A Novel SPICE Compatible Current Model for OLED Circuit Simulation

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ABSTRACT

In this paper we propose a new equivalent circuit model of organic light emitting device (OLED). The physical-based model is considering the effect of high built-in voltage existing between the organic materials and the effect of non-ideal ohmic occurring at the contact between metal and organic. Compared with the measured IV data of RGB OLED samples and the result of conventional OLED model, the new one successfully shows the physical meaning and simulation accuracy. This model is SPICE-compatible and can be incorporated into circuit simulation without numerical difficulties.

Keywords: equivalent circuit model, OLED, RGB, SPICE model, compact model, circuit simulation, high built-in voltage, non-ideal ohmic effect

1 INTRODUCTION

Recent technological advances include the development of display transparency and flexibility that create new ways to integrate displays. Organic light emitting devices (OLEDs) have been proposed in the fabrication of high-brightness, high-quality, and low-power OLED-based display products [1-9]. OLED technology has also been shown that it has potential to overcome many of the limitations of existing display technologies. Continued improvements in advanced materials will enable OLED display manufacturers to enhance lifetime, stability, and light efficiency of display panels. Efforts are also under way to reduce the negative effects of heat, moisture, and dust on OLED performance. Diverse key materials are used in the organic emitter layers and the color of the emitted light depends upon the precise composition of the material. Red, green, and blue emissive materials can be used together to produce the full color spectrum. These improvements provide the product designer with the enhanced performance at lower cost. For examples, OLED technology offers the potential for bright, full color, high-resolution displays with high contrast ratio and power efficiency. It is known that the brightness of the OLED is controlled by the current density of the device; therefore, precisely controlling the current density of active matrix array is required. However, the currently used OLED models have encountered accuracy issues in the SPICE circuit simulation [1-9]. Therefore, physical-based OLED models will benefit the design and fabrication display panel products in microelectronic industry.

In this work, we propose a new physical-based OLED model for the electrical characteristics of the OLED devices. Our model considers the effect of high built-in voltage existing between the organic materials and the non-ideal ohmic effect occurring at the contact between metal and organic. Comparisons between the model and measurement for the OLED with red (R), green (G) and blue (B) three colors have shown very good accuracy. The significant improvement is mainly caused from the correction of the high built-in voltage and non-linear contact resistor effect. The new SPICE-compatible current-voltage model can be incorporated into OLED circuit simulation with numerical difficulties.

This paper is organized as follows. In Sec. 2, we present the equivalent circuit model for OLED with three different colors, RGB colors. In Sec. 3, we compare the simulation results of the proposed OLED model with the conventional OLED model as well as the measured data from the fabricated samples. In Sec. 4, we draw the conclusions.

2 THE PROPOSED EQUIVALENT CIRCUIT MODEL OF OLED DEVICES

The structure of OLED used in our modeling, simulation, characterization, and measurement is shown in the figure 1. This structure of OLED has multilayer of materials. To accurately model the current-voltage (I-V) characteristics of OLEDs, we should consider the effect of high built-in voltage existing among the layers of organic materials and the effect of the non-ideal ohmic that occurs on the contact between metal and organic. As shown in Figs. 2 and 3, the equivalent circuit of the new proposed OLED compact model is presented. The effect of high built-in voltage and the non-ideal ohmic effect are modeled with the variable resistance and the supplied battery. Shown in Fig. 3, we tie a DC voltage source in series with the ideal diode. The linear resistance of the ideal diode is also changed to a non-linear resistance, which reflects the physical model the so-called Schottky barrier [10]. With adding those two items into the ideal diode model, the new model can be directly incorporated into SPICE circuit simulator without any convergence problems.

By using the developed equivalent circuit model of OLED with RGB colors, we have written the corresponding SPICE net list, shown in the table 1, and used in our OLED circuit simulation. The model parameters are extracted with the intelligent parameter extraction technique, which was developed in our recent work [11]. We compare the results between the output of the new model and measurement data of the fabricated samples. Comparison with the result of conventional OLED model is also discussed, shown in the next section.

3 RESULTS AND DISCUSSION

Figures 4-9 are the comparisons between the measured data and the output of conventional model in linear as well as log scales, for the OLED with R, G, and B three colors, respectively. It is found that the conventional model has a totally wrong electrical behavior compared with the measured data. Such deviation not only occurs at the cut-in region but also appears in the turn-on situation. As a result, the brightness of OLED can not be calculated for the electroluminescence intensity, because it is significantly dominated by the current density.

