# Integrated Multilayer Analysis Platform for OLED Evaporation and Encapsulation Based on TOFSIMS

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## Abstract

***TOF-SIMS can expand the range of detectable scenarios and enhance detection capabilities, enabling the construction of a comprehensive detection platform that integrates the entire EVEN process. Specifically, it focuses on the detection of light extraction structures and BPDL.***

## Keywords

Organic Light-Emitting Diode(OLED);Time of Flight Secondary Ion Mass Spectrometry(TOF SIMS); Evaporation and Encapsulation process(EVEN）; Analysis; Reliability Test; OLED films distributions and shadows; Anode Surface Residual Film; Black Pixel Design Layer(BPDL)

## Introduction

Flexible OLEDs have many advantages, such as free forms and super picture qualities. These unique characteristics of OLED offer vast application prospects in various fields, such as smartphones, foldable, laptops, and automotive displays. As Artificial Intelligence(AI) technologies have many advantages in PCs and mobiles such as higher computing power and excellent image capabilities, but also bring many issues such as power consumption and heat dissipation due to the increased computing power of chips. This is reflected in the demand for higher image quality, higher reliability and lower power consumption. High efficiency and long high-temperature life have become the essential parameters for evaluating OLED panel. Currently, there are low-power technologies, such as LTPO technology, DBR structure (such as CVD1, LiF, and CPL layer), Efficiency Enhancement Structure (EES), Color Filter on Encapsulation(COE),tandem OLEDs device, etc.,.Meanwhile, compensation algorithms were developed to solve the burn-in problem caused by temperature rise(1-3).

The production of screens with low power consumption and high reliability is a systematic project, which requires collaborative production and inspection capabilities. The complexity of the layer structure and composition, as well as the refinement of the pixel structure, bring greater challenges to the existing detection process. This requires the introduction of a coating inspection system that can simultaneously separate and image complex components in real time with high spatial resolution. TOF SIMS can obtain multi-dimensional real-time spatial resolution information on the surface and depth of the film through the spatial capture principle of secondary ions, and is not limited by the composition of the layer, the size of the layer, the complexity of the layer and the spatial resolution, which makes it have great potential for multi-scene use. At the same time, the element content information of the coating can be obtained through three-dimensional reconstruction, providing real-time feedback online data in a more humane way.

In addition, TOF SIMS can also help manufacturers solve the detection challenges of fine pixel layouts and complex layer structures. In 2024, we detected and analysed the OLED emission layer and cathode using TOF SIMS and published in SID 2024 DIGEST.506，the layers are shown in **Fig1**. with solid blue lines. On this basis, TOF SIMS was used to detect the LiF layer and residual film in real time. The OLED structure shown in **Fig.1**. The dashed box highlights the corn layers.

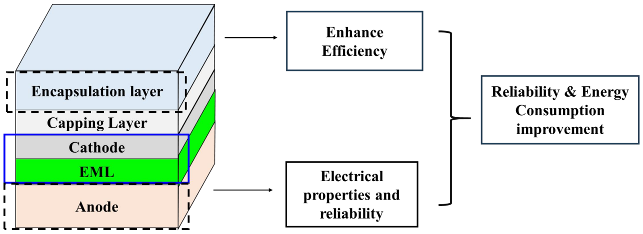

**Figure 1.** OLED Device Structure and the dashed box highlights the corn layers.

In this work, the correlation between the light output efficiency and the growth quality of the LiF layer was established by in-situ spatial detection of LiF and film residues with high precision in original time. At the same time, the influence of residual film on high temperature reliability is analyzed. Through the real-time field detection of TOF SIMS, the detection capability of optical structure film and residual film can be effectively improved, which proves that improving the detection capability of film layer can effectively improve the power consumption and reliability performance of products. The detection of light structure coatings can help us effectively improve energy efficiency and optimize power consumption performance. Residual film detection can help us effectively improve the reliability of the screen at high temperatures.

## Results and Discussions

### *2.1 Microscopic quantitative characterization of OLED films shadows and distributions*

The encapsulation layer has more functions, including flexibility, multi-layer to improve light efficiency, etc. With the advent of AI, improving efficiency has become a strong demand, but the luminous efficiency of OLED materials tends to be a bottleneck, and blue phosphorescent still has certain difficulties in mass production, and it is challenging to increase energy consumption from the perspective of electroluminescence, so we need to optimize the optical path structure to improve the light efficiency. Among them, the use

