Low-Power-Consumption Organic Light-Emitting Diode Display Based on Locally Driven Multi-Domain Segmentation

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Abstract

A 13.2 inch low power consumption-organic light emitting diode (OLED) display panel based on multi-domain segmentation technique is demonstrated. Our OLED display panel is composed of 48 segmented zones, and ELVDD line networks in each zone are spatially separated. Through this particular architecture of the backplane, three different levels of ELVDD voltage are selectively applied to each zone according to the analysis data of the displayed image in the zone. The power consumption of our panel is reduced by up to 25% compared to the normal conventional OLED display panel by decreasing the applied ELVDD voltages locally. Our multi-domain segmentation technique is very promising for large-format displays such as IT devices, TVs, and automotive displays for the next generation due to its excellent energy efficiency.

Author Keywords

Low power consumption-OLED; Multi-domain segmentation; Selective ELVDD application;

1. Introduction

In recent days, since the organic light emitting diode (OLED) display has a lot of advantages such as fast response, high color purity, thin thickness, and wide viewing angle compared to other display technologies, it is widely used for almost all kinds of displays including smartphone, tablet PC, laptop PC, TV, and automotive display. Accordingly, the electro-optical performances of OLED display have been improved remarkably for several decades, and the energy efficiency is particularly regarded as one of the most significant performances because mobile electronic devices adopting OLED display panels are usually suffering from the insufficient battery capacity.

In order to improve the energy efficiency, lots of studies and developments have been done and introduced in terms of display driver integrated circuit (DDIC) dynamics and panel backplane dynamics such as local dimming, multi-frequency driving, and backplane architectures minimizing unnecessary electronic charging. There are also methods for reducing energy consumption of OLED emission itself such as developing OLED materials with high internal quantum efficiency, maximizing light extraction by modulating thickness of organic functional layers or introducing additional optically functional layers, and dynamic driving voltage scaling. Among these techniques, modulating driving voltage according to the displayed image is the most effective and intuitive way to reduce the energy consumption, because the consumed electric power is simply determined by the product of the driving voltage and the current flowing through OLEDs in the panel. However, the amount of reduction margin in driving voltage is quite limited because this value is determined by considering dynamic I-R drop within the entire panel.

In this paper, we demonstrate a 13.2 inch OLED display with low power consumption adopting whole new multi-domain segmentation technique. Our OLED panel is composed of 48 segmented zones, and ELVDD line networks in each zone are spatially separated. Due to this particular backplane structure of our panel, three different levels of ELVDD voltage can be applied to each zone selectively according to the analysis data of the image of each frame in each zone. By reducing ELVDD of segmented zones showing relatively darker image selectively, the total power consumption of our OLED panel was reduced by up to 25% compared to the normal panel without multi-domain segmentation. We also discuss the issues of our panel which should be resolved such as unequal amount of I-R drop of each zone and artifacts between adjacent segmented zones. In spite of these issues, our panel shows the potential of multi-domain segmentation technique to be applied to large-format displays including IT device, TV, and automotive display for the next generation due to its excellent energy efficiency.

2. Basic Concept and Fabrication

Figure 1(a) shows the schematic diagram of our OLED display panel and some parts in the DDIC. The ELVDD voltages are transmitted separately to each zone, and this voltage level is selected among three different values ($ELVDD_{\mathrm{High}}$, $ELVDD_{\mathrm{Mid}}$, $ELVDD_{\mathrm{Low}}$) by MUX in the DDIC. Therefore, three different DC voltage power sources and 48 MUXs are necessary in the DDIC for driving our panel. Figure 1(b) shows schematic diagram of the relation between the OLED current (I_{OLED}) and the drain-source current (I_{ds}) of the driving TFT with respect to the ELVDD and the ELVSS of our panel. In the conventional panel, considering I-R drop in the backplane and degradation of OLED, ELVDD is usually set higher than the voltage value that OLED needs for emitting target brightness. In other words, if the displayed image has low brightness, most pixels are driven by higher ELVDD than they actually need, and this makes energy loss in the panel. Therefore, if some parts of the panel are driven by lower ELVDD voltages than normal ELVDD voltage according to their images, the power consumption would be reduced effectively. In our panel, the most appropriate ELVDD level among three different voltages described above is selected and applied to each segmented zone at every single refreshing time according to our particular driving algorithm, and the highest voltage $ELVDD_{\mathrm{High}}$ is same with the normal ELVDD voltage of the conventional panel.

