Efficient Indium Phosphate based Quantum Dot Light Emitting Diodes using Sol-gel Processed Electron Transfer Layer

Ji Eun Yeom , Dong Hyun Shin, Mude Nagarjuna Naik, Raju Lampande and Jang Hyuk Kwon

Department of Information Display, Kyung Hee University, Dongdaemoon-gu, Seoul 130-701, Republic of Korea
Tel. :82-2-961-0948, E-mail: jhkwon@khu.ac.kr
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ABSTRACT

Here, we report an efficient indium phosphate (InP) based inverted red Quantum Dot-Light Emitting Diodes (QLEDs) by incorporating a sol-gel processed Mg-doped ZnO layer. The red InP-QLED with our sol-gel processed Mg:ZnO layer reveals a maximum EQE of 7.7% , which is significantly higher than the ZnO and Mg:ZnO nanoparticles layers. These results suggest that the sol-gel processed Mg-doped ZnO layer is relatively efficient in terms of performances.

1 INTRODUCTION

Recently, quantum dot light emitting diode (QLED) technology has shown a significant interest for the next generation display and solid-state lighting applications because of its high color purity, wide color gamut and simple fabrication process[1]. Since the first report on QLED, considerable endeavors have been made to understand the fundamental operating mechanism and to achieve high performance in the cadmium-based QLEDs. The efficiency of cadmium based QLEDs has already reached the commercial level, but the toxicity of cadmium limits its application in practical devices[2]. Therefore, indium phosphate (InP) based QDs have been reported as a potential candidate due to its nontoxic nature and broad emission range[3]. However, the performances of InP based QLED are much lower than the cadmium-QLEDs mostly due to the low PLQY and non-optimized QD and device structures. Hence, to improve the performances of InP-QLED, an efficient QD structure with high PLQY and well optimized QLED device structure is highly required. Normally, QLEDs are fabricated with the conventional and inverted approach by sandwiching an emissive QD layer between an inorganic metal-oxide comprised electron transport layer (ETL) and organic hole-transport and injection layers (HTL and HIL)[4]. However, inverted QLED structure has advantages in terms of fabrication and performances compared with conventional architecture. Particularly, in the inverted QLED architecture, electron and holes are injected from the ITO cathode and metal (Al) anode, respectively. Typically, the ZnO nanoparticles (NPs) layer is largely used as an electron transport layer (ETL) in the QLEDs because of its high conductivity and easy film formation process[5]. However, a strong exciton quenching is observed at the interface between emissive QDs and ZnO NPs films via interfacial charge transfer process due to the similar conduction band minimum with QD[6]. Similarly, there is another important factor that limiting the efficiency of inverted QLED, which is charge unbalance in the emissive QDs due to the relatively low hole mobility of the organic HTL materials compared with inorganic ETL material (ZnO) and relatively high hole injection barrier between emissive QD and HTL[7]. Therefore, there is a need for efficient ETL with defect-free surface and higher conduction band minimum as well as comparable electron mobility with HTL.

In this paper, we report high performance InP-QLED by utilizing an optimized sol-gel processed Mg-doped ZnO layer. Furthermore, we investigate the effect of Mg doping concertation on the performances of InP-QLED. Our inverted red QLED exhibits a maximum current efficiency of about 8.43 cd/A. This efficacy value is relatively higher than the ZnO NPs (1.83 cd/A) and Mg-doped ZnO NPs (7.17 cd/A) comprised QLED devices. Such excellent performance in our QLED device is attributed to the excellent surface properties as well as lower conductivity of the sol-gel processed Mg-doped ZnO layer. We believe that this research work will help in realizing high-efficiency in future QLED devices.

2 EXPERIMENT

QLEDs were fabricated with the structure of ITO/ ZnMgO 15%/ RQD/ TCTA/ TAPC/ HATCN/ Al. A schematic diagram of the QLED device structure is shown in Fig.1. Indium -Tin-Oxide (ITO) coated glass substrates (150 nm) were cleaned in an ultrasonic bath with acetone and isopropyl alcohol, and deionized water successively and dried with nitrogen gas. They were treated in UV-ozone chamber for 10 min. Herein, we used the sol-gel processed Mg-doped ZnO layer as the electron transport and injection layer in the InP-QLED. The sol-gel of Mg-doped ZnO is prepared using a previously reported method[4]. Zinc acetate dehydrate and Magnesium acetate were dissolved in 2-methoxy ethanol and ethanolamine at room temperature.

