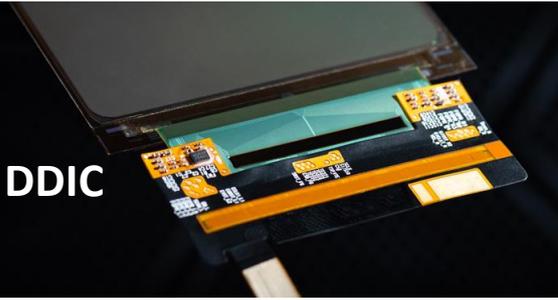


The Future of Display: Mobile OLED Display and OLED DDIC



1. What is OLED?

Types of flat panel display

Flat Panel Display technology is divided into two types: non-emissive display, which requires an external light source and emissive display, which produces its own light organically. Thin-film transistor (TFT) LCD is a non-emissive and older display technology which requires an external light source to work, while OLED (Organic Light Emitting Diode) is considered an emissive display technology that does not require a backlight because each pixel provides its own illumination. OLED (Organic Light Emitting Diode) has three self-emitting phosphorescent organic compounds: Red, Green and Blue. An OLED display utilizes the emissive phenomenon of three-color phosphorescent organic compounds combined with electrons emitted from positive anode and negative cathode particles.

Evolution of OLED

OLED technology is divided into two types by driver scheme: PM (Passive-Matrix) OLED and AM (Active-Matrix) OLED. PM OLED technology drives the display to emit light by placing voltages into both vertical and horizontal axes of light-emitting diodes arrayed on the screen, and producing light at the point of their intersection.

PM OLED, is a simple structure with low manufacturing cost, but it is challenging to produce a high-quality larger-format screen because the larger screen size causes an exponential increase in power consumption. This causes a sharp decline in battery life and device availability. As a result, PM OLED technology typically can be found in small form-factor displays such as wearable devices like smartwatches and wrist-based fitness trackers.

To compensate for the drawbacks of PM OLED, AM OLED has emerged as an ideal technology for smartphone screens and other medium and larger displays, including in automotive and consumer applications such as large-screen televisions. AM OLED is ideal for these applications because each light-emitting diode has a built-in thin-film transistor to individually control each and every light-emitting diode, which eliminates the need for a display backlight. This, in turn, reduces power consumption and enables thinner form factor devices.

Advantages of OLED

OLED has various advantages thanks to its self-emissive characteristics. In terms of Color Gamut, LCD cannot produce its own light, which is why it requires a backlight at the back of the display, and the light emitted from the backlight passes through liquid crystal and a color filter, resulting in loss of color purity. However, AM OLED has a self-emissive characteristic which is not susceptible to color purity loss and can achieve near “true to life” color representation. AM-OLED also consumes less power than LCD. Since each pixel itself emits light individually to display color, no pixel is turned on to represent black color. By contrast, the backlight is “always on” in an LCD screen, which does not allow for a “true black” color.

Without a backlight, light leakage does not occur, which enables a high contrast ratio, making OLED more suitable for mobile device readability in outdoor settings. And with no backlight required, OLED smartphones can be made thinner than LCD-based models, which allow for thinner and possibly lighter mobile products, and enables more space for a larger battery, which means more usage between recharging. Furthermore, OLED is more comfortable on the eyes as its self-emissive mechanism is known to emit less hazardous blue light in the wavelength of 415nm – 455nm (up to 50 percent less than LCD), which can damage the retina.

OLED has another advantage with regard to fast response time. A fast response time enables “blur free” motion, with means clearer boundaries of moving objects without video screen delay. This feature meets the fast response time requirement of HMD (Head Mounted Displays) used in VR/AR, as well as various display applications including TV, tablet, smartphone and an expected wide range of other applications.

These other applications will take advantage of the flexible display capabilities of OLED, which can be folded, rolled or bent. This will play a key role in the growing and highly-competitive mobile market, where differentiated design is critical for success. Since flexible AM OLED display successfully entered mass production in 2013, products in various form factors have been launched and the design freedom OLED enables will enable even more innovation in the years to come.