Figure 2(a) depicts the schematic diagram of ELVDD lines in the active region of our panel. As described above, our panel is spatially separated to 48 zones, and the ELVDD lines compose mesh structure by contacts of vertical metal lines and horizontal metal lines in each zone. Note that these mesh structures in segmented zones are completely separated from other zones. Our panel is driven by n-type indium-gallium-zinc-oxide (IGZO) TFT which is suitable for large-format displays due to its uniformity and cost-effectiveness, and constructed with 6 metal layers as described in Fig. 2(b). The ELVDD voltages are transmitted only from the bottom side of the panel through vertical S/D2 lines which have the lowest electrical resistivity in our panel as shown in Fig. 2(a).

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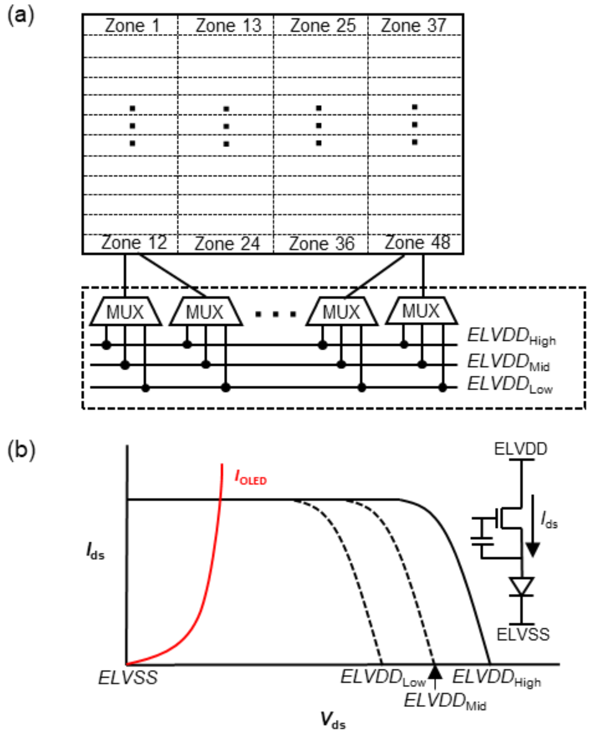

Figure 1. Schematic diagram of (a) our OLED display panel and some parts of DDIC with locally driven segmented zones and (b) I_{OLED} and I_{ds} of driving TFT with respect to ELVDD - ELVSS value and circuit diagram of driving TFT and OLED.

Table 1 shows the specification of our 13.2 inch low power consumption-OLED panel. Our panel has high resolution of 265 ppi which is very appropriate for premium IT device, and since the ELVDD line network our panel is spatially separated to 48 domains as described in Fig. 1(a), the resultant resolution of each zones is 738 X 154.

Table 1. Specification of our 13.2-inch low power consumption-OLED display panel

Diagonal Size	13.2 inch
Resolution	2952 X 1848 (265 ppi)
Pixel Pitch	96.0 μm X 96.0 μm
Aperture Ratio	R: 26.0%, G: 28.5%, B: 41.1%
TFT Type	n-type IGZO

3. Result & Discussion

Figure 3 shows the comparison of displayed images of several scenarios with different average gray levels between the conventional panel with same specification without multi-domain segmentation and our panel. As shown in the captured images this figure, our panel shows image without any brightness distortion or artifacts between segmented domains, and it is measured that the power consumption is reduced by to up to 25% when the average brightness is relatively low as shown in the top image. Since $ELVDD_{Low}$ is applied to more zones when the average brightness is darker, the power consumptions can be reduced more effectively. On the contrary, if the displayed image is bright, the consumed power is hardly reduced because the $ELVDD_{High}$ which is same with the ELVDD voltage of the conventional OLED panel is applied to most segmented domains.