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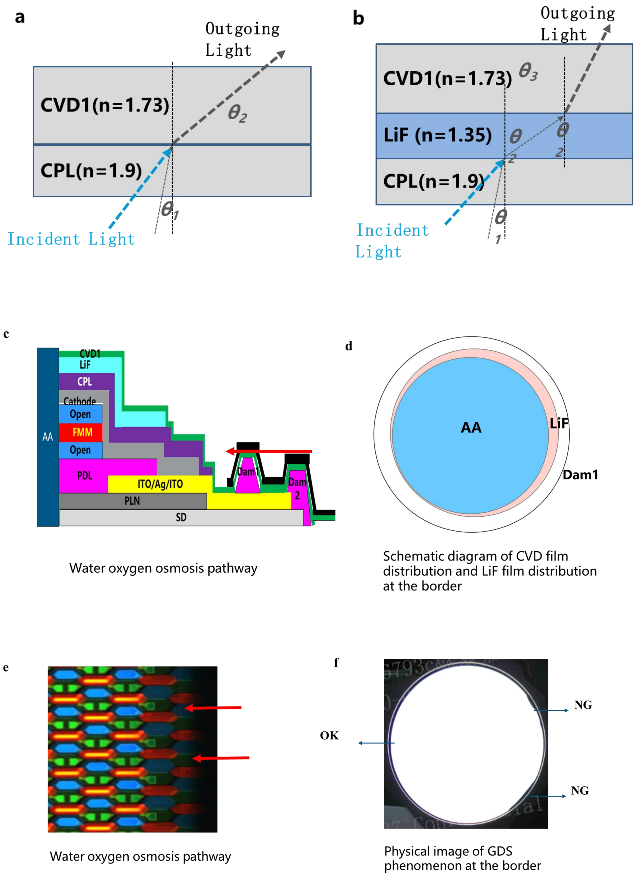
of the refractive index difference of multilayer structure is an effective method to enhance the external light. We use LiF with low refractive index (n=1.3)and high transmittance(above 90% at 300-800nm) between Capping Layers (CPL)  and CVD1 to improve the light output efficiency, as shown in **Fig.1**.

In the OLED production process, since the melting point of LiF material is 848°C, it is necessary to heat the LiF material from a point source and evaporate it onto the panel through open mask patterning. However, there are the two problems in practical production of  LiF. Firstly, LiF is not sensitive to the monitoring equipment of the existing production line, and the specificity is manifested as light microscopy to check the boundary of OLED films, but the transmittance of LiF material is high and no obvious fluorescence reaction, so the distribution of LiF films cannot be effectively monitored. Secondly, LiF materials are easy to absorb water, and once there is LiF on the bezel, water vapor may enter the luminous area through the LiF channel in a high humidity environment, and black spots will appear, as shown in**Fig.2c-2e**. In a previous study (4)， TOF SIMS is able to visualize the microscopic state of material layers as well as distribution using 3D image reconstruction. For this purpose, we performed TOF SIMS analysis on samples with edge GDS（Growing Dark Spot） (**Fig.2f**).



Water oxygen osmosis pathway

Schematic diagram of CVD film distribution and LiF film distribution at the border

Water oxygen osmosis pathway

Physical image of GDS phenomenon at the border

**Figure2**.The function of LiF, the defect caused by LiF and detection by TOFSIMS. (**a**) without LiF; (**b**)with LiF. (**c**) Pixel real photo; (d)and(e) Schematic diagram of the distribution of OLED films in the AA and  bezel;(e)Real shot of GDS;

As shown in **Fig.3a-3f**, the 3D distribution of LiF materials in the Dam1 region at the borders of the NG and OK samples of the sample. It can be seen that there are significantly more LiF materials at the dam at the NG points, and they exceed the boundary of SiNx (**Fig.2-2c**). And, there are no LiF materials in the OK sample, and all of them are completely covered by CVD films( **Fig.2e-2f**). LiF material itself is prone to water absorption. If SiN or other barriers prevent water vapor from entering, water vapor will verify the edge entry, resulting in abnormal display.

