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CAMBRIDGE DISPLAY TECHNOLOGY

A bright future

How chemicals drive the way we display information

Imagine a world where your mobile phone display is soft tailored into your shirt sleeve or where your office window blind is instantly transformed into a giant interactive display screen. Science fiction? Maybe not for long. David Fyfe and Terry Nicklin discuss how the possibilities of organic polymer light-emitting diodes (PLEDs) are becoming a reality.

The availability of immediate information is an essential part of our daily lives. In response, the global display industry is anticipating and fuelling the dreams of product designers and manufacturers for brighter, faster, cheaper, more versatile methods to present information, instructions and entertainment.

What are PLEDs?

The discovery and development of PLEDs began life in the Cavendish Laboratory of Cambridge University in 1989. Although the phenomenon of light emission by small molecule organic systems (SMOLEDs) was discovered a few years earlier, Jeremy Burroughes (working in the research group of Professor Richard Friend) discovered that LEDs could be made using conjugated polymers.

In particular, polyphenylene vinylene (PPV) was found to emit yellow-green light when sandwiched between a pair of electrodes. The initial device efficiencies were very low, but the team quickly realised the potential of this discovery for manufacturing displays that emitted their own light. These would offer significant advantages over the main display technology we use today, such as liquid-crystal display (or LCD) in which a separate light source has to be filtered in several stages to produce the image we see.

Benefits of PLEDs

Unlike existing technologies such as LCDs, PLEDs can be fabricated completely on one sheet of glass or plastic. Benefits include brighter, clearer displays with viewing angles approaching 180 degrees; a simpler construction resulting in cheaper, more robust display modules; and fast response times allowing full colour video pictures at low temperatures.

The potential for PLED technology is not limited to displays. Lighting applications are also feasible as increased brightness can be achieved. Even the reverse (photovoltaic) effect is viable where electric power is generated by light falling on a suitable polymer.

The optimism generated by this ‘new-to-the-world’ technology generated the first ever commercial ‘spin out’ from Cambridge University when Cambridge Display Technology (CDT) was formed in 1992. Since that time over US $100 million has been injected through private equity funding.

