# A Novel Methodology for Evaluating Corrosion Failure Risk of OLED Panels

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## Abstract

***This work suggests a novel methodology for corrosion failure risk detection of OLED panels for the first time. Corrosion on OLED devices is one of the major quality issues, which negatively affect the long-term reliability of the OLED panels. As the screen size and pixel resolution increase, corrosion failure issues have become the most detrimental quality problem for OLED devices. Corrosion failure itself is a well-known electrochemical reaction phenomenon under high humidity and electrical potential load. For its catastrophic effect on device long-term reliability, lots of research has been performed for many years. Still proper methodologies for corrosion failure risk assessment have not been developed due to its complicated electrochemical behaviors. This study identifies three key factors contributing to corrosion failure in OLED devices: (1) moisture penetration through organic layers, (2) anodic oxidation of electrodes influenced by voltage polarity under high-temperature and high-humidity conditions, and (3) internal electrode connections to the panels. To assess the corrosion failure risk in OLED panels, we propose an integrated electromagnetic and circuit simulation methodology to rapidly evaluate corrosion failure risks. Based on the newly developed simulation methodology, robust OLED panel designs are suggested and experimentally verified.***

## Author Keywords

Corrosion failures; Anodic oxidation; Voltage polarity based electrode oxidation; Electrochemical reaction; Internal electrode connections. .

## 1. Introduction

Unlike semiconductors, OLED panels use numerous organic films. In addition to organic materials for the emissive layer, various organic films are employed for preventing electrical shorting between sub-pixel electrodes, defining pixel boundaries through a pixel defined layer (PDL), and facilitating the connection between the panel and the OLED driver IC via an anisotropic conducting film (ACF) during the bonding process. However, this inevitably leads to moisture absorption in high-temperature and high-humidity conditions. Long-term OLED panel operational evaluations in high-temperature, high-humidity chambers are crucial for ensuring the long-term reliability of OLED devices. These evaluations assess various product reliability issues, including moisture penetration through organic layers, mechanical stress-induced cracks due to temperature and humidity fluctuations, and electrode oxidation and corrosion resulting from electrolyte formation within the organic layers. With the trend of increasing resolution in OLED products, the design necessitates narrower spacing between wiring in the panel. This has accelerated the issue of corrosion failure between electrode wirings, which has emerged as the most significant quality issue in current OLED products. In this study, we identified three key mechanisms of corrosion failure within OLED panels (moisture penetration through organic layers, electrode anodic oxidation, and electrode connection) and proposed an integrated electromagnetic and circuit simulation methodology to rapidly evaluate corrosion failure risks.