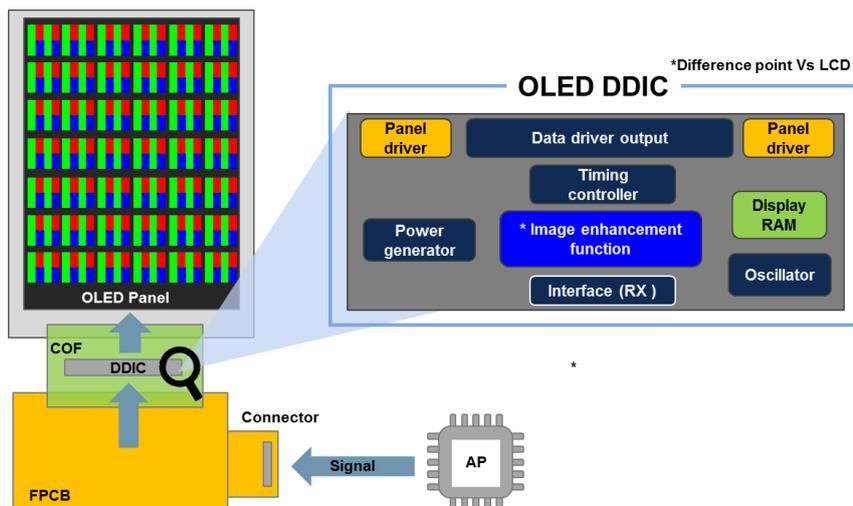
Applications with OLED

Since the first AM OLED product entered mass production in 2007, OLED display has been used in various applications. Initially, OLED had a high unit price, and due to some technical constraint, it was adopted only for an external display of mobile devices such as MP3 players. However, after the launch of AM OLED ‘Galaxy S’ in 2010 by Samsung, the smartphone market has grown rapidly and AM OLED displays grew in earnest with a corresponding increase in demand for OLED DDICs. In addition, the first AM OLED tablet PC, ‘Galaxy Tab 7’, arrived in 2012. This was an indication that OLED display had moved beyond smartphones and was becoming widely adopted for various mobile IT devices. Around the same time, portable gaming devices and digital cameras also started to adopt AM OLED displays, broadening the range of applications for OLED DDIC. OLED displays now are appearing in other consumer electronics products such as HMD for VR/AR applications.

2. What is OLED DDIC?

How it works

An OLED display driver integrated circuit (DDIC) is a component that controls the OLED display panel. It enables thinner and bezel-less displays that are thinner, flexible and foldable and provide a wide range of colors that are true to the content being displayed. OLED also requires less power consumption than LCD, which causes less drain on the battery and extends the useful operating time of a device.

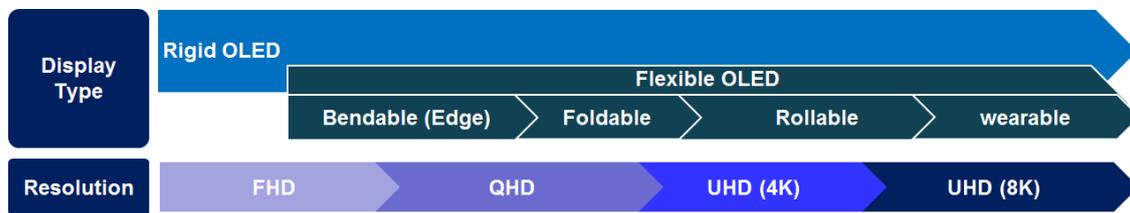


A DDIC sends a driving signal and data to the display panel in a form of electrical signals, to represent image signals such as letters and images. The DDIC resides in the OLED panel and differs between PM OLED and AM OLED panels. In the case of PM OLED, by supplying a current into both vertical and horizontal panel ends, the pixels will emit light where the currents cross, so by controlling the amount of crossing current, the intensity of

light is controlled. As for AM OLED, each pixel in the panel has a TFT (Thin Film Transistor) and data storage capacitor, which is capable of controlling the brightness of each pixel in “degrees of gray,” which leads to lower power consumption and a longer panel lifetime. When the DDIC for AM OLED commands each pixel, the pixel is controlled through TFT. Display pixels consist of subpixels that represent RGB (Red, Green, Blue) -- the three primary colors of light. Those sub-pixels are directly controlled by TFT. By sending signals to the TFT, the DDIC controls the pixels directly. Therefore, the TFT functions as a switch that drives RGB sub-pixels and the DDIC functions as a type of “traffic light” to instruct the switch how to operate.

Technological trend of OLED DDIC

Since Samsung Display first mass produced the world’s first curved display for smartphones in 2013, flexible display technology has advanced rapidly. Overall, display type is classified two ways: rigid or flexible. Rigid type uses a rigid glass substrate while flexible type employs a flexible substrate based on a plastic material called polyimide, which offers the advantage of achieving a variety of form factors including bendable, foldable and rollable displays. Currently, the high-end smartphone market has bendable displays which curve around the edge of the smartphone and foldable or rollable smartphones are widely believed to be on the drawing board.