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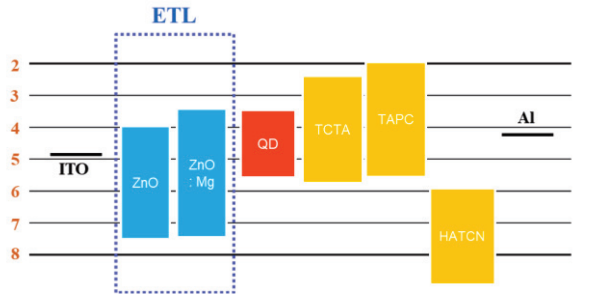

Fig.1 Device structure and energy level diagram of fabricated device structure

The solution was stirred for 12 h and finally filtered through a 0.2 um syringe filter before spin-coating. To make a sol-gel based ETL layer, the Mg-doped ZnO precursor solution was spin-cast on top of the pre-cleaned ITO substrate followed by annealing at 200°C for 1 hour. Similarly, 4,4′,4″-tri (9-carbazoyl) triphenyl-amine (TCTA), 4,4′ Cyclo-hexy lidenebis [N, N-bis(4-methylphenyl) benzenamine] (TAPC), and 1,4,5,8,9,11-hexaaza-triphenylene-hexcarbonitrile (HATCN), were incorporated as HTLs and HIL, respectively, for improving the hole transporting and injection properties in the EML.

3 RESULTS & DISCUSSION

Prior to the fabrication of the QLED, exciton quenching at the interface of ETL/InP-QD films is evaluated using the transient-photoluminescence (TRPL) measurements. Fig.2 shows the transient PL characteristics of InP-QDs deposited on the different ETLs. The InP-QD film on Mg-doped ZnO shows an exciton lifetime of 22.79 ns, which is significantly longer than the pristine ZnO NPs. On the other hand, InP-QD on our sol-gel processed Mg-doped ZnO layer exhibits a slightly improved exciton lifetime of about 25.11 ns. Here, the ZnO based sample displays strong exciton quenching because of the

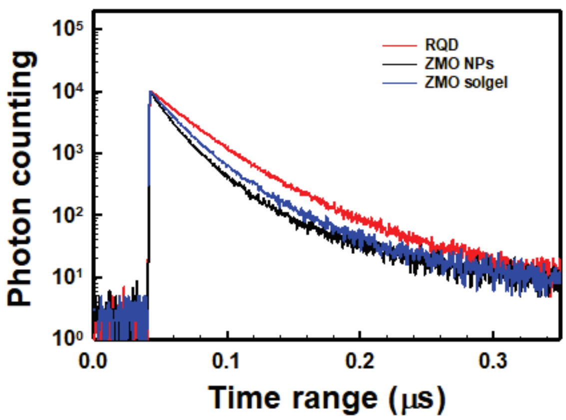

Fig.2 Time resolved photoluminescence measurement of Thin film exciton lifetime - QD(red), ZnMgO NP/QD(black) and ZnMgO Sol-gel/QD(blue)

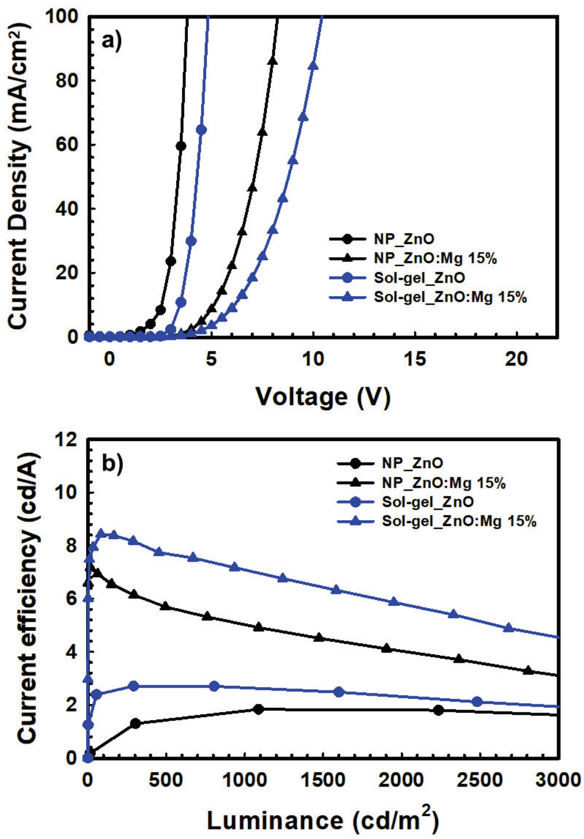

Fig.3 a) Voltage versus Current Density, and b) Luminance versus Current efficiency characteristics of QLEDs with various ETLs

interfacial charge transfer process via well-aligned conduction band minimum with QD or surface defects.

