Impact of Light -Diffusion Film on the Sparkle of OLED Display

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Abstract

This study investigates sparkle irregularities caused by anti-glare (AG) treatments on tablet and laptop displays. Surface morphology variations from frosting etching, photolithography, and abrasive blasting are analyzed. Introducing a light diffusion film with a periodic grating structure improves sparkle in OLED displays, supported by a theoretical model for optimal module-stack design.

Author Keywords

Sparkle; Light diffusion film; OLED; Anti-glare;

1. AG treatment technology of cover glass

In order to solve the glare problem of the display screen under strong light, tablets or laptops are treated with anti-glare on the surface of the display screen to make cover glass(CG) rough and uneven, which can reduce the mirror reflection of ambient light and enhance the visibility of the display screen. As shown in Figure 1, after AG treatment, the surface of the cover glass changes from a mirror smooth surface to a matte smooth surface.

Figure 1. Comparison of AG in cover glass (Left: without AG, Right: with AG)

Currently, there are mainly three AG processing methods: Abrasive Blasting, Frosting Etching and Photolithography. Abrasive Blasting is a process that sprays the glass surface at high speed with fine quartz sand, making the surface rough. Frosting Etching is a chemical erosion process in which insoluble reactants form small crystalline particles that adhere firmly to the glass surface. The particles beneath and those in the gaps between the cover surface exhibit varying degrees of contact with the acid, resulting in different levels of erosion. This leads to an uneven surface, classifying it as a type of chemical treatment. Photolithography refers to the photolithography process to limit the etching area. The mask used in this process can realize the precise control of the shape of the cover glass. It is also a chemical erosion process.

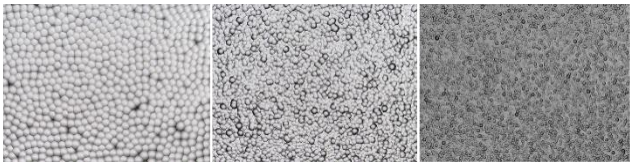

Figure 2. Surface microstructure of AG cover glass (left: Photolithography, middle: Frosting Etching, right: Abrasive Blasting)

Table1. Comparison of AG microstructure size

AG Processing	Width Variance	Depth Variance
Photolithography	4.1um	1.1um
Frosting etching	6.9um	1.4um
Abrasive blasting	2.8um	1.0um

We compared the microstructure of the CG surface after these three processes (Fig. 2), we can see that under the microscopic observation, the AG microstructure is a “small pit”, and the effect of different AG processes varies greatly. We measured the width and depth of the microstructures and calculated the variance, as shown in Table 1. Among them, the structural morphology of photolithography AG is regular pentagonal, with a small size difference between units and uniform distribution; the structural morphology of frosting etching AG is irregular polygonal, with a large size difference between units and uneven distribution; and the structural morphology of abrasive blasting AG is round, with the smallest size difference between units and the most uniform distribution. It can be seen that the microscopic morphology of both photolithography and abrasive blasting AG is better than that of frosting etching AG, which is conducive to the uniformity of the display screen and the reduction of the sparkle problem described below. Photolithography AG depends on mask design and control, the cost is high, and the technology is not mature. Abrasive blasting AG also exists at high cost, the market is not mature. Frosting etching AG is currently the mainstream process used in the OLED industry due to its mature technology and low cost.

2. The display screen with AG cover glass produces sparkle

As we all know, there is a gap between the RGB sub-pixels of the display, and the light emitted from the pixels is uniform on the CG surface when it is matched with a non-AG cover glass. However, when the display is equipped with AG cover glass, the rough and uneven structure on the CG surface makes the light emitted from each pixel of the display converge and disperse in an unordered way, so that the light intensity of the screen becomes spatially distributed in an unordered way, and this unordered distribution manifests itself in bright spots, dark spots, or color spots of about pixel size, i.e., we can see the

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sparkle of brightness and darkness (Fig. 3), and this kind of sparkle makes the imaging quality of the screen lower. If there is no gap between the sub-pixels, no matter how rough the anti-glare surface is, no sparkle will be observed. The effect of sparkle is greatest on green images because the human eye has the highest sensitivity to wavelengths in this range. In addition, this sparkle effect is not static but changes with the light path as the display or observer moves. [1]

Figure 3. Sparkle under white picture (left: with AG, right: without AG)

3. Solutions to reduce the sparkle of display

In the AMOLED display module, we can start from the module material and stacking design to improve the sparkle problem caused by the AG cover glass: Solution 1, optimize the AG treatment process of the cover glass to improve the uniformity of the AG microstructure; Solution 2, change the module stack design, and introduce new materials to reduce the gap between the sub-pixels. For Solution 1, as described in the previous section, the surface structural uniformity of Photolithography AG and Abrasive Blasting AG is better than that of the commonly used frosting etching AG, which can be used as a direction for improvement, and this paper will follow up on the validation and discussion of Solution 2.