To realize such flexible displays, DDIC (Display Driver IC) COF (Chip On Film) technology is a requirement. COG (Chip On Glass) is a method of directly mounting DDIC onto a rigid glass substrate, whereas COF (Chip On Film) or COP (Chip On Plastic) is where the DDIC is directly bonded onto the flexible substrate to ensure realization of flexible displays. COF is a packaging method of attaching DDIC to a panel substrate by bonding thin film, whereas COP is a method of mounting DDIC directly onto the substrate. The Flexible qualities of COF make it possible to design the side area of a screen, often called the bezel, to be narrower compared with COG. This results in a relatively larger screen-to-body ratio. In other words, it can create a “bezel-less” or full screen display. Also, in order to realize flexible display where the screen itself bends, the DDIC package must also be flexible. This is why it is imperative to apply COF technology. By contrast, LCD drivers can not physically fold or bend.



With the increasing resolution of smartphone displays, the number of channels of DDIC connected to an individual pixel of the display panel grows. In order to support high resolution, a ‘double-sided 2 Metal COF’ package technology is required. In general, resolution of FHD (Full High Definition) and below can be achieved by 1-Layer Metal COF, but resolution of QHD (Quad High Definition) and above, with a 30 percent increase in number of channels, requires 2 Metal COF. Therefore, for these high-resolution formats, it is essential that “fine-circuit” technology be embedded on both sides of the COF Package for DDIC.

While smartphone display resolution has continued to improve, it, ironically, leads to more power consumption, thus reducing battery life of mobile devices such as smartphones. Also, when it comes to the RAM (Random Access Memory) for storing display pattern data within a DDIC, a higher resolution increases the amount of display pattern data stored in the RAM. Therefore, RAM capacity must increase, which increases the chip size of the DDIC.

In semiconductor processes, numbers like 55nm, 40nm and 28nm refer to the minimum device length between the source and the drain in a transistor, which functions as a switch in a digital circuit. The smaller the number, the better the switch performs. In other words, the switch operates at a faster speed and consumes less power, making it easier to design products of high performance and lower power consumption. Finer-scale processes mean higher integration density where each and every circuit and RAM in a DDIC become smaller, making the entire chip size smaller and enabling design of smaller and thinner products. Also, finer-scale processes translate to using relatively less energy, reducing power consumption. In addition, DDIC manufacturers will take advantage of 28nm and beyond to make many more DDICs out of a single silicon wafer, raising cost effectiveness. This is why recently DDIC makers are striving to develop finer processes.

Process technology	55nm	40nm	28nm
Power consumption	100%	70%	40%
Chip size	100%	75%	65%
Available Resolution	~ QHD+ (3120 x 1440 pixels)		UHD (3840 x 2160 pixels)

3. Technical Evolution of OLED DDIC

2000 - 2005

In the early and mid-2000s, OLED display entered the market first with a 2-inch range PM OLED sub display of a feature phone, in which the OLED DDIC employed a low-resolution passive current driving method. In the passive current driving method, the core technologies of DDIC included output current matching, controllability and high current consumption control. This was a period of time when -- despite several advantages of an OLED panel -- its high drive current and voltage caused PM OLED and DDIC to face technical challenges to enter the 3-inch or larger main panel market. Therefore, the industry began to address these issues in order to become more competitive with LCD displays.

2006 - 2010

From roughly 2006 – 2010, OLED displays entered the feature phone main display market with the development of the qVGA AMOLED display, which marked the first real competition for LCD. At this point, the OLED DDIC adopted an active voltage driving method, which enables the source output voltage and the controllability of panel voltage noise to improve OLED image quality. This first-generation core technology was also the first to benefit from lower cost mass production capability. This first-generation core technology marked an evolution in several DDIC characteristics. For instance, at that time existing OLED pixels used a current driving method, but newer-generation DDIC was required to adopt a voltage driving method to achieve higher resolution and realize lower power consumption.