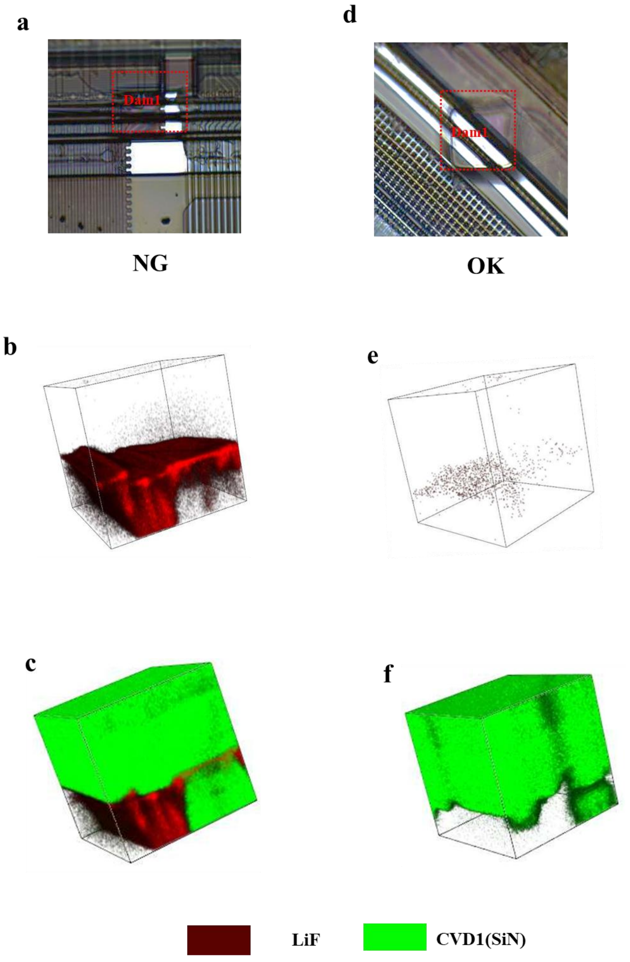
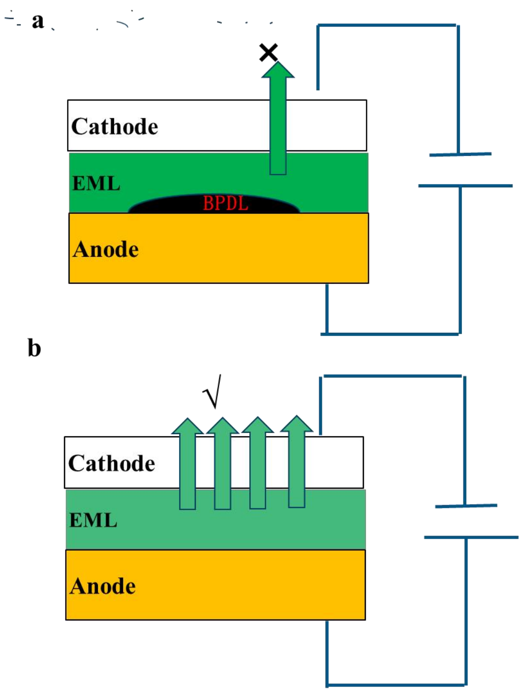


**Figure3**. (a-c) and (e-f) are the results of NG and OK samples induing  3D render of LiF,3D render overlay of SiN and LiF

### *2.2 Study Anode Surface Residual Film and improvement of high-temperature reliability*

Due to its high Optical density value, Black PDL has the effect of blocking  the reflection of external ambient light, and has become the preferred material for reducing reflectivity in COE technology(5-6). The addition of black absorbent ink to BDPL adds to the exposure process, and there will be BPDL residue on the anode. which effects electrical characteristics, This is because the residual film can cause breakdown of the OLED material, resulting in a short circuit between the cathode and anode (**Fig.4a-4b)**and lead to some poor image quality such as discolor(**Fig.4c-4d)**, With TOFSIMS analysis, found the BPDL residue on the anode surface (**Fig.4e)**. After the increase of exposure time and ITO thickness, there was no residue on the anode surface shown as **Fig.4f-4h**. At the same time, adjust the thickness of the OLED micro-cavity, and the OLED efficiency and image quality reached the standard，the results are shown in **Table 1**. **Table 1** shows that the thickness is increased by 20A, and the efficiency and reliability are the best.



