The Challenge of OLED Display Quality in Low Gray Scale

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ABSTRACT

In this paper, two kinds of display defects under low gray scale are analyzed and we find the mechanism of the defect from the driving principle and TFT characteristics.1. Vertical mura.2. Color deviation. Finally, we summarizes the control standards for TFT characteristics in order to meet the display quality of AMOLED at low gray scale, and introduces the temporary measures for improving the problems mentioned using display system.

1. INTRODUCTION

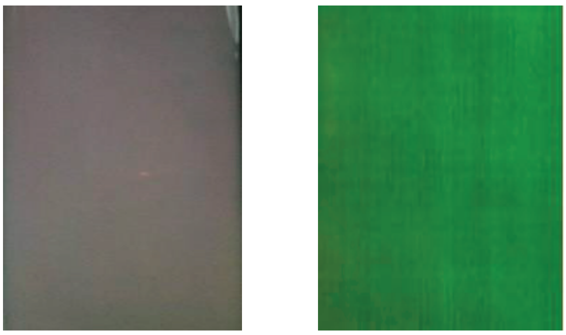


Fig.1 the right phenomenon is mura and the left phenomenon is reddish in 32 gray level

As the next generation display technology, AMOLED has the characteristics of ultra high color gamut and contrast. However, the low gray-scale quality of OLED is seriously challenged due to LTPS mass production characteristics, as showed in Fig1 .The first problem is poor short range homogeneity of threshold voltage(vth) which showed as vertical mura under low gray scale. It is obvious when driving TFT owns lower Sub-threshold swing(SS) and higher Mobility. In addition, since driving TFT of low gray-scale works close to Sub-threshold region, SS has a great influence on gray-scale color level adjustment. When the SS is too large the difference of RGB luminous efficiency is amplified .By appropriately increasing the number of fixed gamma voltage in low gray-scale, the color deviation of white light can be compensated. Finally, we summarize the TFT process capability required to improve the low gray scale display quality, as well as commercial improvement schemes using algorithm of display driver IC.

2. THE ANALYSIS OF VERTICAL MURA AND IMPROVMENT

2.1 Effect of TFT process on mura :

ELA process causes serious OLED mura due to pulse energy deviation and poor uniformity of laser line beam, which is so called shot and scan mura. The mechanism to form mura may be: As showed in Fig2, deviation of ELA energy causes deviation of TFT characteristics. Then deviation of OLED brightness (mura) may occur due to deviation of TFT characteristics. Besides, p-Si is a sensitive part of TFT. Sometimes, deviation of cleaning process can also cause mura issues. For example, if the pressure and flow of water curtain too high or low, mura may appear.

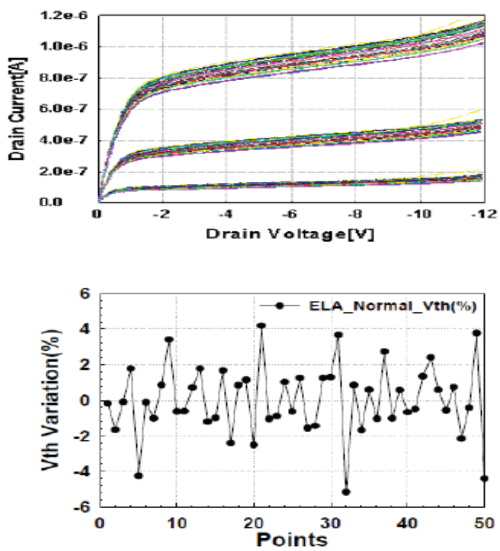


Fig2. Variation of normal ELA TFTs

2.2 Compensation error of the pixel circuit

In order to optimize the homogeneity of Vth in short-range, the pixel circuit adopts Vth compensation design, which is described in Fig3.The method is fixing the VGS (Voltage difference between gate and source) to Vdata+ vth-vdd by driving TFT memory capacitor Cst, when driving TFT works in the saturated region, the current of OLED meets the following formula :