This in turn led to a significantly reduced “non-uniformity” of the pixel circuitry, which converts voltage into current and results in much better noise sensitivity, as compared to an LCD display of an equivalent resolution. To realize completely OLED’s advantages in faster response time, higher contrast ratio and excellent color reproducibility and naturalness, the DDIC was required to perform several times greater output accuracy and noise controllability than an LCD DDIC. To achieve this, it was inevitable that the OLED DDIC would grow in complexity and size. However, the industry addressed this seeming disadvantage by successfully developing lower-cost mass production techniques for AMOLED DDICs used in mobile phones and PMP (Portable Multimedia Player). This development enabled the first generation core technology to become truly competitive with LCD and positioned it well for opportunities to expand the OLED market.

2011 - 2014

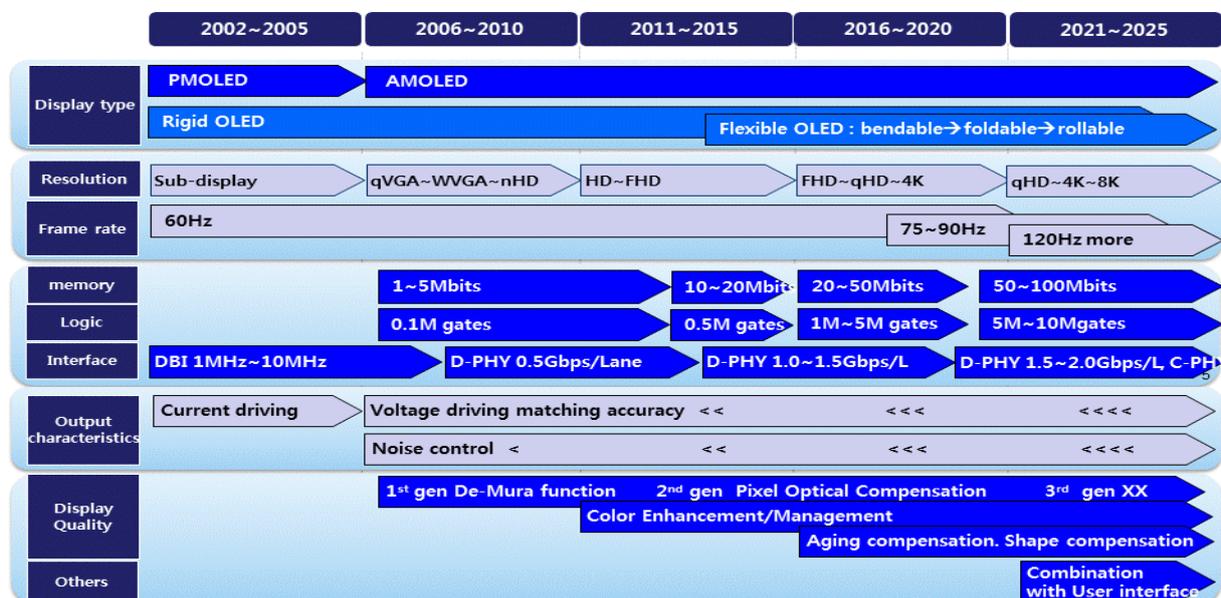
With the proliferation of smartphones from the mid-2010s, high-resolution displays were adopted in earnest and the consumption of video content increased, which brought to consumers a widespread recognition of the advantages of OLED displays, including lower power consumption as compared to the first OLED displays. In addition, the OLED industry made significant strides in solving the screen aging and burn-in issues that led to short product lifetimes. This period marked the second-generation core technology for OLED, which enabled complex functions such as significantly more sophisticated pixel optical compensation capabilities in high resolution (e.g., true HD) formats and low power consumption that did not impair image quality. This led to high-density SRAM (Static Random Access Memory) and diverse compensation functions that could be realized using process technologies of 55nm and below – an important step leading to further cost reductions and development of flexible OLED screens.

2015 and beyond

Beginning in 2015, OLED moved beyond existing LCD by virtue of its own unique characteristics – such as the first bendable type display to extend around the edge of a mobile phone, a true technology milestone. In the coming years, innovations in OLED displays, large and small, will help bring about the changes associated with “Industry 4.0” and its impact on various cultural aspects of society, as will be seen with foldable, rollable, wearable and transparent displays that can be deployed inside and outside. These devices will interact with people on a “touch and see” basis in a “seamless” manner that will appear as part of the “natural environment.”

To keep pace with this forecast development, DDIC technology will enable these natural looking displays without shape or size constraints by integrating Ultra-High Resolution from HD, FHD, QHD to mobile 4K, Ultra-High PPI (Pixel Per Inch) from 250ppi, 350ppi, 500ppi, 750ppi to 1500ppi, ultra-high-speed scan rate from 60Hz, 75Hz, 90Hz to 120Hz, HDR (High Dynamic Range), distortion and optical compensation technology, lower power consumption, lifelike VR driving technology (>90Hz & >1000PPI) and user interface (touch & see).

