

LEDs: EVOLUTION AND INNOVATION

LED lighting has developed hugely in the last few years, and the latest advances are helping to realise a flicker-free alternating current LED.

By Ben Papé



THE LIGHT-EMITTING diode (LED) has been with us since its release in 1962. Early examples of this semiconductor light source emitted low-intensity red light, but modern versions are available across the visible, infrared and ultraviolet wavelengths with high brightness.

They have typically been used as indicator lamps, but developments in the latter half of the technology's lifetime have enabled LEDs to be used in applications as diverse as aviation lighting, automotive lighting, advertising, general lighting and traffic signals.

New text, video displays and sensors have also hit the market, while the LED's high switching-rate is also useful in advanced communications technology. Infrared LEDs are used in the remote control units of many commercial products including TVs,

DVD players and other domestic appliances. However, it is in the illumination of space that the humble LED is arguably making the most progress.

The development of LED technology has resulted in steadily falling costs and ever increasing light outputs. Since the 1960, costs per lumen have fallen by a factor of 10 every decade and the amount of light generated per LED package has increased by a factor of 20. The exponential rise in light output, mirroring Moore's Law for electronic devices, is called Haitz's Law after Dr Roland Haitz.

Typical indicator LEDs are designed to operate with no more than 30-60mW of electric power. In 1999, Philips Lumileds introduced power LEDs capable of continuous use at 1W. These LEDs use much larger semiconductor dies to handle the larger power output

and are also mounted on metal slugs to facilitate heat removal from the die.

High luminous efficacy is an important attribute of LED light sources. In 2002, Lumileds made 5W LEDs with a luminous efficacy of 18-22lm/W (lumens per watt), which compared with standard incandescent at around 15lm/W and fluorescent at 80lm/W. Unfortunately, LED luminous efficiency falls sharply with increasing current – a real problem when it comes to trying to improve efficacy.

Luminous efficacy

In late 2003, a new type of blue LED was demonstrated by Cree of USA to provide 24lm/W at 20mA. This produced commercially packaged white light giving 65lm/W at 20mA, some four times more efficient than standard incandescent lamps. In 2006 Cree demonstrated a prototype



Maoye department store in Shenzhen, Guangdong, lit by ACRE LEDs

with a record white light luminous efficacy of 131lm/W and this was followed by a Nichia white LED with a luminous efficacy of 150lm/W. Cree then responded in 2011 with a commercially available white LED producing 100lm/W at full 10W power input and 160lm/W at 2W power input. Cree has also just reported achieving 200lm/W and Osram has more recently claimed 250lm/W in a laboratory prototype, so greater output efficiencies in white LEDs seem not too far away.

It should be noted that these luminous efficacies are for the LED chip alone and in a controlled low-temperature laboratory environment. Commercial lighting works at higher temperatures and with drive circuit losses which will cause lower efficiencies. The US DOE (Department of Energy) testing of commercial LED lamps designed to replace incandescent lamps or CFLs

(compact fluorescent lamps) showed that average efficacy was still around 46lm/W in 2009 with a range of 17lm/W to 79lm/W from lowest to highest.

Durability

There are reportedly over 10,000 LED manufacturers in China alone, with many others elsewhere. Their products are of varying quality, with many focusing on undercutting their competitors on cost. No wonder then that some pioneer customers are complaining of lower light-outputs and higher failure rates than were promised and expected. This plethora of cheap LED products from a mass of low-quality LED manufacturers has somewhat tarnished the reputation of the LED product. Even so, many of the LEDs made in the 1970s and 1980s are still in service today.

Temperature is the enemy of durability and LED performance is temperature-dependent. Most manufacturers' published ratings of LEDs are for an operating temperature of 25°C, for which a lifetime of 25,000 hours (seven years at 10hrs/day) can be expected. This compares with typical lifetimes of incandescent lamps at 1,200 hours and CFLs at 8,000 hours. The latest LEDs are now being quoted with lifetimes of 40,000 hours and with 100,000 hours achievable in the near future.

Actual lifespans are a subject of some dispute. There are two issues: first, the failure of the device; and, second, the decline in light output with time. Outright failure of the LED is rare, although poor thermal management can expose LEDs to unnecessary heat, leading to a dramatic reduction in lifespan. It is said that bad LEDs don't die they just fade away and sometimes rather quickly. Even good LEDs suffer some fall-off in light output over time but the lifespans quoted from reputable manufacturers guarantee that the luminous output will be at least 70 per cent of original value over 40,000 hours (11 years at 10hrs/day), which is significantly better than any competitive product in the market.

The luminaire design will also have an effect on the lifespan of the LED, along with the lux levels of the space to be lit. Not only is there a transmission loss but the fitting can also increase heating, contributing to a reduction in lifespan.

In terms of physical robustness, the LED can survive some jarring and on-site rough handling, in contrast to the glass-encased, relatively fragile, incandescent and fluorescent lamps.