From the modeling results shown in the figures 9-14, good agreement between the measurement and simulation is found from the proposed OLED model. The superior electrical characteristics are strongly correlated to the improved model accounting for the effects of the Schottky barrier and the high built-in voltage. Figures 9-14 exhibit the comparison results for the output of our model with the measured OLED data with the R, G, and B three colors, respectively. Dissimilar with the modeling results from the conventional diode model, our new model presents very good accuracy when describes the OLED physical characteristics in both the cut-in and the on-state regions.

4 CONCLUSIONS

In this paper we have for the first time proposed a novel OLED model which accounts for the electrical characteristics of RGB OLEDs successfully. The physical-based model has considered the effect of high built-in voltage existing between the organic materials and the effect of non-ideal ohmic occurring at the contact between metal and organic. This model is SPICE-compatible and can be incorporated into circuit simulation without numerical difficulties. With having the accurate simulation results, the current flowing through the OLED circuit can be correctly simulated. Consequently, the brightness of the OLED panel can be exactly controlled without using the area consuming driving circuit which benefits the design and fabrication of OLED panels.

5 ACKNOWLEDGMENTS

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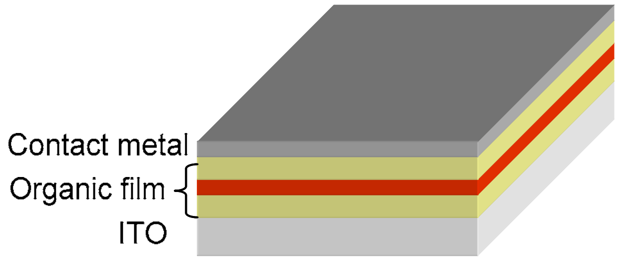

Figure 1: An illustration of the device structure of OLED

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.SUBCKT OLED p n area1=1e-6 pj1=1e-6
D1 p1 n1 Diode area=area1 pj=pj1
Rss p p1 'rss * exp(V(p1, p) / vbh)'
Von n1 n 'von'
.ENDS OLED
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Table 1. A set of the SPICE net lists used in our OLED modeling and simulation.

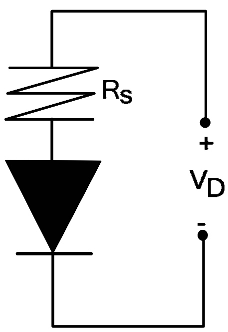

Figure 2: The conventional diode model used in SPICE OLED circuit simulation.

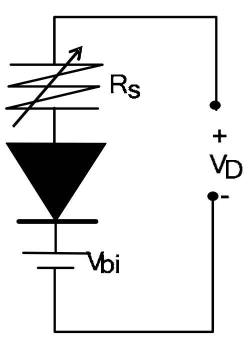

Figure 3: The new proposed OLED model.

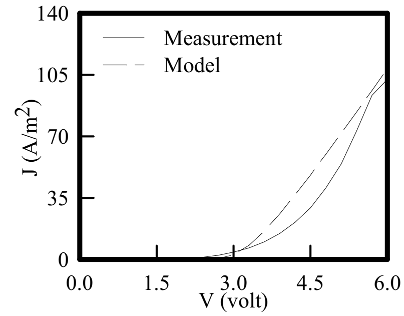

Figure 4: The IV curves of the red OLED with the conventional model.

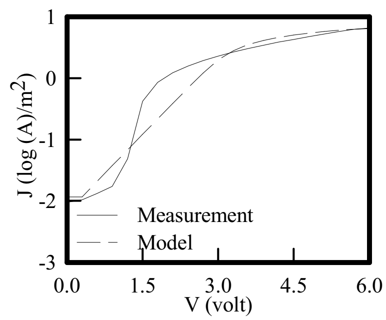

Figure 5: The IV curves of the red OLED with the conventional model in the log scale.

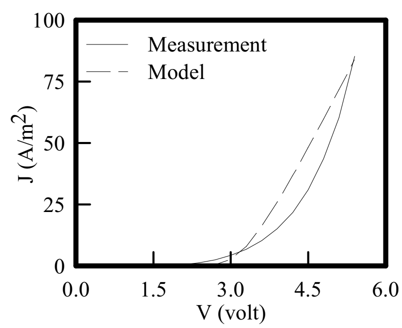

Figure 6: The IV curves of the green OLED with the conventional model.

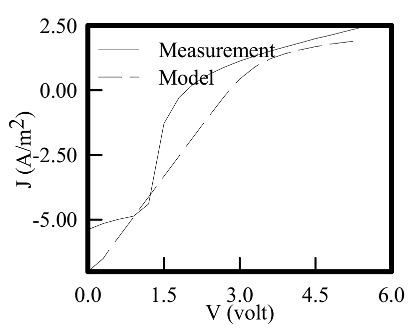

Figure 7: The IV curves of the green OLED with the conventional model in the log scale.

