BRIEFING No.9

ICT

SEVENTH FRAMEWORK PROGRAMME

Nanotechnology for Flat Panel Displays

Display devices play a critical role in information sharing as they are used in our everyday life in different applications. Cathode ray tubes have dominated the display industry for over 70 years but the demand for better quality displays is driving technology development. Consumers call for suitably priced displays with improved features in thinness, brightness, contrast ratio, viewing angle, longevity, size, and reduced weight and power consumption. Nanotechnology, an emerging approach to upgrade flat displays, improves the performance and quality while taking environmental aspects into account. These advances also provide novel features such as foldability and flexibility.

Several competing display technologies have recently emerged to satisfy the needs of the display industry. Each of these emerging display technologies has their advantages and disadvantages and no single technology provides all the required properties.

Background

Since the mid 1990s Liquid Crystal Displays (LCDs) have revolutionized the flat screen and portable electronics market, offering a more energy efficient and safer disposal option to traditional cathode ray tubes (CRT). However, LCDs suffer some unwanted properties encouraging other display technologies with nanoscale solutions to emerge.

LCDs need illumination; for example a backlighting unit to operate. Carbon nanotubes (CNT) offer a promising mercury-free backlight replacement for conventionally used cold cathode fluorescent lamp (CCFL) that suffers from low contrast ratio, motion blur phenomenon and pollution problems on disposal. **CNT-backlit LCDs** additionally offer a fast response time, high luminance and improved video image quality.

The image in a **Field Emission Display (FED)** is produced by electrons provided from large-area electron sources that strike coloured phosphor. Advantages of FED include high contrast and low power consumption. On the downside, FED requires high vacuum levels to operate, which leads to difficult manufacturing. In recent years, CNTs have been extensively studied as electron emitters in FEDs. FED and its competitor Surface-conduction Electron-emitter Display (SED) differ mainly in the details of their emitter component. Both displays are aimed at the TV market, but further commercialisation has been suspended due to difficulties in raising funds for manufacturing.

Organic light-emitting diode (OLED) displays function with organic compounds that emit their own light in response to an electric current and therefore require no external backlighting. OLED displays surpass LCDs in terms of viewing angle, brightness, contrast, response time, and power efficiency. They are also suggested to be of lower cost in the future. However, OLED displays suffer from a relatively short lifespan, poor sunlight readability, and colour balance issues concerning blue OLEDs in particular. OLED displays are in use for TV and computer screens, and in portable devices; new market areas for OLEDs include foldable and flexible displays.

Quantum-Dot LED (QD-LED) displays consist of nanoscale crystals that are both photo- and electroactive. Their structure can be tuned over the entire visible wavelength scale; the colour is determined by the size of the quantum dot. Advantages include brightness, colour vibrancy, colour purity, improved lifetime, and low power consumption. They do, however, suffer from manufacturing difficulties with respect to blue quantum dots and a higher manufacturing cost compared to LCD and OLED displays.

In **Microelectromechanic system (MEMS) displays**, colours are produced through the interference of light. The displays have high contrast ratios, high speed, robustness, clear visibility in ambient light (unlike LCDs) and are designed to conform to industry standards. MEMS displays are being commercialised; an example is Mirasol, a registered trademark of Qualcomm.

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Impacts

According to experts, LCD is not optimal display technology as there is considerable energy wastage. Novel display technologies revolutionise the display industry by offering much improved energy-efficiency. These technologies are especially important for portable and mobile consumer electronic devices. The performance, image quality, and efficiency are superior compared to existing display technologies.

Unlike noble metals, the production of CNTs is not limited by natural resources and thus the fabrication cost related to CNT-based technologies may become more cost-efficient in future. Indium tin oxide (ITO) replacement with CNT (see **Box 1**) in different display types have huge impacts for consumers and environment as it offers flexibility, longer lifetime, a simpler manufacturing process, and environmental benignity.

Environment, Health & Safety aspects of Flat panel Displays have been considered by ObservatoryNANO WP5 partners. At the current time there is no available evidence on the exposure likelihood associated with this particular use for nanotechnologies. Nanomaterials included in displays devices are usually integrated into a host matrix and are unlikely to be released during normal use of these applications. At the current time there is no available evidence on the human or environmental exposure likelihood associated with this particular use for nanotechnologies. However, based on similar products/processes, it is considered unlikely i) that exposure will occur and/or ii) that potential exposure will be sufficient to incite concern.

Economic/Industry

Since the introduction of LCD displays, the display market has grown dramatically. The whole display value chain is now worth more than $700 billion annually. This is mostly due to novel features enabled by new flat panel display technologies that allow manufacturing of both very large area displays for home use and high quality miniature displays for mobile devices.