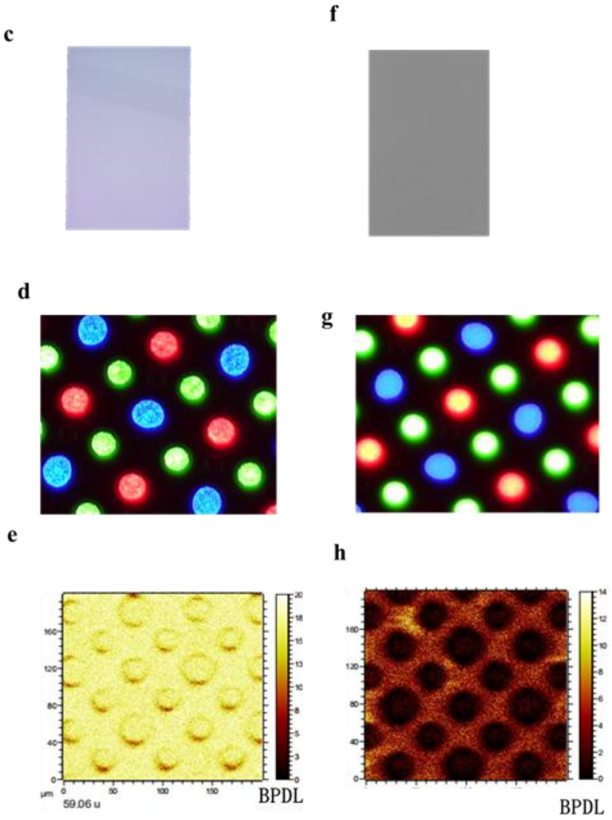


**Figure4.** The effect of residual film, and detect by TOFSIMS. (a)The OLED sample with residual ; (**b**) The OLED sample without residual. (**c-e**)and(**f-h**) are the results of(**c**)and (**f**).

Table 1. Characteristics of ITO and panel.

| ITO thickness | | Ref | Ref +20A | Ref+40A |
|---|---|---|---|---|
| Reflection (%) | 460nm | 89.5 | 87.73 | 85.80 |
| | 530nm | 94.26 | 94.02 | 93.19 |
| | 630nm | 95.37 | 95.43 | 94.77 |
| Rs ohm/☐ | | 432.6 | 431.6 | 434.9 |
| Efficiency | | 100% | 100% | 95% |
| Reliability （85℃） | | NG | OK | OK |

In-Line structure supporting in situ TOF-SIMS was designed, as shown in **Scheme 1**. **Scheme 1a** depicts a schematic of the process for OLED Evaporation process. **Scheme 1b-1d** Indicates the position of the OLED film layer. precisely regulating the characteristics of the film layer, and the operation flow chart and real-time inspection to realize in-situ correction of the vaporized layer through manual real-time comparison or automatic AOI inspection. In the future, combined with AI+big data, it is expected that big data attribution methods such as PCA (cluster analysis) will be used to classify defects, find out defects in real time, and carry out the fastest production line production control.

## Conclusions

This paper mainly describes the application of TOF-SIMS in the detection of optical structure film and residual film, and establishes the standard platform of how to detect and judge its grade in the actual production process, so as to help improve the yield of the product production process. By integrating production line testing, we can not only effectively support the early technical research, but also provide support for the subsequent research and development to mass production, such as TADF three-source co-evaporation, higher generation production line (G8.6). At the same time, the detection method also provides technical support for the quality verification of higher specification products.

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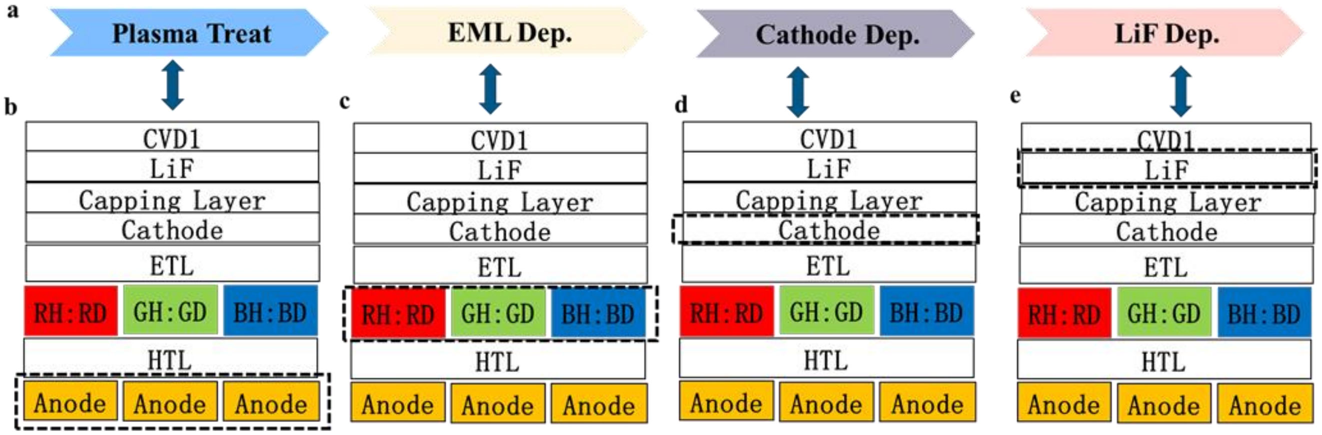

**Scheme 1**. The operation flow chart in the production line.(**a**) the process for OLED Evaporation .(**b-e**) The specific films layer.