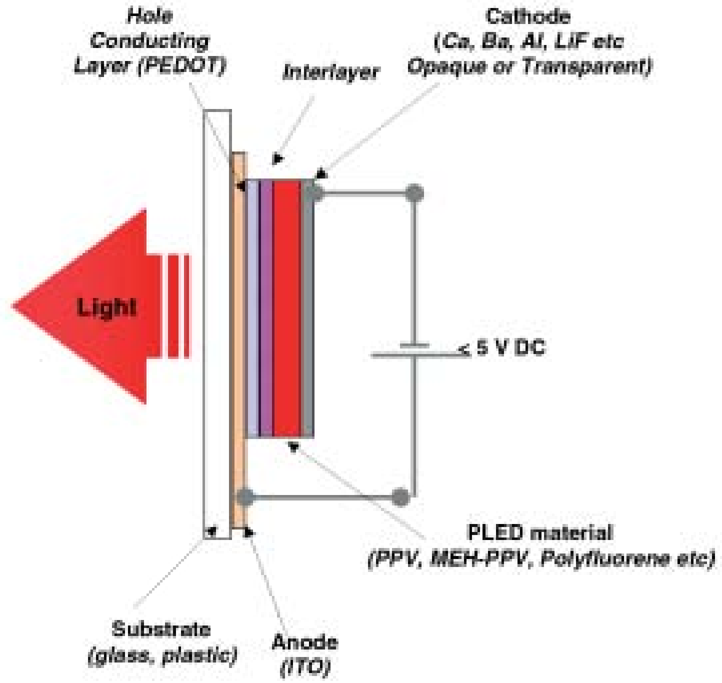

Figure 1 PLED device structure

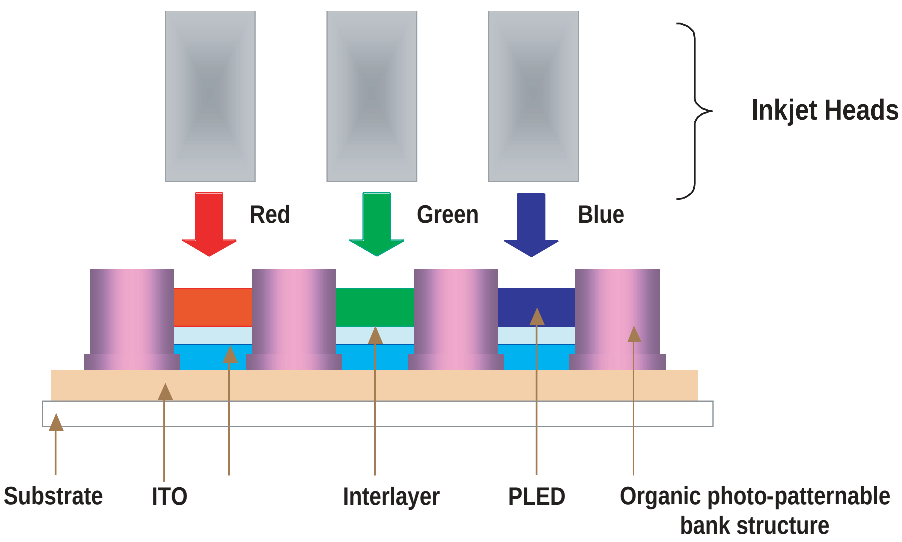

Figure 2 Schematic of the inkjet printing technique for PLED materials

Today, much of that early optimism remains, with perhaps a touch more realism and commercial reality for co-operation between all supply chain members to commit to something new; and not forgetting the dominance of the incumbent (LCD) technology, which in itself continues to be developed for new applications.

No one should doubt the potential for PLED displays to make an impact on the overall market. The total revenue arising from the application of PLED technology in the flat panel display industry is forecast to rise at an 88 per cent CAGR to US$3 billion by 2007.

Device architecture – how it works

One of the attractive features of PLED devices is their simple device architecture. A device is essentially comprised of an anode (usually indium tin oxide on a glass substrate); three thin polymer layers comprising a polymer hole conducting layer, an interlayer (described later) and the conjugated polymer emissive layer (PLED); and a cathode, which is normally a low work function metal such as calcium or barium capped with aluminium (see Figure 1).

The self-emitting nature of PLEDs means that, unlike LCDs, they do not require backlights, opening up the promise of low manufacturing costs in terms of both capital investment and materials. Cost reductions of 20–40 per cent are expected at maturity. This is perceived as the most important producer benefit of PLED displays and has resulted in over a hundred companies investing in research and development, and increasingly, in the manufacture of PLED displays.

The story does not stop there, as PLEDs have another advantage over even their close relatives the SMOLEDs: they are soluble in common organic solvents such as toluene and xylene. As a result, PLEDs can be inkjet printed. This offers the potential of even lower manufacturing costs as material utilisation is expected to be greater than 50 per cent. Conventional techniques, such as spin coating, can have a material wastage greater than 98 per cent. Inkjet printing has become key to the commercialisation of PLEDs and is discussed further below.

SMOLEDs, which cannot be solution-processed, may be thermally evaporated because they use organic materials with a sufficiently small molecular weight. This requires sophisticated and expensive vacuum vapour deposition techniques. In order to pattern the materials, the deposition also has to occur through metal masks. The masks limit the area over which high resolution displays may be manufactured due to difficulties in maintaining alignment between the mask and the substrate, thereby limiting the cost reductions attributable to large substrate size production.