> **Box 1: Indium tin oxide replacement with CNT or graphene**
>
> Indium tin oxide (ITO) is the most widely used transparent oxide electrode film in different display technologies. It suffers from the high cost, a limited supply of indium, fragility, and lack of flexibility. To surpass these difficulties, **CNT** and **graphene** have both been widely studied as promising replacements for ITO due to their excellent electronic properties and suitability for displays. If successful, ITO replacements will remove the need for using scarce indium, and at the same time provide novel, and highly desirable features, such as flexibility.

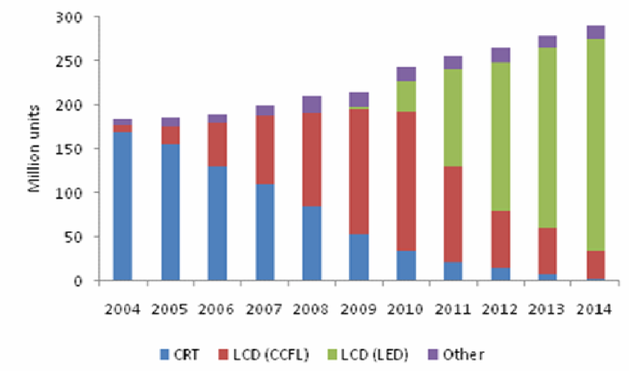

Figure 1: *Market shares of TV flat panel displays*[6]

The display industry value chain is undergoing a phase change as the market share of CRT TVs is decreasing and LED backlit LCD displays are quickly gaining ground over the traditional LCD technology (see ***Figure 1***).

Currently, the largest display market is in large area flat panel displays used for TVs and computer displays and accounted to 527 million units worth more than $70 billion in 2009 (DisplaySearch). An estimate from iSuppli suggests that the whole flat panel display market will be worth $120 billion in 2010, growing to over $140 billion in 2011. Leading manufacturers include Korean LG and Samsung that together have a 50% market share of the large area display market.

The German Flat Panel Display Forum, the largest industry association for displays in Europe, currently reports having about 70 member companies implying there are some hundreds of display technology related companies in Europe. The total number of jobs in the industry is unclear but the displays industry is an important sub-sector of the semiconductor industry that directly employs more than 100 000 people in Europe[7].

Novel display technologies will take time to have a large impact in the display value chain as they require completely new manufacturing methods from equipment and materials suppliers to panel manufacturers. LED based LCD, OLED, QD LED and different CNT applications are all incompatible in sense of manufacturing technologies and therefore their adoption greatly depends on how willing the display suppliers are to invest in new manufacturing capacity.

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Technology readiness levels

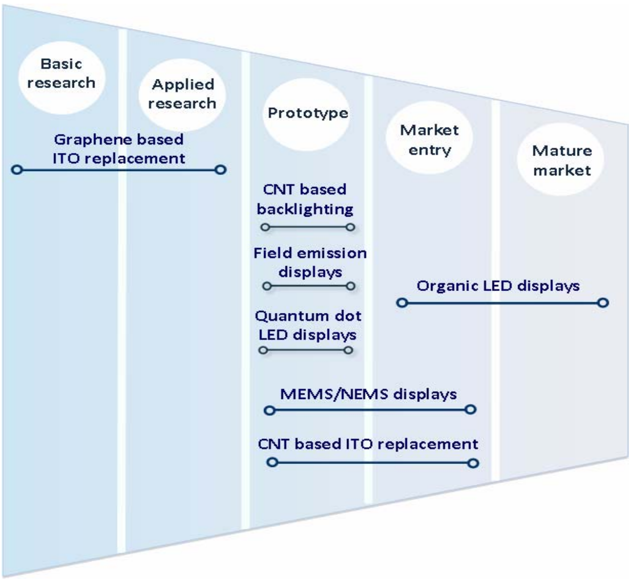

***Figure 2**: TRL for selected nano-enhanced display technologies*

The most predominant display technology in near future will still be LCD because of the mature value chain and constantly evolving technology offering higher picture quality; for example improvements provided by LED based backlighting. According to the expert feedback, QD-LEDs, OLEDs and all-plastic flexible displays driven by CNTs will enter the market in 3 to 7 years.

Commercial carbon based ITO replacements (e.g. carbon nanobuds) will emerge in five years. Their potential lies in improved transparency and less costly manufacturing process compared to traditional ITO[1] .

The most important players developing these technologies, according to expert feedback, are companies with huge amount of investments, industrial maturity, and supportive strategies from local governments. QD-Vision and Universal Display Corporation for QD-LED and OLED development, respectively, as well as Samsung, were mentioned. Universities also play a critical role because development of new technologies needs time and money: Massachusetts Institute of Technology and University of Florida were emphasized in the expert feedback.

