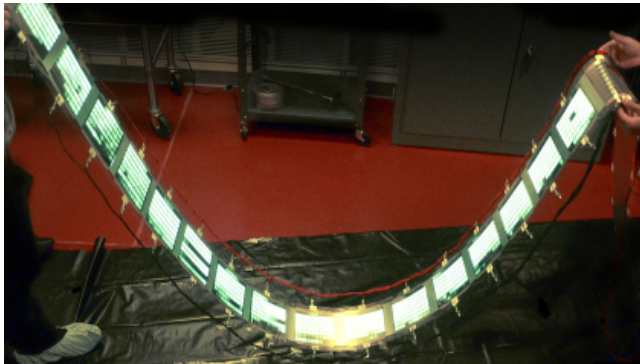


OLEDs and Flexible Products

By Sung Ordaz and Barry Young

OLEDs have the attribute of depositing and patterning at relatively low on a flexible substrate. OLEDs material by definition is transparent, flexible and very thin. A stack of organic light emitting material plus the injection and transport layers can be less than 100um. These characteristics have led to the development of many prototypes and much speculation about when flexible OLED displays and lighting would become commercially available. Members of the OLED Association, such as Samsung Mobile Display (SMD), Universal Display, Novaled, LG Display, Cambridge Display and Corning are leading the way. In lighting, GE is paving the way with the creation of an R&D lab that has produced a roll-to-roll pilot line for OLED lighting. Konica Minolta Holdings recently announced that it will invest 3,500 million Japanese yen on a small scale facility, for OLED lighting. Konica Minolta has been working with GE General Electric Research since 2007 and has developed OLED lighting product demos. Konica already produces high performance blue phosphorescent material, which has been a struggle for other material suppliers. Konica will start with a small pilot line in the 2nd quarter of 2011 and plans to build a new factory to produce high volume flexible OLED lighting in 2013.

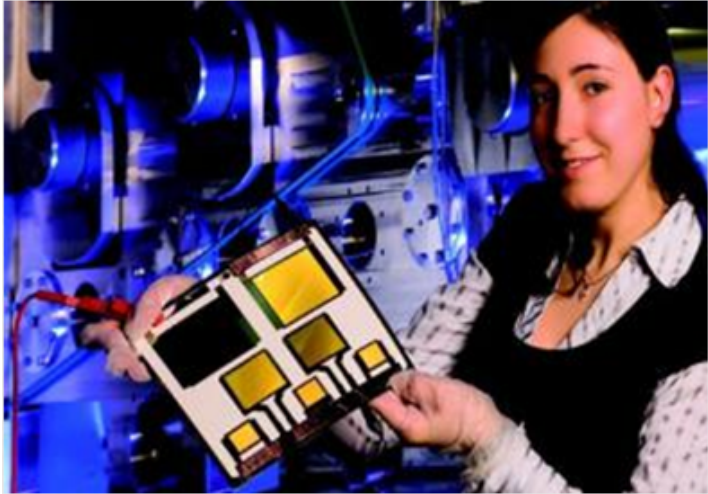
Figure 1: GE Flexible Lighting Prototype



Source: GE Lighting

In yet another example of the progress being made, the Fraunhofer Institute produced a flexible OLED in a roll-to-roll process and encapsulated the device as shown in the next Figure. The work was funded by the ROLLEX project under the auspices of the German government.

Figure 2: Fraunhofer Institute Lighting design



Source: Fraunhofer

In displays, Samsung has shown off a new 3D display design, which uses an OLED display, and is foldable, as shown in the photo below, the display is fitted in the corner of a room. Samsung has already developed a range of flexible OLED display prototypes but this new device shows what to expect from 3D TVs in the future. Recently, a Samsung Mobile Display' senior manager, Kim Seong Cheol, introduced a 0.2mm flexible AMOLED display that can be easily bent as shown below. The company is apparently capable of producing a 0.1mm thick flexible AMOLED display. With such technology in place, Kim Seong Cheol said that they would be able to "commercialize a rolled up OLED TV in 2013 or 2014". Samsung is also said to be developing a digital OLED newspaper that features a touchscreen that allows users to surf through content.

Figure 3: Samsung 3D Foldable TV



Source: SMD

Figure 4 Samsung's Rollable 3" AMOLED Panel



Source: SMD

To date, there have been two flexible display products that have come close to commercial viability:

- Polymer Vision produced a foldable 5" display with a printed a-Si active matrix and an Eink imager. The display was imbedded in a mobile device that was initially positioned as something between a mobile phone and an e-reader. The benefits of flexibility were demonstrated by putting a 5" display into a <3" package. The product never made it to market as it was swamped by the performance and features of the iPhone and the company faced financial difficulties.
- Plastic Logic produced an 8.5x11" flexible display with printed organic TFTs and an Eink imager. While the display was built on a flexible substrate the product was a rigid e-reader. The benefits of flexible displays for this product were its robustness and lightweight. Ironically, this product never made it to market either, done in by the iPad and the company has gone back to the drawing board.

