Swedish LED Revolution, Born in China

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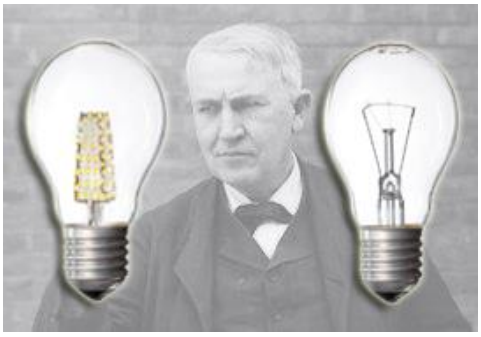


Traditional Outside, Revolutionary Inside

Vision: the Mother of Invention

New technology by Swedish lighting company EcoLights Green Technologies has propagated a radically different range of LED lamps that look surprisingly identical to traditional bulbs. So much so that Edison's familiar design of around 130 years ago and that of the new Ecolights could be twins, were it not for a secret innovation that lies at the heart of the new lamps.

The new bulbs have all the benefits of modern incandescent bulbs: 360° light projection, instant switch-on, they are dimmable, aesthetically pleasing and available in a variety of shapes, sizes and glass renderings.

The differences are that EcoLights are 6 times more energy efficient than incandescent bulbs, have a life expectancy that is 42 times longer and the bulky heat sink of conventional LED lamps is absent.

Remarkably though, EcoLights are not the outcome of meticulous research by R&D scientists through long series of experiments, slowly testing and finally reaching breakthrough. This innovation is akin to other amazing discoveries made by chance that gave us Penicillin, Velcro, Vaseline, artificial sweeteners, potato chips and even Viagra.

LED Lighting Revolution

It is only in the past decade that thanks to rapid advancements in LED technology manufacturers started mass-producing LED lamps for general lighting. Today, industry observers agree that LEDs are the light source of the future. Government regulations in many countries are phasing out incandescent bulbs because of their energy wastefulness and fluorescent tubes, including compact fluorescent lights (CFLs), will eventually follow the same fate over health concerns due to their fragile tubes containing toxic mercury.

LED lamps are 25% more energy efficient than CFLs and last 6 times longer. However, for conventional high-brightness LEDs to dissipate internal temperature they require an awkward heat sink, positioned just above the base, which defaces the visual appeal and prevents an even 360 degrees diffusion of light, rendering them unsuitable – as with CFLs – to fit chandeliers, candelabras and pendants with bulbs in full view.

Owners of such luminaires have so far had no choice but to use incandescent bulbs.

EcoLights Classic LED lamps have no need for spoiling cooling sinks, because they deploy a very different system to control the inner temperature of the bulbs based upon the use of an environmentally friendly gas mixture in combination with an assembly of multiple low-power LEDs. As if this is not enough, unlike standard LED lamps, EcoLights are fully dimmable.

A Fortuitous Discovery

In 2011 former IKEA lighting executives and business partners Patrik Åhman and Christer Petersson, each with more than 30 years' experience in the international lighting business, accepted an invitation from a Taiwanese manufacturer of solar panels and LED street lighting to attend the Intersolar exhibition in Munich.

World LED Lighting Market

Light emitting diodes (LEDs) use less than 20% of electricity compared with incandescent bulbs need and this makes them the most efficient lighting source around. For this reason, many countries have already phased out incandescent lamps, paving the way for LED's rise to the top of the market.

There are three main sectors in the lighting market, namely general lighting, automotive and backlighting (e.g. smartphones, computer displays). General lighting is the largest sector and is likely to exceed sales of 100 billion US Dollars by 2020. Automotive lighting will by then account for around one fifth of the total market with a value of around 20 billion US Dollars. Advances in organic light emitting diode (OLED) technology in smartphones and TV/monitor displays are likely to slow demand for LEDs and liquid crystal displays.

LED prices are significantly higher compared with incandescent bulbs and CFLs, but have been dropping sharply over the past few years. Increased competition and over-investment in manufacturing capacity are contribution factors to the price erosion. LED lighting product prices dropped by 20-25% this year and are likely to decline further by almost 37% next year.

Today the global LED lighting market is worth around US$ 28 billion, which is around double the market size of last year. Japan has the highest LED lighting market penetration rate of any region and will reach 72% by next year. Annual production of LEDs increases by around 48% in South Korea and 31% in China annually. In 2015, the People's Republic will account for almost a third of total global output.

