Organic Electronics 11 (2010) 1870–1875

Contents lists available at ScienceDirect

Organic Electronics

journal homepage: www.elsevier.com/locate/orgel

Electroluminescence characterization of FOLED devices under two type of external stresses caused by bending

Chien-Jung Chiang [a,*], Chris Winscom [b], Andy Monkman [a]

[a] Institute of Photonic Materials, Department of Physics, Durham University, Durham DH1 3LE, UK
[b] Centre for Phosphors and Display Materials, The Wolfson Centre for Materials Processing, Brunel University, Uxbridge UB8 3PH, UK

ARTICLE INFO

Article history:
Received 19 April 2010
Received in revised form 27 August 2010
Accepted 28 August 2010
Available online 8 September 2010

Keywords:
OLED
Flexible OLED
Bending strain
Stress

ABSTRACT

Conventional organic light emitting diode (OLED) devices were fabricated on a plastic substrate with the structure of aluminum (100 nm)/lithium fluoride (0.8 nm)/tris–(8-hydroxyquinoline) aluminum (Alq_3) (40 nm)/*N*,*N*′-bis(naphthalen-1-yl)–*N*,*N*′-bis(phenyl)-benzidine (NPB) (50 nm)/indium-tin-oxide (ITO) (100 nm)/polyethylene terephthalate (PET) (0.127 mm). The devices were then bent with three designated radii of curvature, some in a concave direction and others in a convex direction, to apply either a tensile or compressive stress to the OLED layers. The brightness was then measured while the device was bent while supplying a constant current. Atomic force microscopy (AFM) images of the OLED devices surface (the aluminum surface) after the bending tests were shown to compare the damage caused by the different type of the stresses.

1. Introduction

Multilayer thin-film organic light emitting diodes (OLEDs), since being introduced in 1987 by Vanslyke and Tang [1], have reached the commercial stage in recent years as more and more gadgets, notably Google's smart phone Nexus One, become equipped with a delicate OLED display panel. Moreover, OLED technology, as an eco-friendly method of generating light, has attracted the interest of many big lighting companies such as Thorn, Philips, Osram, and General Electronics in the last few years. These trends indicate that the technology of putting OLED and electrical circuits onto a glass substrate is getting steadily more mature. Meanwhile, however, liquid crystal display (LCD) technology, OLED's biggest rival and currently the most popular display technology, has advanced. The viewing angle has improved by various technologies such as in-plane switching [2] (IPS) and multi-domain vertical alignment [3] (MVA), and the power consumption lowered by using light emitting diodes (LEDs) as backlight source, so that the advantages that OLEDs once held have been gradually eroded. Nevertheless, the potential to be transparent or flexible still allows OLED technology distinguish itself from the others. So far, the most prominent manufacturers incorporating OLED's, such as Sony and Samsung, have demonstrated their flexible OLED (FOLED) display prototypes at some industrial exhibitions. While their examples may demonstrate that the OLED device can still emit light while being bent, the extent to which the luminescence efficiency and brightness would be affected because of bending, or how tightly it could be bent, has not been reported. The answer to both these questions constitutes the first step in evaluating the possibility of whether an OLED device could be made flexible.

The stress within the OLED thin-films of a flexible OLED (FOLED) device is mainly from three sources: residual stress, thermal stress, and the external stress. Residual stress is from the deposition process no matter it is thermal evaporated, spin-coated, or printed. It is unavoidable for a soft substrate based OLED device [4]. Thermal stress comes from the different coefficients of thermal expansion

* Corresponding author.
E-mail addresses: Chien-jung.chiang@durham.ac.uk (C.-J. Chiang), chris.winscom@brunel.ac.uk (C. Winscom), a.p.monkman@durham.ac.uk (A. Monkman).

1566-1199/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.orgel.2010.08.021

of the adjacent layers when the environmental temperature changes [5]. External stress comes from the application of an external bending moment [6]. For example, when the FOLED device is bent, strain is introduced in the thin-films and stress is generated. Stress can make each film to crack or buckle when the deformation exceeds what it can bear. In a conventional multilayer OLED device structure, the indium-tin-oxide (ITO) is the most vulnerable film with the Young's Modulus of 120 GPa and yield stress of 1.2 GPa. Mechanical studies of ITO under external stress have been widely conducted [7]. Stretching-type stress can cause ITO to crack and increase its sheet resistance [8]. However, compression-type stress could promote buckling at first, and eventually crack or delaminate when the stored energy exceeds what the film can bear. When the ITO/plastic composite film is bent, the ITO film can suffer from either compressive or tensile stress, and this depends on the way it is bent.

