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# Flexible characteristics of novel OLED Materials

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**Keywords:** organic light-emitting device, flexible, crack.

**Abstract.** Based on two novel organic materials coded as EB515 and EB 47 for fabricating a flexible OLED device, we, herewith, propose a noval testing experiment to demonstrate the electrical, optical, and lifespan performances of a flexible OLED by continuously bending it mechanically. The testing model is designed as the following: continuously cyclic bending 5000 times on a flexible OLED. After foregoing test, the findings show that the leakage current increased in the beginning of bending, then decreased; also the luminance of OLED reduced first, then recoverd. We, therefore, conclude that the reduction of leakage current and luminance may stem from the OLED surface microcracks in the process of bending. Also, after further examination to the surface of substrate by lift-offing the organic layer, we found the organic layer has been impaired and damaged, but the ITO layer remained in good condition.

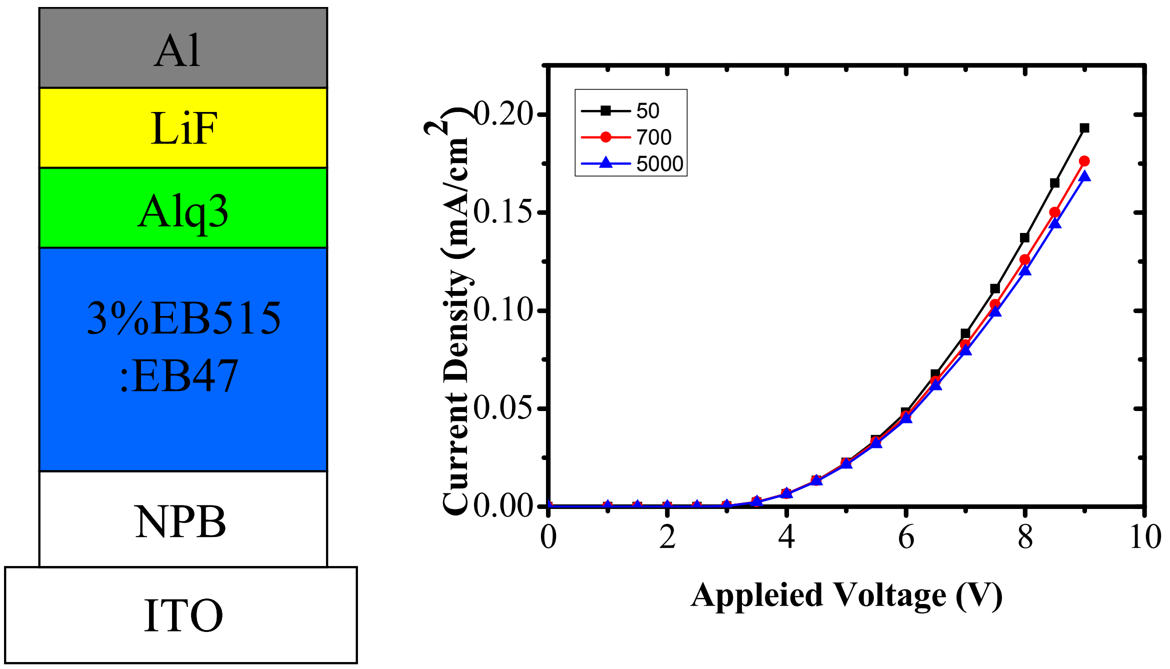
## Introduction

Flexible organic light-emitting diode ("OLED") has attracted the limelight in the current FPD development for its flexibility, lightweight, thinness, and broad application [1]. In this paper, we analyzed the electrical, optical, and lifespan characteristics of a flexible OLED upon continuous cyclic mechanical bending. The tested OLED was fabricated on a polyimide (PI) film with a glass carrier substrate. We found out current density would increase if we removed the flexible OLED from the glass carrier. Such phenomenon may contribute to the micro-contacts of ITO anode and cathode due to formation of micro-cracks upon bending [2]. When we bended the tested OLED for the first 50 times with a radius of curvature (Rc) of 14 mm, the current density increased again. To our belief, such a result was originated from the increase of current density of those micro-cracks. However, if further bending continued, the result showed the opposite --decrease of current density. That means: (1) density of micro-crack stopped increasing, and (2) depth and width of micro-cracks increased which resulted in an open-circuit, rather than micro-contacts. After 1000 times bending, the current density was kept at low value until 5000 times bending. At the same time, luminance decreased to 64% of its initial value when bending for 300 times. After 700 times bending, the luminance was back to 92% of its initial value and stayed almost the same level until 5000 times bending. Besides, although there is microcrack formation, no obvious degradation in storage lifetime. Also there is little change of dark spots of the flexible OLED in spite of mechanical bending.