Growth of the general lighting market is likely to propel LED sales from a trot into a gallop thanks to the rise of LED TV applications and with LEDs replacing conventional lighting technology. By next year, LED lighting is likely to claim just under 40% of the global lighting market, which will then be worth US$ 45 billion.

The meeting with the Taiwanese lighting executive was encouraging enough for the two Swedes to pay a visit to the Taipei plant. While deliberating cooperation in the factory's show room, an unusual yet familiar looking bulb displayed on a bookshelf caught Patrik Åhman's attention: "I could not believe my eyes when I saw an Edison style bulb with LEDs inside".

The lamp in question was a GLS prototype that the company had developed one year earlier. EcoLights' co-founder Greger Scholander explains, "Engineers had started experimenting with a cooling gas mixture the factory had patented earlier in combination with several low-Watt LEDs. This in contrast to the few high-power LEDs in lamps currently on the market. They tested a theory that the gas could cool the diodes sufficiently to eliminate the need for a heat sink and to reduce the amount of ballast electronics. This effort was by no means an overnight success, but perseverance paid off and a workable prototype saw the light of day."

Patrik Åhman elaborates, "In other LED lamps up to half of the bulb consists of driver electronics housed in a heat sink that is supposed to air-cool the interior. The insulation of the electronics is quite delicate and is a potential weakness of conventional LED bulbs. Insulation leakage in sub-standard LED lamps is the main cause of failure."

In short, the engineers had succeeded in circumventing the need for the dreaded heat sink, opening the opportunity for the manufacturing of dimmable Edison style LED lamps.

A Brief History of the Incandescent Bulb

Although Edison is commonly credited for discovering the light bulb in 1878, several other inventors - mostly British - pioneered the development of an embryonic incandescent lamp over 70 years before Edison even began serious research into evolving a practical electric light bulb. As a businessman cum inventor, Edison was instrumental in advancing technology developed by earlier scientists to design a commercially viable light bulb.

By passing an electric current through a highly resistant filament or wire, it reaches such a high temperature that it starts to glow. Scientists already understood this phenomenon in the early 1800s, but struggled for decades to identify filament material that could sustain the glowing for an extended period. Early experiments with high melting point materials such as charcoal; platinum; graphite; carbonised paper, cotton, linen, wood splints and bamboo filament produced mixed results. For years, there were no significant breakthroughs. The filaments were either not durable enough or too expensive for commercial production. Edison's first successful test in 1879 lasted just 13.5 hours and generated 2 Lumens per Watt.

Exposed to continuous high temperatures of around 2,500 °C, the filaments gradually evaporate losing luminosity and durability in the process. The early inventors explored solutions by attempting to control the inner environment of the glass envelope. Creating a vacuum helped reduce gas molecules to react with the filament and thus promoted longevity. In the early 20th century, experiments with filling the bulb with nitrogen, argon and even krypton produced encouraging results. These inert (electrically non-conducting) gases flush out all air in the bulb and conduct heat from the glowing filament to the glass surface area for it to radiate out.

Edison discovered that a carbonised bamboo filament in a vacated glass bulb could last over 1,200 hours and this outstripped earlier designs. It rang in the commercial manufacturing of light bulbs in 1880 by the Edison Electric Light Company.

From the end of the 19th into early 20th century, scientists at manufacturers such as US General Electric Company (GEC) continued their R&D to improve the commercially produced incandescent bulbs that were now gradually replacing light sources that up to then consisted of candles, oil lanterns and gas lamps.

Production of osmium and tantalum filament bulbs started, but the scarcity of these metals made them expensive and therefore not practical for mass production. In 1904, Hungarian manufacturer Tungsram began production of tungsten filament bulbs that outlasted any other material and gave brighter light than their carbon counterparts gave. Three years later GEC launched bulbs with sintered tungsten filament.

Tungsten's qualities of strength, ductility and workability made it possible for it to be readily formed into filament coils, which reduce convective heat loss, allowing the filament to operate at the desired temperature. Its high melting point, low evaporation rate and low cost made it the ideal material.

From the 1920s onwards, manufacturers produced bulbs with different glass renderings, such as frosted and silica coated to improve light quality, and launched the shapes and sizes we know today.