Whilst glass substrates have been a necessity for conventional displays, PLEDs can be deposited on flexible plastic substrates to offer manufacturers greater versatility of display form, as well as potential for

Applications of PLED Technology

Figure 3 Philips Electric shaver with orange gauge display

The first PLED products were launched in 2002 by CDT licensees. Philips introduced an electric shaver with an orange battery gauge display and launched a secondary cellphone screen in early 2004. Delta Optoelectronics used a green 16 × 64 display in an MP3 player. Dupont launched a PLED display for the APED range of MP3 players marketed by Evolution Technologies. The display is marketed with the brand name Olight and it is 2.1 inches diagonally with a 128 × 64 resolution.

Osram Opto Semiconductors is also close to launching its first product incorporating PLED technology. It currently offers evaluation displays kits branded as Pictiva. The displays are available with a resolution of 94 × 54, 96 × 64 or 128 × 64.

Whilst the first PLED products are small (< 2 inches), low information content, single colour, passive matrix displays, Philips, Toshiba-Matsushita Display, DuPont, Microemissive Display Ltd., Casio, Samsung SDI and Seiko-Epson have demonstrated full colour active and passive matrix displays. Toshiba-Matsushita Display exhibited an inkjet printed, full colour, video capable, 17 inch, 1280 × 768 PLED prototype display at the SID trade show in 2002.

Dai Nippon Printing (DNP), another CDT licensee, recently showcased PLED displays incorporated into book covers and posters for dynamic advertising.

further production cost reductions if the displays are manufactured on a roll-to-roll line. Formable substrates allow the production of displays that conform to unique, non-planar shapes – imagine a ‘wrap round’ car instrument module perhaps; whilst truly flexible substrates open up a world of display and lighting opportunities we can only begin to imagine.

PLEDs have switching speeds in the order of nanoseconds – much faster than LCD displays, which take milliseconds – and so they are ideal for video display applications and television. They also offer more vibrant, high contrast images with real ‘zing’ and wide viewing angles. They can do all of this at a wide range of temperatures (minus 40°C to plus 70°C), making them attractive for automotive and military applications.

Inkjet printing

Although inkjet printing is well established in printing graphic images, only now are applications emerging in printing electronics materials.

Approximately a dozen companies have demonstrated the use of inkjet printing for PLED displays and this technique is now at the forefront of developments in digital electronic materials deposition. However, turning inkjet printing into a manufacturing process for PLED displays has required significant developments of the inkjet print head, the inks and the substrates (see Figure 2).

Creating a full colour, inkjet printed display requires the precise metering of volumes in the order of 10 picolitres. Red, green and blue polymer solutions are jetted into well defined areas with an angle of flight deviation of less than 5°. To ensure the displays have uniform emission the film thickness has to be very uniform. For some materials and display applications the film thickness uniformity may have to be better than ±2 per cent. A conventional inkjet head may have volume variations of up to ±20 per cent from the hundred or so nozzles that comprise the head and, in the worst case, a nozzle may be blocked. For graphic art this variation can be averaged out by multi-passing with the quality to the print dependent on the number of passes. Although multi-passing could be used for PLEDs the process would be unacceptably slow.

Recently, Spectra, the world’s largest supplier of industrial inkjet heads, has started to manufacture heads where the drive conditions for each nozzle can be adjusted individually – so called drive-per-nozzle (DPN). Litrex in the USA, a subsidiary of CDT, has developed software to allow DPN to be used in its printers. Volume variations across the head of ±2 per cent can be achieved using DPN. In addition to very good volume control, the head has been designed to give drops of ink with a very small angle-of-flight variation. A 200 dots per inch (dpi) display has colour pixels only 40 microns wide; the latest print heads have a deviation of less than ±5 microns when placed 0.5 mm from the substrate. In addition to the precision of the print head, the formulation of the ink is key to making effective and attractive display devices.

The formulation of a dry polymer material into an ink suitable for PLED displays requires that the inkjets reliably at high frequency and that on reaching the surface of the substrate, forms a wet film in the correct location and dries to a uniformly flat film. The film then has to perform as a useful electro-optical material. Recent progress in ink formulation and printer technology has allowed 400 mm panels to be colour printed in under a minute.