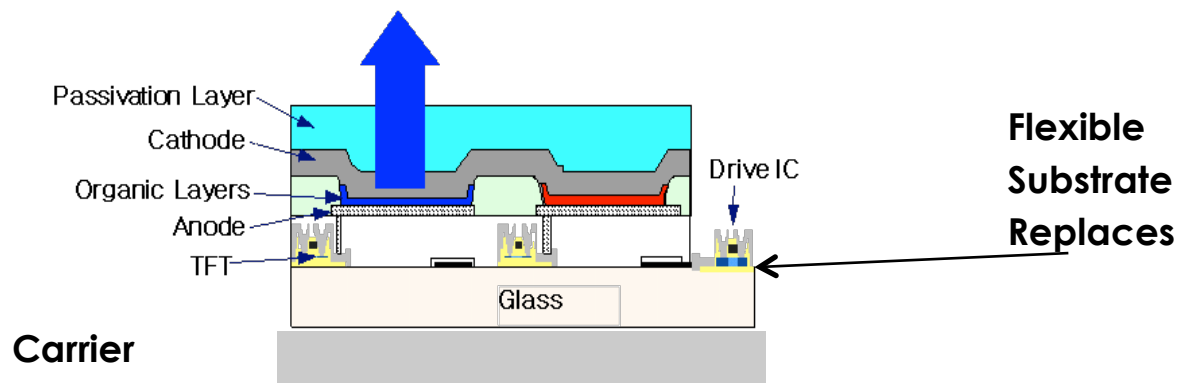
These companies took advantage of the performance requirements of electrophoretic material in that the mobility, uniformity and reliability of the active matrix were substantially less than AMOLEDs. Can AMOLEDs be used to make commercial flexible or Rollable displays in high volumes and what are the challenges?

The challenges for proper development of flexible AMOLEDs can be summarized:

- Flexible Anode and Cathode
- Thin Film Encapsulation
 - Process Time
 - Material Cost
 - Flexible Driver Circuits

- Flexible Substrates
 - Moisture
 - Delamination after Liftoff
 - Cost
 - Adhesive
- TFT Process Architecture
 - Low Temperature Process
 - High Reliability
 - Cost
- Flexible Anode and Cathode – ITO with some form of metallization has been working, although using ITO at low temperature increases the resistance and causes cracking. There are many new materials coming on the market to compete with ITO and some form of CNT's may be the best alternative. Samsung has recently signed a development agreement with Unidym, which specializes in CNTs for transparent conductors.
- The active matrix is the most critical element for flexible AMOLEDs because it has the most challenging requirements. Rigid AMOLEDs use LTPS because of the need for high current and therefore high mobility and high reliability. The 2nd TFT is a sub-pixel design must be on for more than 90% of the frame rate and therefore is susceptible to the generation of heat. A-Si TFTs degrade when faced with heat and the threshold temperature changes. The high temperature required for LTPS and the even higher temperature of Rapid Thermal Annealing (RTA) is difficult for glass and likely impossible for plastic substrates. The approach Samsung uses in their demos is to make the active matrix on glass and then apply a lift off process to place it on glass. Others, i.e. Universal Display use metal backplanes which are flexible but not rollable. The next figure shows a schematic of the AMOLED, made on a carrier allowing the device to be lifted off the glass and laced on the plastic substrate.

Figure 5: Samsung's Rollable 3" AMOLED Panel



The next table compares the active materials that could be used for the backplane, indicating that p-Si and oxide TFTs are the only viable candidates to date.

Table 1: Alternative Active Material for TFTs

	Poly · Si*	ε · Si	Oxide TFT	Organic
Mobility	◎	×	○	×
Reliability	◎	×	△	×
Flexibility	△	○	○	◎
Mass Productivity	◎	◎	○	×

Source: SMD

In terms of moisture barriers used for both the flexible substrate and thin film encapsulation there are several options:

- Barrier Coatings of multiple layers of organic and inorganic materials
- Barriers at the edges of the substrates
- ALD for the inorganic and MLD for the organic layers

The barrier coatings, which have received the most attention are expensive and relatively thick (>5um) while the ALD/MLD solutions are immature but less expensive thinner and have low TACTs. The edges approach eliminates the use of the desiccant, but does not provide a solution to the barrier issue.

The challenges for OLED lighting are more material performance and cost related but the process looks to be available. OLED material performance must grow from 3,000 lm/m² to over 10,000 lm/m² at lifetimes exceeding 30,000 hrs. and substrate costs with a patterned TCO must drop to <\$5 m² from the current \$20m². Another challenge is developing a low cost outcoupling layer that does for lighting what DBEF does for displays.

The challenges for flexible/rollable displays are process and material related and are being addressed by a number of AMOLED manufacturers. Plastic substrates have been qualified, the process is compatible with AMOLEDs on glass, new encapsulation and barriers are available and the initial results look good. It is likely that small flexible displays will be in the market in 2011 or 2012, but that TVs are much further off.

As to the availability of OLED lighting on flexible substrates, demonstration products will be in the market in 2011 but mass production is not likely until 2013.