Roll-to-roll printing of electronics

Contributed by Sara Ver-Bruggen

Up until now inkjet has been the favoured manufacturing technique of the burgeoning organic light-emitting diode (OLED) industry, but a growing number of companies and organisations are looking to roll-to-roll (R2R) manufacturing for making OLED displays.

The Holy Grail of the flexible display industry is to be able to manufacture the entire display, on a flexible substrate, at fast speeds, with minimal handling and at low cost. R2R manufacturing, traditionally a low-tech method for making disposable items such as packaging and newspapers, is seen as the solution to this challenge. Indeed many companies involved in the development of flexible electronic components from power cells to organic thin film transistors are using the principles of R2R manufacturing to build equipment that can manufacture their devices at high speeds for lower cost. Whilst continued interest and investment in inkjet are helping to prepare the technology to handle mass production of OLED and PLED displays, several initiatives are testing the capacity of R2R for manufacturing these displays.

According to Stanford Resource, the forecast for market size of organic light-emitting diode/polymer light-emitting diode (OLED/PLED) displays is expected to reach $US1.5 billion in 2007. So industrial production equipment is needed to meet this demand. Inkjet equipment and component suppliers such as Litrex, Xaar and Spectra are already supplying products designed for depositing materials for OLED displays. Inkjet lends itself to printing OLED and PLED materials because of its precision. Inkjet is computer-controlled so it doesn’t need to make contact with the substrate and so is a great tool for designing devices and use in the research and development stage. And inkjet is gradually matching the speeds of other industrial printing machinery, making it a viable technology for mass-producing these devices. However many companies that are anticipating future demand for displays on disposable, everyday items such as packaging or point-of-sale (PoS) signage, shelf labels and other advertising are looking to high-speed manufacturing based on R2R systems. In the US alone, annual spending on PoS advertising exceeds $17 billion and it’s still growing. How much of this market that low-cost printed displays could account for is anyone’s guess but make no mistake – it will be a large portion.

According to Jonathan Halls, Strategic Technology Planner at Cambridge Display Technology (CDT), a pioneer and key technology developer within the OLED/PLED display industry, unless these displays can be manufactured in a cost-effective way and in enough volume to satisfy the large demand of the display market, OLED and PLED displays will never get beyond niche applications. Halls says the manufacturing technique that shows the greatest potential for making full-colour high-resolution PLED and OLED displays is inkjet printing. The process allows a controlled number of drops of the polymer solution, or ink, to be dropped onto specific locations on the display substrate.

Seiko-Epson, Philips, Samsung, Toshiba and CDT, among others, have all demonstrated full-colour PLED and OLED prototype displays fabricated by inkjet printing in a range of sizes and resolutions. Yet though they are in various stages of development, none of these full-colour displays produced by inkjet are commercial yet. Despite the rapid improvements and advances in inkjet technology by companies such as Spectra, Xaar and Litrex, the main challenges are increased drop placement and volume accuracy for inkjet print heads. Another challenge is the move towards larger display sizes, already evident in the more established LCD industry. Last year Gen 7 plants, equipped to make displays roughly 2m2 in size, began to come online and it follows that PLED versions in these sizes must also be achievable. According to Halls, inkjet technology is already being developed by Litrex to produce these supersize displays whilst keeping “takt” time to a minimum. Takt time is the average time it takes for a production process to produce one unit. Ideally the optimum use of the inkjet equipment can occur through the development of multiple print heads that can apply red, green and blue LEP inks in as few passes of the print head over the substrate as possible.

There is also lots of focus on developing OLED displays for an altogether different application: packaging. The demands on OLED displays for this application are very different. A display on a throwaway item does not need to achieve the same resolution as a flat panel TV screen made from these same classes of organic materials. To cope with consumer demand, packaging has to be produced at breakneck speed with minimum breaks in production. DVD packages will probably be one of the first platforms where we will see low-cost digital displays in action, to provide clips and previews of the film inside.

In the US alone, 1.2 billion DVDs were sold last year. Then, as the OLED/PLED display technology matures and becomes cheaper to produce, it may eventually be used to promote something as ubiquitous and pervasive as bottles of Coca-Cola. On average 1.2 billion servings of the beverage are purchased from stores every day. Even if it is a fraction of this number that is given over to carry a low-cost digital promotional display, we are still looking at production runs of millions on a daily basis.

