Diamond & Related Materials 57 (2015) 68–73

Contents lists available at ScienceDirect

Diamond & Related Materials

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

Technical issues in graphene anode organic light emitting diodes

Jaehyun Moon [a], Jin-Wook Shin [a], Hyunsu Cho [a], Jun-Han Han [a], Nam Sung Cho [a], Jong Tae Lim [a], Seung Koo Park [a], Hong Kyw Choi [b], Sung-Yool Choi [c], Ji-Hoon Kim [d], Min-Jae Maeng [d], Jaewon Seo [d], Yongsup Park [d], Jeong-Ik Lee [a,*]

[a] Soft I/O Interface Research Section, Electronics and Telecommunications Research Inst. (ETRI), Daejeon, Republic of Korea
[b] University of Science and Technology, Daejeon, Republic of Korea
[c] Dept. of Electrical Engineering, Korean Advanced Inst. of Science and Technology, Daejeon, Republic of Korea
[d] Dept. of Physics, Kyung Hee University, Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 28 November 2014
Received in revised form 25 March 2015
Accepted 25 March 2015
Available online 27 March 2015

Keywords:
Graphene
Organic light emitting diode
Optical properties
Interfacial properties
Patterning

ABSTRACT

Optical, interfacial and patterning issues of anode graphene films in organic light emitting diode (OLED) applications were investigated. In the optical part, the microcavities of graphene and indium tin oxide (ITO) anode OLEDs were contrasted. With the use of graphene one may avoid spectral and organic stack design problems related to microcavity problems. However, due to the weak microcavity, emission enhancement using interference designs is practically impossible. By inserting an electron acceptor insert at the graphene/hole transport layer (HTL) interface, it was possible to enhance the current density by factor of three. Based on in situ ultraviolet photoelectron spectroscopy (UPS) results, the insert was interpreted as being a charge generation layer. Graphene patterning using laser or plasma methods turned out to be problematic. None of those methods could offer acceptable dimension accuracy and preserved graphene quality.

1. Introduction

Graphene is a two-dimensional film, in which carbon atoms are arranged in a hexagonal array. The thickness of one layer graphene is only 0.345 nm. Since the publication of Geim and Novoselov's article in year 2004, various outstanding properties and perspectives of graphene have reported in the literature [1–4]. As an ordinary course, graphene and multilayered graphene have been experimented in a variety of applications. As being thin, electrically conductive, optically transparent and mechanically flexible, graphene has gained extensive attention as a possible replacement for indium tin oxide (ITO), which has been so far dominantly used as the material for anode or transparent electrode in OLEDs [5–7]. Potentially, due to its thinness, electrical conductivity and mechanical compliance, graphene films can be used in various flexible electronics. In this article, we deal with the technical issues of graphene as an anode for OLEDs. Because graphene and ITO are different in many aspects, one needs to pay close attention to the differences to make most of the graphene anode. In this article, we focus on three aspects, which we consider as of high importance in realizing efficient graphene anode equipped OLEDs. Three topics are optical, interfacial and patterning considerations. In the optical part, we discuss microcavity and contrast its role to that of ITO anode case [8,9]. In the interfacial consideration, we compare the energy alignments of ITO and graphene with respect to adjacent organic layer, hole transport layer (HTL), and discuss a strategy which is useful in improving the hole transport [10,11]. In the patterning part, we investigate the patterning issue of graphene films [12]. So far, the patterning issue has been treated as a cursory issue. However, to realize graphene film as a component in integrated electronics devices, the patterning is an actual hurdle which has to be overcome.

2. Actual examples

Before investigating the aforementioned technical issues, it is useful to compare the actual performances of OLEDs which have ITO or graphene anodes, and figure out the technical issues. We have used a multi-layered graphene (MLG) grown by a chemical vapor deposition (CVD) method [13]. We will refer an OLED with ITO anode as ITO-OLED and an OLED with MLG anode as MLG-OLED. Fig. 1 shows various characteristics of phosphorescent green OLEDs. The green emitter was tris(2-phenylpyridinato-C^2,*N*)iridium(III) ($Ir(ppy)_3$), which was doped into a host of 2,6-bis[3-(carbazol-9-yl)phenyl]pyridine (DCzPPy). Both the current density (J) and luminance (L) levels of ITO-OLED were observed to be higher than those of MLG-OLED (Fig. 1(a)). Correspondingly the ITO-OLED showed higher external quantum efficiencies (EQEs) than that of MLG-OLED (Fig. 1(b)). The EQE of MLG-OLED is approximately 90% of ITO-OLED at a 1000 cd/m^2. The results of Fig. 1(a) and (b) can be attributed to various factors. The hole injection of MLG is not effective as ITO. The hole injection is closely related to the energy alignment of the work function of the anode and the highest occupied

* Corresponding author.
E-mail address: jiklee@etri.re.kr (J.-I. Lee).