PLED developments

Since the discovery of PLEDs in 1989, significant effort has been directed into the development of red, green and blue materials that exhibit high efficiency and stability under normal operating

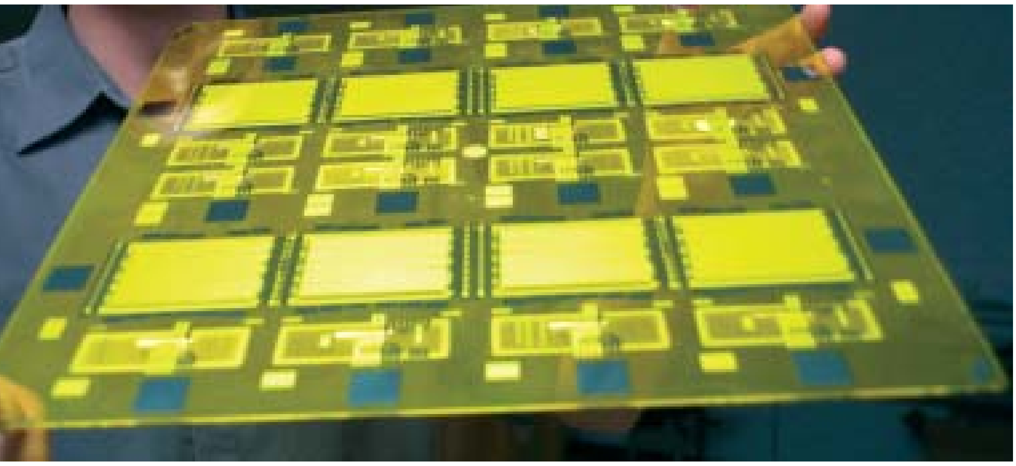

Figure 4 PLED test cells

conditions to enable integration into flat panel display applications.

For a wide range of consumer electronic products, the ‘useful lifetime’ (time taken for the device luminance to drop to half of its initial value) must exceed 10,000 hours. Full colour displays typically use groups of three adjacent pixels emitting red, green and blue. Although the green and red polymers currently available easily meet the stability specifications required for a range of consumer electronic products, a stable blue LEP has presented a greater challenge.

In the past several years, Dow Chemical, Sumitomo Chemical, CDT and Covion (a subsidiary of Britain’s Avecia) worked on developing new blue LEP materials and optimised device structures. CDT has now announced the achievement of an extrapolated lifetime of 30,000 hours from 100 cd/m^2 at room temperature.

A recent significant development is the discovery that inserting a thin polymer interlayer (about 10 nm thick) significantly improves both the device efficiency and the lifetime of PLEDs.

With the interlayer, the external quantum efficiency (EQE) increases by 170 per cent for a typical red-emitting PLED and by 58 per cent for green-emitting PLEDs. Blue PLEDs gain around 35 per cent higher EQE. These increases in efficiency are accompanied by a significant increase in the lifetime of the devices.

Equally important, this breakthrough has made it possible to develop a new range of blue PLED materials that require a simple barium/aluminium cathode structure – one which is also compatible with red and green.

One of the hurdles facing any new technology is the resistance from those using incumbent technologies. LCD remains dominant in the display market and continues to develop at an impressive rate despite being thirty-year-old technology. Nonetheless, all the current major LCD manufacturers are

Glossary (Primary source: http://www.cdtltd.co.uk)

DPN	Drive-per-nozzle	an inkjet printer head nozzle with drive conditions that can be adjusted individually
LCD	Liquid crystal display	an electrically activated material composed of a crystal with a polarising material on each surface. The crystal twists 90^0 when an electrical charge is applied to it, thus blocking light transmission.
LEP LEP-OLED PolyLED	Polymer emissive layer	alternative terms for PLED.
OLED	Organic light-emitting diode	devices that use organic materials to produce light through electrical stimulation. The term OLED includes PLED, SMOLED and dendrimer technologies.
PLEDs	Polymer light emitting diodes	the most advanced display technology, based on the use of organic polymers that emit light when stimulated electrically. Also described as polymer light emitting device or polymer light emitting display. PLEDs are a form of OLED. Developed after SMOLEDs, PLEDs have the major advantage of being solution processable, and can therefore be applied to substrates using techniques such as inkjet printing.
SMOLEDs	Small molecule organic light emitting diodes	the original technology developed to exploit the light emitting property of some organic chemicals. It has been the basis of most commercial products to date, but has the disadvantage of requiring complex and expensive production methods such as vacuum deposition.

