Teaching-Learning of Phosphor-based LEDs Using Science, Environment, Technology and Society (SETS) Approach

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Abstract. In order to face the industry 4.0, Indonesia uses the so called K-13 curriculum which prioritizes in student’s character building based on local wisdom. Therefore, teachers have responsibility to continuously improve the teaching-learning method along with the rapid technological development. Up to recently, there are many teaching-learning approaches has been introduced such as science, environment, technology, and society (SETS). One teaching-learning approach emphasizes in the connection between the real event in our everyday life with science, environment, technology, and social life. Phosphor-based (Light Emitting Diode) LED is one of the current increasing attention topics in the lighting technologies, which plays a very important role as general lighting source. Therefore, it is important to introduce this technology from the earliest stage of education. This paper will describe the teaching-learning method of the current technology, phosphor-based LED, using SETS approach in K-13 curriculum.

1. Introduction

Teaching is not just passing on knowledge to the next generation. Teachers in this 21\textsuperscript{st} century, in all educational sectors, have to cope with an ever-changing cultural and technological environment. Similar with other professionals such as architects, engineers, and programmers, teachers have responsibilities to work out creative and evidence-based ways of improving what they do. Every day, teachers design and test new ways of teaching, using learning technology to help their students. Students learn in many ways by seeing and hearing; reflecting and acting; reasoning logically and intuitively; memorizing and visualizing and drawing analogies and building mathematical models; steadily and in fits and starts. Teaching methods also vary. Some instructors lecture, others demonstrate or discuss; some focus on principles and others on applications; some emphasize memory and others understanding. However, we believe that the “best” method of teaching at least below the graduate school level is induction, whether it be called problem-based learning (PBL), discovery learning, inquiry learning, or some variation on those themes. On the other hand, the traditional
college teaching method is deduction, starting with “fundamentals” and proceeding to applications [1].

In order to face the industry 4.0, Indonesia uses 2013 curriculum (Bahasa: Kurikulum 2013 called as K-13) which emphasizes communications, collaborative, critical thinking, and creativity called 4C abilities [2]. Currently, one of the increasing attention methods to stimulate student’s creativity that leads to innovation is Science, Technology, Engineering and Mathematics (STEM) or Science, Technology, Engineering, Arts and Mathematics (STEAM) approach [1] [3]. It is an interdisciplinary approach to learn where rigorous academic concepts combined with real world lessons [4]. However, in the K-13 system is prioritizing character building in several aspects such as religious, nationalism, integrity, independence, and mutual cooperation which based on the local wisdom. Therefore, Prof. Binadjia proposed a teaching-learning approach called science, environment, technology, and society (SETS) [5]. He explained that the vision of SETS is a way of perspective that leads to the understanding that everything we face in this life contains aspects of science, environment, technology, and community life as one mutually influencing unity. According to his work, technological advances cannot be separated from science that impacts human life as well as its environment both positively and negatively. It leads changes in the learning paradigm, which is characterized by changes in curriculum, media, and technology. The teaching-learning SETS approach is not only suitable for science subjects but also social subjects, which is related to the social life in the community. It has been proven that SETS approach improves the student’s learning outcomes [6] [7].

Light Emitting Diodes (LEDs) is one example of the current increasing attention topic in the lighting technologies. As the most promising energy-saving light source, LED has been applied in many electronic devices such as laptop, smartphone, automotive headlamps, advertising, general lighting, traffic signals, camera flashes, lighted wallpaper, and medical devices. The LED used for general lighting source is the white LED. It was constructed from a blue LED chip coated with phosphor(s) such as yellow phosphor or red phosphor. Despite of its big role in our daily life, it has been rarely discussed in the K-13 of primary and secondary education stages. Since the early introduction of the to date lighting technologies is necessary, here we discuss the teaching-learning of current lighting technology i.e., phosphor-based LED using SETS approach.

2. Theory

Since about 150 years ago incandescent bulbs had been used for general lighting. When an electric current passes through a wire, they yield a warm yellow light. However, this process is very inefficient due to the generation of heat. Nowadays fluorescent lamps are the most widely used lighting system. They are more efficient than light bulbs and they generate white lights with high color rendering. However, they contain toxic mercury vapor. To improve the energy efficiency further and to solve the above environmental problem, a new kind of lighting device is desired. In 2014, the Nobel Prize in Physics was awarded to Prof. Isamu Akasaki, Prof. Hiroshi Amano and Prof. Shuji Nakamura for the invention of efficient blue light emitting diodes (LED) which has enabled bright and energy-saving white light sources. Using the blue LED, white light can be created in a new way. This development on the solid state lightings has begun to replace the conventional incandescent and fluorescent lamps.

