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Research Paper

Inspiring Minds: Teaching the Transition from Incandescent Bulbs to Noble Prize Winning LED Technology

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Abstract
The shift from incandescent bulbs to Light Emitting Diode (LED) lighting technology is not just a technological achievement but also an excellent case study for science, technology, sustainability and inspiration in education. In 2014, Isamu Akasaki, Hiroshi Amano, and Shuji Nakamura were awarded the Nobel Prize in Physics for developing blue LEDs, that had made it possible to create energy-efficient white light sources. This article is an attempt to discuss the progress in the lightning technology and the methods to teach students about the evolution of the technology and its uses, with a focus on scientific and historical context which lead to real-world applications and motivation. By integrating discussions, experiments and multimedia resources, teachers can foster both conceptual understanding and environmental awareness about the LED technology. The present study emphasizes on the importance of the journey of Nobel Prize-winning breakthrough in blue LED technology. By teaching this historical and scientific journey in higher education system, educators can inspire and motivate students to pursue in the field for higher studies and can contribute towards the technology which have an impact on human development. It is also important to realise and teach the impact of the LED lightning technology on environment besides the power consumption and efficiency.

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I. Introduction

Light is the central part of our modern civilization. Its evolution from candles to using electricity to light up lamps is pivotal in shaping human development and technological progress. The history of using electric lighting has undergone ground breaking changes, from Thomas Edison's incandescent bulbs [1,2] in the 19th century to the present-day LEDs that have been used to illuminate homes, cities and making many other devices because of its versatility [3,4]. The invention of the incandescent bulb was a milestone back then, however, the transition to LED technology has revolutionized efficiency and sustainability. Conventional incandescent bulbs consume a large amount of energy to generate light and also produce heat in the process, resulted in wastage of energy. So, they are no longer in use. On the other hand, LED technology is highly efficient and has the potential to minimize wastage [5,6]. The increased efficiency, less power consumption and low prices had made it available in a number of household and industrial products. Because of the availability in different colours, it had found applications in toys and other decorative items. It would be of great interest to discuss the journey of development of LED with students.

1.1 Historical Context of LED

Light-emitting diode (LED) technology has its roots in many decades of scientific, technological, and innovative advancements. The origin of LEDs may be traced back to the early 1900s, when researchers noticed that there are many materials that have the ability to produce light [7–12]. However, the work for the development of different coloured LEDs was undergoing and did not give desired results until 1960s. By the mid of 20th century, researchers found out that elements like gallium arsenide were used to create red and green LEDs [10]. However, white light could not be produced without the development of blue LED. Scientists kept working to expand the colour range and to increase the efficiency of LEDs in the subsequent decades. However, the challenge of producing blue light-emitting diodes kept scientists busy in finding suitable material with wavelength which corresponds blue colour and which can finally develop all-purpose LED lighting.

The significant advancement in the direction took place in the 20th century with the first development of blue LED by the researchers Isamu Akasaki, Hiroshi Amano, and Shuji Nakamura [13,14]. This innovation enabled the creation of white light by combining blue LEDs with other colours, or by using a phosphor coating. The introduction of blue LEDs transformed the lighting industry by enabling the production of bright, more efficient white light sources. This marked a crucial shift from traditional lighting technologies such as incandescent and fluorescent bulbs to more sustainable and long-lasting alternatives. The global significance of this breakthrough was recognized when the three scientists were awarded the Nobel Prize in Physics in 2014 [14]. The development of blue LED was possible only after Gallium Nitride (GaN), a semiconductor material having a band gap corresponding to blue colour was developed that was the main requirement to unlock white LED lightning. Researchers Akasaki, Amano and Nakamura have developed various methods [15-26] to grow GaN material which made it possible to develop blue LED. The blue LED when coated with phosphor produce white light.

It took them around twenty years to see the fruits of their labor [14, 27–30].

In recognition of their achievements, Akasaki, Amano, and Nakamura received the 2014 Nobel Prize [13,14] in Physics from the Royal Swedish Academy of Sciences for creating effective blue light-emitting diodes, which have enabled the development of efficient, cheap and low power consuming white light sources.

1.2 Scientific Context of LED

Semiconductor is a material whose conductivity can be modified with the addition of impurities (called doping). The highest occupied energy band is called the valence band (V.B) and is full of electrons for an undoped semiconductor, while the next band higher in energy is called the conduction band (C.B) and is completely empty in an undoped semiconductor. The energy difference between the minimum energy of the conduction band and the maximum energy of the valence band is called energy band gap of the semiconductor. When an electron jumps from the conduction band to an empty state in the valence band, the energy equal to the band gap is released in the form of a photon. The band gap of the semiconductor material can be changed by doping with suitable dopant. This results in the change of emitted energy in a p-n junction diode which is responsible for different wavelengths/colours being emitted.

It is very important to understand that the doping controls the electrical properties of semiconductors. As the band gap changes with different impurity elements, the energy of the emitted photon in the transition from C.B to V.B changes and hence the colour.