The majority of flexible package and label printing is done using R2R manufacturing where a continuous roll, or web, of flexible plastic or metal foil runs through the processing machinery and rollers are used to define its path and maintain proper tension and position. It is sometimes called web processing or reel-to-reel printing/manufacturing.

Unlike sheet-fed presses, R2R presses require minimal handling and when time is money, any time that is spent not printing impacts on potential earnings and profits. Like traditional semiconductor manufacturing, R2R builds devices layer by layer, but instead of a silicon wafer uses a roll of flexible plastic or metal substrate for the deposition of various layers. R2R also allows for the building of paths between devices, resulting in a complete device and not one that needs connectors to be attached and soldering. In the display field by replacing glass with flexible film, it is possible to convert the entire display manufacturing process from inefficient batch production to continuous-flow R2R processing, which occurs at very high speeds.

In recent years R2R systems are seen as the key to producing flexible electronic components, such as organic thin film transistors.

Already this year, stateside industry body the US Display Consortium (USDC) has awarded funds to two projects to help boost R2R manufacturing technology for display components and other electronic devices. The USDC recently awarded $10 million (e7.8 million) to Binghamton University in New York State to develop an R&D centre that will evaluate the potential R2R technology for the microelectronics industry.

USDC is providing the facility, the Center for Advanced Microelectronics Manufacturing (CAMM), with technology from flat-panel display lithography expert Azores Corporation and from CHA Industries, a maker of high-vacuum deposition systems for precision coating.

CAMM will be located on the premises of Endicott Interconnect Technologies. The company supplies organic semiconductor chip packaging, printed circuit boards and assembly services. The Center will make equipment available to university and industry researchers. Among the CAMM’S R2R research capabilities are flexible displays, foldable radars, electronics, integrated sensory patch systems and protective clothing. It will also be collaborating with the army-funded Flexible Display Center in Arizona.

The other project to win funding from the USDC is being run by Silicon Valley firm Vitex. It will use the $2 million (e1.5 million) grant to develop R2R manufacturing of its flexible plastic barrier film. The thin, clear substrate, Flexible Glass, offers the same barrier properties as a sheet of glass and so could be used to protect OLEDs and PLEDs in flexible displays from oxygen and water damage.

Flexible Glass is based on Barix, a barrier coating composed of alternating layers of polymer and ceramic thin films. It is made by depositing the coating directly onto a continuous roll of plastic base film, such as polyester. Display manufacturers can then use it as the substrate for their flexible OLED displays. Two years ago Korean display maker Samsung agreed to apply Barix to the packaging of its OLED displays.

However, USDC’s Chief Technical Officer Robert Pinnel says that R2R manufacturing for electronics is still in its infancy. He predicts only a gradual evolution over the next ten years into low-volume production of flexible displays. According to Pinnel, centres such as the CAMM will enable industry to evaluate new R2R manufacturing tools, establish a cost model and to find out who would want to use them.

Despite its support of inkjet as a key solution to producing full-colour PLED displays, CDT is also pursuing other techniques for making these displays. The company recently entered the second phase of its joint project with Japan’s Toppan Printing to explore R2R printing.

The first phase, completed at the end of 2004, focused on proving the feasibility of using a roll printing process to deposit LEP materials onto a glass substrate. This technique would enable device manufacture based on R2R processing with the associated low costs of production.

The second phase will focus on the performance of R2R printed displays and aims to produce displays that have lifetime efficiency and colour fidelity comparable to displays produced by inkjet. The two-year programme will result in full-colour demonstrators of medium resolution and 12in diagonals.

Terry Nicklin, Marketing Director at CDT, says that the project is focusing on displays that might eventually be used in portable DVD players and other hand-held devices. The displays will not be rollable – they will have some degree of flexibility. According to Nicklin the attractions of R2R manufacturing are its high throughput rates and relatively low production costs. Though inkjet is central to OLED and PLED display R&D and production, Nicklin says that CDT is keen to exploit other printing systems and techniques, hence its recent tie-up with Add-Vision Inc. (AVI). Silicon Valley-based AVI has a licence to intellectual property (IP) from CDT for specialised low-resolution display applications. This licence is required to make and sell P-OLED products.

