Technology Sector Report

Technology Analysis of Nanotechnologies for Displays

April 2010

Table of Contents

1. Definition

Displays are a sub-sector of the ICT technology sector. This report covers electronic display devices which are designed to show a still or moving image. Nanotechnology has an important role to play in this sub-sector, by enabling novel approaches to display design such as Organic LEDs (OLED) or Field Emission Displays (FED).

Nanotechnology also impacts a number of the components that go into a display, whether transparent electrodes, thin film transistors, coatings and other materials.

2. Short description

Display technologies can be grouped into three broad technology areas; Organic LEDs, electronic paper and other devices intended to show still images, and Field Emission Displays.

Before looking at the technology development in this area, a word about existing approaches. Liquid Crystal Displays are used in a wide variety of applications, but the technology has limitations of a slow refresh rate (meaning that rapidly moving images can appear blurred) and a restricted viewing angle. LCD screens also require backlighting in all but the simplest applications, which increases power requirements.

The other important technology for large format displays such as televisions is Plasma Display Panel (PDP). These displays have higher power requirements, and lead to a risk that displaying the same image for a long period of time would lead to burn-in of the pixels. LCD and PDP have increasingly replaced Cathode Ray Tube (CRT) displays in most application areas.

These limitations spur the development of new approaches, as well as other drivers such as production cost and new end-user devices and form factors.

2.1. Organic LED (OLED)

OLEDs are constructed by sandwiching an emissive and conductive organic layer between a cathode and anode, and then mounting this on a substrate. OLEDs operate by applying an electrical current to the device, causing electrons to be added to the emissive layer and to be removed from the conductive layer. This causes electron holes to appear at boundary between the two layers; when electronics find these holes, they emit energy in the form of a photon. An active matrix OLED would use a Thin Film Transistor array to the control which pixels are operated at any given time.

OLEDs have a number of advantages relative to existing LCD devices, the foremost of which is that they do not require backlighting, thus reducing power requirements. This is particularly important when considering the use of OLEDs in electronic devices. Picture quality is also better then with existing devices.

Transparent Electrodes

The top cathode layer of an OLED is a transparent electrode. Transparent electrodes are also used in a number of other situations, with a more recent need being devices with touch-screen displays. The technology currently used is a thin film of Indium Tin Oxide (ITO) or Indium Zinc Oxide (IZO), which offers a combination of conductivity and transparency.

ITO films have several drawbacks. The process used to create them, typically vapour deposition, requires high temperatures which limit the choice of substrates that can be used. Indium itself, a by-product of Zinc mining, is becoming increasingly expensive. ITO films are also slightly opaque, impairing display quality or increasing power requirements.

A very active field of research is the use of nanomaterials as an ITO replacement. An approach which is gaining in popularity is to use a Carbon Nanotubes (CNTs) based thin film. A variety of deposition methods can be used, ranging from sputtering to spray coating and, eventually, roll to roll printing. This has the potential to reduce cost, both in terms of simplifying the production process and because the price of the material ingredient (CNTs) is dropping.

Research also addresses other nanomaterials which could take the place of ITO, such as nanostructured Al-doped zinc oxide.

Coatings

The materials used to create OLEDs are particularly sensitive to disruption by water or other substances, and therefore packaging of OLEDs is a key research challenge. One of the limitations is that existing packaging materials are either too brittle to be used in flexible screens, or require a high temperature production process that would destroy the device.

The current approach is to use alternating layers of organic and inorganic materials, which withstand some flexing and delay (but do not entirely inhibit) the ingress of foreign substances. Recent research has developed a method using nanoparticles to fill the pores in these organic and inorganic layers, which exponentially increases the integrity of the packaging.

2.2. Field Emission Displays

Field Emission Displays are the technological successor to cathode ray tube displays, which uses an electron gun to fire electrons at phosphors on a screen. The major disadvantage of this technology, and the reason why CRT has been largely superseded by LCD and Plasma screens, is that the technology increases the size, specifically the depth, of a screen. The electron gun needs to be set far enough back from the screen that the electron gun can strike every pixel.

More recently, FEDs that are configured with an electron emitter behind every pixel have been designed. As the name suggests, an electronic emitter is a material that when placed in an electrical field, emits electrons. These aim to take advantage of the field emission properties of carbon nanotubes or other nanoscale structures, but face challenges such as the use of lithography to produce precise gate holes, and the need to use emitters with tips to direct the electron beam.

CNTs appear to be one of the most promising materials for use in FEDs, as the high aspect ratio of CNTs produces very high field amplification. The production process for a CNT FED begins with synthesizing nanotubes and then attaching them to a substrate. There are a number of approaches to this production step, ranging from using adhesive substances to vapour deposition.

Typical approaches do not necessarily attempt to align the nanotubes, but instead rely on having a density of nanotubes such that a sufficient number are emitting electrons in the correct direction.

