

40.1: Invited Paper: AMOLED Technology for Mobile Displays

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Abstract

In this paper we describe current trends in mobile display technology, and analyze the requirements for those displays as well as the ways of their fulfillment. We also show how active matrix displays based on organic light emitting diode (OLED) technology should provide basis for the economic manufacture of displays for mobile applications.

1. Introduction

Display market can be divided into two major categories; one category is for medium to small mobile displays and the other is for medium to large fixed displays. Due to the nature of mobility, mobile displays have different priority in requirements compared with fixed displays such as monitors and TV's. It becomes very important to achieve low power consumption, low weight and small dimensions, high durability and outdoor readability, while maintaining high picture quality and low cost.

The flat panel industry has been dominated by liquid crystal displays (LCDs). LCD technology is advancing rapidly, but AMOLED has an apparent advantage over TFT LCD in mobile applications due to its superior inherent properties such as slim structure and low weight (since there is no need for backlight and color filter), no viewing angle dependence, wide operating temperature and fast response time. Many have also described the OLED structure as being simple and have suggested that it may be possible to build OLED fabrication facilities at a fraction of the cost of AM-LCD plants. However, a high-resolution display is far more complex than a light source, which poses some challenges to be solved in order to compete in the marketplace. The spatial separation of pixels and the time modulation of the emission indeed require the fabrication of very complicated structures in both mechanical and electronic aspects.

The current trend in mobile display application technology asks continuously for higher and higher resolution of displays, which makes widely utilized shadow mask patterning method not sufficient enough for their fabrication. The complexity of LTPS and sensitivity of OLED processes are the origin of low yield in AMOLED production.

This report concentrates on the strategies currently employed and being developed to manufacture highly efficient, low cost and high-resolution active matrix OLEDs for mobile applications.

2. Mobile Display Trends

The mobile market have been continuously expending in recent years through the introduction of new technologies. One direction of this development was the increase of a quality media content. And as such in 2005 DMB (Digital Multimedia Broadcasting) technology was introduced in South Korea. It is a digital transition system for sending data, radio and TV to mobile devices such as mobile phones. A competing standard called MedeaFLO should follow it within this year.

Simultaneously the high-speed wireless technologies are being developed. WiBro (Wireless Broadband) is a wireless broadband Internet technology that will offer an aggregate data throughput of 30 to 50 Mbit/s through its base stations that will allow the use of portable Internet within the range of 1-5 km when launched.

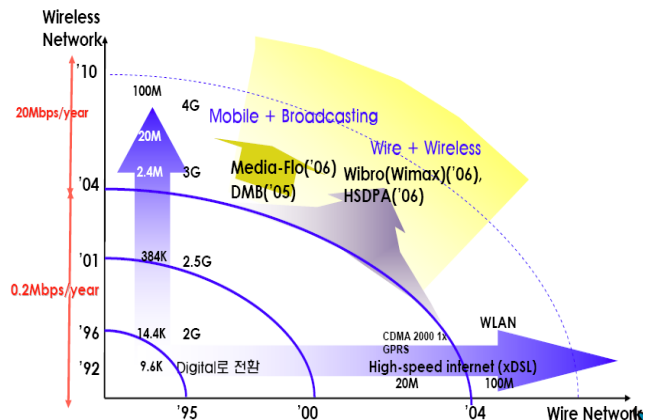


Figure 1. Wireless Networks vs. Wired Networks

Another protocol named HSDPA (High-Speed Downlink Packet Access) will allow a 5-time increase of data capacity comparing to existing WCDMA standard.

All this new technologies put a lot of stress on mobile communication devices, and first of all on device displays. The increased data and media content causes battery life shortening and demands increased resolution to cope with such an extent of information. In light of this the demand of low power consuming, high resolution and low weight display panels is difficult to overestimate.

3. Requirements for a Mobile Display

When we consider what kind of display is required to fulfill all the demands of rapidly developing mobile market, we can introduce a concept of the Ultimate Display (UD). For a display to become the UD, it has to have following characteristics:

- low power consumption;
- high outdoor readability;
- durability;
- thin and lightweight display;
- high picture quality;
- low production cost.

Given the harsh realities of competition in the flat-panel display market, the last advantage may become the critical one. The price of mobile devices has been steadily decreasing over the years

(approximately by 30% a year). The scaling-up and simplification of technological basis are mainly responsible for this trend.

