# PIONEERS OF BLUE LEDS dazzle Nobel Committee

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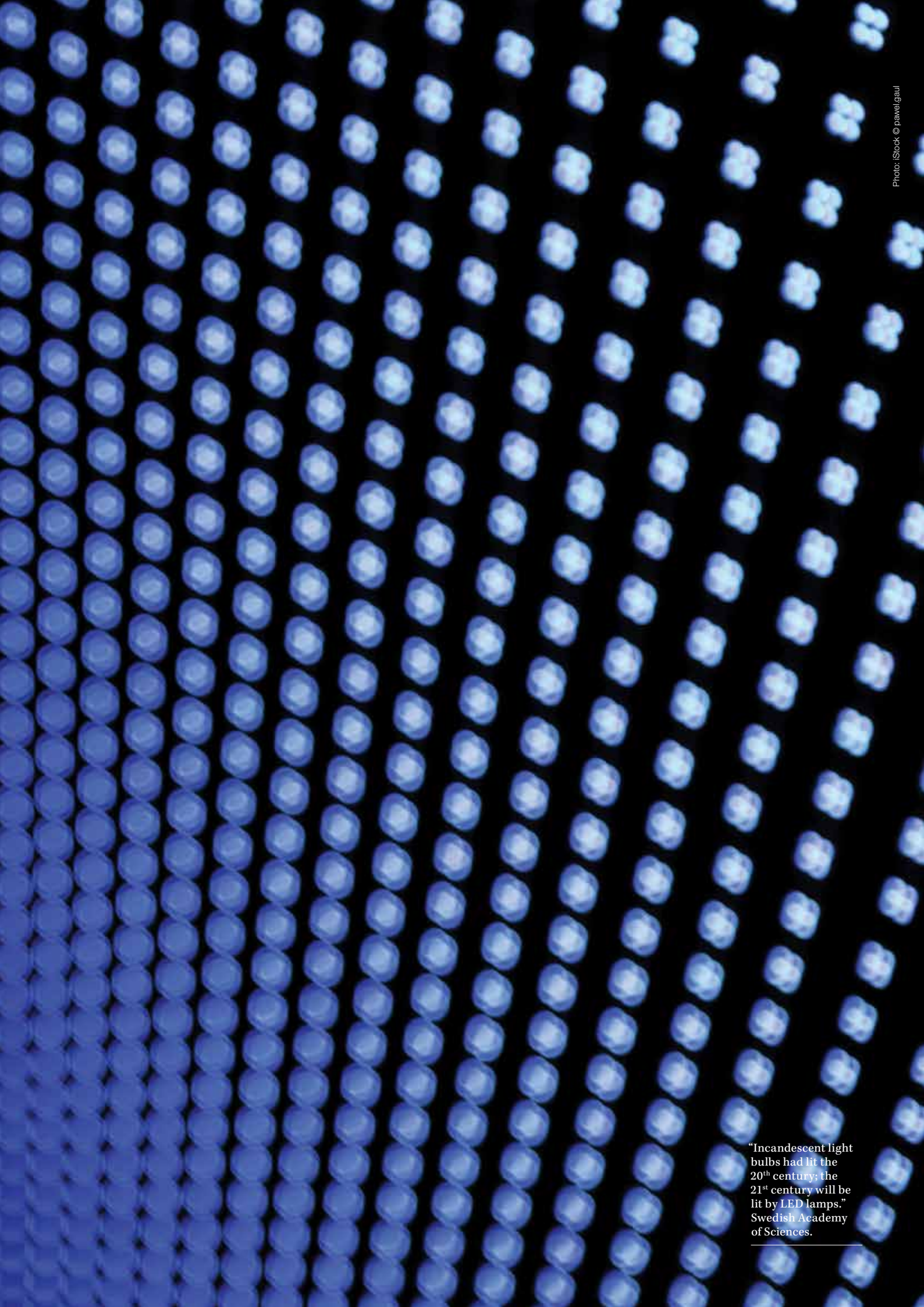