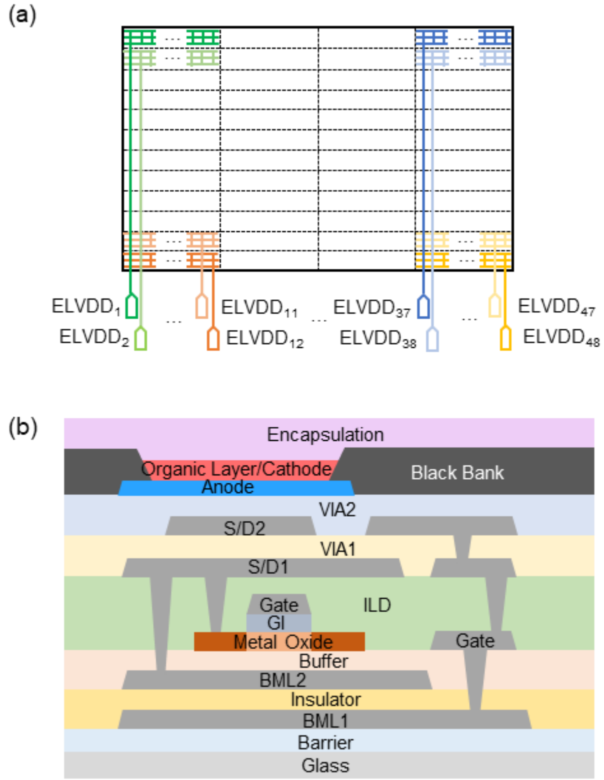

Figure 2. Schematic diagram of (a) ELVDD line networks and (b) layer structure of our OLED panel.

Under most video scenarios, artifacts of our panel resulting from segmented zones are not noticeable as shown in Fig. 3. However, these artifacts can be noticed as the difference in brightness of adjacent segmented domains under certain scenarios such as less actively moving images which different ELVDD levels are applied to the adjacent domains. In order to clarify the properties of these artifacts in our panel, several tests were conducted on our panel.

First, the luminance of segmented zones are measured with respect to the ELVDD voltage. Figure 4(a)-(b) and Fig.4(c)-4(d) show these properties according to the background status and the emitting ratio of the zone at the top region and the bottom region of our panel, respectively. In this measurement, the emitting ratio was controlled by area of full-white region in the measured zone, and the background status was controlled by the gray level of the image on the panel except the measured zone. This luminance curve shifts right when the emitting ratio of the zone increases due to the I-R drop in the panel, and figure 4(e) shows the summary of the ELVDD voltages that luminance starts to decrease in each case. I-R drop in the OLED display panel can be divided into ELVDD I-R drop and ELVSS I-R drop, and these two values are difficult to be distinguished in the conventional OLED display panel. However, since the ELVDD metal lines are spatially separated completely in our panel, the amount of ELVDD I-R drop and ELVSS I-R drop can be estimated by this measurement. If the background status are same, change in I-R drop according to the emitting ratio of segmented zone can be regarded as the ELVDD I-R drop of the measured zone approximately, because the ELVSS electrode in not separated and the change of the ELVSS I-R drop according to the emitting ratio of the segmented zone is nearly negligible. On the contrary, since there is almost no ELVDD I-R drop if the emitting ratio of the segmented zone is very small, the change of I-R drop according to the background status when the emitting ratio is 10% can be regarded as the ELVSS I-R drop approximately.