AVI specialises in developing simple P-OLED displays and backlights using fast screen printing on plastic substrates. Breaking into the point-of- purchase (PoP) display market is its immediate target, although its technology will also be useful in electronic signs, packaging, gaming machines and toys. CDT has also taken a stake in AVI.

ROLLED project run by VTT

The ROLLED project, which started in August 2004, is developing R2R manufacturing systems for OLED and other flexible displays. The project is concerned with low-resolution displays that could animate posters, signage and packaging, as opposed to rollable displays being developed by Philips that can plug into mobile phones and other hand-held devices.

The project is funded under the Sixth EU Framework Programme. It ends on 31 July 2008. Consortium members are Technical Research Centre of Finland (VTT), Centre Suisse d’Electronique at de Microtechnique (CSEM), Leibniz-Institut für Neue Materialien Gem (INM), UPM-Kymmene, Hansaprint and Ciba Specialty Chemicals. The four-year project is split into work packages (WPs). WP1 deals with the fabrication of a complete OLED device on web using R2R manufacturing and will focus on developing patternable transparent conducting coating on polyethylene terephthalate (PET) foils based on indium tin oxide (ITO) nanoparticles and deposited by a continuous wet chemical R2R process. WP2 will focus on developing a patterning technology for OLED and/or PLED devices that will be applied to the R2R fabrication process on flexible substrates.

WP3 is concerned with developing front and back side encapsulations for OLEDs with low oxygen and water permeability, in other words ultra-high barrier materials.

WP4 will fabricate OLED demonstrators using R2R compatible manufacturing techniques. The demonstrators will consist of several predefined arbitrary size and shape pixels with one or more emission colours.The first demonstrator, which will produce single-colour images, must be produced by the end of 2007 and the final demonstrator, which will have several colours, must be produced by 31 July 2008 when ROLLED is scheduled to end.

According to Arto Maaninen, Group Manager at VTT, who is also involved in ROLLED, an R2R manufacturing system is being developed because it has the potential to produce millions of displays fairly cheaply on a daily basis. The R2R system will probably rely heavily on gravure printing techniques although alternative patterning methods are being investigated as well. Inkjet is not being investigated in this project. Though the displays can be passive or integrated with active matrix backplanes, this aspect is not a primary focus of the project.

In a much larger pan-European project, two types of flexible display are the focus. These are OLED and electrophoretic. FlexiDis, which began in the second half of 2004, defines a flexible display as “a technology for making flat panel displays on thin, flexible substrates”. The project, which draws on the resources and knowledge of Philips Research (UK and Netherlands), Nokia, NovaLED, BMW, IMEC and the University of Cambridge, among other partners, will focus on the direct preparation of active matrix circuitry on novel substrates, including metal and plastic. Active matrix displays have been chosen because they have the potential to impact the largest range of display products. Each pixel in an active matrix display is driven by a transistor, resulting in high-resolution displays, capable of achieving images as good as those we see on our TV screens.

Of the two demonstrator displays to be produced in the three-year project, this article is concerned with the OLED demonstrator, which will be a full-colour, ultra-thin video display. The display will be prepared directly onto bendable metal or plastic foils with inorganic thin-film driving transistors. Initially sheet by sheet handling will be used to make the displays, employing inkjet and photolithography techniques. However by mid-2007, FlexiDis will explore R2R production techniques.

Conclusion

The best system or technique for printing OLED displays depends on the application. For large-area, high-resolution OLED displays that are the future versions of the plasma and LCD screens that are gradually making their way into consumers’ homes today, inkjet is without doubt the technology for the job. But as the display industry moves towards bigger and better devices (Gen 7 screens measure 2m2) it becomes feasible to make these screens on lighter, more rugged, even flexible, substrates, using R2R systems.

But the future picture may not be so clear as R2R replacing inkjet. Both have their advantages and it would make sense to marry them within one system and couple the precision of inkjet with R2R’s ability to process at high speeds. This is already happening within another industry where inkjet is beginning to gain a foothold: packaging. MAN Roland signed an agreement with print head developer Xaar to integrate its web offset press technology, including the innovative DICOweb press, with inkjet systems. What is certain is that both R2R and inkjet are just beginning to fulfil their potential as dominant manufacturing systems for OLED displays.