Societal/Impact on European Citizen

The impact of novel display technologies on EU citizens can be considered from various aspects. Emerging information technologies, including nanotechnology enabled displays require new kind of expertise from companies, presenting an opportunity for Europe to gain ground in the sector.

The German Flat Panel Display Forum states that the assembly of displays has increased in Europe recently and today, for instance, most flat panel TVs are actually assembled in Europe even though the panels are mostly manufactured in Asia.[2] The introduction of novel display technologies including OLED, flexible displays, and nano enabled displays may induce job creation in the EU.

Novel display technologies have already created new market segments, for example in mobile devices, due to their high picture quality and relatively low power consumption. It is likely that displays will also gain more ground in application areas such as cars, very large area public displays, and electronic paper. Moreover, technological advancements enable more sustainable displays mainly through their lower power consumption and by replacing limited natural resources such as indium with artificial materials such as carbon nanotubes.

New materials (e.g. carbon nanotubes), display technologies (e.g. OLEDs) and manufacturing technologies (e.g. printed electronics) play an important role in the market entry of totally new segments such as flexible displays. However, the key technological driver in the segment is plastic electronics and nanotechnology mainly offers incremental improvements in the technology.

Challenges

The largest barriers inhibiting the use of the mentioned technologies in displays are manufacturing readiness, cost, and the dominance of existing LCD technology. Development of more low-cost methods for the manufacturing process of these low-power consuming display technologies is under development as current costs are relatively high compared to the predominant technologies. When the technological and economical variables are adjusted, these display types can be brought to mass-production lowering their total cost.

According to experts, scalability of production and the display size are hindering the use of OLEDs in displays. The manufacturing process cost of OLED TV is exceedingly high compared to LCD. Their manufacturing tools are similar; however, for example LCD uses more easily processed amorphous silicon thin film transistors while OLED utilises more challenging low-temperature polysilicon backplanes. This difference is caused by the size constraint of OLED technology; the difficulty is to scale OLEDs to larger sizes hindering their market entry to TV markets, which relies on constantly increasing display sizes. As the pixel circuitry is very similar to QD-LEDs, the challenge for both these technologies is to find suitable low-cost structure to enable production[3]. Due to the size constraint, the main target area of OLEDs and QD-LEDs are small and rigid displays as well as flexible new applications[4]. As the chemical nature of CNT is different compared to other forms of carbon, the possible toxicity of CNTs must be carefully studied. Also, the synthesis of CNTs is challenging to control, which makes it rather costly[5]. In addition, CNT processing for displays requires good dispersion and mats of CNTs results in material wastage. For this reason, more research is required in this area. According to expert feedback the transparency and resistance of CNT compared to ITO must be improved and technologies for large panel production should be developed. For CNT-based backlighting, the difficulty lies in vacuum packaging and disadvantages in thickness, weight, and power efficiency. The vacuum packaging is also a challenge for FEDs. For nanostructured FEDs and SEDs, the cost, lifetime and scalability of size are also barriers.

EU Competitive Position

By the introduction of novel technologies, EU has a good chance of re-entering the display industry. There is a high level of expertise present in European companies and research organisations including Cambridge University (UK) and Fraunhofer Institute (DE). However, the largest challenge lies in the industrial eco-system and completeness of value chains. Instead of trying to cover the whole value chain, EU should establish itself as a strong player in some aspects accompanied by strong 'mini value chains'[8]. However, experts still believe, that Europe's largest competitive edge is in the provision and development of the new technologies, and not in manufacturing. Europe should contribute to the development of next-generation displays in order to share the market benefits.

Experts believe that Europe's strengths in long-term science and technology research benefit especially the demand of inventions of new principles, new materials and technology breakthroughs for new displays. Also the mature industry (as LCDs) needs continuous technique evolvement and upgrades.

One example of new European display industry is Plastic Logic that builds on the expertise from Cambridge University's Cavendish laboratory and has recently announced to build a production plant in Russia while continuing production in their existing plant in Dresden.

Summary

- LCD is predicted to dominate the display technology for the next one or two decades.
- LCD should be replaced by other nano-enabled display technologies due to its moderate display performance, cost, high power consumption, and environmental impacts.
- OLEDs, CNT-backlit LCDs, FEDs/SEDs, MEMS/NEMS, QD-LED displays are promising candidates to surpass existing display technologies.
- The high cost and dominance of existing LCD technology are the largest barriers inhibiting market share growth of these technologies.
- QD-LED displays and all plastics flexible displays driven by CNTs are the most promising display technologies for the future.
- The flat panel display market is huge; an estimate from iSuppli suggests that the market will be worth $120 billion in 2010, growing to over $140 billion in 2011.
- Experts believe Europe should seriously contribute to the development of next-generation displays in order to ensure a share of the new markets.

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