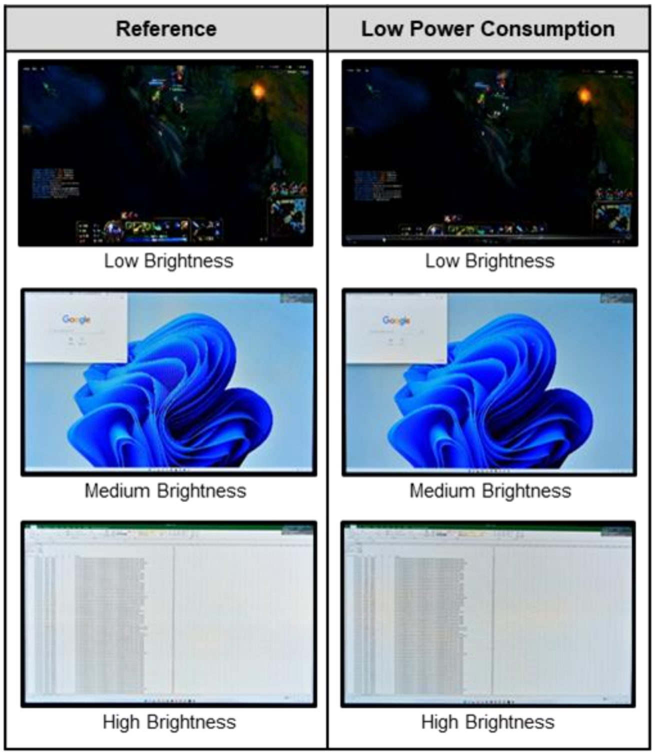

Figure 3. Displayed images with different average brightness of conventional OLED panel without multi-domain segmentation (left) and our panel (right).

The ELVSS I-R drop increases as the background status changes from black to white, and the amount of change is larger in the zone at to top region as shown in Fig. 4(e), because the ELVSS voltage is supplied from the bottom of the panel, and this property is also shown in conventional OLED panel. However, different from the conventional OLED panel, the ELVDD I-R drop doesn't increase as the background status changes from black to white because the ELVDD lines are separated from each segmented domain. Instead, the amount of I-R drop is much larger in the segmented zone at the top region of the panel although the areas of all segmented zones are same, and these values are constant regardless of the background status. This ELVDD I-R drop dependence to the location of the domain is resultant form the different electrical resistance of ELVDD line of each zone. Since the length of the ELVDD line connecting the segmented zone and the bottom peripheral region of the panel depends on the location of the segmented zone as shown in Fig. 1(a), the electrical resistance of the ELVDD lines of the segmented zone at the top region is much bigger than that at the bottom region. It should be noted that the difference in ELVDD I-R drop can make difference of brightness of adjacent zones. Therefore, some revisions in panel architecture or driving algorithms should be studied and applied further in order to mitigate the difference in ELVDD I-R drops of segmented zones.