$$I_{Saturation} = 0.5K(Vgs - Vth)^2; \quad K = \mu * Cox * \frac{W}{L}$$

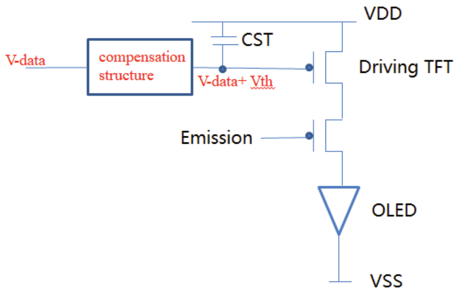


Fig3.Schematic diagram of compensation circuit

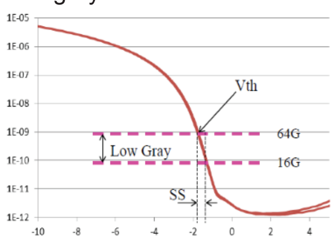
In ideal conditions, VGS-vth = vdata-vdd, and this difference has nothing to do with Vth. In this way, we offset the influence of Vth on the current flowing through the oled by internal compensation mechanism. However, due to the limitation of charging time and driving TFT characteristics, the compensation circuit cannot charge the Cst to the target value. In fact, VGS-vth = vdata-vdd +Verror, which is related to the Vth of driving TFT.

$$Verror = -\frac{Vdata + Vth - Vint}{(Vdata + Vth - Vint) * \frac{KT}{Cst} + 1}$$

T is the time used to sample Vth, and Vint is the initial voltage of gate voltage. When the OLED display low gray scale images, driving TFT works in the sub-threshold region. The modulation mode (VGS to current)of sub-threshold of driving TFT is different from that of saturated region: the relationship of sub-threshold current with VGS approximately meets the following formula：

$$I_{Sub\text{-}threshold} \propto \exp\left(\frac{-(VGS - Vth)}{SS}\right)$$

From the formula, we can find that the sub-threshold current has an exponential relationship with VGS, while the saturation current has a quadratic relationship, which means that the effect of Verror on current will be amplified in low gray scale.



Gray	Brightness	I_OLED(A)
1	0.0%	2.5E-13
16	0.2%	1.1E-10
32	1.0%	5.2E-10
64	4.8%	2.4E-09
96	11.7%	5.8E-09
128	22.0%	1.1E-08
255	100.0%	5.0E-08

Fig4. Gray scale working in the sub-threshold region

In the industry, The VGS modulating about 1e-9A current is the threshold voltage, and the driving current corresponding to level 64 gray is about 2.4e-09a, so all the gray below level 64 use the sub-threshold areas to display. The detailed correspondence is shown in figure 4.In conclusion: When the the uniformity of Vth becomes worse, the medium-high gray scale is almost unaffected, but the brightness difference in the low-gray scale is obvious, resulting in the phenomenon of mura.

2.3 RESLUTS AND DISCUSSION：

With the resolution growing, the layout space of panel is limited, Cst and W/L cannot be increased randomly；T is related to the refresh rate, and product specifications cannot be changed after they are determined. So the result is Verror can hardly be changed. In order to solve the low-gray scale mura, we need to optimize the key parameters that affect the low-gray scale current: Vth and SS.

Optimizing Vth uniformity: Improving TFT GI interface defect states and adjusting channel injection dose are common means to optimize Vth uniformity .In order to ensure the brightness uniformity of 80% within the panel, the difference of Vth in the plane needs to be controlled at 0.15v.

Increasing SS appropriately: As the described in the formulation of the sub-threshold IV curve. When SS increases, the effect of Verror on current will be weakened. Making S.S > 0.4v /dec can improve mura of low gray scale significantly.

Optical compensation by De-mura: By capturing the image of mura through optical camera, we optimized the panel brightness uniformity by adjusting the data voltage through algorithm, the yield of mura can be rapidly improved. However, De-mura is a one-time compensation, which cannot compensate for the change of TFT characteristics in the aging process.

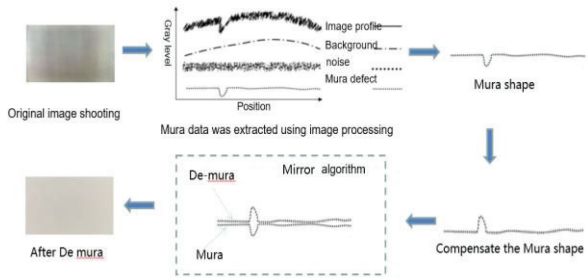


Fig5. The process of De-mura

3. THE ANALYSIS OF COLOR DEVIATION AND IMPROVMENT

Source dimming replacing PWM dimming will be a trend in the future considering the effects of visual fatigue. However, the chromaticity accuracy of low gray scale using source dimming is also susceptible to the influence of TFT characteristics and OLED characteristics. The figure 6 is the white color coordinate fluctuation curve of our product containing 256 gray levels. After automatic gamma calibration, it was found that there was reddish phenomenon near 32 gray scale .To cover this deviation, we analyzed the reasons of low gray order deviation from the three aspects: SS characteristics of driving TFT, the difference of OLED efficiency and fixed gamma voltage distribution.