The 1960s saw the launch of brighter halogen-filled incandescent lamps. Halogen gas slows the filament evaporation rate allowing it to operate at higher temperatures, delivering better efficacy at reduced power consumption.

By 1964, improvements in production of incandescent lamps had reduced the cost of a given quantity of light by a factor of thirty, compared with Edison's earlier lighting system. By the beginning of this new millennium some 12 billion incandescent bulbs were sold annually worldwide; 40,000 times higher than when production first began.

Prototype Refinement

Clearly, the lamps were perfectly suited for replacing incandescent bulbs. However, the specifications of the demonstrated prototype were inappropriate for the European market and engineers started work on tuning the calibration to 230 Volts, a colour rendering[1] of Ra 80+ and temperature of 2,700 Kelvin[2].

Laboratories in Sweden tested many samples in quick succession over several months before the bulbs achieved the desired results.

Thereafter, the team designed the full range of 28 variants available today and the factory started producing dozens of samples for certification applications and presentations to potential customers.

EcoLights Green Technologies Ltd.

The initial business plan focussed on marketing the new LED lamps in Scandinavia and work started on establishing a distribution network. This is when entrepreneur and compatriot Patrik Hedkvist came onto the scene who, a few years earlier, had established one of the first LED lighting companies in Sweden - aptly branded EcoLights - and had developed a successful business in supplying LED lamps to lighting system contractors.

Patrik had earlier understood the potential of LEDs: "Traditional lighting is inefficient with so much energy wasted on heat. LEDs are good for the environment, use less power and are not toxic. You can put LEDs anywhere." He remembers the initial scepticism of his customers when LEDs first entered the market and explains: "The big multinational brands were not actively promoting LEDs in order to protect their sales of incandescent bulbs and so the brands that were available in the early days few people had heard of and this drove the apprehension."

Patrik also knew the shortcomings of conventional LEDs often not meeting the requirements of lighting system designs because of the partial light diffusion, clumsy heat sinks and poor dimming capability. "Now people have a better understanding of the benefits of LEDs, but they do not like the heat sinks because they are an eye sore and so you cannot have them in chandeliers."

It soon dawned on the three EcoLights partners that Scandinavia alone presented too small an arena for a discovery as formidable as EcoLights and they invited another former IKEA colleague and lighting heavyweight Greger Scholander to join the board. For the past two decades, Greger had established a global multi-million business in home products with major retail groups as clients.

Greger's additional string on the EcoLights bow opened new networking doors to access major markets in Europe, the Americas and Australasia. Furthermore, Greger had lived in China for over a decade, could speak Mandarin, understood the Chinese culture, and had developed state of the art quality control and logistics information systems for use by the EcoLights factory in China.

By early 2012, Ecolights acquired the worldwide rights to the LED bulbs it had developed and preparation for production and marketing began.

Made in China

The four directors negotiated with a Chinese factory of incandescent bulbs conversion of part of its installed capacity of 15 million lamps per month to production of its range of dimmable Classic EcoLights in line with increasing demand. Essentially this meant replacing the traditional filament and argon at the assembly line by the LED light engine and special cooling gas.

The EcoLights team appointed Taiwanese Harvatek Ltd. to supply the LEDs on the strength of the manufacturer specialising in compact surface-mounted low power LEDs for backlighting in cell phones and computer screens.

Market Entry Strategy

The challenge to EcoLights is that the brand still has little brand awareness to speak of, let alone an image or reputation. Furthermore, availability is nascent.

Patrik Hedkvist: "True, but there is no other LED light on the market that has the exceptional features of EcoLights in terms of degree of diffusion, visual appeal and dimming qualities. In the short term, our marketing efforts concentrate on cultivating awareness with end-users of these unique physical benefits. Developing a distinctive brand image that seizes the needs of bulb buyers starts with

[1] A measurement of a light source, reproducing true colours on a scale from 1-100.

[2] Colour temperatures over 5,000K are cool colours (bluish white), while lower temperatures (2,700–3,000 K) are warm and typical of incandescent light.

customer satisfaction and that is what we aim to deliver."

"We intend to achieve initial market penetration," Patrik Åhman adds "By focussing our efforts on contracting business, online shopping, securing listings with major retailers and signing up distributors." Several leading FMCG[3] and home improvement retailers have already placed orders and of course their role in increasing visibility of EcoLights with consumers is undeniable."