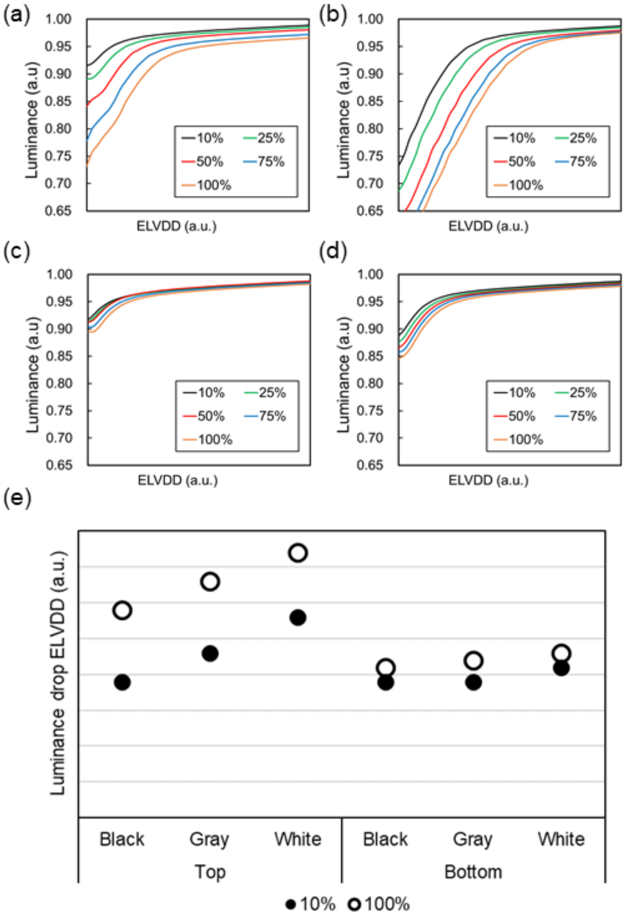

Figure 4. Luminance of the segmented zone at (a) top region with black background, (b) top region with white background, (c) bottom region with black background, and (d) bottom region with white background with respect to ELVDD voltage according to the emitting ratio of each zone. (e) EVLDD voltage that the luminance starts to decrease of segmented zone with 10% and 100% of emitting ratio according to the location and the background.

Secondly, the artifacts between adjacent segmented zones where different ELVDD voltages are applied are also studied. In the case that same ELVDD is applied to two adjacent zones, no difference in brightness was observed regardless of gray level. However, if different ELVDD voltages are applied to two adjacent zones, a slight difference in brightness can be observed as shown in Fig. 5(a) showing two adjacent segmented zones under different ELVDD levels at 100 gray. Moreover, it was observed that this difference in brightness is more visible at low gray level. As shown in Fig. 4(a)-(d), as ELVDD increases, the luminance also increase slightly even under the ELVDD voltage higher than the luminance drop ELVDD, and this make the difference of the brightness described above. In order to mitigate this artifacts, a new driving algorithm were developed, and it can be seen that no difference in the brightness is noticeable between adjacent segmented domains after this algorithm is applied as shown in Fig. 5(b).

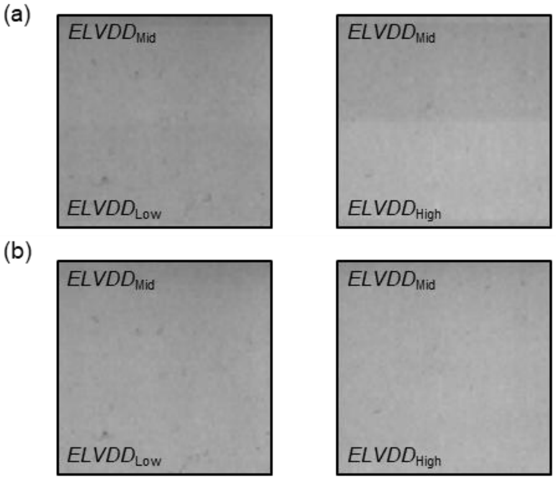

Figure 5. 100 gray image of two adjacent segmented zones with different ELVDD voltages (a) before and (b) after applying compensation algorithm.

4. Summary

A 13.2 inch OLED display with low power consumption based on multi-domain segmentation technique was demonstrated. The total power consumption of our OLED panel whose active region is separated to 48 locally-driven domains was reduced by up to 25% compared to the conventional OLED panel without multi-domain segmentation. Although our panel shows excellent electro-optical characteristics, it still suffers from artifacts resulting from the unequal I-R drop of segmented domains and multiple ELVDD voltage levels, and new architectures and driving algorithms resolving this artifact issues completely should be studied further. Our multi-domain segmentation technique is very promising technique for large-format displays including IT device, TV, and automotive display of the next generation due to its excellent energy efficiency.

5. References

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