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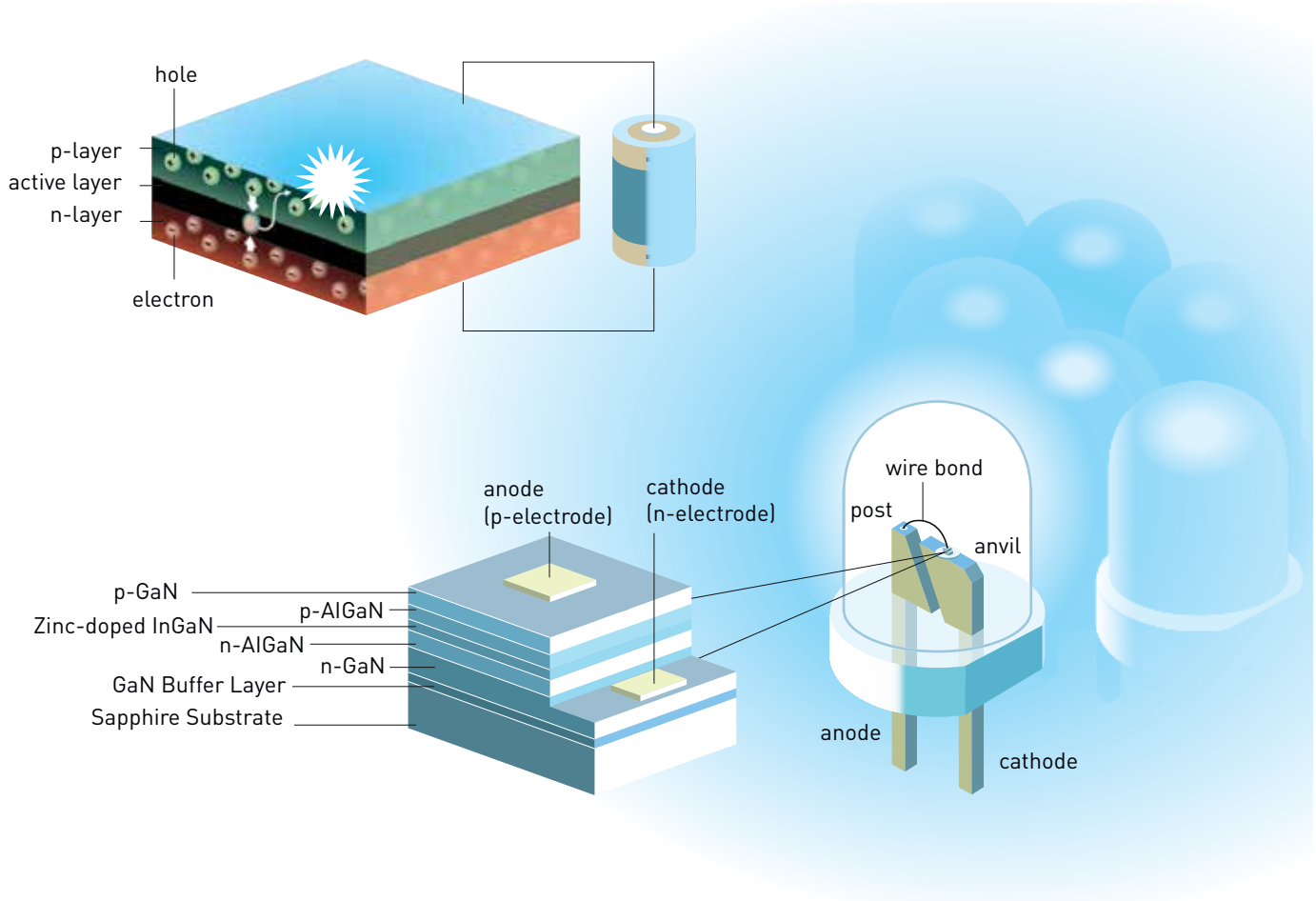
"Incandescent light bulbs had lit the 20th century; the 21st century will be lit by LED lamps." Swedish Academy of Sciences.




Photos: © Swedish Academy of Sciences

A light-emitting diode consists of several layers: an n-type layer with a surplus of negative electrons, and a p-type layer with an insufficient amount of electrons, also referred to as a layer with a surplus of positive holes. Between them lies an active layer to which the negative electrons and the positive holes are driven when an electric voltage is applied to the semiconductor. When electrons and holes meet they recombine and light is created. The light's wavelength depends on the semiconductor; blue appears at the short-wave end of the rainbow and can only be produced using certain materials.

Blue light emitting diodes (LEDs) are firmly embedded in our daily lives. They backlight the screens of mobile phones, TVs and computers; they illuminate homes, streets and vehicles and are used in an impressive array of other applications from Blu-ray discs and traffic lights to digital communication and dentistry. This high-quality source of light offers significant economic, social and environmental benefits. Some have put the impact of blue LEDs on a par with the transformations brought about by the invention of the traditional (incandescent) light bulb in the early 20th century. Others have heralded blue LEDs as the "most successful semiconductor material of the 21st century." So it seems only fitting that this year's Nobel Prize for Physics, an accolade that recognizes an invention of great benefit to humanity, has been awarded to its inventors – Professor Isamu Akasaki, Meijo University and Nagoya University (Japan); Professor Hiroshi Amano, Nagoya University (Japan); and Professor Shuji Nakamura, University of California, Santa Barbara (USA).