In 2013, the company signed up several distributors in Europe. Negotiations with more potential suppliers are on their way "Priority" Greger Scholander explains, "Is to secure a strong foothold in Europe, where we can showcase our products to a discerning market governed by strict market regulations. Here we can earn our spurs and this will put us in good stead to venture into other markets."

It does not mean that efforts are singularly focused on Europe. Christer Petersson: "Scandinavia is our home turf, but our network spans well beyond Western Europe's boundaries into the former Soviet Union territories, the Americas, Australasia and the Middle East just to name a few. We currently serve these countries through regional agents[4]."

Packaging Design

The EcoLights partners agreed that an extraordinary lamp deserves extraordinary packaging and designers started developing concepts in response to a simple brief:

- Distinctive packaging for instant brand recognition and to stand out of the crowd when merchandised on in-store shelving.
- Should convey the unique physical attributes of the bulbs.
- Must drive home the environmentally friendliness.
- Clear information in plain language about the bulb's specifications:
  - Energy efficiency category.
  - The luminous flux of the bulb (Lumens).
  - The electricity consumption of the lamp in Watts.
  - Expected operating life in hours.
  - Certification endorsements.
  - Number of switch cycles.
  - Speed of ignition.
  - Volts, Hertz and Milliamp ratings.
  - Colour temperature and rendering grade.
  - Fitting type and size.
  - Dimensions of the bulb.
  - Article number.

The new packaging – made of recyclable transparent material – came on stream in the middle of 2013 and has since adorned the shelves of major retailers.

Brand Values

Greger Scholander: "There are no alternative LEDs to our candle bulbs in the market. Versions with heat sinks just shine in one direction. Churches, hotels and other places that use a lot of chandeliers with bulbs pointing upwards cannot fit conventional LED lamps because they leave the floor dark with all light projected towards the ceiling and usually cannot be dimmed. Our Classic LED Dimmable Candle bulbs are just the same as the traditional incandescent bulbs, except for a dramatic reduction in energy consumption. With the amazing response we received, we believe churches and hotels will be our biggest customers for these types of bulb. Imagine how much they could save!"

"Regarding the big globe bulbs" Greger continues "Millions of ceiling lamps designed for these lights were mounted over decennia, but today's LED lamps do not do the job: reflectors don't work, the bulbs don't fit the lamp shades, no dimming function for most of them and so forth. Our big 95 mm and 125 mm globe bulbs fit the bill like-for-like with the old ones."

Greger: "The story with our small 45 mm golf balls is the same again. It is very difficult to find dimmable and full beam LED bulbs. The unique dimming ability of all our bulbs has been widely acclaimed. Not just over 10 or 20% that other LED lamps offer, but the full 100% spectrum! Millions of households are looking at their spotlights made redundant by standard LED bulbs because they cast shadows where before top-mirrored incandescent bulbs shone brightly. With our Top Silver Reflector GLS lamps – to be released in the next few months – we aim to address this frustration."

[3] FMCG: fast moving consumer goods (e.g. sold in supermarkets).

[4] In contrast to distributors, agents do not carry stock.

Pricing

EcoLights bulbs use more LEDs compared with conventional designs and this has a direct bearing on the production cost, though mitigated somewhat by the absence of a heat sink and the use of standard glass envelopes used for incandescent bulbs.

The initial outlay for an LED lamp is roughly 16 times higher than the retail price of a comparable incandescent bulb and 3 times that of a CFL.

However, the power consumption of LEDs is much lower and they last considerably longer than either of these older light sources.

Patrik Hedkvist explains: "Consumers benchmark LED prices against what they used to pay for incandescent lights and CFLs. Sure enough, they are more expensive to buy, but if they were to work out the cost including electricity usage over the full lifetime of the LED lamps, they would be pleasantly surprised to find that standard LEDs are 80% cheaper to use compared with the old bulbs.

The good news is that with accelerating mass-production and stiffening competition, prices for quality LED lamps are falling.

Marketing Support

The company has developed display stands for its retail customers appropriate to their in-store location, such as near the checkout or main shelving. "We design them" Greger Scholander explains "Closely with our customers and once agreed no effort is spared to produce something amazing. It is after all in our own interest to create awareness for EcoLights through in-store visibility."