It has been proven that the sparkle problem can be effectively improved by installing a layer of a special structure of light diffusion film (hereafter referred to as LDF) material between the Pol and the CG. The structure of the LDF is a periodic grating diffractive element (Fig. 4) formed by periodic arrangements of high refractive index and low refractive index materials, which can be rectangular, sinusoidal, etc., and is characterized by high diffraction efficiency in a small angle. T is the grating period, and A is the grating amplitude. By placing the LDF of this structure between the Pol and the CG (Fig. 5), the light emitted by the pixel can be diffracted, the gap between the sub-pixels is filled with diffused light, so that the light through the AG cover glass, the intensity of the spatial distribution ig more uniform. Therefore, the Solution 2 is not only can maintain the anti-glare effect of the AG cover glass, but at the same time reduce the sparkle, so that the quality of the display screen has been better improved.

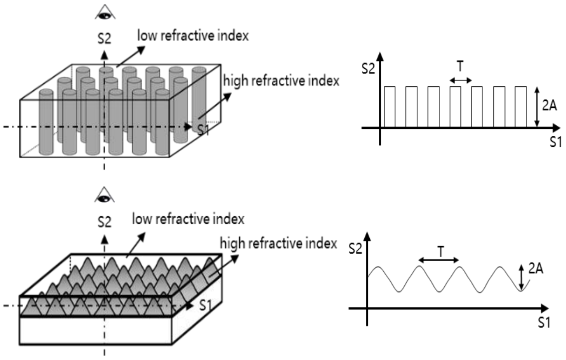

Figure 4. Structure of LDF (rectangular, sinusoidal)

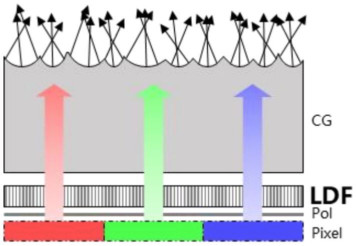

Figure 5. Module stack with light diffusion film

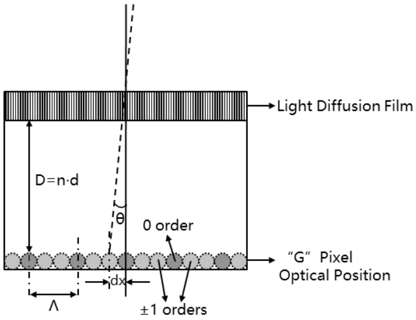

Figure 6. Optical Model of OLED Module Stack with LDF

AS shown in Fig. 6, each sub-pixel in the OLED-emitting layer is duplicated into three images by diffraction, and these duplicated images have a lateral displacement of dx, which can be given by the following equation:

$$dx = D \cdot \tan\left(\theta_m\right) \tag{1}$$

Where D is the optical distance from the pixel layer to LDF, obtained by multiplying the physical distance d by the refractive index n of the material between the LDF and the pixel. θ_m is the diffraction angle of the order m, which can be given by the following equation:

$$\sin\left(\theta_m\right) = \frac{m\lambda}{T} \tag{2}$$

Where λ is the wavelength, T is the grating period, m is the diffraction order, for the rectangular, sinusoidal grating structure of the LDF described in the previous section, most of the light will be at the m=0,±l order[2], so we only consider the case of m=0 and m= ± l order, then, for the positive incidence and the small angle θ_m, |m|=1, the grating period T is:

$$T = \frac{\lambda n d}{dx} \tag{3}$$

When the gap between sub-pixels perfectly matches the grating period, the sparkle can be minimized. According to the OLED pixel design solution, when the lateral displacement dx is equal to about 1/3 of the pixel pitch Λ, the gaps between the sub-pixels are fully filled, this is an ideal situation. In order to simplify the model, Fig. 6 is illustrated with a green pixel, and the ideal grating period T' is given by the following equation:

$$T' = \frac{3\lambda n d}{\Lambda} \tag{4}$$

From this, we can obtain the relationship between the optimal grating period and the distance from the LDF to the pixel layer. It can be seen that the larger the grating period of the LDF is, the larger the distance between the LDF and the display pixel layer needs to be. Moreover, as the pixel density of the display increases, the pixel size will become smaller and smaller. So the distance between the LDF and the display pixel needs to be reduced, or to increase the grating period of LDF.