Their seminal work in the mid-1980s sparked an intensification of research and development in the field, triggering a surge in patent filings as well as the rapid evolution of the technology, the emergence of a global multi-billion dollar industry and numerous far-reaching social and environmental benefits.

## BREAKTHROUGHS SPAWN FIERCE BUSINESS RIVALRY

In the early years, the two companies responsible for initially commercializing the technology – Toyoda Gosei (with whom Isamu Akasaki and Hiroshi Amano worked in partnership) and Nichia Corporation (Shuri Nakamura's employer at the time) – dominated the lucrative market for blue LEDs. The two companies locked horns in a fierce business rivalry as each fought for pole position. Despite multiple rounds of litigation over patent rights (which ultimately resulted in a comprehensive cross-licensing agreement), their race for market dominance fuelled the technology's rapid advance as each sought to outdo the other by producing brighter, higher quality blue LEDs.

The inventions of this year's Physics Nobel Prize winners have revolutionized lighting technology. LEDs are extremely flexible sources of light capable of producing many different colors at varying intensities, as required.

Breakthroughs in blue LED technology and its commercialization coincided with the growing popularity and explosive demand for mobile phones and liquid crystal displays. Huge sales and even bigger profits transformed the fortunes of both companies as well as those of Nagoya University. Thanks to Japan's adoption of a law akin to the US Bayh-Dole Act, whereby universities gained ownership of patents deriving from government-funded research, Nagoya University was able to generate significant licensing revenue from its blue-LED-related patents. New market entrants including manufacturers of consumer electronics (e.g. Philips and Samsung) and innovative lighting solutions (e.g. Cree and Osram), seeking to tap into the technology's huge commercial potential, added further impetus bringing about multiple advances in performance and an expanding range of applications which go far beyond those of conventional light sources.

## LED TECHNOLOGY IN A NUTSHELL

A LED is a solid state lighting solution. Unlike traditional incandescent bulbs where light is produced by heating a filament, a LED consists of several layers of (man-made) semiconductor material which, through a process of electroluminescence, converts electricity into light particles (photons). The wave-length of the light generated by a LED – its color – depends on the semiconductor material used; blue light which appears at the short-wave end of the spectrum, and which is required to create white light, can only be produced using certain materials.

A white LED can be made either by mixing several colored LEDs or by using blue LED with a type of phosphor to create light that is white in appearance. A white LED bulb currently converts around 50 percent of the energy it uses into light compared to just 5 percent in an incandescent bulb. This makes it an increasingly favored, energy-efficient and environmentally friendly source of high-quality light.

## A LITTLE LED HISTORY

Red and greens LEDs, invented in the 1950s and 1960s, were created using gallium arsenide phosphide; a material which proved unsuitable for creating blue LEDs. Recognizing the huge technological and commercial potential of blue LEDs (which would complete the palate of colors – red, green and blue - required to make white light), leading industrial labs invested significant time and resources into developing them, but to no avail. Harnessing the properties of the material gallium nitride (GaN), which is the basis for growing and mass producing the crystals needed to efficiently generate high-quality blue LEDs, proved difficult. It took some 30 years to crack the process. Researchers faced three key challenges: how to create high-quality crystals using GaN; how to change their conductivity; and how to boost their light emitting properties.

The lack of progress in working with the material caused many to abandon GaN research in favor of other seemingly more promising materials. But Isamu Akasaki, Hiroshi Amano and Shuji Nakamura remained convinced that GaN would yield the results they sought. Their dogged determination eventually paid off enabling them to succeed where others had failed.

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LEDs use less power to emit light than traditional lighting sources. As around one quarter of the world's electricity consumption is used for lighting, energy-efficient LED light sources can support efforts to tackle climate change.

