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Technological Advances in Flexible Displays and Substrates

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Abstract: *Nowadays, whether it is about watching television, surfing the web or playing video games, screens are part of everyone's daily life and until now users have been limited to rigid formats of screen that can easily be broken. This physical inflexibility restricts designers and users who have to choose between various screen size function of the media they want to watch or share. The emergence of new flexible displays could be a real improvement and change the way people interact with electronic devices. This paper will discuss about how work these new screens, what special user experience will it bring and how it could change the market. The discussion will be focused on flexible displays and its implementation in mobile phone screens.*
Keywords: *Screen, flexible display, roll-able display, mobile phone, smartphone, organic light-emitting diode, OLED, FOLED, AMOLED, TOLED, e-paper.*

I. Introduction

1. Thin-Film Transistor Technologies for AMOLED Displays

Active-matrix organic light-emitting diode (AMOLED) displays use a current-driving method, while active-matrix liquid-crystal displays (AMLCDs) use a voltage-driving method. AMOLED displays consist of a thin-film transistor (TFT) backplane, organic light-emitting diodes (OLEDs), and an encapsulating fixure. The pixel circuit, which is a major part of the backplane, provides digital switching and a stable current supply. The role of the OLEDs is light emission from current flowing from the pixel circuit. Typically, the characteristics of OLEDs strongly depend on the current density through the driving TFT. Accordingly, the electrical performance and uniformity of the transistor circuits is important for AMOLED displays. In this section of the report, recent progress on various TFT technologies for large-area AMOLEDs is described.

II. Si-based TFT Technologies

Amorphous Si (a-Si) TFTs are used for the backplanes of conventional AMLCDs. However, a-Si TFTs have limitations for large high-resolution AMOLED displays due to their low field-effect mobility (< 1.0 cm2/Vs) and poor reliability in bias illumination stress (BIS) tests. Accordingly, polycrystalline Si (poly-Si) TFTs, which have high mobility (~100 cm2/Vs) and better reliability, are more suitable for AMOLED displays. Although diverse methods of producing low-temperature poly-Si (LTPS) for AMOLED displays have been studied, several problems remain, such as the electrical non-uniformity originating from the distribution of different grain sizes. This drawback prevents poly-Si from producing uniform electroluminescence (EL) and causes non-uniform brightness within the panel. To overcome this problem, a pixel compensation circuit is essential for AMOLED backplanes.

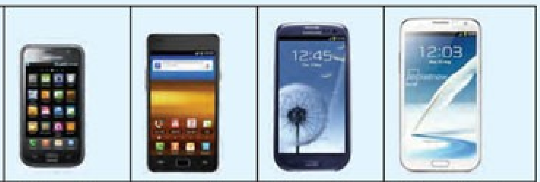
2.1. Oxide-based TFT Technologies

Recently, amorphous oxide semiconductors have been attracting attention as a key material for AMOLED backplanes because of their high transparency, high mobility, excellent uniformity, and high reliability,

Properties	a-Si	LTPS	Oxide
Field-effect mobility (cm^2/Vs)	~1	50 to 100	~100
Sub-threshold voltage swing (V/decade)	0.4~0.5	0.2~0.3	0.1~0.6
Leakage current (A)	$\sim 10^{-12}$	$\sim 10^{-12}$	$\sim 10^{-14}$
TFT reliability	Low	High	High
Process temperature (°C)	~300	~500	RT to 350

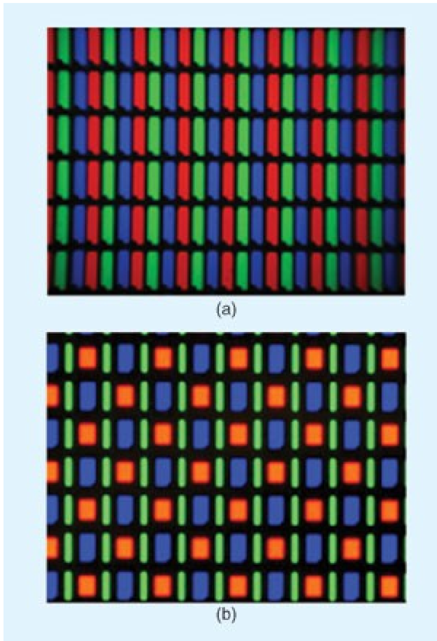
AMOLED Display Products

AMOLED displays provide an optimized realization of video due to their vivid colour, high contrast, wide-view angle, and fast motion-picture response time. They have superior portability and ultra-thin form factors due to the external elimination of the backlight unit (BLU). AMOLED displays for mobile phones have been developed with the current trend for high resolution and large displays due to the popularization of smart phones such as the “seeing cell phone”, which include multimedia content such as the Internet and video (Table 2). PenTile technology is being applied to mobile phone AMOLED panels to provide better moving pictures at limited pixel resolutions. Due to the limitations of the fine metal mask (FMM), discussed in section 2.3.1, a method to decrease the sub-pixel size and integrate only two sub-pixels (red and green/blue and green, compared to three sub-pixels of the “RGB-stripe”) has been applied (Fig. 7). Since the human eye is most sensitive to green, mapping the green on a one-to-one basis and forming one-third fewer red/blue sub-pixels than conventional RGB shows similar or better apparent resolution.



Model	Galaxy S	Galaxy S2	Galaxy S3	Galaxy Note2
Display size (inch)	4.0	4.3	4.8	5.5
Resolution	480×800	480×800	720×1280	720×1280
Pixel structure	Pentile	RGB-stripe	Pentile	RGB-stripe
PPI(the conversion of RGB)	155(233)	217	204(306)	267

Flexible OLEDs with enhanced portability have also been developed. These include displays that are bendable, lightweight, and unbreakable. In the 2013 Consumer Electronics Show (CES), Samsung demonstrated a flexible OLED known as “YOUM”.