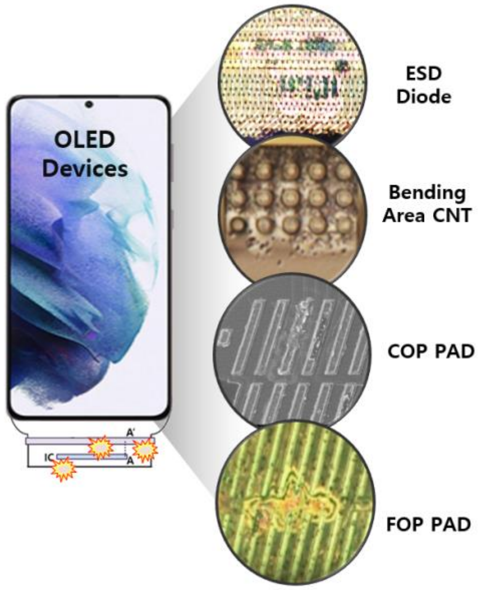

**Figure 1.** Major corrosion failure hotspots in OLED devices

## 2. Corrosion Failures in OLED Devices

Corrosion defects, one of the chronic quality issues in OLED panels, are challenging to diagnose accurately and continue to impact the yield of many OLED products. Typically, the evaluation of corrosion, which affects the reliability of OLED panels, is conducted by applying electrical signals to the OLED panels in a high-temperature and high-humidity chamber over an extended period. The process involves monitoring for any abnormalities in the electrical signals. When corrosion causes metal wiring to oxidize or break, the resistance within the conductor increases, leading to signal wiring issues in the panel and changes in the display brightness characteristics. If such screen anomalies occur, destructive analysis techniques such as SEM (Scanning Electron Microscopy), FIB (Focused Ion Beam), EDS (Energy-Dispersive X-ray Spectroscopy), and TOF-SIMS (Time-of-Flight Secondary Ion Mass Spectrometry) used to confirm corrosion-related failures by identifying metal oxidation, electro-migration, or ion migration. As shown in Figure 1, the hotspots for corrosion failures in OLED panels are mainly concentrated near the PAD bending areas, where moisture permeation through the organic film is more likely. Many corrosion defects have been detected near COP (Chip on Plastic) PADs, FOP (Film on PCB) PADs, or ESD diodes through OpHS (Operating Heat Soak) reliability evaluations. Component analysis of the defective locations revealed that oxides formed on the

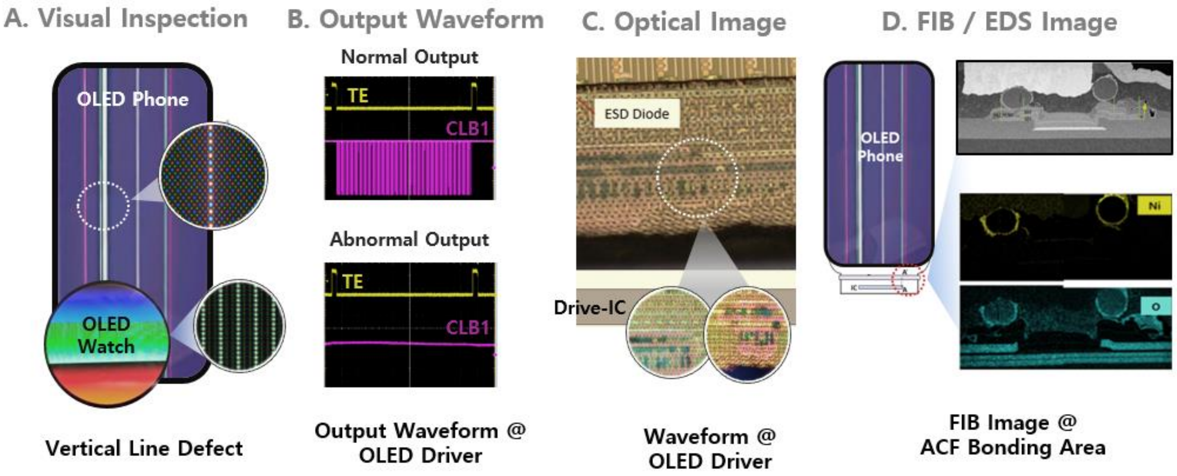

**Figure 2.** Analysis of corrosion failure location in OLED Devices

surfaces of metal wiring and conductive balls, or electro-migration caused disconnections or increased resistance. As shown in Figure 2, various forms of OLED screen abnormalities have occurred during the reliability evaluation of several OLED products. Observations of defective samples revealed many bright lines in the form of vertical or horizontal stripes. These line defects are identified by applying different signals to the OLED driver for each area, confirming output anomalies due to increased resistance in the signal wiring. After verifying abnormalities in the electrical signal waveforms, observations of the defective areas using an optical microscope revealed various forms of blistering and discoloration. These corrosion phenomena were found to be randomly distributed across the entire sample surface, rather than being confined to localized areas. Generally, corrosion defects manifest as blisters with discoloration. However, some corrosion spots did not exhibit discoloration or blistering, yet surface destructive analysis later revealed oxidation. When surface destructive analysis, such as FIB and EDS, was conducted on blistered and discolored areas of corrosion defects, it was found, as shown in Figure 2D, that the Ni-coated conductive balls in the ACF bonding areas, which electrically connect the display panel with the driver IC and PCB, were degraded. The chemical element analysis via EDS detected oxidation of the nickel conductive balls. In contrast to areas that exhibited normal output signals, FIB image analysis of various corrosion defect areas clearly showed nickel loss and oxidation

