# Self Assembled Cathode Patterning for AMOLED

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**ABSTRACT**

*Patterning of the cathode layer in top-emission AMOLED displays has been a technological barrier to realize both large area top emission AMOLED displays, and high transparency AMOLED displays. Using ConducTorr™ Electrode materials we demonstrate the first mass production ready cathode patterning process in a high-resolution OLED using self-assembly.*

## 1 INTRODUCTION

The top-emission AMOLED display architecture has been successfully commercialized in the market for small size mobile panels, while the bottom-emitting OLED architecture has been successfully commercialized for large area TV size panels. However, the bottom-emitting OLED display architecture does not scale-down well to smaller size panels and/or high-resolution panels due to the low aperture ratio, which limits the practical resolution to about 100 ppi. [1]

For OLED display technology to continue to gain market share, larger size, high resolution top-emission AMOLED displays are thus required. However, the top-emission AMOLED display architecture does not scale-up easily due to several manufacturing challenges. One of those challenges is the use of a semi-transparent common metal cathode layer that covers the entire emitting surface of the display.

The top cathode is typically made of a thin layer of metal, such as an alloy of magnesium and silver (i.e., MgAg) that is only 10 – 20 nm thick, and thus has a relatively high sheet resistance of 10 – 15 ohm/sqr. [2] Thus, as the size of a top-emitting AMOLED display panel increases, and hence the total current flowing through the top cathode increases the sheet resistance of top cathode layer becomes a significant performance bottleneck, resulting in a so-called “IR drop”. [3]

In addition to the IR drop problem in the top-emitting AMOLED architecture, the top cathode also causes a performance bottleneck transparent OLED displays. Since the top cathode is a semi-transparent metal layer, and since it is a common layer that covers the entire surface of the display, it is the strongest absorbing layer in the OLED stack. As a result, the transparency of the top cathode layer directly impacts the transparency of transparent OLED displays.

The transparency of the top cathode layer is particularly problematic for transparent OLED display applications that require very high transparency, particularly in the near infrared (NIR) wavelength range. A recent example of such an application is a transparent display for Under Panel Sensor (UPS), where the front facing camera or NIR sensors are integrated under the panel, requiring high transparency.

To date, transparent OLED displays have been limited to low resolutions, typically about 100 ppi, and low transparency, typically < 45%. [1] To overcome this limitation, patterning of the top cathode layer to increase transparency in the non-emitting regions of the display, is thus required. However, since high temperature metal deposition is not compatible with Fine Metal Mask (FMM) patterning methods, there is currently no mass production viable solution for patterning the top cathode. [4]

In this paper we demonstrate the use of the ConducTorr™ Electrode technology, a new method for self-assembled cathode patterning to realize a 240 ppi OLED panel (without TFT) with high transparency, including in the NIR wavelength range.

## 2 EXPERIMENT

The ConducTorr™ Electrode technology is a novel top cathode patterning technology developed by OTI Lumionics based on a self-assembly process. The fabrication process is compatible with existing vacuum thermal evaporation techniques used in AMOLED mass production and does not damage the underlying front plane when used to pattern an auxiliary electrode on top of an AMOLED display panel.

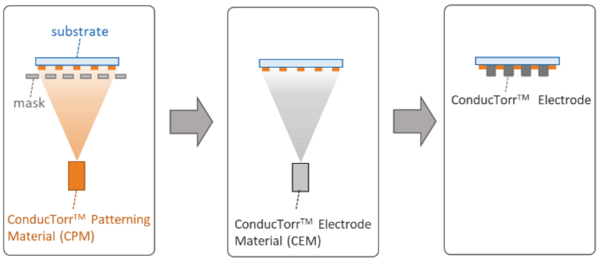


**Fig. 1**
ConducTorr™ Electrode patterning process using FMM.

Fig. 1 shows the typical two-step patterning process based on vacuum thermal evaporation. The first step is the deposition of the ConducTorr™ Patterning Material (CPM) layer, which can be patterned using a standard FMM or other techniques. The second step is the deposition of the ConducTorr™ Electrode Material (CEM) layer with an open-frame mask. During the CEM deposition step the CEM layer undergoes a self-assembly process by which the material only deposits on areas of the substrate not covered with the CPM layer.

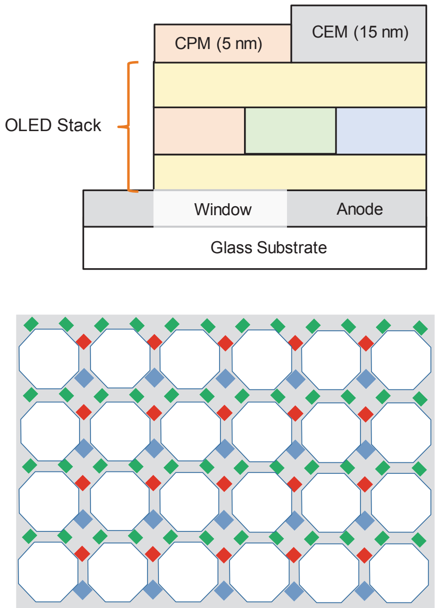


**Fig. 2**
Transparent OLED panel design.

Fig. 2 shows the schematic structure of the transparent OLED panel (without TFT). A diamond PenTile pixel configuration was used with a 480 ppi equivalent resolution. The panel was fabricated on a glass substrate using Ag/ITO anode. The top half of the panel was patterned with photolithography to leave an open window for every other pixel (i.e., 240 ppi window resolution). The RGB subpixels where defined using a photoresist Pixel Defining Layer (PDL) on top of the anode. Note that the PDL also covered the transparent window region of the panel.

