THE Nobel Prize in Physics 2014 was jointly awarded to Isamu Akasaki, Hiroshi Amano and Shuji Nakamura for the invention of efficient blue light emitting diodes (LEDs). By using blue LEDs along with the already existing red and green LEDs, energy-efficient white light can be produced. With the advent of LED lamp we now have long lasting and energy-saving alternative to its nearest rival – the compact fluorescent lamp (CFL). Moreover, unlike fluorescent lamps, they do not contain any poisonous substances like mercury.

Isamu Akasaki (b. 1929) is a Japanese citizen who is currently a distinguished professor at Nagoya University, Japan; Hiroshi Amano (b. 1960) is also a Japanese citizen who is currently a professor at Nagoya University, Japan, and Shuji Nakamura (b. 1954) is a Japanese born U.S. citizen. He is currently a professor at the University of California, USA.

LEDs have been with us for more than half a century. They produced radiation by a process known as electroluminescence, in the visible and in the invisible spectrum of electromagnetic waves, except in the blue end. (The “invisible” LED radiating in the infrared is more ubiquitous and it silently helped us to change the channels of our TV, while relaxing in our bed!) Only the triad of red, green and blue light can combine to produce the white light that lights up our world. Despite great efforts by the research community, the discovery of blue light emitting diodes was made just twenty years ago, after many fruitless attempts.

While making this discovery in the late 1980s, Isamu Akasaki and Hiroshi Amano were employed at the Nagoya University, while Shuji Nakamura was employed at Nichia chemicals, a small company located on the island of Shikoku. Using specifically doped layers of semiconductor materials they independently produced the holy grail of blue LED.

A strange coincidence – while the incandescent bulb was discovered in the beginning of the twentieth century to light up our world, the LED bulb was discovered towards the end of the twentieth century and is all set to light up the twenty-first century.

Basically all LEDs are made up of several layers of n-type and p-type semiconducting materials. An n-type material contains excess number of electrons that are not bound to any particular atom. This is achieved by adding certain “impurities” to the semiconducting material. A p-type material contains excess number of “holes” that are bound to a particular atom.

Holes do not have a physical existence. They are just absence of valence electrons that are normally bound to a parent atom. Even though holes are attached to a parent atom, a valence electron in the neighboring atom migrates to a hole in the vicinity, thereby creating a hole in its original location. This gives an impression of holes being mobile, simply because they are absence of valence electrons.

But strangely, according to quantum mechanics, the holes do behave as though they are true positive charges, migrating in the presence of an electric field. A phenomenon called Hall-effect can be
understood only by considering holes as being effectively made up of migrating positive charges and not as absence of valence electrons.

In an LED, between two semiconducting p and n layers, many active layers exist (we will see the reason later). When a forward bias is applied, holes from p-type layer and electrons from an n-type layer meet in the active layers. They annihilate each other by recombination, and produce photons of light in the process. Practically no heat is generated in this process of recombination of electrons and holes. The wavelength of the resulting photon depends entirely on the nature of the semiconducting material.

The blue light emitting diode consists of several layers of Gallium Nitride (this had a high band-gap energy). By mixing Indium and Aluminium, the Laureates succeeded in increasing the lamp’s efficiency. In incandescent lamp, a filament is heated, producing heat and light. Even in fluorescent lamps, a gas discharge is produced creating heat and light. For every watt of power that is spent, LED lamps produce more lumens of light. The recent record for LED is 300 lumens per watt (it is increasing even more as research in this area is getting “hotter”) compared to the 16 lumens per watt for incandescent light and 70 lumens per watt for the fluorescent lamp.

Since about 25% of the world’s electrical consumption is used for lighting purpose, lighting up the world with LED amounts to substantial reduction in power being used. Every unit of energy saved is equivalent to a unit that is generated, contributing to the saving of Earth’s resources.

The reason for the existence of the active layers is to increase the efficiency of recombination of electrons and holes. Classical mechanics requires that momentum be conserved in an encounter between these particles to produce a photon. This requirement is very stringent, and the probability of recombination by such a direct encounter is very small. By introducing “traps” or recombination centers between the layers, a third body is created which helps to satisfy the momentum conservation criteria.

It is rather surprising to note that the production of light by electroluminescence was reported way back in 1907 by a researcher named Henry J. Round. Round was a co-worker of Guglielmo Marconi, who is credited with long distance radio communication. He applied voltage across two contacts on a carborundum crystal. At low voltages, a yellow electroluminescence between the contacts was observed. At higher voltages, different colours were observed (except blue, of course!).

In the late 1920s this research was revived by Oleg V. Losev in the Soviet Union, who published several papers on his discoveries. However, no concrete progress could be made, since these two researchers were way ahead of time. A true understanding of semiconductors and electroluminescence came only after Bohr’s atomic model (1913) and the work done by researchers in the Bell Telephone labs (Bardeen, Brattain and Shockley in 1945).

Thomas Alva Edison once said that genius is one percent inspiration and ninety nine percent perspiration. When somebody asked him if he had failed 1000 times before making a working incandescent lamp, he quipped: “I have not failed 1000 times. I have discovered 1000 ways of how not to make a light bulb” (there are many versions of this, but I will not go into all of them!). The discovery of the blue LED also appears to have been a product of many fruitless attempts.

Many researchers in the past found Gallium Nitride and Zinc Selenide to be promising materials for producing blue LED (because of the large band gap energy). But they gave up their attempts since it virtually appeared to be impossible to create p-type layers in these materials.

In 1986, Akasaki and Amano succeeded in creating high quality gallium nitride crystal by placing a layer of aluminium nitride on a sapphire substrate and then growing the gallium nitride on top of it. A few years later they made a breakthrough by creating a p-type layer.

As a serendipitous discovery, they noticed that their material was glowing more intensely when it was studied under a scanning electron microscope. This suggested that the electron beam of the microscope was making the p-type layer more efficient by removing the hydrogen that was preventing the p-type layer to form.

In 1992, they presented their first LED, producing an intense blue light. Nakamura found his own clever way of growing high quality crystals by first growing a thin layer of gallium nitride crystal at low temperature and growing subsequent layers at high temperatures. Nakamura’s technique was also cheaper than that of Akasaki in producing a p-type layer.

Akasaki, Amano and Nakamura also invented the blue laser, in which the blue LED, the size of a grain of sand, is a crucial component. Since blue light has a shorter wavelength than red light, the blue laser can store more information. This led to the discovery of blue-ray discs with longer play back times. It also contributed to better laser printers.

Televisions that are sold in the market as LED TVs are not true LED TVs. They are actually LCD TVs that are illuminated by an array of LED devices at the back. The LCDs are absolutely passive devices requiring a back-ground lighting. In the older version of pure LCD displays, this background lighting was provided by cold cathode fluorescent lamps. Currently LEDs are not small enough to be used for individual pixels in domestic televisions, and so the use of true LED is restricted to much larger screens found in places such as cricket stadia.

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