## Experimental design

In this study, the tested flexible OLED was fabricated upon the glass substrate with the size of 275 x 335 $mm^2$. PI film (with Tg>200$^o$C) was spun on the glass carrier, then cured as the flexible substrate [3]. Before OLED fabrication, transparent passivation was formed on the PI film. Organic thin-films and Al cathode was evaporated upon the low-temperature sputtered ITO anode. After OLED thin-film deposition process, the afore-said device was encapsulated with stainless cover. Test device was scribed from the mother glass with 50 x 60 $mm^2$ [4]. Dimension of each test pixel was 3 x 3 $mm^2$. Flexible OLED was detached from the glass substrate before bending tests.

Fig. 1 (a) shows the novel materials for OLED device. Fig 1 (b) shows the J-V characteristics before and after detaching OLED from the glass carrier. One can see leakage current increased after peeling process, especially at low driving voltage, i.e. < 6V [5]. Micro-cracks were also observed under microscope with the dimensions of several μm (not shown here). It may result from: (1) different thermal expansion properties between glass carrier and PI film, and (2) strain when peeling PI film from the glass. Although the macroscopic lit-on pictures before and after detaching from glass substrate look similar, as shown in the inset of Fig. 1, there are some defects formed at microscopic range. Those micro-cracks resulted in micro-short-circuits and raised on the leakage current.




(a) (b)

Fig. 1 (a) Schematic diagram of the novel materials. (b) J-V characteristic of flexible OLED before and after detaching from the carrier glass substrate. Inset: pictures of flexible OLED with pixel lit on.

Afterwards, we bent the testing devices by different Rc.

When Rc=6 mm, open circuit was observed after 10 mins. ITO cracks across the device were formed from microscope image, which resulted in open-circuit failure. Furthermore, no obvious change was observed when Rc=14 mm is applied for several days. Hence, we selected this criterion for cyclic bending tests. Fig. 2 showed the current density and luminance variations under different bending cycles. One can see that current density increased and reached maximum when bending test lasted for 50 times[6]. Such a result may arise from the current density increase of micro-cracks, resulting in the micro-short circuits. Then current density decreased to a minimum value and reached a steady state after 1000 times bending. The final current density is even lower than the initial one. With continuously bending the flexible OLED, depth and width of the micro-cracks increase, which resulted in partially open-circuit condition, which not only reduced the leakage current, but also impeded the current spreading path. In Fig. 2(b), luminance under constant voltage driving decreased from 570 cd/m$^2$ to 430 cd/m$^2$ after 300 times bending. However, luminance returned again to 620-630 cd/m$^2$ after 1000-5000 times bending. When bending for several tens to hundred times, the micro-cracks resulted in a local heating and yielded a reduction in current efficiency, which in turns reduced the luminance under constant voltage. With increasing bending cycles, short-circuits became open-circuits, which resulted in an increase in current efficiency, which boosted up the luminance.