The OLED stack was deposited on top of the PDL using vacuum thermal evaporation. A 5 nm CPM layer was deposited on top of the OLED stack, over the open window in the anode, using an FMM. A 15 nm CEM layer was then deposited on top of the CPM layer using an open mask. An outcoupling layer was deposited on top of the CEM layer using an open mask. The panel was encapsulated using a glass cap with UV cured epoxy, resulting in an air gap between the OLED and top cover glass.

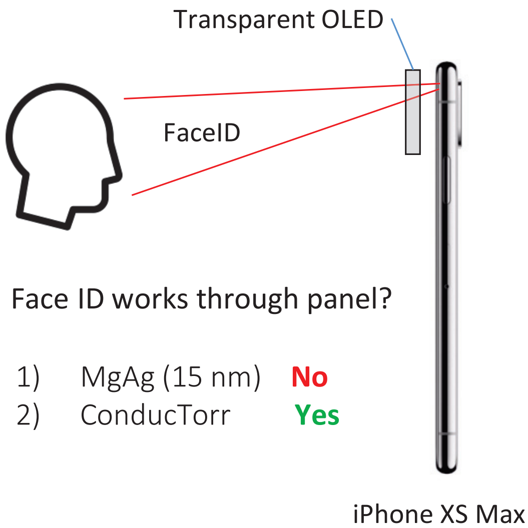


**Fig. 3**
Test configuration for FaceID unlock testing using the transparent OLED panel in a UPS application.

UV-VIS transmission of the finished OLED was measured using an Agilent Cary 300 from the back side of the panel. NIR performance with in a UPS application was tested by mounting the OLED panel on top of the front facing camera and IR sensor of an iPhone XS Max (i.e, the display notch region), and testing the FaceID unlock function. Fig. 3 shows the configuration used for the test.

## 3 RESULTS

Fig. 4 shows a microscope image of the finished OLED panel from the front with the R subpixels illuminated. The transparent windows appear as black circles.

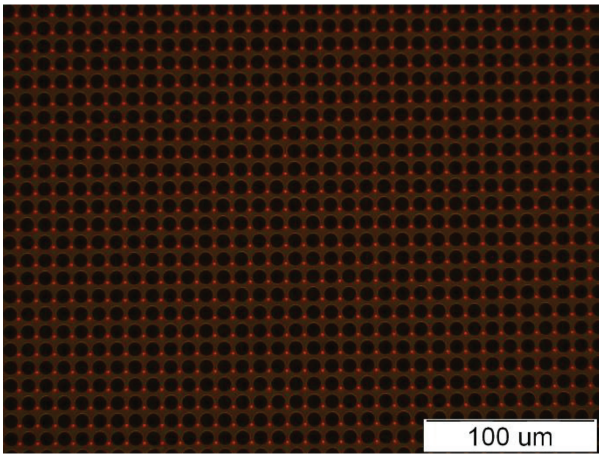


**Fig. 4**
Microscope image of 240 ppi transparent OLED panel with R sub-pixels illuminated.

Fig. 5 shows a photograph of the finished OLED panel in the OFF and ON state with red sub-pixels illuminated. The top half of the panel is the region with the transparent window (half resolution) and the bottom half of the panel is the region without the transparent region (full resolution).


**Fig. 5**
Microscope image of 240 ppi transparent OLED panel with R sub-pixels illuminated.

Fig. 6 shows the UV-VIS transmission spectrum of the transparent OLED panel with un-patterned MgAg (15 nm) cathode and patterned ConducTorr™ cathode.

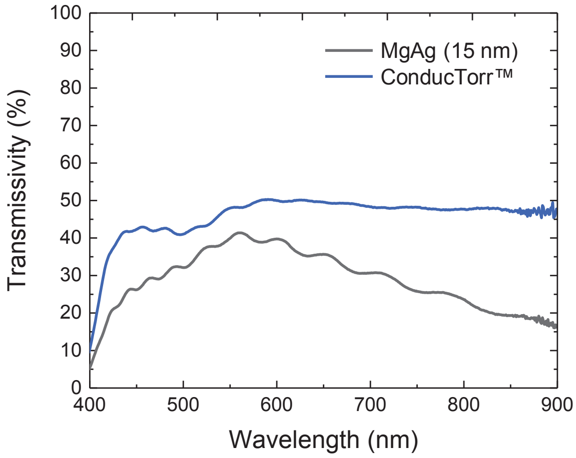


**Fig. 6**
UV-VIS of transparent OLED panel with un-patterned MgAg and patterned ConducTorr™ cathode.

## 4 DISCUSSION

As shown in Fig. 6 the transparency of the transparent OLED panel is increased across the visible wavelength range using the patterned ConducTorr™ cathode as compared to an un-patterned MgAg cathode that covers the entire surface of the panel. The transparency of the panel with the patterned ConducTorr™ cathode reaches >50%. Moving towards longer wavelengths the transparency of the un-patterned MgAg cathode drops significantly due to the strong absorption of the metal. In contrast the transparency of the patterned ConducTorr™ cathodes remains high out into the NIR at >45%.

The results of testing the FaceID unlock feature of an iPhone XS Max through the transparent OLED panel, indicates the significant benefit of the higher transparency using the patterned ConducTorr™ cathode. Using a standard un-patterned MgAg cathode the FaceID unlock feature fails to function through the transparent panel due to the low transparency in the NIR wavelength range. In contrast, the FaceID unlock feature works correctly through the transparent panel with patterned ConducTorr™ cathode.

## 5 CONCLUSIONS

A high-resolution transparent OLED with equivalent resolution of 240 ppi was successfully demonstrated with the self-assembled ConducTorr™ Electrode used as the top cathode. A >50% transparency was achieved in the visible wavelength range and >45% transparency was achieved in the NIR wavelength range.

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