The device needs to be a vacuum in order that electrons are not distorted by air molecules, though this in turn requires a way of holding the two glass sheets apart (without placing spacers in the middle of a display). The device also becomes hotter in use, which could distort the alignment of emitters and phosphors. An approach to solving this is to use components with the same heat coefficient.

The field emission properties of nanowires and other carbon nanostructures, such as nanobuds have been investigated. Indeed, this latter material exhibits field emission properties superior to those of CNTs.

Nanoemissive Display

Nanoemissive Displays (NEDs) are Motorola's efforts to develop nanotube FEDs. The company grew CNTs onto a glass substrate, and produced a 5 inch display.

Surface-conduction Electron-emitting Display (SEDs)

Another technology closely related to FED is Surface-conduction Electron-emitting Display (SED), which uses a single emitter per area of display, rather than the multiple emitters that are used in FEDs.

Quantum Dot LEDs QD/LEDs

Another nanotechnology-based approach to the construction of displays is to use quantum dots as replacements for phosphor pixels. The colour emitted by a quantum dot can be controlled by changing its size (e.g. 6nm quantum dots are red). These quantum dots would then be arranged in alternating colour blocks which and would be excited by electrons. Organisations working on this technology include MIT and the company QD-Vision. More on this in report X.

Advantages of FEDs

FEDs have lower power requirements than other display technologies, as they require no backlighting, and because the field emission efficiency of CNTs is so high that the lower voltages are required to activate them.

The picture quality generated by FEDs is also likely to be much higher than LCD or Plasma, with brighter, stronger colours and representation of true black.

2.3. Material Innovation

Rather than changing the underlying technology, nanotechnology is being used to improve the performance of existing large-scale displays. The glass substrate is the major weight item in a PDP. Nanotechnology-based approaches to increase the strength of glass would enable the glass panels to be thinner and lighter.

2.4. Electronic Paper

Electrophoretic displays employ electrophoresis – the movement of particles when an electrical field is applied to them. Unidym and Samsung have recently demonstrated a CNT-based active matrix electrophoretic display (EPD) e-paper, in which the transparent electrode is a CNT thin film.

Work by Geoffrey Ozin at the University of Toronto has used photonic crystals which are electrically tunable. These have subsecond switching speed, so while they would not be suitable for video, they may be appropriate for still images and text.

Another display technology uses thermochromatic thin films, which change colour with a change in temperature. Small displays have been demonstrated by Weijia Win at Hong Kong University of Science and Technology. This is relatively simple to manufacture using soft lithography, but the technology is limited to a wire image, rather than individual pixels.

3. State of R&D

This research area is largely application oriented, as indicated by the large number of companies involved in this field.

Some of the work on the field emission properties of nanomaterials is essentially fundamental science, with field emission measurements being carried out as part of experimental work to synthesize nanomaterials.

OLEDs is a commercially available technology which is currently used for mobile devices and some displays. The largest commercially available OLED displays appear to be 11inchs, and only limited quantities of these; around 1000 per month, are sold. However, there is still a great deal of research activity being carried out on OLEDs, including for use as light sources, as well as displays.

There is also very active research work on using CNTs or other nanomaterials to produce TFTs and transparent electrodes. This research is driven by the clear limitations of existing solutions (ITO), and the ubiquity of such components and the large potential market size. Electronic Paper is another active field of research, with a major new development being announced in the week of writing.

FEDs are still at a development stage. Some manufacturers have released proof of concept devices, but these are not currently in production.

4. Additional demand for research

For nanotechnology-based displays to become widely used there are a number of highly demanding criteria that would need to be met. These can be separated by technology area:

4.1. FEDs

One of the reasons that FED research appears to have lessened over the last couple of years is the daunting prospect of competing on cost with technologies like LCD and PDP. These are both technologies that have benefited form massive investment in production efficiency in order to compete in a market with high price competition.

Other research directions for FEDs include controlling the emission properties of nanotubes. This is a function of the both the nanotubes themselves, finding ways to control chirality and the proportion of length to width, and ensuring that nanotubes are spaced so as to work most effectively

Deposition methods are another important area of research, with a wide range of methods used to attach nanotubes to a substrate. Investigation of low cost methods such a spray deposition would be very important.

There is also an engineering challenge of device assembly, insuring that the FET structure supports the integrity of the vacuum interior without using interior spacers which interfere with the image.

4.2. OLED

The most pressing area of research in OLED is in organic materials for the emissive and conductive layer. Current OLEDs suffers from a short lifetime of the films (it appears that blue organic film is particularly prone to failure).

There is also a manufacturing challenge of applying organic layers to the substrate – some substrates require high temperature processes which affect the organic layer. Low cost production methods are required for OLED to truly take off, and therefore research into roll to roll printing or inkjet printing are very important.

As has previously been described, research is also being carried out into packaging of OLED devices, and to develop TFTs which are compatible with flexible substrates.

5. Applications and perspectives

Applications for this technology include the following:

- Flat panel displays are perhaps the largest single market for displays, and is a highly competitive application area. There is a need to balance image quality, video performance and power consumption with cost considerations.