## 3. Identification of Corrosion Failure Mechanism in OLED Devices

Corrosion defects generally result from electrochemical reactions where metals react with oxygen, hydrogen, or hydroxides to form oxides. This phenomenon, especially corrosion caused by moisture, has been extensively studied in industry [1]. Notable forms of corrosion include galvanic corrosion [2], where different ionization tendencies of two materials in contact cause corrosion via an electrolyte; pitting corrosion [3], where ions like chloride destroy surface films and create small holes that rapidly corrode the interface; and crevice corrosion [4], where corrosion spreads through gaps between metals or between metal and non-metal surfaces. Despite extensive theoretical and experimental research in these areas, traditional electrochemical theory struggles to explain the mechanisms behind corrosion observed during OLED reliability evaluations under high temperature, high humidity, and electric field conditions. Conventional electrochemical theories approach redox reactions using the *Butler-Volm*er Equation and *Tafel* Equation, assuming that surface concentration and solution concentration are nearly identical at low current and voltage and that the corrosion rate is proportional to the activation over-potential. However, these assumptions fall short of explaining the corrosion mechanisms observed during OLED reliability evaluations. This study meticulously observed failure phenomena during OLED reliability tests, identifying common conditions across various products. A numerical analysis model was developed and experimentally validated to better understand the underlying causes of these corrosion defects.

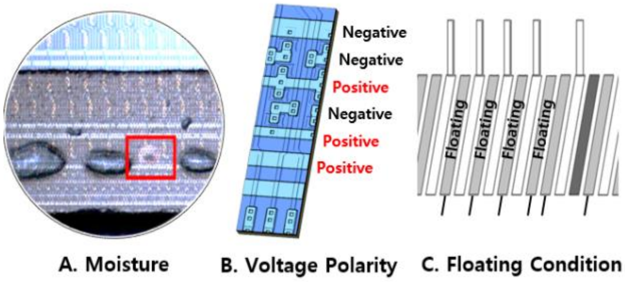

**Figure 3.** Key factors contributing to corrosion failure

Corrosion defects in OLED devices manifested only when all three of the following conditions were met, and the severity of the corrosion defects was found to be proportional to the intensity of the electric field. The first condition is moisture penetration through the organic film. Corrosion in OLED products is observed only in layers that are in direct contact with organic films such as VIA and ACF. It is believed that high temperature and high humidity reliability testing leads to the formation of electrolytes due to moisture penetrating through the organic film. The second condition is voltage polarity-based electrode anodic oxidation. Even when the potential difference of the pads where corrosion occurs is the same, corrosion manifests only at the anode. It was observed that the nickel coating on the conductive balls was lost or formed nickel oxide only in the anodic region, leading to electrical short circuits due to increased resistance. The third condition is the presence of an electrical connection to the electrode. When observing electrodes where corrosion occurred, it was noted that dummy floating pads with significant potential differences between the pads but no current flow exhibited significantly less loss of the nickel coating on the conductive balls. Regardless of the strength of the electric field between the wires, if the wiring is not connected to the internal panel and remains as dummy floating, the current density decreases, and the incidence of corrosion defects is significantly reduced. Figure 3 shows the three key factors contributing to corrosion failure in OLED devices.

## 4. Corrosion Failure Prediction Methodology

In this study, we developed a simplified analysis methodology that integrates electromagnetic simulation and circuit simulation to predict corrosion failure risk for the first time. We validated the effectiveness of this model through experiments and proposed an improved PAD design, which we also verified to be effective in practice. The simulation procedure developed in this study to detect corrosion risk in the COP PAD area within OLEDs is illustrated in Figure 4. Essentially, to assess the risk of pad corrosion, the electric field and current values generated by the driving signals applied to each wire are extracted over a minimum repetition timing and then integrated to calculate the corrosion risk. At this stage, the selection of wires for data extraction and the extraction of values are screened and evaluated only if they meet the three corrosion conditions described in the previous sections. First, for electromagnetic simulation, a GDS layout-based 3D modeling is constructed. To enhance the accuracy of the simulation model, it includes the nickel-coated conductive balls necessary for electrical continuity between the OLED panel's lower part and the signal wiring. Next, the minimum repetitive driving timing signals used for OLED operation are applied to the pad electrodes. The electric field and current values at the pad section are then spatially integrated over each time frame, and the average values are extracted for use.