For the display module shown in Fig. 6, the pixel size Λ of the display is about 97 um, the distance d between the LDF and the light-emitting pixel is about 145 um, and the refractive index n is about 1.5. Since the human eye is more sensitive to green light, we will choose to use green light (λ = 530 nm) as the design wavelength, but at the same time we also need to accept the other wavelengths under the display effect degradation. Substituting the parameters into Eq. (4), it can be concluded that in this module structure, the ideal grating period is 3.6um.

In order to verify the sparkle improvement effect of the LDF with different designs, we selected four different LDF designs (A/B/C/D), and made display modules with AG cover glass, finally produced five schemes. The distance d between the LDF and the pixel and the grating period T are different for each model, and the optimal grating period T' is calculated according to Equation (4). And, according to $|T'-T| \cdot 100\% / T'$, we calculated the deviation ratio K between the actual grating period T and the optimal grating period T' of the LDF. Finally, we used the SMS1000 equipment to test the sparkle values of the green picture and made a subjective judgment according to the sparkle effect, and the relevant test results are shown in Table 2.

As can be seen from Table 2, the smaller the deviation ratio K is, the smaller the sparkle value is, and it can be effectively matched with the visual sensory evaluation. Moreover, according to the results of Split3 and Split4, it can be seen that the LDF can be adjusted to the optimal grating period T' by changing the distance between the pixels layer to LDF. Then we can obtain a better effect of the sparkle. According to our visual judgment, the sparkle performance of Split1 and Split2 can already meet the user's needs. Based on this result, it can be assumed that under this experimental model, the deviation ratio K within 40% can satisfy the demand, which is helpful for the development and selection of LDF materials.

We chose to use the LDF A to further verify the difference in the display effect with different AG cover glass. For testing and verification, we made AG cover glass with different haze and roughness, and compared with the module stack without LDF, the results are shown in Table 3.

Table 2. The improvement effect of different design solutions of LDF on sparkle

Split	1#	2#	3#	4#	5#
LDF	A	B	C	C	D
Grating type	rectangle	rectangle	sinusoidal	sinusoidal	sinusoidal
d	145um	130um	170um	415um	145um
T	5um	2um	8um	8um	10um
T'	3.6um	3.2um	4.2um	10.2um	3.6um
K	39%	38%	90%	22%	178%
Sparkle Value	2.4	2.4	3.4	1.2	3.6
Visual Evaluation	Slight sparkle	Slight sparkle	Serious sparkle	Almost no sparkle	Serious sparkle

Table 3. Comparison of sparkle effect of different AG cover glass with LDF

Split		6#	7#	8#	9#
AG Parameter	**Haze**	40%	30%	30%	20%
	Roughness(Ra)	0.35um	0.35um	0.25um	0.25um
Sparkle Value	**Without LDF**	5.5	4.9	6	4.8
	With LDF	1.9	1.5	2.2	1.8
Sparkle improvement ratio		65.5%	69.4%	63.3%	62.5%

Based on Table 3, the following conclusions can be drawn:

1. When there is no LDF: Split7# and 9# have low sparkle, which means that when the haze of the cover glass is the same, the higher the roughness, the more serious the sparkle; Split6# and Split8# have serious sparkle, which means that when the roughness of the cover glass is the same, the lower the haze, the more serious the sparkle.
2. With the LDF: The sparkles of all the solutions were substantially improved, with the improvement ratios exceeding 60%, among which Split7# had the lowest sparkle with the AG parameters of Haze30% and Ra0.35um.

The above conclusions have certain reference significance for the AG parameter design of cover glass.

4. References

1. Paz, V. F., Kohlenbecker, S., & Persidis, E. (2018). *8-2: Sparkle Characterization of Anti-glare Layers on Displays with a Grey Value Histogram Analysis. SID Symposium Digest of Technical Papers, 49(1), 76–79.*
2. Moharam, M. G., & Gaylord, T. K. (1982). *Diffraction analysis of dielectric surface-relief gratings. Journal of the Optical Society of America, 72(10), 1385.*