In this 21st century, the white LEDs are in high demand as general lighting source used in residential houses, offices, stores, etc. The most popular white LED [8] constructed by coating a blue InGaN LED chip with yellow Y3Al5O12 (YAG): Ce3+ phosphor has been widely commercialized since 1996. The emitted blue light from the LED chip is converted into white light by the yellow phosphor. Due to the characteristics of low energy cost, long lifetime, free of mercury, compact, and lightweight, these LEDs have been used for various applications such as liquid crystal display (LCD) backlighting, traffic signal, and the replacement of conventional light bulbs or fluorescent lamps and also light source for projectors and for experiment on plant growth. This lighting source is known to be high efficiency, durability, and stability, thus expected to reduce energy consumption and emission of heat and accordingly provide a solution to the global warming problem.
Generally, the quality of the emitted light of a certain light source is mainly determined by its color rendering index (CRI) or its correlated color temperature (CCT). However, with the current two-color white LED it is impossible to obtain high quality of white light as produced by fluorescent lamp. The fluorescent lamp emits ‘warm-white’ light with 90 CRI and CCT ~3500 K. On the other hand, in the case of white LED, the combination of yellow YAG:Ce$^{3+}$ emission and blue LED radiation gives ‘cool-white’ light with CCT more than 4000 K and CRI values of 70-80. This type of white LED produces a pseudo white light due to a deficiency of red emission. Many efforts have been made both experimentally and theoretically to overcome the above problem. The combination of primary colored LEDs such as blue, red, and yellow LEDs seems to be ideal, however this type of white LED is expensive. Therefore, a modification on the current white LED such as adding a red phosphor into the system is preferable.

Search of novel red phosphor materials or those containing red emission components is a useful approach for the realization of white LED applications. Based on the practical point of view, an ideal red phosphor for white LED should have good luminescence properties such as broad maximum excitation band in blue, high chemical and thermal stability, and high luminescence efficiency. Most importantly, they need to have an emission peak in the red region. Among the various red phosphor materials, those including rare earth (RE) ad transition metal (TM) ions have been regarded as a good class of phosphor and popularly used. However, these elements are in strong demand but short supplies. Especially after China’s export restriction, has led to a substantial increase in the exploration and mining. In Indonesia, a potential deposit was found in Sulawesi and Papua or Irian Jaya island [9]. Although it is not as promising as China and the United States, or other countries in Southeast region such as Vietnam and Malaysia in terms of resource occurrence, Indonesia’s position in the market can be improved further by creating some policies such as enabling resource exploration, adopting advance tailing capture technologies and establishing a global scale recycling center [10]. These will advantage Indonesia in economic terms.

3. Results and discussion
Figure 1 shows the schematic illustration of teaching-learning method of phosphor-based LEDs using SETS approach, which explained by the interconnections among SETS component.

3.1. Science studies
The science term on teaching-learning phosphor-based LED can be started with “What is LED?” and “How does the LED work?”. Unlike ordinary incandescent bulbs, LED does not have a filament that will burn out. LED also does not contain gas such in the fluorescent lamp. The material used in LEDs is basically semiconductor such as InGaN. In its original state, the atoms of this material are strongly bonded. Without free electrons, conduction of electricity becomes impossible here. By adding an impurity, which is known as doping, extra atoms are introduced,
effectively disturbing the balance of the material. These impurities in the form of additional atoms are able either to provide free electrons (N-type) into the system or suck out some of the already existing electrons from the atoms (P-Type) creating “holes” in the atomic orbits. In both ways the material is rendered more conductive. Thus in the influence of an electric current in N-type of material, the electrons are able to travel from anode (positive) to the cathode (negative) and vice versa in the P-type of material. Due to the virtue of the semiconductor property, current will never travel in opposite directions in the respective cases. The intensity of light emitted from LED will depend on the energy level of the emitted photons which in turn will depend on the energy released by the electrons jumping (P–N junction) in between the atomic orbits of the semiconductor material. When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor. This topic can be studied by lecture and student experiment in the physics or electronic labs.