- Displays for portable devices
  The requirements for portable device screens are a combination of image quality and low power consumption.

- Foldable displays are likely to be used as devices in themselves, or as additions to portable devices. The requirements are likely to be high brightness and good image quality with high resilience – these devices are likely to be flexed and manipulated many times a day.

- Head-Up Displays (HUDs) have both military and civilian applications, and require the ability to display information on a surface which retains high transparency.

- Labelling and Packaging could employ OLED displays, and though this would not have severe display quality requirements, it would necessitate a low price per unit.

6. Current situation within the EU

Asia is the global leader in display research, reflecting the fact that many Japanese and Korea companies are market leaders in this area. However, Europe has a position of relative strength, with a number of key research groups and active companies.

7. Key Projects

7.1. EU Projects

A number of European Commission-funded projects have worked in display-related areas.

The ROLLED project, coordinated by Finland's VTT, is developing mass production of OLED elements using roll to roll technology. The project has already released the first demonstration OLED displays which are currently capable of displaying a single, static image. The project aims to produce OLEDs at a very low per unit cost.

The FlexiDis integrated project is developing flexible active matrix displays. The project has two technology approaches – OLED displays on a flexible substrate, and an electrophoretic display on a plastic substrate with organic transistor components.

The OLED100 group is coordinated by Philips Lighting and is developing OLED lighting solutions with high power efficiency, a long lifetime, large area and low cost. Another OLED lighting project is the 7-partner CombOLED, which is coordinated by Osram Opto Semiconductor.

8. References and Literature (selection)

8.1. Articles, Proceedings

Dijon, J. (2005), *Field Emission Display: a good application for carbon nano tubes*, Presented at Nanotube '05 conference, www.fy.chalmers.se/conferences/nt05/talks/NT05_JDijon.ppt

S Baluschev1, V Yakutkin, T Miteva, G Wegner, T Roberts, G Nelles, A Yasuda, S Chernov, S Aleshchenkov and A Cheprakov (2008), *A general approach for non-coherently excited annihilation up-conversion: transforming the solar-spectrum*, New J. Phys. 10

Fei Liu, Jifa Tian, Lihong Bao, Tianzhong Yang, Chenming Shen, Xinyu Lai, Ziming Xiao, Weiguo Xie, Saozi Deng, Jun Chen, Juncong She, Nisheng Xu, Hongjun Gao,, *Fabrication of Vertically Aligned Single-Crystalline Boron Nanowire Arrays and Investigation of Their Field-Emission Behavior,* Advanced Materials, Volume 20 Issue 13, Pages 2609 – 2615

Liyu Liu, Suili Peng, Weijia Wen, and Ping Sheng (2007), *Paperlike thermochromic display*, Applied Physics Letters May 21

André C. Arsenault, Daniel P. Puzzo, Ian Manners & Geoffrey A. Ozin (2007), *Photonic Crystals Full-colour Display*, Nature Photonics, Vol. 1 No. 8 August

S. H. Jo, J. Y. Lao, and Z. F. Ren, R. A. Farrer, T. Baldacchini, and J. T. Fourkas, (2003) *Field-emission studies on thin films of zinc oxide nanowires*, Appl. Phys. Lett. 83, 4821

8.2. News Items and other References

Unidym, Samsung Announce Further Agreement to Integrate Carbon Nanotubes into Display Devices, 12th August 2008, http://www.nanowerk.com/news/newsid=6716.php

NEDO: Nanotechnology Glass Project, http://www.nedo.go.jp/english/activities/1_sangyo/3/p01018e.html

FlexiDis project, https://share.philips.com/QuickPlace/flexidis/Main.nsf/h_Toc/8C01B07342CD2FE7C12571D90052F8A4/?OpenDocument

Report questions Sony's next-gen TV claims, May 8th 2008, http://news.cnet.com/8301-17938_105-9939636-1.html

Nanotech on Display, November 2004, http://www.technologyreview.com/computing/13880/?a=f

Nanotubes enter flat-panel display market, Nanotechweb.org http://nanotechweb.org/cws/article/tech/22244, Accessed 30th October 2008

COMBOLED Project, http://www.comboled-project.eu/

Nanocrystal Displays, May 2006, http://www.technologyreview.com/read_article.aspx?id=16830&ch=nanotech&a=f, Accessed 30th November

Nano-Proprietary and Universitaet Stuttgart advance carbon nanotubes, June 26 2008, http://www.idtechex.com/research/articles/nano_proprietary_and_universitaet_stuttgart_advance_carbon_nanotubes_00000976.asp

Super-vivid, super-efficient displays, Monday November 6th, http://www.technologyreview.com/computing/17733/page2/

CONTACT Project, http://www.contactprintelectronics.org/

Nanoengineered barrier invented to protect plastic electronics from water degradation, EurekAlert, 29/4/08, http://www.eurekalert.org/pub_releases/2008-04/afst-nbi042808.php, accessed 31/10/08