4. Issues Critical for Display Manufacturing

Since the mobile display market has already been dominated by LCD displays, in order to effectively compete, OLED displays should show a lot of advantages over LCDs. In this respect the following issues become critical for OLED success:

- reduction of the production costs to the levels lower than those of LCDs;
- achieving a ultra low power consumption levels;
- creation of high resolution displays;
- design of ultra thin and ultra light displays.

These are all challenging tasks and their achievement requires the development of novel highly effective strategies.

4.1 Cost Reduction Strategies

As it has been mentioned above the low cost of the devices is becoming one of the most critical issues for OLED technology success. One of the big OLED advantages in this respect is that the material cost for its production is significantly lower than for LCD. The proportion of fabrication costs for AM-LCDs represented by the bill of materials has been rising steadily and is now over 50% for some manufacturers. The costs of the necessary OLED materials are substantially less. That derives from the fact that unlike the LCD it doesn't require color filters and backlight, it can use two times less polarizer and instead of using separate Driver IC it can utilize System on Panel (SOP).

Despite this the overall fabrication cost of OLED displays is still higher than that of AM-LCDs. Different strategies to reduce this cost are being developed.

4.1.1 Process Simplification

One of the strategies is to simplify a fabrication process for the OLED displays. Among other approaches the introduction of a common layer with a dual functionality to reduce the number of fabrication steps presents an obvious way of production simplification. The perfect example of this approach is a so called Blue Common Layer (BCL), that effectively maintains two functions being a blue emissive layer and at the same time hole blocking layer (HBL) for the device.

Blue common layer (BCL) : 2 step patterning

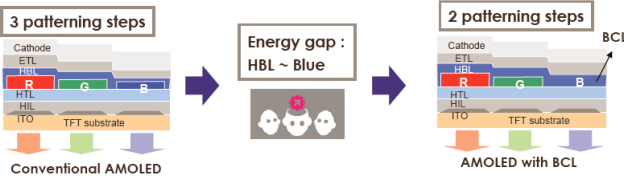


Figure 2. The reduction of patterning steps number by introduction of Blue Common Layer (BCL)

This technology requires a precise recombination zone control, but when used it improves the efficiency of the device and allows for one less patterning step. This structure has been verified by Samsung SDI through fabrication of different displays in the range from 2.2 inches to 17 inches using Shadow Mask and Laser Induced Thermal Imaging technologies [1].

Lately the manufacturers of OLED devices have turned to top emission structure, as it allows a utilization of Optical Micro-cavity effect. In a micro-cavity OLED, spontaneous emission occurs through irradiative exciton decay in a Fabry-Perot (FP) resonator, in which interference effects alter the internal angular power distribution. With an appropriate cavity design, some photons can be moved from the total internal reflection regime to the extraction cone, enhancing the coupling efficiency. Meanwhile, the spontaneous emission rate can be enhanced due to Purcell effect. Therefore, a micro-cavity OLED should emit more

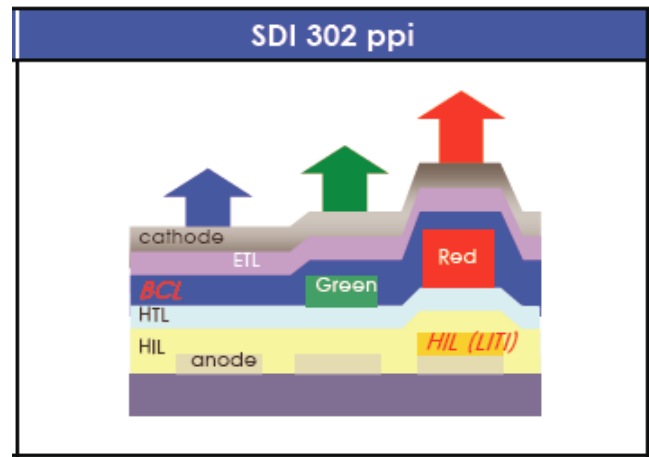


Figure 3. Cavity effect control in top emission design

light than a non-cavity one.