For a valid comparison of the device performances, we also fabricated reference device with Mg-doped ZnO NPs layer and widely used ZnO NPs layer. Initially, we optimized the doping concentration of Mg into the sol-gel processed ZnO layer by fabricating inverted red QLED with different Mg concentrations (0, 10 and 15 %). QLED with a pristine sol-gel processed ZnO layer displays a driving voltage of 4.1 V (at the luminance of 1000 cd/m^2). However, devices with 10% and 15% of Mg concertation into ZnO shows a relatively higher driving voltage of about 4.9 V and 6.6 V, respectively. Such higher driving voltage in 10% and 15% Mg-doped ZnO layer is attributed to the reduced electron mobility Mg-doped ZnO layer. Similarly, 10% and 15% Mg-doped ZnO based device ZnO shows current efficiency of 4.60 and 8.43 cd/A, respectively. Such improvement in the efficiency of Mg (15%) doped ZnO based device is originated to the improvement of charge balance via a reduction in the conductivity of the ETL layer. The detail performances of all three QLED devices are summarized in Table 1.

	Voltage(V)		Current Efficiency (Cd/A)		Max EQE (%)	Max Luminance (cd/m^2)	Color coordinate (CIE 1931)
	Turn-on @1 cd/m^2	Driving @1000 cd/m^2	Max	@1000 cd/m^2			
NP_ZnO	2.0	3.4	1.83	1.82	1.71	4875	(0.68,0.32)
NP_ZnO:Mg15%	2.3	5.9	7.17	4.90	6.78	4221	(0.68,0.32)
Sol-gel_ZnO	2.2	4.1	2.71	2.62	2.51	4544	(0.68,0.32)
Sol-gel _ZnO:Mg15%	2.3	6.6	8.43	7.10	7.70	5001	(0.68,0.32)

Table 1. The performances of QLEDs with various ETLs

Furthermore, the current efficiency of our sol-gel processed Mg-doped ZnO layer is relatively higher than the ZnO NPs (1.83 cd/A) and Mg-doped ZnO NPs (7.17 cd/A) comprised device. Moreover, all fabricated devices show almost identical CIE color coordinates of (0.68, 0.32). And Fig.4 shows Full width at half maximum (FWHM) is almost similar with 38 nm. These results indicate that the sol-gel processed Mg-doped ZnO is relatively efficient in terms of performances as well as electrical properties. Further details about our investigation will be covered in the presentation.

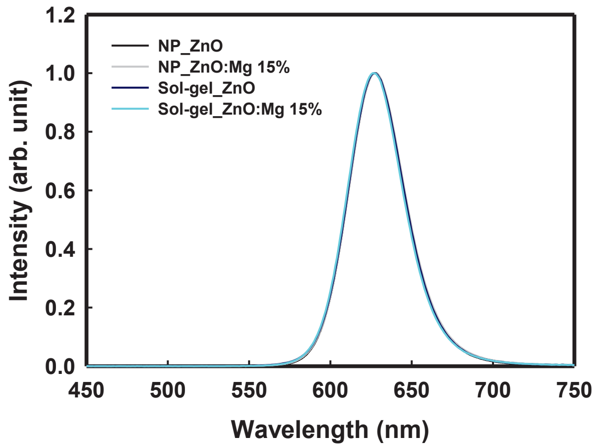

Fig.4 Electroluminescence spectrum of device with various ETLs.

4 CONCLUSIONS

Here, we present high performance inverted InP based red QLED by incorporating the sol-gel processed Mg-doped ZnO layer. Our sol-gel processed Mg-doped ZnO layer is easy to fabricate and also efficient in terms of performances. Inverted QLED with our sol-gel processed ETL layer shows significantly higher current efficiency of about 8.43 cd/A compared with both ZnO (1.83 cd/A) and Mg-doped ZnO NPs (7.17 cd/A) layers. We anticipate that our research will help in attaining high performances in next-generation QLED displays.

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