Comparing these two types of strain conditions, people have found the increase in sheet resistance behaves asymmetrically. This might arise from the residual stress of the ITO/plastic composite, which is usually compressive in terms of the ITO layer [9] or the different course for the cracking or buckling to the electrical resistance. Thus the two different types of stress may also change the electroluminescence (EL) of OLED device differently. Apart from these stress effects, creep [10] (which is more likely to happen to the metal thin-film and plastic substrate) and film delamination [11] are two other key factors which affect soft multilayer thin-film structures.

2. Experimental

The ITO/polyethylene terephthalate (PET) composite substrate used in this study was purchased from Sigma–Aldrich, with the ITO thickness to be 100 nm and sheet resistance to be 60 Ω/□. The substrate was then cleaned with acetone and isopropanol in the ultrasonic bath for 7 min each, and exposed in the UV–Ozone Oven for another 7 min.

The component layers of the OLED device with the structure aluminum (100 nm)/lithium fluoride (0.8 nm)/tris–(8-hydroxyquinoline) aluminum (Alq_3) (40 nm)/*N*,*N*′-bis(naphthalen-1-yl)–*N*,*N*′-bis(phenyl)benzidine (NPB) (50 nm)/ITO (100 nm)/PET (0.127 mm) were deposited by evaporation under vacuum (2×10^{-7} mbar) using the Kurt J. Lesker small molecule deposition system. The FOLED device was mounted on the sample holder and the brightness was measured by the Konica-Minolta LS-110 Luminance meter as shown in Fig. 1a. The holder enables the device to be bent about one axis with three different conditions: R_1 = position A, R_2 = position B, and R_3 = position C in both concave and convex directions. Furthermore, the device pattern (as shown in Fig. 2) was designed in order that during the bending tests, the active area (5 mm × 10 mm) was located around the furthest point of the curve from the electrical contact caused by bending, i.e., the axis referred to above was parallel to the short side and the area between the electrical contacts and the active area was relatively flat.

In order that uninterrupted optical access can be made in the "bent" positions, a 2-point bending method was used. However, this method has the disadvantage of having to define the radius of curvature at the device position (R_c). Two methods were applied to estimate R_c for bending

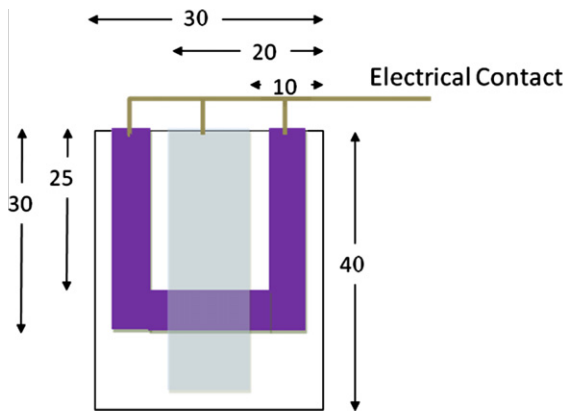

Fig. 2. The FOLED device plan. The darker area is the ITO layer. The lighter oblong shape covered on it is the aluminum layer. The dimensions are in unit of mm. The OLED is thermal evaporated everywhere on the 40 mm × 30 mm PET substrate and between these two electrodes. The OLED active area is 10 mm × 5 mm.

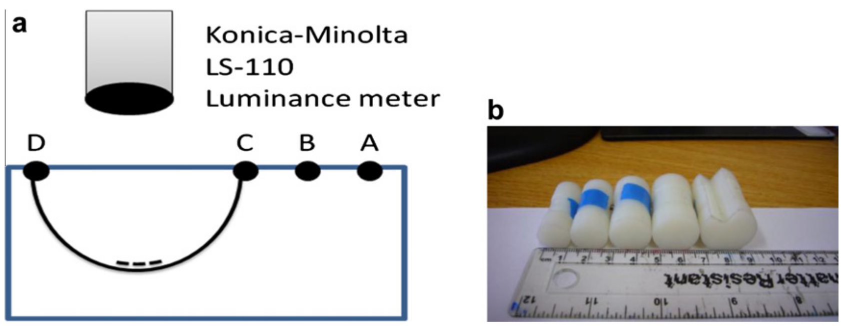

Fig. 1. The FOLED device was mounted and bent on the sample holder to be measured by the Konica-Minolta LS-110 Luminance meter fixed above the sample holder as shown in (a). The curved line is the FOLED device. It is fixed at the left end of the long side (position D). The dash line is the active OLED area which emits light. The right end is to be fixed at the positions A, B, and C for different radius of curvature. $\overline{DC}$ = 25 mm, $\overline{DB}$ = 35 mm, $\overline{DA}$ = 45 mm. (b) The cylindrical rods used to estimate the bending radius of curvature of the device.