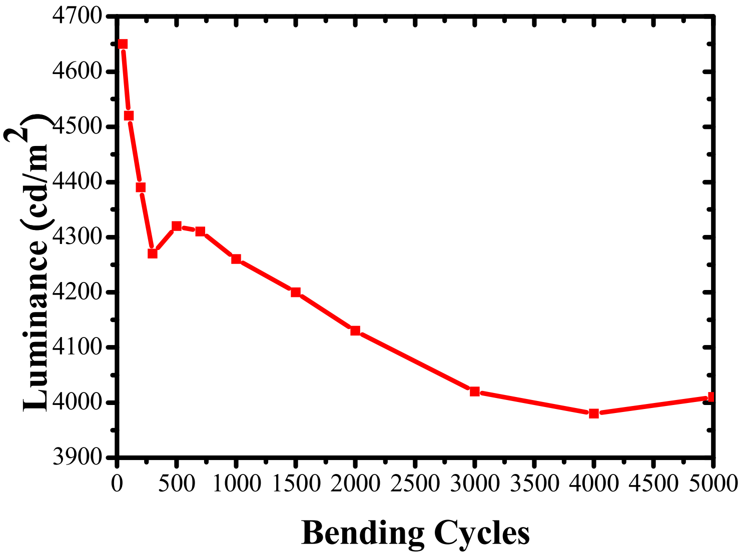



Fig. 2 Luminance under different bending cycles.

Fig. 3 showed the device with over 5000 times bending and compare with no bending device

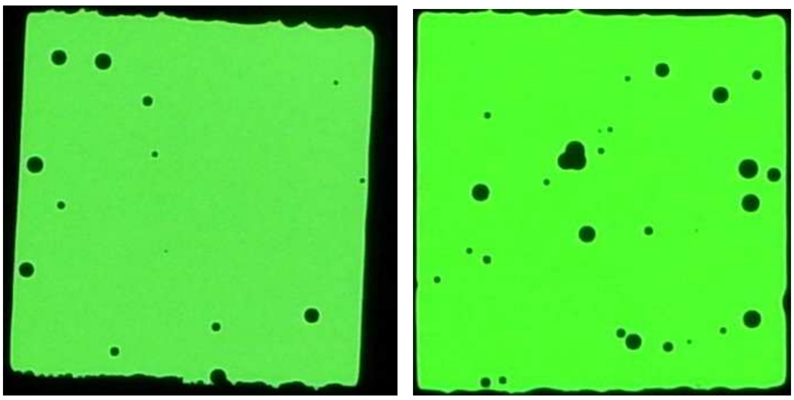


Fig. 3 Pictures of. device turn on . Left was after bending and right was plate.

## Conclusion

Based on two novel organic materials coded as EB515 and EB 47 for fabricating a flexible OLED device, we complete a novel testing experiment to demonstrate the electrical, optical, and lifespan performances of a flexible OLED by continuously bending it mechanically. After foregoing test, the findings show that the leakage current increased in the beginning of bending, then decreased; also the luminance of OLED reduced first, then recovered. We, therefore, conclude that micro-short-circuit may result from the density increase of micro-cracks in first stage, then with further bending, the width and depth of micro-cracks increased, which resulted in micro-open-circuits. Although those defects did affect the electrical and optical characteristics of the OLED, there was little effect on the storage lifespan performances. Also, after further examination to the surface of substrate by lift-offing the organic layer, we found the organic layer has been impaired and damaged, but the ITO layer remained in good condition.

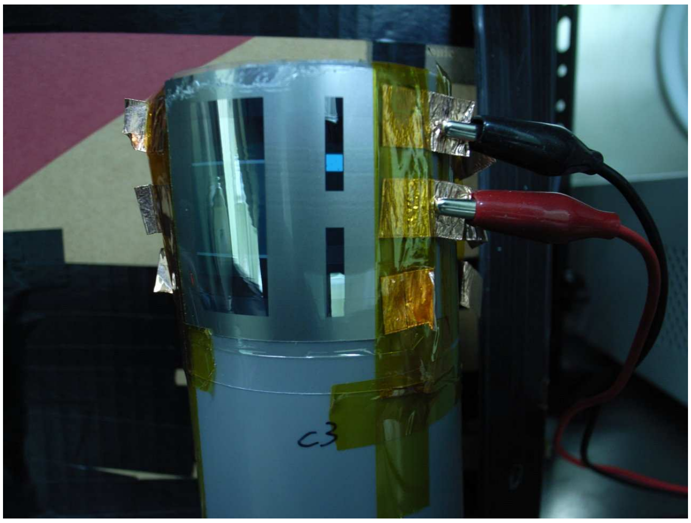



Fig. 4 Pictures of measurement setup.

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