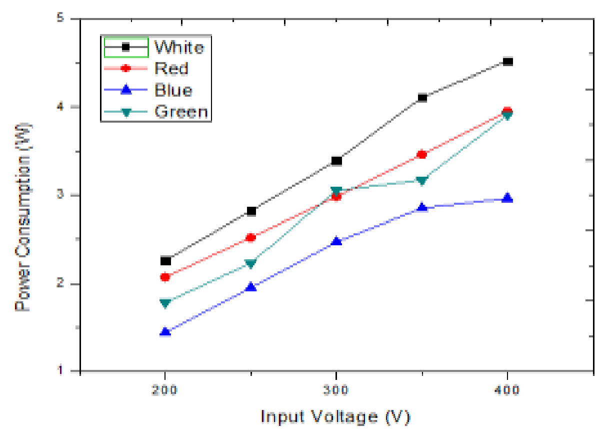

Figure 5. Power consumption vs. Input voltage for LEC dimension 50 × 50 mm

C. Optical Characteristics

Fig. 6 – Fig. 8 show the emission spectra for the three types of phosphor color samples. As shown in the figures, it is clear that each of the phosphor shows higher intensity of light according to its color wavelength of visible light. For the blue phosphor sample, it has higher intensity of light at the wavelength from 400 nm to 450 nm. The green phosphor sample has the higher intensity of light from 500 nm to 550 nm wavelength whereas the red phosphor has

the higher intensity of light at the wavelength from 700 nm to 750 nm. Nevertheless from naked eye observation, light intensity from each samples are relatively very in order to be used as domestic lighting.

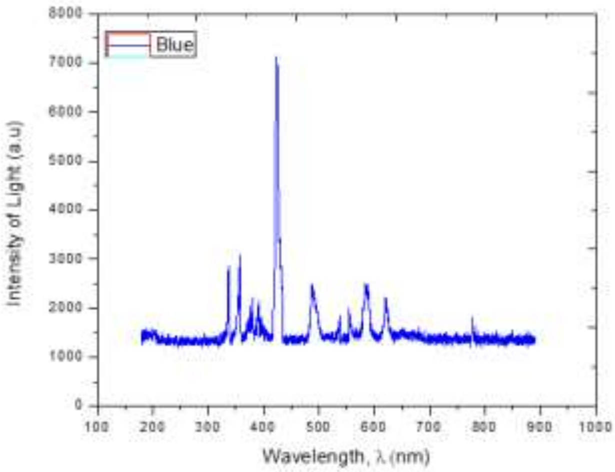

Figure 6. Emission spectra from blue sample

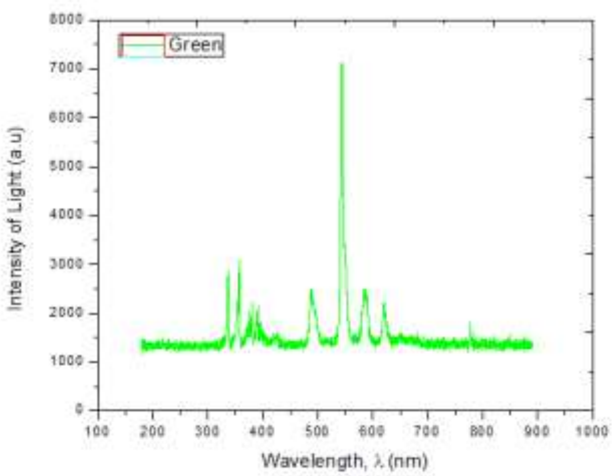

Figure 7. Emission spectra from green sample

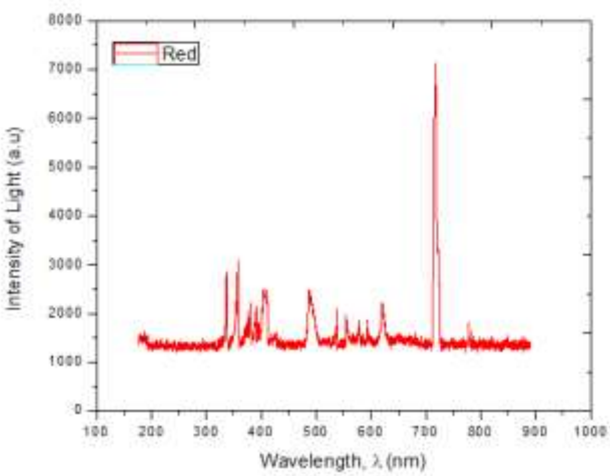

Figure 8. Emission spectra from red sample

IV. Conclusion

The power consumption for developed LEC gives competitive values where it ranges from 1 W to 5 W which can be considered very low as energy saving lighting. However light intensity is still very low which makes their efficacy or lumen per watt value is lower compared to fluorescent and LED lamps. From the results, the dimension of LEC can affect the brightness and the minimum voltage needed for ignition. The emission spectra show the color output is in visible range. This is a beginning step in order to develop inorganic LEC as new lighting technology products. In order to improve this work in the future, there are many room of improvement can be considered such as electrode material and phosphor coating thickness. The work is ongoing.

Acknowledgment

The author would like to thank all the laboratory staff of Physic Electronics and Instrumentation programme in UMT for all the assistance during experimental work. Many thanks to undergraduate students Rohaida, Sabariah and Azmisah who did a lot of effort in doing this work.

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Ahmad Nazri Dagang received B. Eng in 2000 and M.Eng in 2004 both in Electrical and Electronic Engineering from Ehime University, Japan. In 2007 he received Dr. Eng in Plasma Engineering from the same university. He was appointed as a researcher at University of Toulouse, France from 2008 to 2011. His expertise is in electrical discharge, plasma application and lighting engineering. He is currently working as a senior lecturer at Universiti Malaysia Terengganu.