Domestic acceptability

Most homeowners liked the incandescent lamp. They were used to the warm light which could be switched on/off immediately and could also be dimmed to create the desired ambience. When the government prohibited these much-loved and affordable incandescent lamps in varying shapes, sizes, colours and hues, the alternative was a CFL which was over-bright, did not light immediately, flickered, generally could not be dimmed, was relatively

HISTORY DEVELOPMENT OF THE LED

The discovery of electroluminescence and LED phenomena dates back to 1907 in the Marconi Labs in UK, followed by further research in Russia and USA. In 1961, American researchers at Texas Instruments found that the simple gallium arsenide (GaAs) diode emitted infrared radiation when electric current was applied across the p-n junction. This discovery formed the basis for the subsequent patent for the infrared LED.

The first practical visible-spectrum (red) LED was developed in 1962 at General Electric Co of USA, followed by a brighter red-orange. However, these devices were still too costly and insufficiently bright for commercial use. In 1968, Hewlett Packard produced the first brighter red LED (as a replacement for neon indicator lamps) for use initially in instrumentation such as laboratory and electronic test equipment, but later in consumer appliances such as TVs, radios, telephones, calculators and digital watches. At that point in the early 1970s, LEDs were discovered by the general public.

These first red LEDs were bright enough for use as indicators on instruments or appliances but insufficiently bright for space lighting. What was needed was a white light. With developing material technology, other colours steadily became available in ever improving output and reliability. However, it wasn't until 1995 when the first high-brightness blue LED was demonstrated by Shuji Nakamura of Nichia Corporation, augmented by further developments in Nagoya and Cardiff. The invention of these high-brightness high-efficiency blue LEDs led to the development of an LED which employed a yellow phosphor coating to produce a white light. This was the birth of white LEDs.

ugly and limited in design and cost much more. Hardly the basis for encouraging a wholesale changeover; no wonder many homeowners have been stockpiling incandescent lamps before they disappear completely from the marketplace.

The other option was extra-low-voltage halogen spotlights (another incandescent version to the traditional tungsten variety), which could be dimmed and were compact and unobtrusive but were better suited to a bathroom or kitchen environment. They were also rather costly and suffered from a relatively short lifespan. There were also inherent fire risks when recessed into ceilings.

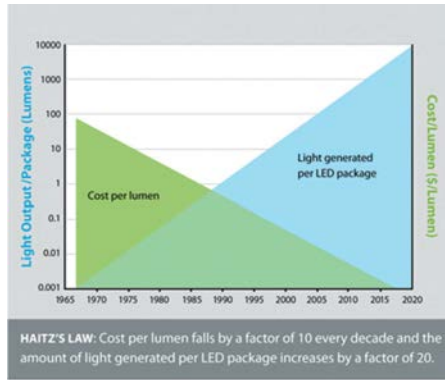
So the CFL can only be an intermediate and temporary replacement for the household incandescent lamp until a better option comes along. That selection is likely to be the LED with all its advantages of on/off immediacy, colour variability, dimmable intensity and compactness. The one remaining obstacle is affordability, and that should be overcome very shortly.

DC issues

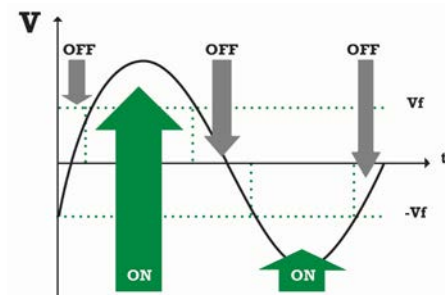
The basic LED is an inherently DC device – emitting light only when forward-biased. This DC characteristic has two major drawbacks. First, there is the requirement to incorporate electronic components within the luminaire to convert AC to DC, so that the LED can work off mains electricity. This need for rectification increases component/packaging costs and reduces efficiency. Second, these additional electronic components generate heat, which is difficult to dissipate in a compact lamp design required for internal and domestic applications. As a consequence, DC LED lamps are significantly de-rated (up to 50 per cent) and therefore need additional dies and components to achieve the desired luminous output.

All this makes compact domestic internal LED lamps relatively unaffordable. Any visitor to a local supermarket will see that 100W equivalent (1,200lm output) domestic LED lamps retail at £20 to £30, compared with CFLs at £5 to £15, and incandescent lamps at 50p to £1 (although increasingly unavailable). No homeowner will replace all the lights in their home at such a cost penalty until there is a significant price reduction.

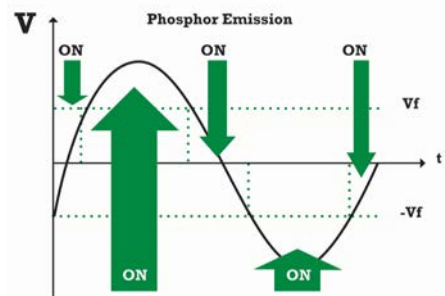
Costs of DC-LEDs will undoubtedly reduce in time as production quantities



Source: DOE SSL Multiyear Program Plan



AC LEDs will turn off (flicker) when the applied voltage falls below V_f



The ACRE LED uses photoluminescence to eliminate flicker



A greatly reduced component count is one major advantage of the ACRE LED (left)

DC LED street lighting, Binghe Road, Meizhou



increase. However, there seems to be an intrinsic cost disadvantage in a design which adds unnecessary components and thereby de-rates luminous output. So what is the alternative?