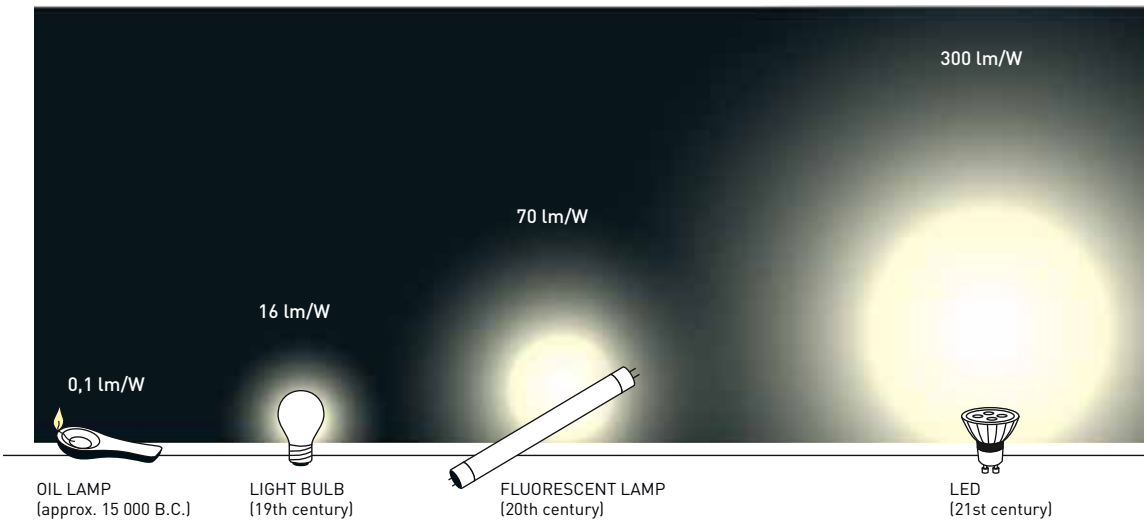


Photo: © Swedish Academy of Sciences

**A NEW LED IS BORN**

In 1986, Isamu Akasaki and his (then) doctoral student Hiroshi Amano were the first to produce and patent high-quality blue LEDs (US Patent 4855249). The following year, they went into partnership with Toyoda Gosei Corporation under a project funded by the Japan Science and Technology Agency (JST) to further develop GaN-related blue LEDs. Toyoda Gosei began commercial production of its blue LEDs in 1995.

Independently of the Nagoya researchers, Shuji Nakamura (then employed by Nichia Corporation) began developing his own blue LEDs (US Patent 5290393) and the techniques and processes for their large-scale production. In November 1993, Nichia became the first company to commercially produce high-quality blue LEDs.

A year later, drawing on its chemical expertise, Nichia produced the world's first white LEDs by combining yttrium aluminium garnet phosphor with blue LEDs (US Patent No. 5998925). These breakthrough developments spawned the growth of a multi-billion dollar global industry and triggered a seismic shift in the traditional lighting sector.

**MULTIPLE BENEFITS; WIDE-RANGING APPLICATIONS**

White LED light bulbs are a high-quality, energy-efficient and environmentally-friendly light source. They are around 20 times more efficient than conventional bulbs generating around 300 lumens per watt – a 40 watt incandescent bulb produces just 450 lumens – with a lifespan of around 100,000 hours – compared to around 1,200 hours for an incandescent bulb. They can also operate using cheap local solar power, making it possible to light up the lives of over 1.5 billion people who currently lack access to electricity grids.

As lighting accounts for around 20 percent of the world's electricity consumption (around 6 percent of greenhouse gas emissions), the widespread uptake of LED bulbs promises to significantly reduce global electricity consumption. In the US alone, if energy usage for lighting is cut by 40 percent with the uptake of LED lighting, the technology has the potential to reduce annual energy costs by USD53 billion according to a recent PricewaterhouseCoopers' report (*http://tinyurl.com/optdh6k*).

LED technology is also being used within the healthcare sector to help reduce energy costs and inhibit the spread of infections within hospitals. Its use in managing pain, insomnia and various behavioral disorders and illnesses, including Alzheimer's, is also being explored.

It also holds promise in alleviating the "broadband crunch" resulting from current mass data usage. LiFi, the latest technique in the field of optical wireless communications, "focuses on establishing communication links via LED lighting networks," a report by the technology consultancy iRunway explains (*http://tinyurl.com/muz9crg*).

**A FERTILE ENVIRONMENT FOR PATENTS**

The Japanese-born scientists' groundbreaking work sparked renewed global interest in blue LEDs and a surge in patenting activity. Patents continue to be an important means by which companies involved in the development and production of LEDs are able to protect their intellectual property (IP) rights and their market position. "Patents are very important because they give companies a competitive advantage in the marketplace," notes Professor Nakamura.

A recent study by iRunway found that since the early 1990s in the US alone, around 22,662 patents have been granted in the LED field – 17,869 of those relating to LED technology and 4,793 of them relating to the application of the technology. "The breadth and complexity of technologies and applications of LED, and the innovation needed to bring them all together, have resulted in aggressive patenting activity over the years," the study notes.

