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Development and Practical Applications of Blue Light-Emitting Diodes

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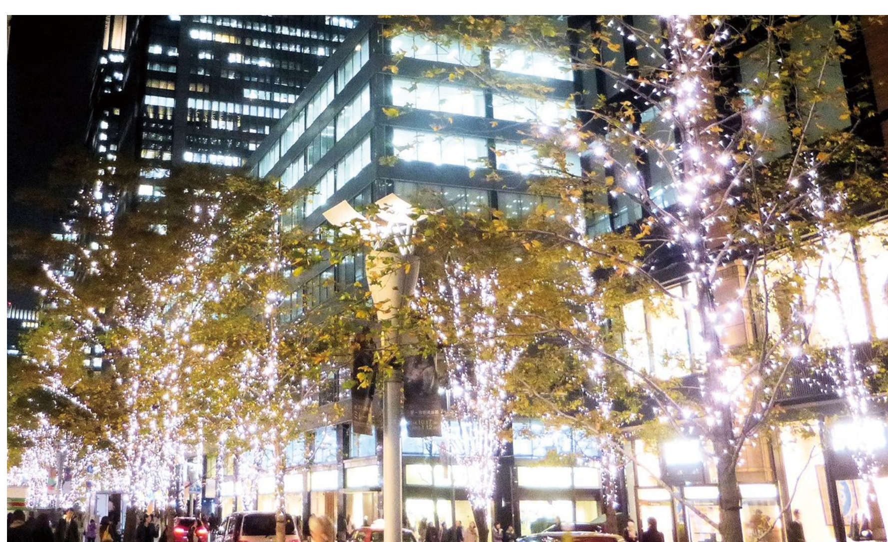
The practical application of semiconductor-based high-efficiency white-light sources, also known as light-emitting diodes, or LEDs, is a recent development of Japanese engineering. This development could be a game-changer for lighting worldwide, given that current power consumption for lighting accounts for 16% of the total electricity consumption in Japan. Since it leads to more efficient use of electricity, this technology can help to alleviate global warming. In fact, after changing all the lighting in my house to LEDs, the lighting power consumption was reduced to about 20% of its former amount. Previously, the electric bulbs in my home required frequent changing; now, they last considerably longer. Because LED bulbs use less power than older, more traditional bulbs, it is likely that this technology will be disseminated widely to every corner of the world in the near future, particularly in consideration of continuing worldwide cost-reduction measures.

The white color of an LED bulb comes from mixing red, green, and blue light. As the source of one of these three primary colors, blue LEDs with a short wavelength are essential to the creation of a white LED bulb. However, the initial development of blue LEDs was difficult; so much so, that at one time it was hard to imagine that the production of white-light LED sources would occur as early as it did—before the end of the 20th century.

Three Japanese researchers received the Nobel Prize in Physics in 2014 for the development of efficient blue LEDs: Isamu Akasaki, Hiroshi Amano, and Shuji Nakamura. Of these three researchers, the first had great foresight and initiated the research; the second overcame the technical challenges before anybody else; and the third directly connected the research results to practi-



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cal applications. Although this award is called the Nobel Prize in Physics, the content of these researchers' achievements is closer to engineering: While science involves uncovering and understanding the world of nature, engineering focuses on creating products that do not exist in nature.

Isamu Akasaki is a professor emeritus at Nagoya University, a member of the Engineering Academy of Japan (EAJ) and a life-time professor at Miyagi University. Akasaki started research on gallium nitride (GaN) around 1973, while at the Matsushita Research Institute Tokyo, Inc. At that time, growing high-quality GaN crystals was considered to be an extreme challenge. Due to a lattice mismatch of 16% between the sapphire substrate and the GaN LED materials, it was difficult to produce crystals of sufficient quality. Hiroshi Amano, a professor at Nagoya University and at that time a member of Akasaki's lab, undertook a major initiative in this research. After overcoming many setbacks, the lab succeeded in producing GaN PN-junction blue LEDs in 1985, by making a buffer layer at a low temperature, doping GaN crystals with magnesium atoms, and radiating electron beams to the crystals.

Shuji Nakamura, the third award-winner, is a professor at the University of California, Santa Barbara. Nakamura began his research while working for Nichia Corporation, located in Tokushima Prefecture, Japan. Although the commercial development of blue diodes was still in its infancy, Nakamura directly appealed to the company's president Nobuo Ogawa for funding in this endeavor. At Nakamura's request, the company provided $300 million USD for related research expenses—an unusually large sum for a small- to medium-sized corporation. In addition, Nakamura was allowed to study at the University of Florida. President Ogawa's broad-mindedness in this matter was admirable: He accepted a young researcher's passion and enthusiasm wholeheartedly, and was willing to take a risk on him. As a result, high-luminance blue LEDs were realized in 1993, using indium gallium nitride (InGaN) grown by the improved version of the metalorganic chemical vapor deposition (MOCVD) system, or the two-flow MOCVD, featuring the horizontal flow of NH_3 gas in addition to vertical flow. This important method has been patented.

The processes leading to the development of blue LEDs reveal an overlap between basic and applied research. Many breakthroughs similarly find their roots in foresight and technological developments and require engineering processes to bring them to fruition. In this case, once a direction was set by the basic research on GaN, it took about 20 years of development to achieve practical applications. This time frame applies to many new technologies. It is often the case that for truly novel developments, 10 years of basic research and another 10 years of development research are required before achieving practical applications. Given the time it takes to materialize new innovations, it is vital to establish an innovation ecosystem that allows us to promote the process of innovation over many long years; an important perspective that must be addressed by national technological policy.