AC LEDs

A logical option would be to use AC power drivers rather than the DC used to date. This solution does not come without its own problems as the LED semiconductor will switch off when the drive voltage falls below the turn-on voltage for a period in each cycle, resulting in flicker.

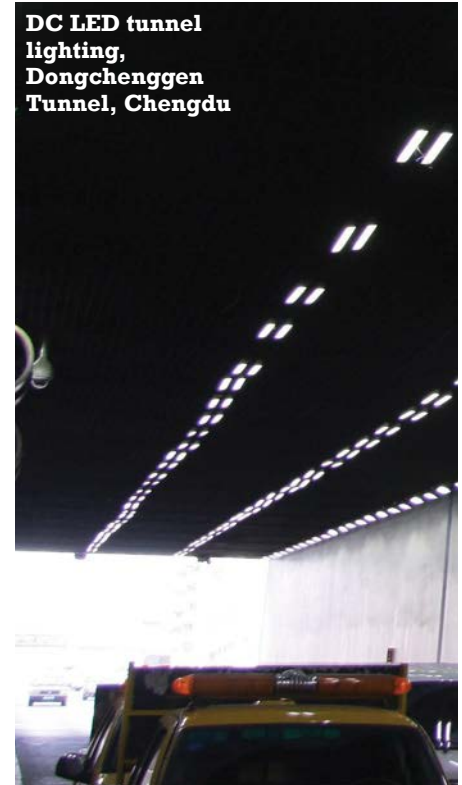
AC LED lamps have been introduced, which, cleverly, use LEDs to form the diode bridge and so use both half-cycles of the AC input power. The downside is that, without the output-smoothing capacitor, the drive voltage will still fall below the turn-on voltage for a period in each cycle, resulting in some flicker although less severe than in the unregulated AC input. So there is significant, but only partial, reduction in electronic components and in concomitant de-rating.

ACRE LEDs

White light is most widely produced by coating LEDs of one colour (mostly blue) with phosphors of different colours (mainly yellow) to form the emitted light (desired

Links

UK_China Eco-Cities Group:
www.ukchinagroup.org
The China Greentech Report
May 2012:
[www.china-greentech.com/
node/3242](http://www.china-greentech.com/node/3242)
Sunfor: www.sunfor.com.cn



DC LED tunnel lighting, Dongchenggen Tunnel, Chengdu

white), and the resultant LEDs are called phosphor-based LEDs. The latest innovation in LED technology uses rare earth phosphors to overcome the flicker in AC LEDs. The use of these rare earth phosphors makes the diode coating photoluminescent, i.e. it will absorb and then, almost immediately, emit photons (particles of light).

By careful selection of the rare earth phosphors, the time between absorption and emission in a ACRE (alternating current rare earth) LED can be tailored to ensure that the LED continues to emit light during the period when the AC drive voltage is below the turn-on voltage of the LED, producing a continuous light. There is still some residual flicker, but its amplitude and frequency are beyond the range discernible by humans in normal life.

The invention of the ACRE LED offers an AC-LED design without any unnecessary electronic components. Voltage regulators and resistors are eliminated at the circuit board level within the lamp modules, component costs are reduced, heat management issues are overcome and power efficiency is increased. The ACRE LED technology addresses the heat, component cost, reliability and power efficiency issues faced by LEDs in an innovative way that is now commercially

tested and proven to be robust for outdoor and indoor industrial and general lighting.

AC versus DC

For the present, the DC LED remains the dominant technology. DC LEDs already offer significant energy savings, and are the conventional choice for exterior lighting applications, such as street lights. The AC LED is still somewhat experimental, with various manufacturers offering complex circuitry to overcome the inherent flicker problem.

The ACRE-LED resolves the flicker issue in a simple, elegant way using the photo-luminescence of rare earth coatings to prolong the luminance of the lamp during the AC voltage cycle. Such products are now available initially for interior lighting applications, and it would appear that the ACRE-LED offers the best prospect to become the replacement of choice for incandescent and fluorescent lamps in the foreseeable future.

The DC-LED celebrated its 50th anniversary in October 2012, as narrated by its inventor Professor Nick Holonyak on www.bbc.co.uk/news/technology-19886534. The next half-century could well belong to the AC-LED and particularly the ACRE-LED. ❄

Ben Papé is a former chairman of the IET Built Environment Technology and Professional Network. Between 1997-2006 he was the China Business Adviser to UK Trade & Investment, where he focused on the introduction of energy-conserving and low-carbon development concepts. He subsequently helped form the UK-China Eco-Cities Group, working in partnership with China to develop 250 Eco-Cities in China. He was a co-author of the research paper 'Progressing Eco-City Policies into Mainstream Practice in China'.

One of the objectives of the Eco-Cities Group was to identify technologies for transfer that would bring low-carbon benefits to both China and the UK. The ACRE LED lamp was one of such potentially beneficial technologies identified by the group.

The ACRE LED has been developed by Sichuan Sunfor Light Ltd – finalists in the Built Environment and Power/Energy categories of the IET 2012 Innovation Awards.