Figure 5 Futuristic example of how LEP technology could evolve

looking closely at PLED technologies and investing significant sums developing them for future product ranges.

Despite the early stage of production, one extremely encouraging feature for faster commercialisation of PLEDs is that Philips have reported manufacturing yields higher than 85 per cent. Products can therefore be expected to meet market expectations in terms of both performance and cost. The rate of progress has been rapid, especially in the past two years, as the additional investment in resources has paid dividends.

Future

The future is bright for products incorporating PLED displays. Ultra-light, ultra-thin displays, with low power consumption and excellent readability allow product designers a much freer rein. The environmentally conscious will warm to the absence of toxic substances and lower overall material requirements of PLEDs, and it would not be an exaggeration to say that all current display applications could benefit from the introduction of PLED technology.

CDT sees PLED technology as being first applied to mobile communications, small and low information content instrumentation, and appliance displays. With the emergence of 3G telecommunications, high quality displays will be critical for handheld devices. PLEDs are ideal for the small display market as they offer vibrant, full-colour displays in a compact, lightweight and flexible form.

Within the next few years, PLEDs are expected to make significant inroads into markets currently dominated by the cathode ray tube and LCD display technologies, such as televisions and computer monitors. PLEDs are anticipated as the technology of choice for new products including virtual reality headsets; a wide range of thin, lightweight, full colour portable computing; communications and information management products; and conformable or flexible displays.

The exciting possibilities opened up by these new generation materials does not raise the question whether they will make it to the mainstream market, but just how big that market will be and in what time frame. ■

David Fyfe is a graduate in Natural Sciences from Cambridge University and has a PhD from London University. He has been CEO of Cambridge Display Technology, which holds fundamental IP rights for light emitting polymers, since July 2000. Previously he has held a number of similar positions in companies involved in rapid strategic or technology change. He is a member of the UK's Chemistry Leadership Council recently established to advise the UK Government on creating an innovative, strong British chemical industry.

Terry Nicklin is a Chemical Sciences graduate with an MBA from Warwick University. He has recently joined CDT as Marketing Director.

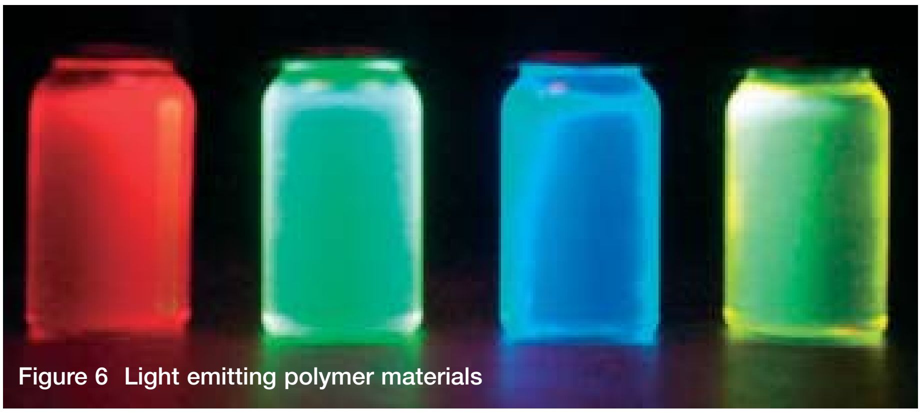

Figure 6 Light emitting polymer materials