The industry will build upon the first and second core technologies in several aspects, such as: improved output voltage accuracy, enhanced noise controllability to remove flicker, and compensation for the growing number of source channels and improved luminous efficiency of OLED. More specific to the second generation core technology, pixel non-uniformity compensation and aging compensation will need to adopt more complex operations in order to accomplish more sophisticated functions. These advances in the first and second generation core technologies mean that the forthcoming third generation core technology will incorporate larger memory and higher order processes from 40nm, to 28nm and under 20nm. This progression in manufacturing will minimize power consumption arising from more complex DDIC operations such as: pixel compensation and comprehension distortion compensation, higher speed operations and integrated modules sensor functions for enhanced “touch and see” interactive features. Figure below represents this progression of OLED display technologies.



4. OLED display market

Mobile & Flexible OLED Display

A 9-inch or smaller panel display is classified as “small - medium” and 9-inch or larger panels fit in the “large” category. Therefore, displays for mobile devices fall into the small-medium category. Traditionally, the OLED display market has been dominated by large displays, particularly TVs. In Q4 2014, the large display segment recorded \$19.7B revenue, whereas the small and medium display segment recorded \$11.7B revenue – a difference of more than 50 percent. However, the recent growth trend in mobile displays is reshaping the display market.

According to market search firm IHS Markit, in 4Q 2017 the small and medium display sector hit \$17.0B while the large display segment exceeded the \$15.7B mark for the first time. Recently, as high- resolution and full-screen smartphones have hit volume production -- and leading flagship products such as the Galaxy S, Galaxy Note, and iPhone X are adopting OLED panels -- the mobile display market has begun to show hyper-growth.

Moreover, some analysts point to the replacement cycle of electronic products as accelerating the growth of smartphone displays. It is known that the smartphone replacement cycle is typically three years or less, while the TV replacement cycle averages eight to ten years. As a result, a ‘tornado effect’ hit the display market when comparing revenues and shipments of mobile phone and TV display. According to IHS Markit, revenue of smartphone display hit \$6.8B in 1Q 2014 and increased by almost a factor of 2 to \$13.7B in 4Q 2017, whereas TV display revenue grew just slightly from \$9.1B to \$9.6B for the same period.

Flexible OLED for smartphone is now leading the growth of the mobile display market. According to IHS Markit ‘AMOLED Industry Market Report,’ flexible OLED for smartphone hit \$3.1B in 2016 and is expected to grow to \$35.0B in 2020, an increase of 1,111%, with shipments during the same period growing from 40.3 million units to 411.8 million units, an increase of 1,020%. This tremendous growth in the flexible OLED segment is directly attributable to product design changes in the intensely competitive smartphone market. Flexible OLED makes smartphones thinner and lighter and allows greater variety in “product shape.” For instance, the flexible OLED market is forecast to grow even faster as foldable and roll-able smartphones start to enter mass production in the not-too-distant future.

Market position of MagnaChip

MagnaChip Semiconductor began to develop OLED DDIC (Display Driver IC) with Samsung Display in 2003, and the company succeeded in mass producing the first-ever AMOLED DDIC in 2007. As a result of the company’s 15-year development track record and design expertise, the company holds a number of key patents, widening its technology gap over the LCD DDIC vendors that have recently entered the OLED market segment. At the same time, by building and maintaining its long-time and close relationship with panel customers, MagnaChip has consolidated its leading position in the OLED DDIC space.

LCD DDIC suppliers have begun to develop OLED products, but face significant challenges due to a lack of sufficient DDIC experience and design engineering expertise as well as the long-standing working relationships with the two leading OLED panel makers that happen to be located in Korea. Given the significant difference in OLED panel characteristics as compared to LCD, OLED DDIC will realize the best display quality only with the specialized IP (Intellectual Property) to a lower cost mass production capability, as well an optimized Analog IP and processes for chip size, power consumption, and ESD (Electrostatic Discharge). Further Samsung Display is widely expected to lead the small and medium OLED display market for years to come, which will make it difficult for emerging players to establish a foothold. As MagnaChip has been developing OLED DDIC with Samsung Display since 2003 and has secured many other customers in that time, MagnaChip will continue to hold a leading position in the OLED DDIC segment.

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