Despite its attractiveness the fabrication of a micro-cavity OLED is a very complicated process, usually requiring an ITO thickness control and color filters, but Samsung SDI was able to simplify it using LITI technology, and have successfully created a 302 ppi 2.6-inch AMOLED display utilizing this effect. The simplification of the process was achieved by LITI patterning of green and red emissive layers, while using BCL as blue emissive and hole blocking layer. The cavity control was realized through the control of the hole-injection layer.

Further simplification of AM-OLED manufacturing can derive from the LTPS process. Introduction of new non-laser crystallization methods should greatly decrease initial investment and maintenance costs.

4.1.2 System on Panel

It has become a new trend to integrate functional low temperature poly-Si TFT circuits on AM-OLED panels to make the module compact and practical [2][3][4]. However, it is difficult to integrate analog circuits in AM-OLEDs without sacrificing image quality because OLED electro-optical characteristics is much more sensitive to the applied signals than LCD. RGB individual gamma compensation is needed. Furthermore, we need to control display image brightness and gamma characteristics under different illumination condition in order to save power consumption and to achieve the best visibility of the image. For example, smaller gamma value is suitable under very high illumination because it can minimize the power consumption and maximize the visibility. On the other hand, larger gamma value is suitable under lower illumination to achieve impressive image with wide dynamic range.

Pixel Pitch : 66μm X 167μm
Pixel Number: 256 X 3 X 228
Delta Type Pixels

Level Shifters and Output Buffers

Scan and Emission Control Driver

DC-DC

Timing Controller

Voltage Generator

Shift Register(128stage)

6bit Sampling Latch

6bit Holding Latch

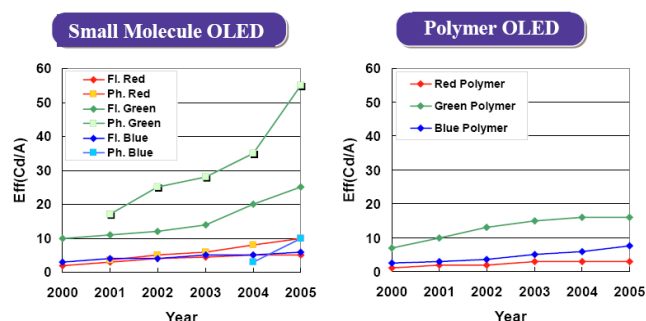
Level shifter

6bit D/A converter (128stage)

1:2 DeMUX

sampling latches in the first half horizontal period. After transferring the data from the sampling latches to the holding latches, the data driver writes the other 128 even line data to the sampling latches in the second half of the scanning period.

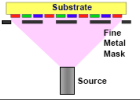
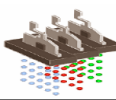
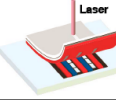
The reduction of power consumption is essential for the displays for mobile applications. There are different ways to achieve this goal: development of new electronic materials with higher efficiency, optimization of OLED structure, optical optimization.



In recent years we have witnessed a significant improvement in material performance, especially in case of phosphorescent emitting materials. The effect becomes even more pronounced when combining with structure optimization. For instance, for the bottom-emitting fluorescent OLED average power consumption at brightness of 100 cd/m² of white light would correspond to 0.669W, while for bottom-emitting phosphorescent OLED at the same conditions power consumption would be reduced to 0.456W, but the most efficient of them all would be a top-emitting phosphorescent OLED – 0.367W.

Another advantage of the top-emitting structure over bottom-emitting is improved color purity due to the cavity effect. The search for the optimal cathode materials is being actively pursued. Matching work functions to the lowest unoccupied molecular orbital (LUMO) levels of the organics, assuring chemical compatibility, while maintaining the transparency of the cathode 70% or better as required by top-emitting structures, has proven to be not an easy task.

With increasing content ready for the mobile devices it is of the great importance to supply those devices with high-resolution

Items	Evaporation (Shadow Mask)	Ink-Jet Printing	LITH
			
Materials	Small Molecule (SM)	Polymer (LEP)	LEP, SM, Hybrid
Position Accuracy	$\pm 15\mu\text{m}$	$\pm 10\mu\text{m}$	$\pm 3.5\mu\text{m}$
Resolution	~200ppi	~200ppi	~400ppi
Aperture Ratio (Top Emission)	30~50%	40~50%	40~60%
Remarks	- M/P: Gen. 2 - Develop: Gen. 4 - Glass handle limit - Mask align limit	- Size: >2m - Simple/Economic process - Material development issue	- Size: >4G - Dry Patterning /multi-stacking - Donor film required

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displays. Until recently the pixel resolution limitation of AMOLED display was caused by conventional evaporation method, which uses fine metal masks (FMM). Even though FMM is the most common method for patterning primary colors for full color AMOLED, it is almost impossible to realize a resolution higher than 230ppi in a mass production environment. Lately some alternative methods, such as ink-jet printing and laser induced thermal imaging (LITI) have become available.

