OLED Full-Color Panels for Mobile Application

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1. Introduction

These days, portable devices for personal use have been developed with remarkable speed. Especially, the performance and functions of mobile phones have been dramatically improved and the requirements for display panels for such mobile phones are continuing to increase accordingly. For example, camera-equipped mobile phones have been very popular and as a result, high-resolution full-color displays are required for both a main and outer display in one folding type mobile phone. In fact, a 2.1 to 2.4-inch QVGA full-color display panel is used as a main display and a 1.2-inch color display panel is used as an outer display in a recent folding type mobile phone. With such a trend, many companies are keenly trying to adopt organic light-emitting diode (OLED) display panels, area-color and/or full-color, for their mobile phones' outer display. In addition, development of active-matrix high-resolution full-color OLED displays has been actively conducted in order to adopt such active-matrix OLED displays for mobile phones' main display and such products are about to be brought into the market.

Another important trend for digital portable devices for personal use is the commencement of digital broadcasting for portable devices. Requirements for the performance of display devices for portable devices will become severer along with distribution of high quality digital moving images and as a result, the importance will also be placed on excellent performance in displaying moving images. In addition to good visibility, low power consumption will be the critical requirements so that TV reception with such portable devices will be widespread.

It has been almost six years since the OLED display was first introduced into the market as a car audio display. Considering above-mentioned OLED's various advantages, portable devices are the most probable application for OLED. This paper covers the analysis of the actual state of OLED displays used in mobile phones and the hurdles for OLED to overcome in order for OLED to play important roles as displays in portable devices.

2. Application of OLED Displays to Mobile Phones

It was Motorola, Inc. that commercially adopted OLED displays for mobile phones for the first time. The first mobile phone with an OLED display was introduced into the market in the United States in 2000 (see Fig. 1 and Table 1). The first commercialized OLED display was a simple area-color display with a green dot-matrix part and green, blue and orange icons. The product was highly reputed because it had extremely low power consumption and excellent

visibility compared to conventional LED displays. In 2001, NEC Corporation adopted passive-matrix full-color OLED display panel as a main display of FOMA type mobile phone and introduced the product into the market in Japan. The product drew public attention because it was the first product in which a color OLED display panel was used. In 2002, area-color OLED displays were becoming popular as outer displays of folding type mobile phones in Japan and Korea and finally passive-matrix full-color OLED displays were commercialized as outer displays last year. Several companies in Japan, Korea and Taiwan are currently supplying passive-matrix full-color OLED displays as outer displays of folding type mobile phones. Fig. 2 shows the example of the full-color OLED display used as an outer display for folding type mobile phones. Such development of practical applications for OLED displays gives us the impression that it is becoming established.

Meanwhile, preparation for commercialization of active-matrix OLED displays has been acceleratingly made. The active-matrix OLED display has already been adopted into one of digital cameras and such active-matrix OLED displays are expected to be used in mobile phones in the near future. Fig. 3 shows a prototype of a 2.4-inch active-matrix QVGA OLED displays as an example of active-matrix OLED display panel for mobile phone, which was collaboratively developed by Semiconductor Energy Laboratory, Ltd., ELDis, Inc. and Tohoku Pioneer Corporation. Many excellent features of OLED displays exist in this prototype and its future development is highly expected.

3. Requirements for displays for portable devices and features of OLED

The following are the required performance and functions for displays for portable devices:

1) Small, thin, light weight and robust
2) Good visibility in most ambient-light conditions
3) Low power consumption
4) Wide range of operating temperatures

In addition, displays for camera-equipped mobile phones are required to have the following features:

5) High resolution
6) Excellent color saturation

Needless to say, there are severe requirements to reduce production costs.

It is extremely difficult for any display panels to satisfy all the requirements above. Among all the display devices, TFT-LCD is the most popular display device at the moment despite the fact that it still has some problems to be solved. However, OLED display devices have the potential to fully satisfy the requirements above if its originally expected features and performance are realized. In addition to a fast response time, which is a significant feature to display moving images, OLED devices have various advantages, such as their thin and lightweight body, good visibility due to high luminance and contrast, and wide range of operating temperatures which

includes very low temperatures, some of which LCD cannot achieve. As mentioned above, the performance and functions of portable devices for personal use are getting more improved and as a result, the requirements for displays for such portable devices are getting severer. Especially, considering that more and more moving images will be received with portable devices along with the popularization of digital broadcasting, such a trend would be the best opportunity for OLED displays to be competitive. Therefore, digital broadcasting receivable portable devices are considered to be the killer application which can make the most of OLED displays' various advantages satisfactorily.