The research community understand this [9,10], and created p-type, n-type semiconductors and pn-junction diodes with different band gaps including the ones where emitted light falls in the visible spectrum, which are known as light emitting diode (LED) and further choose different combination of elements to form compound semiconductor material to get desired wavelength (colour) LED. The first LED using GaAs was demonstrated in 1962 [10] where the emitted photon lies in the infrared region, however soon the first visible LED was also developed by research groups which used GaAsP alloy to demonstrate the first visible semiconductor diode laser [11]. This begins the journey to produce LED of different colours with the challenge to be able to reach the technological maturity to produce desired band gap and efficiency. In 1960s and 1970s, the growth of high-quality semiconductors progressed at a large pace. Over the course of time between 1990 to 2000, a number of improvements took place and ultimately resulting in the production of LED with larger efficiencies [31].

Tremendous efforts [10-12,32] were made on producing coloured LEDs based on different compounds, however researchers understood the importance of producing white light, which was possible with the development of a blue LED. A blue LED could be used in a number of ways to produce white light.

Despite a large number of attempts in 1960s and 1970s, the blue LEDs have certain hurdles in the path compared to their red and yellow counterparts. Actually, to produce blue LED, a bandgap close to 3eV is required and scientists were struggling to find the compound which matches the requirement then finally they found out that the compound GaN corresponds to a bandgap of 3.4 eV which corresponds to a wavelength of 365 nm which could be used to make short-wavelength LEDs.

After the key inventions by Amano, Akasaki, and Nakamura, blue LEDs continued progressing in efficiency while production costs were reduced. White LEDs are then obtained by surrounding the blue LED with a phosphor that partially absorbs the blue and reemits at longer wavelength: the mixing of the remaining blue and the phosphor emission yields white light, the quality of which depends on the phosphors that are used [33].

This innovation in lightning industry has a huge impact on the society [34, 35].

1.3 Impact of LED on society

- LED has revolutionized the lightning technology and is considered as an electricity conserving source of lightning [34]. It offers high efficiency, low cost and sustainability. Research [35] shows the impact of LED lightning on various quality parameters of electricity.

- LED lightning offers improved lightning quality besides offering a customised range of colours.
- LED technology is also considered as an environment friendly source.
- LED are used in the cultivation of many plant species as well. Research [36] shows the improvement in the production and growth of plants using LED lightning technology.
- LED, because of its high efficiency and low cost, is being used abundantly in various areas. Researches [37] points out the environmental and economic impact of the technology.

II. Educational Value of the Lighting Transition

Teaching this progress in the lightning technology which not only reduces the cost and makes it more efficient and environment friendly but also the journey of researchers in this technology inspires young minds to integrate various disciplines like physics, chemistry, history, environment and other areas in the education sector to pursue their passion. These intersections of various disciplines make the study an ideal for STEM (Science Technology Engineering and Mathematics) education which fosters critical thinking and motivation at the same time.

2.1 Core Scientific Concepts to Address

While teaching the LED lightning journey, following concepts need to be emphasized.

- **Incandescent Lighting** works by heating a filament usually made up of tungsten until it glows. This converts ~5% of electrical energy into visible light whereas the rest of the energy is lost as heat.
- **CFL Technology** involves gas discharge, phosphor coating, mercury etc. and hence is posing environment at risks.
- **LED Technology** requires an understanding of p-n junctions, band gaps, and photon emission. The technology involves low cost, higher efficiency and lifespan.
- **Energy Efficiency** of white LEDs are considered as multiple times more than incandescent bulbs so are preferred to be used in homes, street lighting, automotive headlamps, display technologies, and even agriculture (e.g., plant growth lights).
- **Environmental Benefits** of LEDs are far more as they contain no toxic elements and are having a larger lifespan. So they generally produce less waste therefore the frequency of replacements decreases.

Due to low power consumption in LEDs, they provide affordable lighting alternatives.

Pedagogical Strategies for Teaching the Transition of LED technology

Integrating the LED story into science and engineering can be approached through:

- **Hands-On Demonstrations**
  Practically making comparison of filament bulbs with LEDs in terms of brightness, heat output, and energy consumption.
- **Using Multimedia Resources**
  Using simulations and animations to teach the working of LEDs i.e. the transition from C.B to V.B where the student can visualise the effect of change in band structure of the semiconductor material. Video segments can also be considered from the Nobel Prize lectures on blue LED development which makes the picture clearer in student's mind.
- **Design and test a lighting project using LEDs.**
  Students can be assigned projects to design simple lighting systems which can be used in homes besides fulfilling their curiosity. This will promote real-world problem-solving skills.

III. Conclusion

The journey of progress in the lightning technology particularly the story of the blue LED represents a narrative about science innovation which have a global impact. Teaching the change from incandescent bulbs to LED technology is not only a way of providing scientific literacy but also of raising awareness about the impact of innovation on society. By teaching this transition, educators can ignite curiosity, highlight the importance of science and its role in society, and encourage the next generation of innovators. The tale of blue LED is not only about light but enlightenment and motivation in every sense of the word.

By integrating theoretical knowledge with practical experiments, teachers can also provide a sense of curiosity and purpose in students. The success of LED technology, which is the result of decades of research and finally the Nobel Prize, is a clear example of the importance of persistence in the field of science, which can lead to innovations for the betterment of mankind. Educating the change from incandescent bulbs to LED technology is a way of preparing the students for understanding the world and making it a better place. The examples always make understanding physics and technology a fun.

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