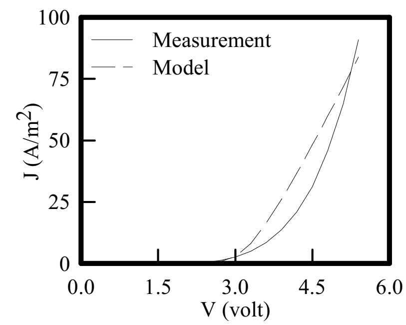

Figure 8: The IV curves of the blue OLED with the conventional model.

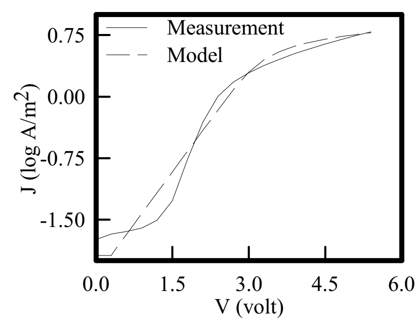

Figure 9: The IV curves of the blue OLED with the conventional model in the log scale.

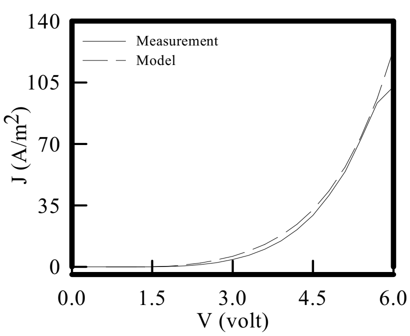

Figure 10: The IV curves of the red OLED with our new model.

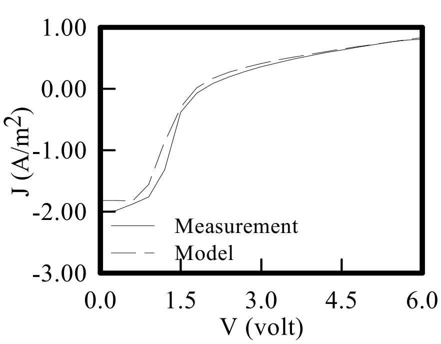

Figure 11: The IV curves of the red OLED with our new model in the log scale.

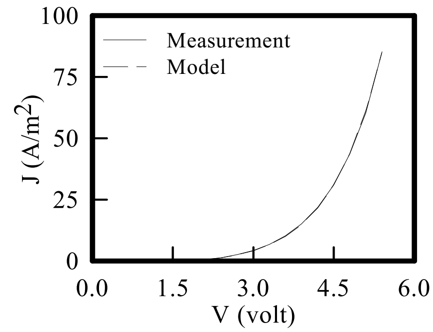

Figure 12: The IV curves of the green OLED with our new model.

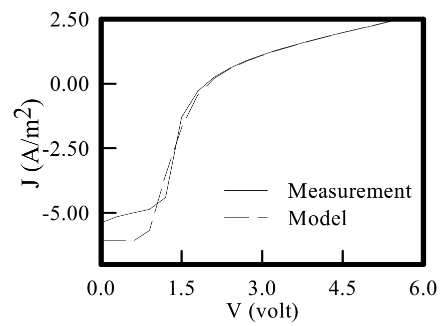

Figure 13: The IV curves of the green OLED with our new model in the log scale.

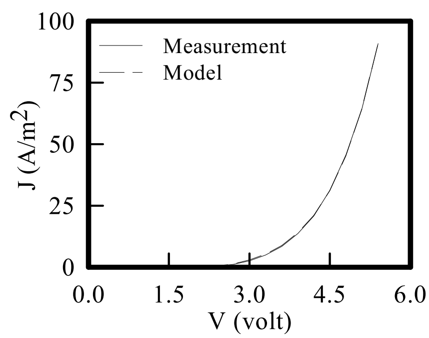

Figure 14: The IV curves of the blue OLED with our new model.

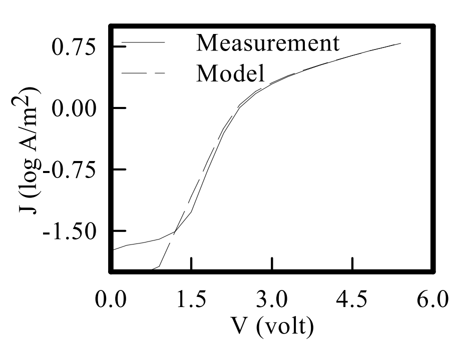

Figure 15: The IV curves of the blue OLED with our new model in the log scale.