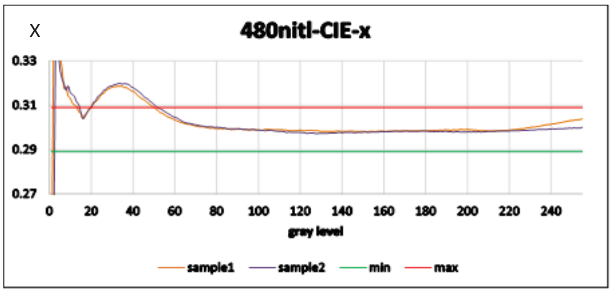


Fig6. The relationship of chromaticity X with gray levels

3.1 the process of gamma tuning of mobile screen

Before introducing the mechanism of color shift, it is necessary to understand the principle of OLED gamma curve calibration: Mobile phone products adopt the optical automatic calibration method, that selects 13-30 fixed gray levels from 256 gray levels for the automatic calibration (called fixed point voltage) .these brightness and color accuracy is set at the standard center value. The remaining gray levels located between the fixed points are set by linear interpolation algorithm without automatic optical calibration. The output accuracy depends on the characteristics of the TFT and OLED. The detailed gamma circuit Settings are shown in figure 6.1

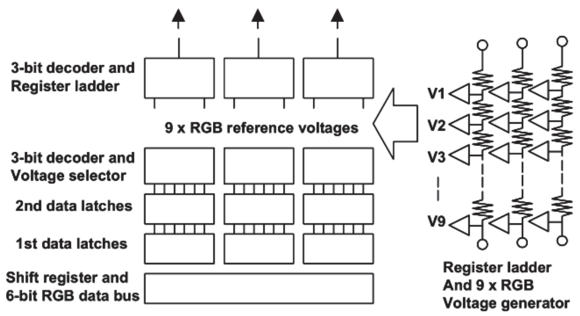


Fig6.1 Schematic diagram of fixed voltage in source driver

In other words, OLED determine the brightness relying on adjusting the gate voltage to control the current of TFT and the ratio of RGB brightness determines the white light color coordinate. Optical automatic calibration can't function on all the 256 grays, so the optical accuracy of unfixed point gray scale is related to the slope of v-data-lv curve to a certain extent. We get monochromatic RGB curve of v-data with brightness using computer programming, as showed in Fig 7.Because the current of low gray level is very little, so you can ignore the IR drop impact on the test. We found the slope of the curve in 32 gray-scale is different between RGB pixels, which leads to the ratio of RGB in the white color is distortion .Because linear interpolation method does not match the shape of the curve. The result is white color coordinates will move to the color having higher brightness proportion.

Gray level	Slope of red	Gray level	Slope of red	Gray level	Slope of red
Red 36	2.0	Green 36	1.3	Blue 36	1.9
Red 16		Green 16		Blue 16	

Chart1：The slope of 16-36 gray level corresponding to RGB V-data under 450 nit

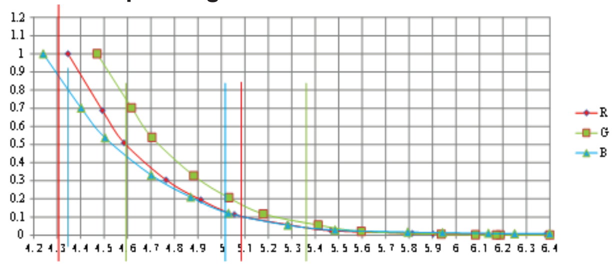


Fig7.RGB curve of low gray scale after brightness normalization

3.2 RESLUTS AND DISCUSSION

The slope of V-data–brightness curve will have a large level of mutation between medium and low gray level, if the SS move to larger trend .Based on the analysis of mura phenomenon we have pointed out that low gray-scale current mainly depends on SS adjustment, saturated zone's current change faster with vgs compared with sub-threshold area, So when SS become larger, the current of green pixel will change more slowly than RB pixels between fixed voltages. Because the TFT of green pixel have entered in the sub-threshold area while the RB stayed in the saturated zone near threshold location.