AMOLEDs for TVs are being developed with the current trend to improve the appearance and three-dimensionality of displays. AMOLEDs are being used because they are thin and have fast motion-picture response times compared to LCDs. Figure 9 shows a paper-slim OLED TV and a curved OLED TV (released at the 2013 CES). The curved OLED TV has an optimized picture quality and delivers a comfortable viewing experience because the distance between the user and the TV screen is the same from almost any angle.

III. Device Architecture and Pixel Patterning Processes for Large-area AMOLEDs

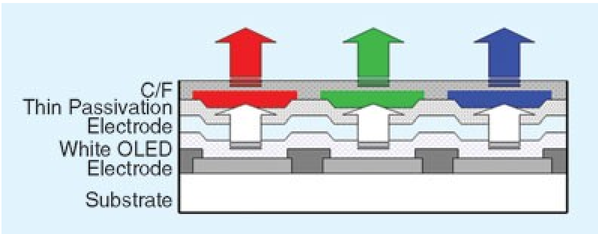
As the light-emitting efficiency and integrity of OLEDs improves [34–36], the use of a top-emitting OLED configuration is one approach to maximize the aperture ratio, which reduces the required luminance level and provides improved external emission efficiency and colour purity by micro-cavity effects [37–39]. Recent exhibitions of commercial AMOLED TV products suggest that the era of using AMOLEDs in ultimate large-size displays is near. However, a number of technical hurdles must still be overcome to achieve low-cost production with high yield and superior performance and resolution (e.g., more than 4K × 2K or 3840 × 2160 pixel resolution for TV). Therefore, more efficient OLED material/device structures as well as optimum colour patterning technologies will play an important role. In this part of the report, recent progress on modern OLED device architectures and patterning processes for large-area AMOLEDs is discussed.

3.1. Inverted OLED Devices

The distinct characteristics of inverted OLEDs compared with conventional OLEDs result from direct electron injection from the bottom n-type electrode, especially when it is integrated with an oxide transistor-based active-matrix display. This provides better pixel geometry for overall integration for AMOLEDs. However, making an inverted OLED is not a trivial upside-down task because it is not straightforward to obtain a good electron-injecting electrode in an inverted geometry

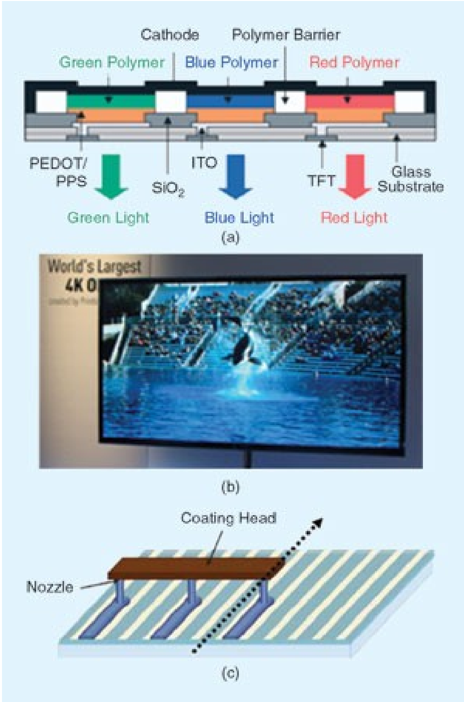
3.2. High-performance White OLEDs

The use of a white OLED with a colour filter is advantageous for large substrate processing and provides superior productivity due to the nature of pattern-less organic layer deposition. However, cost issues and restricted colour ranges compared with RGB OLEDs are major disadvantages of using colour filters. The colour saturation problem of a white/colour filter AMOLED can be improved by use of thicker colour filters, but the brightness of the white OLEDs must be increased correspondingly. Figure 10 shows a cross-sectional view of a top-emission white OLED with a colour filter on an EL (COEL) structure, which will possibly provide higher resolution, a better aperture ratio (higher luminance at the same driving condition), and a thin form factor compared with a colour filter on an array (COA) with bottom-emission white AMOLEDs.



3.3. Solution Printing Process

For the fabrication of large OLED panels, solution-processed printing gives high yields with low cycle times for evaporation or transfer processes. Inkjet printing is an attractive deposition technique for organic semiconductors [64] and provides non-contact, mask-less, and drop-on-demand printing with lower consumption of materials (See Fig. 15(a) for the basic scheme). Although there have been many reports about polymeric OLEDs obtained through inkjet printing, technical limitations, such as film/stripe instability, sensitivity to surface energy conditions, and the intrinsic low performance of soluble OLED material still exist. Optimized ink formulation and development of high-performance OLED ink materials are important issues. Recently, a 4K OLED 56-inch panel produced through an inkjet printing process was demonstrated by Panasonic (Fig. 15(b)), suggesting the cost-competitiveness of OLEDs over LCDs. Continuous nozzle printing developed by Du Pont is another candidate for high-speed RGB colour patterning processes [65]. In nozzle printing, solutions of RGB materials are continuously jetted through an array of nozzles moving at high speed, providing a process that is less sensitive to the surface energy of the solution and substrate layer.



IV. Conclusions

Recent progress in backplanes and colour patterning technologies for OLED displays has been reviewed. Because the market for OLED displays is fast growing and the major industrial players, such as Samsung Display, LG Display, Japan Display, AU Optics, BOE Technology Group, Panasonic, and ChimeiInnolux, have already demonstrated AMOLED panels, the competition between each technology used for the backplanes and color patterning is of increasing importance today.

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