Utilizing LITI technology has allowed us to fabricate the world highest resolution 302-ppi displays. At present LITI technology is the only method capable of achieving resolution higher than 300 pixels per inch.

In order to achieve such a high resolution in AM-OLED display a very compact LTPS substrate design is required. In our 302-ppi displays we realized a compensation circuit with a 2 μ m design rule, lower resistance metallization to minimize signal delay and top emitting structure with flatness for LITI process. The scan driver has been integrated into the LTPS TFT array on the glass substrate and data driver has been directly connected to external driver IC. We have applied our own 6 TFTs and 1 capacitor structure to compensate the V_{th} variation of the driving TFT in the pixel. This pixel circuit is well suited to realize a high image quality and high resolution for AMOLED panel.



Figure 7. New top-emitting full-color OLED display on a stainless steel foil substrate

4.4 Thin and Light

In a race to reduce thickness and weight of displays glass substrate is starting to play a limiting role. In a search for a robust and lightweight display a lot of work recently has been focused on Si TFT on such flexible substrates as stainless steel foil and plastic. Since the melting point of stainless steel foil is similar to that of silicon, it is possible to exploit high temperature process to crystallize the amorphous silicon precursor. Additional advantage of the stainless steel foil substrate is its low water and oxygen permeability – comparable to those of the glass.

In addition to being thin and lightweight flexible substrates can allow fabrication of curved, bendable and even rollable displays for future applications as an integral part of a car, a book (or newspaper), or human clothes.

Recently Samsung SDI has been successful in development of the novel top-emitting full-color OLED display on a stainless steel foil substrate utilizing LTPS technology and thin-film encapsulation technique. It resulted in the ultra lightweight display with overall thickness less than 0.2 mm.

5. Conclusions

With introduction of mobile broadcasting and Internet services we expect another explosive growth in the display market. This market requires low cost, high-resolution, light and slim display with low power consumption. If the rate of progress that has been made in past five years in respect of material properties can be continued, AMOLED can become an ultimate display. Ultra low cost, ultra low power and ultra thin and light displays can be realized with AMOLED technology innovations.

6. References

- [1] M.H. Kim, B.D. Chin, M.C. Suh, N.C. Yang, M.W. Song, J.H. Lee, T.M. Kang, S.T. Lee, H.D. Kim, K.S. Park, J.S. Oh, H.K. Chung, "Novel structure of a full-color AMOLED using a blue common layer (BCL)"
- [2] A.Y. Matsueda, R. Kakkad, Y.S. Park, H.H. Yoon, W.P. Lee, J.B. Koo, H.K. Chung, "2.5-in. AMOLED with integrated 6-bit gamma compensated digital data driver", SID Symposium Digest, Vol. 35. pp. 1116-1119
- [3] K. Abe, M. Shimoda, H. Haga, H. Asada, H. Hayama, K. Iguchi, D. Iga, Y. Iketsu, H. Imura, S. Miyano, "A poly-Si TFT 6-bit current data driver for active matrix organic light emitting diode displays", Eurodisplay 2002, pp. 279-282
- [4] J.C. Tseng, W.T. Sun, C.C. Chen, S.H. Yeh, H.Y. Hung, S. Hopf, C.F. Sung, C.H. Li, S.H. Li, T.H. Hsiao, Y.F. Wang, J.J. Lih, C.S. Yang, "A new 6-bit digital type current-driven AMOLED display employing an improving gray scale structure", SID Symposium Digest, Vol. 35. pp. 1512-1515
- [5] N. Komiya, C.Y. Oh, K.M. Eom, J.T. Jeong, H.K. Chung, O.K. Kwon, "Comparison of V_{th} compensation ability among voltage programming circuits for AM-OLED panels", IDW03, pp. 275 - 278