**PATENT LITIGATION IS COMMON**

Patent litigation is a common feature of the LED sector. In the early days, Nichia Corporation and Toyoda Gosei set the tone, suing and counter-suing each other in some 10 LED

patent-related lawsuits over six years. From 1996 to 2010, 168 LED-related patent lawsuits were filed worldwide according a 2013 paper by Amy J.C Trappey *et al.* in the *International Journal of Automation and Smart Technology* (www.ausmt.org) The LED sector remains in "active litigation mode" with major players currently involved in "almost three active litigations per company" according to iRunway.

**LICENSING AGREEMENTS**

Licensing and cross-licensing agreements remain the means by which many patent disputes are settled within the industry. "Patent licensing has been one of the leading impetuses for international technology transfer," Amy Trappey *et al* note.

Patent licensing deals, however, also enable companies in a competitive market to avoid patent infringement and costly litigation. Toyoda Gosei, for example, has from the outset been favorably disposed to licensing its technologies to other companies. The company is currently licensing, in collaboration with its international partners, a white light technology patent using blue LED and silicate phosphor to over 30 LED manufacturers according to a recent report by *LEDinside* (*www.ledinside.com*).

While the most basic LED patents are currently controlled by key industry players – Philips, Nichia, Osram, Toyoda Gosei and Cree – enabling them to effectively "control the industry supply chain," and making it difficult for new market entrants, many of these patents (including US Patent 5998925) relating to white LED manufacture) are due to lapse in the coming years, signaling potential changes to LED market dynamics and structure.

**TECHNOLOGY TRANSFER**

Patents continue to be instrumental in transferring technology within and across the industry through licensing and cross-licensing agreements. They also enable the transfer of technology from university research labs to industry. For example, as holders of patents covering their breakthrough blue LED technology, Isamu Akasaki and Hiroshi Amano at Nagoya University were able to license it to their industrial partner, Toyoda Gosei. By 2006, Nagoya University's GaN-related blue LED licensing revenue rose to around JPY5.6 billion (around USD48 million in today's money) representing at the time around 90 percent of royalties from government-held patents. These revenues have funded the establishment of the University's cutting-edge semiconductor research facility. "Patents […] give universities a mechanism for transferring technologies they develop to the market through appropriate commercial partners. This way, important university innovations can be turned into products that will benefit society. Without the competitive advantage that patents offer, companies would not have the same motivation to commercialize these products," explains Professor Nakamura.

"Through the patent system, inventors and companies are able to retain exclusive rights to their inventions for a certain period of time, which allows them to present these inventions to the world via academic conferences and scientific papers. Without the patent system, I believe there would be no room for friendly competition between inventors or the advancement of science and technology," explains Professor Yasumasa Iwatani, a close colleague of Professor Akasaki at Meijo University.

**BLUE LEDS AND THE PCT**

A significant number of GaN-based LED patent applications, as well as key pioneering patents filed by this year's laureates have passed through WIPO's Patent Cooperation Treaty (PCT). This is a cost-effective mechanism for applicants (individuals, companies or universities) seeking patent protection in multiple countries. "The advantage of the PCT is that it is easy to expand the patent right to other countries in order to protect the right of the inventor," notes Nagoya University's Hiroshi Amano.

"University technologies are generally very early stage. The PCT is critical for these early stage technologies because it gives us the opportunity to protect our patents globally while allowing the market and the technology to mature further before determining which countries might be most valuable to commercial partners," Professor Nakamura explains.

A simple search of WIPO's Patentscope – a free public database hosting over 43 million patent applications – for GaN-related blue LED patent applications indicates that over 8,250 international applications were filed during the period 2004 to 2013. A similar search revealed that Professors Nakamura, Akasaki and Amano have filed 207, 65 and 53 patent applications respectively over the years.

The pioneering achievements of Professors Akasaki, Amano and Nakamura, are transforming the global lighting industry and have given rise to a broad range of applications in other areas, including, consumer electronics. "Incandescent light bulbs had lit the 20th century; the 21st century will be lit by LED lamps," notes the Swedish Academy of Sciences. LED lights are fast becoming the lighting source of choice. By 2020, LED bulbs are expected to occupy around 70 percent of the lighting market, the value of which is expected to rise to EUR83 billion (Mckinsey 2012). The impact of the achievements of this year's Nobel Physics laureates is far-reaching and dramatic, promising significant environmental benefits on top of significant energy and cost savings. The on-going technological and commercial dynamism of the sector suggests that the party is far from over. It may have only just begun. ◆