EcoLights introduced special evaluation sets of seven different bulbs that enquiring customers anywhere in the world can receive in a matter of days via air express.

Patrik Hedkvist: "We need to demonstrate how distinctive we are and relevant to the needs and wants of customers. Our marketing efforts at this point focus on below the line marketing activities aimed at increasing awareness at the point of sale; that is in stores and through direct marketing with contractors."

Patrik continues, "Our display stands already support major retail groups in raising awareness and educating potential end-users of the benefits of EcoLights. Our transparent packaging is distinctly different with clearly marked specifications and certifications printed on it, so that customers immediately know without confusion which of our bulbs to

Ecolights' Features

- Familiar and aesthetically pleasing shapes that fit all lampshades and fixtures designed for incandescent bulbs.
- 360° Light projection as with traditional incandescent bulbs.
- Fully dimmable from 1-100%. Conventional dimmers do not function well below 20%. EcoLights can use any dimmer, direct control or digital, and can fade up or down in combination and proportionately with incandescent bulbs.
- 2,700K Warm white colour similar to incandescent bulbs. 3,000K And 5,000K are also available.
- Produced in clear, frosted, opal or amber glass renderings as well as top or bottom mirrored.
- True colour rendering (Ra > 80).
- High Lumen/Watt ratio: Energy Class A and A+, Power Factor >90 with savings of over 82% compared with incandescent bulbs.
- Life expectancy of 50,000 hours with >85 % of the initial Lumen value maintained during the first 25,000 hours.
- Integrated circuit-fuse that breaks power when it exceeds the rated value.
- Direct ignition, no flickering; not even when used at freezing temperatures of -20 °C.
- Minimum 10,000 on/off switching.
- A newly developed and patented internal cooling system that relies on a combination of multiple low-power diodes in combination with a cooling gas mixture.
- The design uses 5 times more low-power LEDs than few high-power diodes in conventional LED lamps, reducing internal heat to a maximum of 80 °C.
- Parallel design of the LEDs means that if one diode malfunctions the remaining LEDs continue with 97 - 99 % of Lumens intact.
- Surface temperature never exceeds 50 °C compared with a scorching 127 °C for incandescent bulbs. The larger the bulb, the cooler its surface.
- Contains no mercury or other heavy metals; RoHS compliant: environmentally friendly.
- No emission of UV rays.
- Outdoor lamps not degraded by sunlight.
- Low weight compared with aluminium heat sink LEDs.
- Zero-rated import duty in most countries.
- Ecolights only use first bin (top class) components to ensure consistent quality.
- Fully certified and audited production standards.

choose to replace their old incandescent bulbs or CFLs.

Market Response

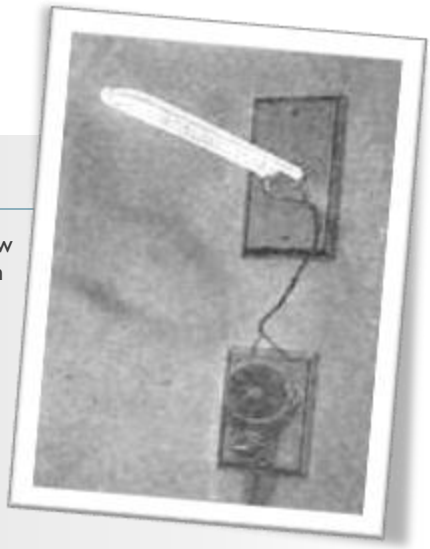
Patrik Åhman recalls, "We launched Ecolights at the Stockholm Furniture & Light Fair in February 2013 and the response was overwhelming. Perhaps not surprising because customers always get excited about features others do not have. After all, our design is revolutionary and stood out of the crowd."

Christen Petersson: "Three major Swedish lighting stores were the first to place orders, followed by a leading German home improvement chain. Orders from the United Kingdom also started flooding in from retailers, online shopping companies and lighting system designers.

Institutional sales to farms, hotels and even churches gained traction. Patrik Hedkvist clarifies, "Hotels and churches have many chandeliers, armatures and candelabras. Old style LEDs are not suitable because light projection is upwards rather than downwards and then there is of course the unsightly heat sink and most cannot dim."

Greger Scholander: "Over the past 8 months our agents have despatched lots of trial packs to Holland, Belgium, France, Spain, Italy, Poland, the Middle East and Australia. The dialogue with these customers is promising and several have requested sole distribution rights for their country."