http://dx.doi.org/10.1016/j.diamond.2015.03.020
0925-9635/

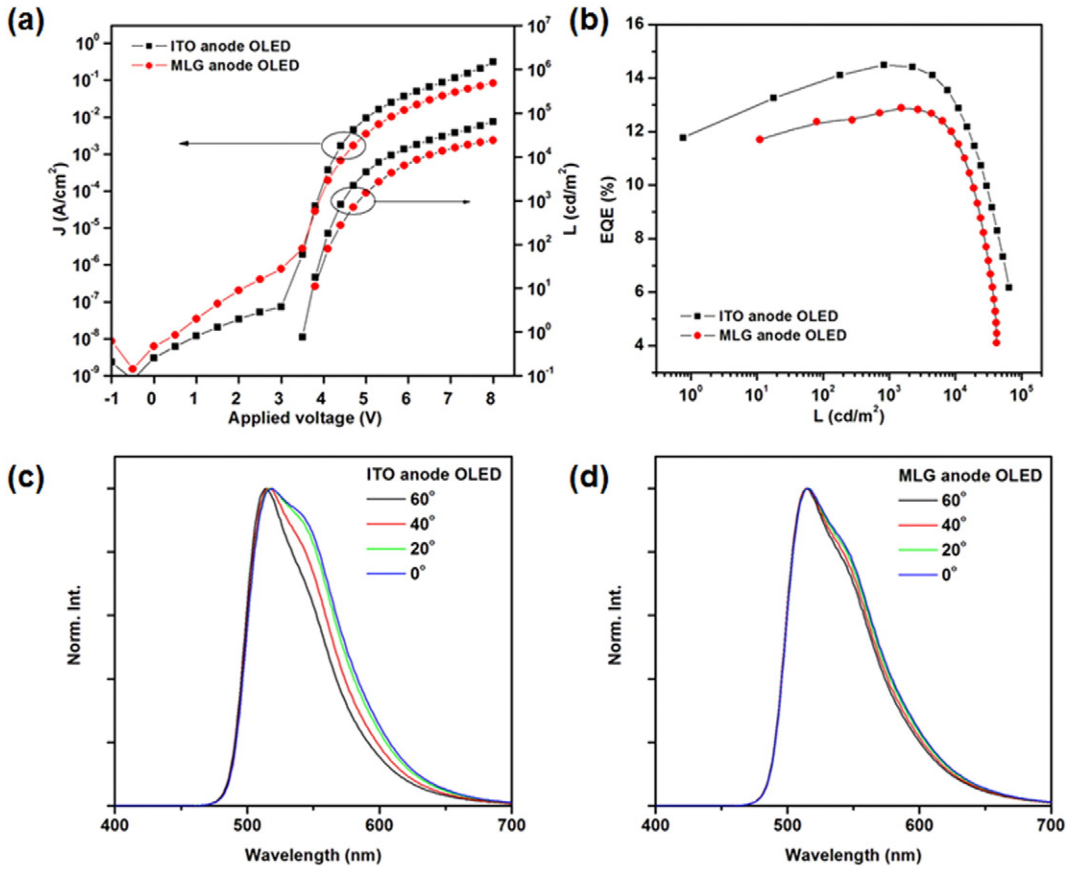

Fig. 1. (a) The JVL characteristics of ITO anode and MLG anode OLEDs. (b) The EQEs of ITO anode and MLG anode OLEDs. (c) The EL spectra of ITO anode OLED as a function of viewing angle. (d) The EL spectra of MLG anode OLED as a function of viewing angle.

molecular orbital (HOMO) level of the adjacent organics. Also, the sheet resistance can be a factor. Typical OLED ITO anode has a sheet resistance (R_s) lower than 50 Ω/sq, while typical MLG has approximately 250 Ω/sq [14]. The high R_s of MLG causes the increase of the operating voltage of the OLED. Potentially, the high R_s can be problematic in achieving luminance uniformity over large area OLED lighting panels. The optical properties of MLG can be a factor. The extinction coefficient (k) of graphene is reported to be high as 1.3 [15–17]. Such high k will cause significant absorption loss of the generated light. Fig. 1(c) and (d) compare the normalized electroluminescence (EL) spectra of ITO and MLG OLEDs as a function of viewing angle. In the case of ITO-OLED, shoulder development in the EL spectrum is apparent as the viewing angle changes.

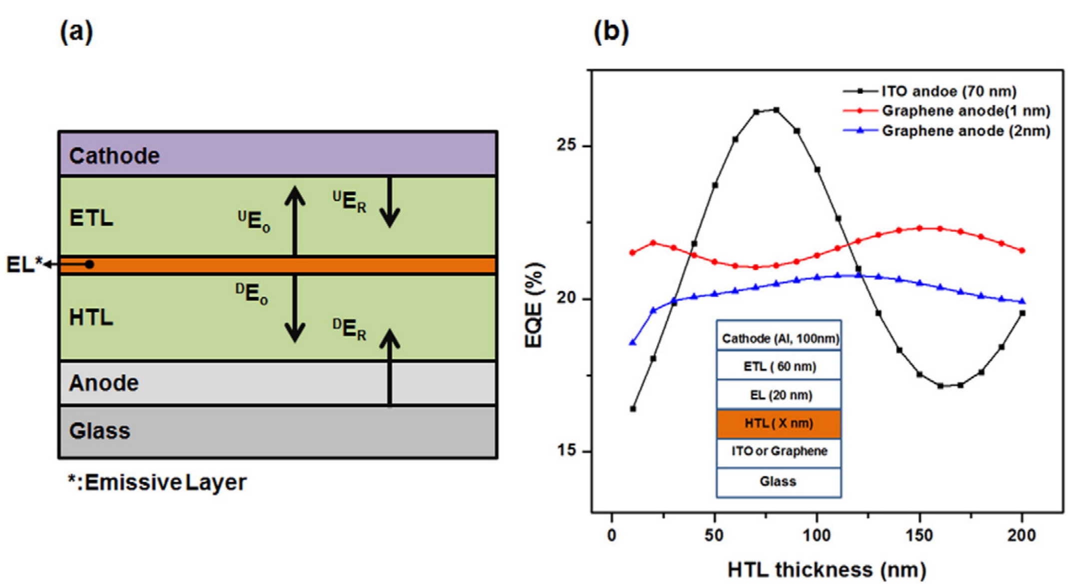

Fig. 2. (a) Schematics of simulation cell and optical components. (b) Simulated EQEs of ITO anode and MLG anode OLEDs as a function of HTL thickness. Inset is the actual OLED structure used in simulations.