For products with different SS value, the color deviation of low gray scale was tested, as shown in the figure 8, the result is SS(0.41-0.47v /dec) was better than SS(0.6-0.8v /dec). Considering the effect on mura when changing SS, we limited the reasonable range of SS of driving TFT to 0.4-0.6v/dec.

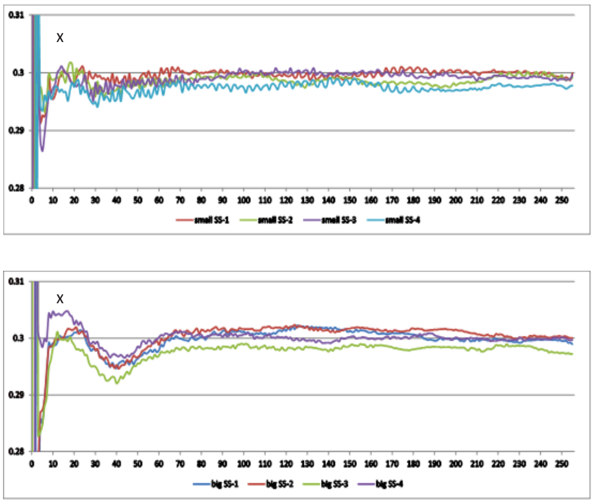


Fig8.the above is product owning SS(041-0.47),the bottom is product owning SS(06-0.8),

The material efficiency of OLED RGB decreases in the low gray level, which is described in Fig 9 .But the decline rate is different when current become lower. The test of the monochrome efficiency of RGB shows that the efficiency of red light decreased in 186 gray level, while the green and blue light have the change about 60 gray level, and the difference value between RG efficiency in the range of 20-60 gray reaches the peak, which corresponds to the position showing us color deviation.

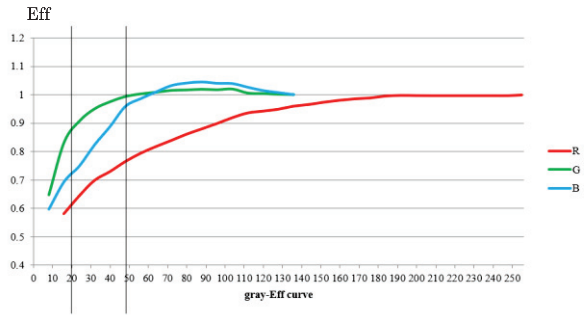


Fig9.RGB curve of low gray scale after efficiency normalization

The difference in efficiency finally determines that the TFT of RG pixels works at different positions in the IV curve. We will find out the reason why OLED efficiency changes with current density and shorten the difference of RG efficiency in low gray scale in the future.

At last, Increasing the amount of fixed voltage points in low gray scale can effectively calibrate the color accuracy, but the change of fixed point voltages will cause the cost of IC rising and affect the speed of automatic optical adjustment, resulting in the module productivity strain; Through experimental comparison, we found out a relatively suitable fixed point voltage setting of 20-64 gray scale, which requires 4 fixed voltages. Fig 10 showed us the fixed point design change and the contrast of color deviation.

Fixed voltage optimization experiment													
Original	0	1	4	9	16	36	64	96	128	160	200	224	255
New	0	1	2	5	10	22	32	48	64	96	128	192	255

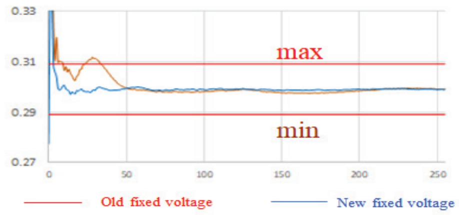


Fig10.The new fixed voltage design can significantly improve the color deviation in white light

4.CONCLUSION

In this paper ,we analyzes the impact factors of mura and color deviation in the low gray level, When the SS becomes lower, compensation error caused by Vth and the Mobility will be obvious in low gray-scale, When the SS become larger , differences of luminous efficiency of RGB material at low current density will reflect in white chromaticity. Considering the above two points, we put forward the suitable scope of SS =0.4 -0.6 V/dec; In addition, the poor uniformity of Vth is the root cause of mura, the fluctuation range needs to be controlled within 0.15v; Finally, we proposed a rapid improvement scheme using the driving IC: De-mura can effectively improve the brightness uniformity in the panel and increasing the number of low-gray fixed point voltage can prevent the white light coordinate from exceeding the specification.

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