Asked about how the multinationals of the likes of Philips, Osram and GE might respond, Patrik Åhman muses: "There is always room for news brands, even though the big ones are there. We now have something they do not have, but the lighting market is dynamic and for sure, our innovation will inspire further research and development by manufacturers at large. We are proud to have this catalytic effect on other players. This is good for the industry and keeps us on our toes."



A Brief History of Fluorescent Tubes

Early 19th century scientists knew about the radiant glow that occurs when an electrical current passes through an evacuated glass vessel. In 1856, a German glassblower produced a vacuum in a glass tube to an extent not previously possible. When electricity passed through it, a strong green glow appeared on the tube's walls at the cathode-end. Subsequent experiments showed that the glow in the tube gravitated towards an electromagnetic field and thin coatings of luminescent materials generated fluorescence in budding proportions, still inefficient and short-lived.

In 1896, even Edison dabbled briefly in the development of fluorescent lighting for its commercial potential, but with the success of his incandescent bulbs, there was little incentive for him to pursue an alternative light source. One of his former employees - Daniel McFarlan Moore - did however pursue the idea and created 2-3 metre long tubes filled with carbon dioxide or nitrogen that emitted white or pink lights respectively. He also developed an electromagnetically controlled valve that maintained constant gas pressure that extended operating life. The tubes were efficient and produced a more natural light than incandescent bulbs, but were complicated, expensive to install and required high voltage. Around this time, another American - Peter Cooper Hewitt – designed a lamp that lit when an electric current passed through mercury vapour at low pressure. Unlike Moore's lamps, the lights were made in standardised sizes and operated at low voltage, therefore suitable for a wider market, but the blue-green light they produced still limited their applications.

Step-by-step advances in technology for mercury vapour lamps continued – especially in Europe - and by the 1930s the lights became more common in factories, office blocks and warehouses. Until then the tubes could still not produce clear white light suitable for homes, but the discovery of neon (an inert gas with luminescent qualities) changed all of that. French inventor Georges Claude filled tubes with neon as well as argon and mercury vapour as alternate gases and improved the electrode that overcame the "Spluttering". Another Frenchman - engineer Jacques Risler - solved the unattractive colour problem of fluorescent lighting by inventing a coating on the inside of the tubes that absorbed ultra-violet light, commonly emitted by argon/mercury gas mixes, and re-emitted it as visible light. By around the 1930s neon lighting became more popular in France, but it was no more energy-efficient than conventional incandescent lighting and its applications still largely limited to eye-catching (advertising) signs.

Up to that time, US General Electric had acquired and controlled the patents from key American inventors and effectively blocked the introduction of fluorescent lighting in the US for over 20 years to prevent competition with its incandescent lights. Eventually, war production required 24-hour factories with economical lighting and fluorescent tubes became available. By 1951, more light was produced in the United States by fluorescent lamps than by incandescent lamps.

In 1991 Philips – the Dutch company – used magnetic as opposed to electrical induction to excite a gas to emit light. The use of magnetic ballast removed most of the flickering and slow starting traditionally associated with fluorescent lighting.

Historically fluorescent tubes were straight in varying lengths, but manufacturers started producing compact fluorescent lights (CFLs) to provide the same amount of light in a smaller area. They have several small-diameter tubes joined in a bundle of two, four, or six, or a single tube coiled into a spiral.

In 1980, Philips introduced its model SL, which was a screw-in lamp with integral magnetic ballast. This was the first successful screw-in replacement for an incandescent lamp. In 1985, Osram started selling its model EL lamp, which was the first CFL to include electronic ballast.

A Brief History of LEDs

In 1907, British engineer Henry Round at UK-based Marconi Labs discovered the occurrence of electroluminescence by connecting a silicon carbide crystal with a springy piece of thin metal wire, called the Cat's-Whisker detector. He described his finding in a scientific journal as a yellow glow the crystal gave out with strengthening intensity as voltage increased. Experiments with other crystals emitted green, orange or blue light. The discovery lay dormant for a couple of decades before Russian radio technician Oleg Losev started meticulous research on Cat's Whisker style detectors. He studied the light emission from zinc oxide and silicon carbide crystal rectifiers and concluded that the light emission was not a thermal effect, but arising from the semiconductor action. However, no practical use was made of the discovery for several years.

