Application of Liquid Crystal Films for Micro-LEDs Inspection

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ABSTRACT

We demonstrate a method for inspecting micro-LEDs by placing a liquid crystal (LC) film over the micro-LED wafer. When illuminated, micro-LED dies can generate an open circuit voltage through the photovoltaic effect, which can be detected by observing changes in the transmittance of the LC film.

1. Introduction

Manufacturing RGB full-color micro-LED displays at reasonable costs comes with several challenges, such as mass transfer and reduced luminous efficiency [1-3]. The large-scale transfer of micro-LED dies from the wafer to the display substrate can lead to LED die loss or misplacement, which results in defects and lowers production yields. Much of the research in micro-LED display manufacturing has concentrated on mass transfer technologies, while studies focused on the mass inspection of micro-LED dies remain limited [4]. Given that micro-LED dies are too small to be repaired, it is crucial to screen for those with the necessary EO quality before mass transfer. Electroluminescence (EL) technology is widely used to detect the quality of conventional LED dies [4]. However, it poses challenges for micro-LED dies due to the small size of their electrodes, making it difficult to contact them with probes. Additionally, the small probe tips are challenging to manufacture and tend to wear out quickly, which results in high costs and time-consuming inspection processes.

In this study, we propose an alternative method for inspecting the quality of micro-LED dies. LEDs and solar cells exhibit a reciprocal physical interaction [5]. Specifically, LEDs convert electrical energy into light, while solar cells convert light into electrical energy. Consequently, micro-LED chips can generate an open circuit voltage when illuminated by light, a phenomenon known as the photovoltaic (PV) effect. The generated open circuit voltages from micro-LED dies reveal distinct EO characteristics that differ from the EL and PL methods [6,7]. The varying quality of micro-LED dies produces different open circuit voltages, which can be detected using LC films as the voltage sensing medium.

2. Experimental

The operational principle resembles that of an LC display, as shown in Fig. 1. The open circuit voltages generated by the micro-LED dies create electric fields of varying magnitudes that rotate the liquid crystal directors. This results in different levels of light transmittance when light passes through the LC film under a crossed polarizer configuration.

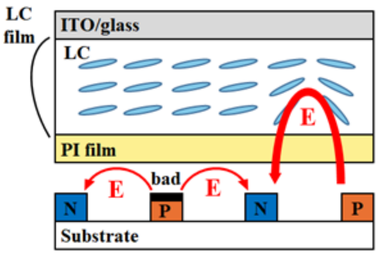

Fig. 1. Schematic diagram and working principle of liquid crystal film as a voltage sensing device. Different qualities of Micro-LED will produce different open circuit voltages and lead to different magnitudes of electric fields to rotate the LC directors, resulting in different transmittances when light passes through the LC film under the crossed polarizer scheme.

In order to demonstrate the proposed approach, the open circuit voltages generated by the PV effects of the micro-LEDs are simulated by applying a voltage on a gold interdigitated electrode (IDE) substrate (5 um/10 um, electrode/gap) instead of using real micro-LED wafers as shown in Fig. 2. The LC film consisting of a conductive indium tin oxide (ITO) glass substrate and a 5 μm polyimide (PI) film is filled with nematic LC (E7, $\Delta\varepsilon$ = 14.5, $\varepsilon_{\perp}$ = 5.1, ne = 1.75, no = 1.52). The gap of the LC film is maintained by a pair of 5 μm mylar spacers, as illustrated in Fig. 2. The distance between the LC layer and the IDE substrate should be as small as possible to allow the LCs to sense the small voltage produced from the IDE substrate. Therefore, the single substrate LC film is applied in this scheme, where a thin PI film is used to replace the conventional thick glass substrate (~ 700 um). Several methods have been developed to fabricate single substrate LC films for various applications [8-10]. Here, our single substrate LC film is fabricated by using the conventional bonding and debonding process and is provided by the Industrial Technology Research Institute [11,12]. The LC film is operated as a hybrid alignment nematic (HAN) mode with a set of IDE gold electrodes connected to the ITO substrate to optimize the EO performance of the LC film based on simulation results, which will be published in elsewhere.

3. Results and discussion

The POM photos of LC film under the influence of the different voltages applied on IDE electrodes are shown in Fig. 3, where the dark stripes are the opaque gold electrodes. The results indicate the LC film can senses the change of voltages of IDE. The voltage dependent grayscale values of Fig. 3 are further extracted and analyzed by using Image as shown in Fig. 4. The

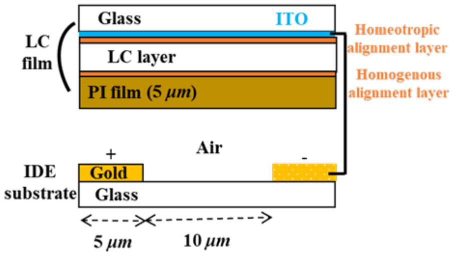

Fig. 2. Schematic diagram of the single substrate LC film, IDE structure and electrode connection.

grayscale of LC film decreases with the voltages applied on the IDE. Different quality of micro-LEDs can produce different open circuit voltages through light illumination, which can be distinguished by using LC films as the voltage sensing medium. It shows that our proposed scheme of detecting open circuit voltage of micro-LED is feasible. It is also possible to classify each of the micro-LEDs quality according to the grayscale level.

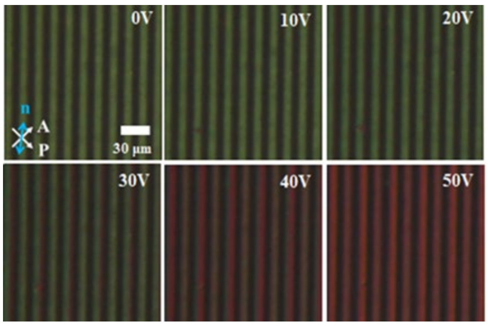

Fig. 3. POM photos of LC films under the influence of the different voltages applied on IDE electrodes, where the dark stripes are the opaque gold electrodes.

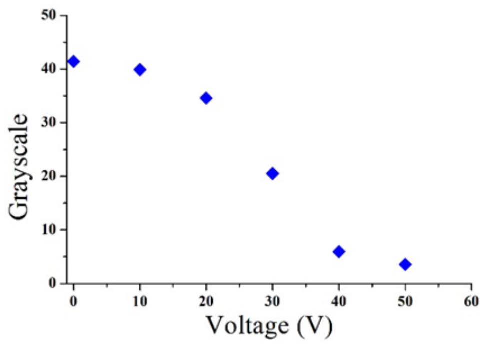

Fig. 4. Grayscale values as a function of IDE voltages. Different voltages are applied on the IDE substrate to simulate different qualities of micro-LEDs.

4. Conclusion

In summary, we presented a method for inspecting micro-LED using an LC film as a voltage-sensing device. This approach demonstrates that the LC film can produce different grayscale variations for differet voltages from PV effect. It indicates that our method can effectively differentiate the quality of micro-LED dies based on their varying open circuit voltages through the PV effect.

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