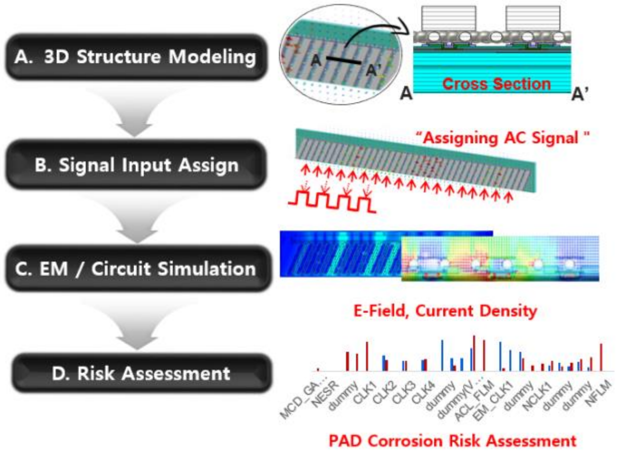

**Figure 4.** Simulation procedure for corrosion risk detection

We also propose two different simulation strategies to overcome multi-scale transient limitations. The first method involved reducing the modeling size to focus on areas that directly impact the electric field and current levels between pad electrodes.

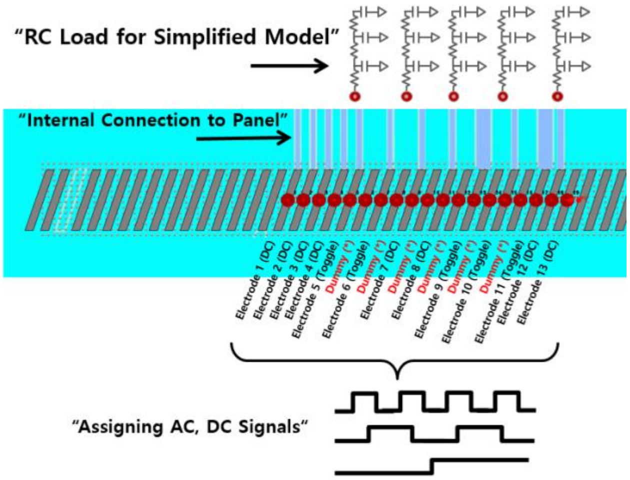

**Figure 5.** Circuit integrated co-simulation mode

This was based on findings from high-temperature and high-humidity operational reliability (OpHS) evaluations, which showed that corrosion defects occurring near COP, FOP, or ESD diodes accounted for over 90% of all corrosion defects. To appropriately handle the RC load imposed on the entire OLED panel as boundary conditions and thus reduce the size of the electromagnetic analysis modeling, the RC values across the connecting wires were first extracted using simulation. As shown in Figure 5, these values were then used as inputs for Circuit-Integrated EM Co-Simulation to construct the model. Secondly, to reduce the computational cost of transient analysis, which extracts the electric field variations over the entire time frame based on the OLED driving waveform, we developed an in-house multi-state static EM Solver. This allows the simultaneous execution of dozens of Static analyses, effectively replacing the time-consuming transient analysis