Both Round and Losev experimented with Silicon Carbide (SiC), but it is inefficient as a material for light-emitting diodes. After the Second World War, experiments continued with different semiconductor materials such as Gallium Arsenide, Gallium Antimony, Indium Phosphide and Silicon-Germanium and other alloys generating infrared emissions. Texas Instruments was the first company to commercially produce infrared diodes in October 1962. Thereafter in quick succession over the following two decades, significant improvements in fabricating semiconducting materials were made, leading to the emission of visible light at increased levels of brightness, ultimately creating HBLEDs (High Brightness).

Initial commercial applications of LEDs were mainly in seven-segment displays (SSD) for "digital" numbers and some letters. First, in expensive equipment such as laboratory and electronics testing equipment, then later in such appliances as TVs, radios, telephones, calculators and even watches. Until 1968, visible and infrared LEDs were costly, but with the onset of mass production – notably by the Monsanto Company and Hewlett Packard – first in red and low brightness LEDs, prices dropped exponentially. In the early 1970s other colours became available and appeared in appliances and equipment.

In the 1970s Fairchild Optoelectronics invented the planar process to fabricate compound semiconductor chips in innovative packages and this reduced the production cost of LEDs to less than five percent of earlier ones. Technological advancement accelerated rapidly and with it efficiency, reliability and light output that doubled every 36 months since the 1960s. Brightness levels increased to the extent that they could be considered for applications other than simple indicator lamps.

By 1987 the Hewlett Packard AlGaAs (Aluminium Gallium Arsenide) diodes were bright enough for the first applications within lighting in the automotive industry where red LEDs were used for more reliable vehicle brake lights and for traffic lights. A year later production began of AlInGaP (Aluminium Indium Gallium Phosphide) which doubled light output. Later in 1993 HP started to use GaP (Gallium Phosphide) to provide high output green LEDs, followed by high output orange lamps.

In 1994, Japanese Nichia Corporation demonstrated the first high-brightness blue LED, based on Indium Gallium Nitride (InGaN). Nine years later, US Cree Inc. produced a new type of LED that produced white light that was four times as efficient as incandescent bulbs. In 2012, Osram demonstrated high-power InGaN LEDs grown on Silicon substrates and announcements by the Nichia Corporation and US Cree revealed better still Lumens per Watt. The race for high-brightness white-light LEDs had truly begun, foreshadowing the retreat of incandescent and fluorescent lamps.

Comparison of Light Sources

	Incandescent	CFLs	LEDs	
			EcoLights	Other
				
Life span in hours	1,200	8,000	50,000	50,000
Approximate degree of light projection	360°	270°	360°	180°
Dimmable	Yes	No	Yes	Some (cost 40%+)
Dimming range	100%	-	100%	80%
Aesthetic appeal	Good	Poor	Good	Medium
Range of shapes and sizes	Wide	Limited	Wide	Medium
Size in comparison with incandescent	-	Taller	Identical	Taller
Cooling system	Inert gas	None	LP-LEDs/cooling gas	Heat sink
Switch-on start	Immediate	Slight Delay	Immediate	Immediate
Wear effect of on/off cycle	Some	Yes	None	None
Durability (e.g. jarring, bumping)	Fragile	Fragile	Durable	Durable
Colour Rendering Index (Ra)	100	82	>80	>75
Colour temperature (Kelvin)	2,700	2,700	2,700	2,700
Sensitivity to temperature	Some	-23 °C /49°C only	None	Some
Sensitivity to humidity	Some	Yes	None	None
Failure modes (e.g. smoke, odour, fire)	Some	Yes	None	Not typically
Surface temperature	127 °C	95 °C	Max 50 °C	50-60 °C
LED connections	-	-	Parallel	Serial
RoHS Compliant	Yes	No	Yes	Yes
Hazardous materials	None	5 mg mercury/bulb	None	None
UV Radiation	Negligible	Yes	No	No
Weight	Low	Medium	Low	Medium
Watts consumption for 450 lm brightness	40W	10W	6.4W	7.5W
Lumens per Watt	11.3 Lm	45 Lm	71.7 Lm	60 Lm
Average retail price worldwide (40W)	$0.98	$5.49	$16.10	$16.10
Cost saving compared with incandescent	-	71.1%	82.5%	79.9%

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