4. Future development and hurdles to be overcome

Unfortunately, many people have the impression that OLED displays have been developed more slowly than they had expected. One of the reasons is that almost all the technological aspects of OLED displays contain undeveloped elements and require leading-edge research and development. On the other hand, the technology of LCD displays has been progressing year after year and the fact that it is hard for OLED to catch up with LCD technology gives us the impression that OLED displays are developing slowly.

It is necessary to improve the basic performance of OLED displays such as luminous efficiency and operating lifetime in order to compete with LCD technology, which has a long history and has been making certain successes. It is also important to maximize the advantages of OLED displays, which are difficult for LCD displays to achieve. For example, low power consumption, a thin shape and flexibility are the key features to make the most of OLED displays in portable devices and realization of those features enables it to enhance the overall value of OLED displays. OLED displays, which are self-emissive, can substantially secure higher energy efficiency compared to LCD displays, which require backlights. However, there are still many challenges for OLED technology to be solved in order to largely reduce power consumption; for example, highly efficient luminescent materials such as phosphorescent materials, highly efficient device structures such as the top emission, and driving methods which enable it to reduce non-effective power, etc. should be developed. At the same time, in order to make displays as thin as possible, expectation is placed on the development of optimum encapsulation methods which can make the most of the single substrate structure. Ultimately, the flexible OLED displays, which are lightweight, thin and break resistant, are expected to be achieved. If such flexible OLED displays are realized, it is possible for OLED displays to precede other display panels for portable devices. Fig. 4 shows the example of a prototype of a flexible OLED display developed by Pioneer Corporation.

In addition to the above-mentioned improvement of basic performance, huge cost reduction lead by the establishment of mass production processes is indispensable in order for OLED displays to become a great success. Though the development challenges lie in a wide range of technology from very basic technology to industrial technology for mass production, the OLED display is still very attractive as a display panel for portable devices and it is worth devoting much effort to the research and development of OLED displays.

Fig. 1. Mobile phone with an area-color OLED display

Table 1. Specifications for an area-color OLED display

Structure	Passive matrix
Number of dots & icons	96 x 32 dots and two rows of icons
Dot size	0.34 x 0.32 (mm)
Gap size between dots	0.05 x 0.04 (mm)
Size of display area	30.8 x 16.1 (mm)
Duty	1/32
Colors	Green, Blue, Red
Luminance	100 cd/m^2
Lifetime (time for luminance to decrease in half)	5,000 hours
Contrast	More than 100:1 (500Lux)
Power consumption	0.08 W (When 30% of dots are on)
Power voltage	3 to 6 V

Fig. 2. Passive-matrix full-color OLED display used as an outer display of a mobile phone

Fig. 3. Prototype of 2.4-inch active-matrix QVGA full-color OLED display developed by SEL, ELDis and Tohoku Pioneer

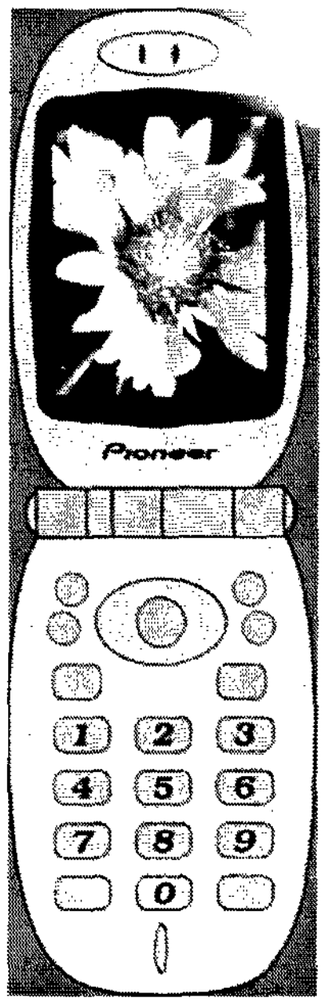

Fig. 4. Prototype of film-based OLED display Panel developed by Pioneer Corporate R&D Laboratories