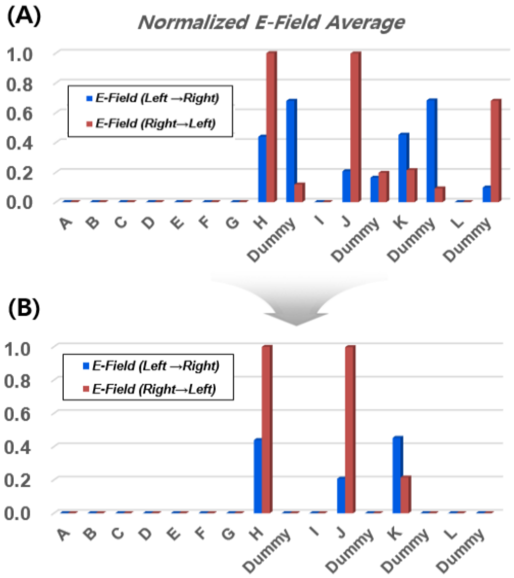

**Figure 6.** Corrosion risk assessment process in COP PAD

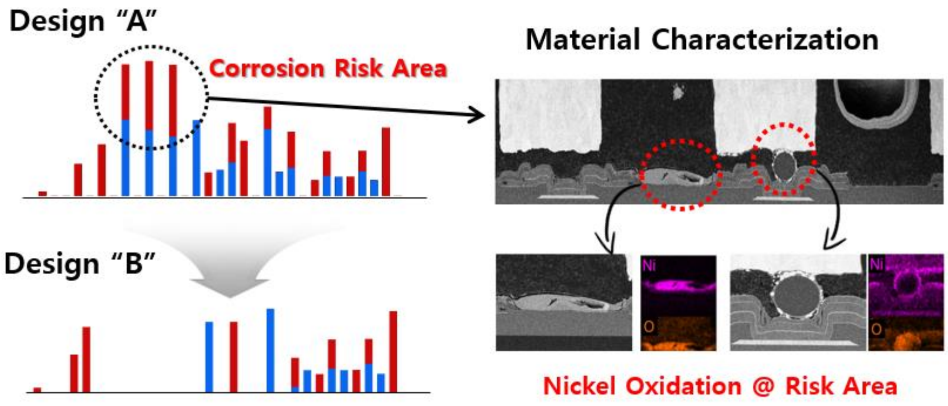

**Figure 7.** Corrosion risk assessment and improvement of COP PAD based on the newly developed simulation methodology.

## 5. Corrosion Risk Assessment Process

To prioritize the corrosion risk of the OLED pad area, we first conduct a simulation to extract the electric field for the entire pad-included region without considering the conditions for corrosion occurrence. As shown in Figure 6, we extract the average electric field for all pads based on the overall drive signal variations. Next, by selecting pads with potential anodization considering voltage polarity, the number of pads is reduced, as depicted in Figure 6A. Each pad electrode has two differently colored bar graphs: the blue bar represents the average electric field strength when forming an anode relative to the adjacent right side, while the red bar indicates the electric field strength when forming an anode relative to the adjacent left pad. Finally, by applying the condition that the PAD electrode is connected to the panel, we can prioritize the electric field strengths of pads that directly affect corrosion, as shown in Figure 6B. Consequently, the corrosion defects occurring within the OLED pads are primarily influenced by the electric field strength generated by the OLED drive signal. This process is determined by the relationship with surrounding wiring, contributing to corrosion when anodization is possible, and further determined by whether the pad itself is floating.

## 6. Results

Previously, assessment of the corrosion failure risk in OLED panels has been conducted only by time-consuming trial-and-error long-term reliability experiment processes. A lot of design modifications were required to address the potential design risk factors for corrosion failure. With a newly developed simulation methodology, we can extract averaged E-field values in each pad and easily assess the corrosion failure risk based on the three mechanisms (permeability, voltage polarity, and current path) that we found in this research. For the "Design A" in Figure 7, corrosion-failure risks were evaluated by using the simulation methodology and verified via material characterization. As shown in the figure, corrosion-induced nickel oxidation and electro-migration were observed in the COP pad. Thereby resistance of the pad electrode was increased and abnormal screens were displayed during the OpHS reliability test. We also suggested an improved COP pad design based on the simulation results as shown in "Design B" and verified by the experiment

## 7. Conclusion

As the demand for high-resolution, high-quality OLED panels continues to grow, the importance of corrosion-related reliability issues within panel design has become increasingly significant. Recently, corrosion issues have become the most critical defect issue, accounting for up to 20% of product defects. Analyzing the causes and verifying the risks of corrosion in OLED panels has long been a challenge in the display industry. Additionally, it was previously impossible to analyze the multi-physics and multiscale corrosion phenomena in OLED pixel design and driver stages through simulation. In this paper, we identified the mechanism of moisture permeation through the OLED organic film and voltage polarity-based anodic oxidation in a high-temperature and high-humidity environment, as well as the internal electrode connections within the OLED. Based on this understanding, we propose a simplified analysis methodology that integrates electromagnetic simulation and circuit simulation for the first time. We validated the effectiveness of this model through experiments and proposed an improved PAD design, which we also verified to be effective in practice. Our work demonstrates that a newly developed simulation methodology can maximize OLED productivity and inspire robust OLED panel designs

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