Next is “Why does LED use phosphor to emit white light?”. Generally, the topic of light is delivered in the physics subject. In High School, topic related to light, optics and wavelength is delivered at grade XII. On the other hand, in Junior High School, material related to light and optics is delivered at grade VIII. Whereas in the Elementary School, it is delivered at grades 4 and 5. For example, when we are working on a computer, the colors we see on the screen are created with light using the additive color method. Additive color mixing begins with black and ends with white; as more color is added, the result is lighter and tends to white. This principle is also applied for sun light or lamp. Light that appears white to us, is actually composed of many colors. Since the current white LED emits bluish white light, a red component obtained from phosphor is needed to produce warm white light. There are many ways to search this red component both experimentally and theoretically [10–15]. In order to support the teaching-learning of this topic referring to the K-13 curriculum, using props is highly recommended [17] [18].

3.2. Environmental studies

Energy-efficient lighting is one of the key measures for addressing electric power shortages and climate change mitigation. The total environmental impact, including the energy and natural resources needed to manufacture, transport, operate and dispose of light bulbs has been examined for incandescent, fluorescence, and LED lamps has been reported [19]. Fifteen different impacts were considered when evaluating environmental footprints, including the potential to increase global warming, use land formerly available to wildlife, generate waste and pollute water, soil and air. That analysis revealed both LED and fluorescence lamps are substantially more environmentally friendly than traditional incandescent lamps, which consume far more electricity. For example, the specific incandescent light bulb the team was found to consume 60 watts of electricity, while the LED model they studied uses just 12.5 watts and the representative fluorescence lamp only uses 15 watts to create the about same amount of light. It shows that we could reduce the environmental impact of lighting by three to 10 times by using more efficient lamps instead of incandescent lamps. The overall environmental impact is largely determined by the energy and resources needed to make them. The one standout area is that LED generates hazardous waste that must be taken to a landfill. This is because LED lights include a component called a heat sink, a ribbed aluminum segment that is attached to the bottom of LED bulbs. Aluminum heat sinks absorb and later dissipate heat that’s generated by the light bulb, preventing it from overheating. The process to mine, refine and process the aluminum in heat sinks is energy-intensive and creates several byproducts such as sulfuric acid that must be taken to a hazardous waste landfill. Nevertheless, this waste is incomparable with the mercury risk from the fluorescent lamp [20].
3.3. Technological innovation

Generally, the words science and technologies can and often used interchangeably. Basically, the goal of science is the pursuit of knowledge for its own sake. On the other hand, the goal of technology is to create products that solve problem and improve human life [21]. In other words, technology is simply the practical application of science. Since their introduction in the early 1960s, LEDs have evolved from simple indicator lights and alphanumeric displays to an exciting new source. Today more and more people are switching to LEDs in order to open up creative possibilities and save energy. The latest innovations in current trend are revolutionizing home lighting and garden lighting. Examples of these revolutions are (1) smart light, controlled via smartphone, tablet, mobile switches or even with human voice; (2) illuminate small spaces using LED tape and ropes, so that we can light up every nook and cranny in our home from wardrobes and drawers, to parasols and stairways; and (3) healthy light that mimics the color of sunrise.

3.4. Social studies

Despite of the numerous advantages of using LED, not everybody wants to switch their lighting source. It is because at the present, a single high-power LED is quite expensive. An investigation on the factors affecting the intention to buy LED lamps has been performed by Dr. Orose Leelakulthanit’s group [22]. The results suggested that the factors affecting the intention to purchase LED lamps in the low-income household are quality, compatibility of LED lamps with lighting fixtures, product availability, and corporate social responsibility. On the other hand, in the high-income household, they are energy saving and perceived effectiveness of environmental behavior. Actually, despite of the high cost, LED has long lifespan which makes it much cheaper than the other lamps. Considering the positive effects on the LED usage environmentally and economically, replacement of the traditional lamps with LED is strongly recommended. Most importantly, the energy-efficient lifestyle must be developed gradually.

4. Summary

To achieve the educational goals set by the Indonesian government, the K-13 curriculum should be strategically arranged involving child development, the development of science, the development of society’s needs and employments, etc. In this case, the student’s character building based on the local wisdom is highly prioritized. SETS is one of the teaching-learning method which connects science, environment, technology and society transdisciplinary. Phosphor-based LED is currently popular technology that utilized in many applications for everyday life. It is important to introduce this technology from the earliest stage of education in any ways. The complete understanding on this topic will encourage society to develop energy-efficient lifestyle so that benefit us environmentally and economically.

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