Double EML color-tunable Quantum Dot Light-Emitting Diodes by PCBM doping at QD

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ABSTRACT

This study is to propose a QD-LED device that can control the distribution of electrons and holes through the doping of other materials on the QD and modulate the color by the applied voltage of the device. In this study, the presented QD-LED device was coated with EML emitting different colors on the same device and doped with PCBM to control the holes distributed in the green QD. Three characteristics that vary depending on the concentration of PCBM doping were analyzed, and a color-tunable device capable of controlling the emission color and color range was fabricated.

1 INTRODUCTION

In a high-resolution RGB sub-pixel display, since the light-emitting area is small, it is vulnerable to material deterioration by applying a voltage to the light-emitting layer to increase the luminance per unit area. Because the number of transistors in the backplane for driving increases exponentially, reducing the luminous area. Displays capable of driving R, G, and B colors without sub-pixel division can reduce the number of transistors and wires incorporated per pixel. By reducing the number of transistors and wiring, it is possible to improve device deterioration with an increased light emitting area. To take these advantages, color-tunable studies that enable light emission of different colors in one pixel are being conducted in a double EML structure and a tandem structure. In the study of double EML, add a functional layer that can control the distribution of electrons and holes between different color layers [1]. In a study of tandem structure, Colors are emitted according to the direction of the applied voltage by overlapping devices capable of emitting different colors [2]. In this paper, PCBM, which can change the characteristics of QD, is doped instead of coating the functional layer previously studied in the double EML structure. An all solution-processed color-tunable double EML QD-LED that can change its color according to the size of the applied electric field by adjusting the distribution of electrons and holes was proposed and analyzed its characteristics.

2 EXPERIMENT

Figure 1 shows the vertical structure of the double EML QD-LED device, which is composed of glass substrate / ITO (anode) / PEDOT:PSS (hole injection layer and electron blocking layer: HIL & EBL) / PVK (hole transport layer: HTL) / green QD or doped green QD by PCBM(1st EML) / red QD (2nd EML) / ZnO NPs (HTL) / Al (cathode). All layers except Al and ITO are processed by the solution process using a spin-coater. PVK is dispersed in chlorobenzene at a concentration of 1.0w%. Green and red QD is dissolved in toluene as 10mg/ml concentration. ZnO nanoparticle is dispersed in ethanol at a concentration of 10w%. The anode, aluminum, is deposited in a vacuum chamber to a thickness of 100 nm by thermal evaporation. PCBM was doped on green QD with 0.05w%, 0.1w%, 0.3w%, 0.5w%, and 1.0w%.

3 RESULT

In the case of the device in which green QD/red QD is superimposed with a double EML, as in previous studies, most of the red QD adjacent to the ETL emitted light.[3] In Figure 5, when PCBM was not doped, the EQE decreased as the current density applied to the device increased. This is because auger recombination increased due to imbalance between electrons and holes in the Conduction Band Minimum(CBM) and Valance Band Maximum(VBM) of green QD. The QD LED device is easier to inject electrons than holes due to the QD having the characteristics of low VBM and high bandgap, so the number of holes is small in VBM of green QD, causing an imbalance. Doping of other materials was examined to increase the work function of green QD or to decrease the hole mobility so that holes can be well injected and distributed. Hole mobility can be controlled by doping PCBM.[4] PCBM HOMO level is -6.1ev, LUMO level is -3.7eV. Through doping, it is possible to shift the work function of green QD. In order to observe the distribution change of electrons and holes through doping, the doping concentration of PCBM was changed in green QD. In Figure 3, the color range of the doped devices increased compared to the non-doped devices. As the voltage increased, the emission of green QD increased compared to the red QD, resulting in a decrease in x value and an increase in y value. Devices with a low doping concentration of 0.1w% or less have a higher green spectrum than the red spectrum and operate in a color range from yellow to green. Radiative recombination occurred more in green QD than in red QD, resulting in an increase in the amount of emission of green QD. This is because more holes are distributed in VBM of green QD by lowering hole mobility through the doping of PCBM than non-doped devices. In Figure 4, the low roll-off in devices with a doping concentration of less than 0.1w% is because auger recombination is reduced in green QD, and the valance of holes and electrons in green QD is improved compared to existing devices. In devices doped with concentrations of 0.3w% and 0.5w%, the red spectrum increased, and the turn-on voltage decreased by 1V compared to the low concentration doped devices. As the doping concentration of PCBM increases, the work function is shifted compared to the previous one, reducing the difference between the homo level of PVK and the level of the doped green QD valance band, so that the hole can be injected at a lower voltage. Hole injection increased at low voltage, but Electron injection was the same as that of a low-concentration PCBM-doped device. Therefore, the radiative recombination of red increased relative to that of the low-doped device, and the red spectrum increased. Devices doped with PCBM less than 1w% emit light in different colors, but operated in a similar color range. In the device doped with 1w%, the color range, which was maintained similarly, was expanded. In a device doped with 1w% or more of PCBM, it is difficult to confirm the distribution characteristics of electrons and holes because PCBM affects the luminous efficiency of Green QD.

4 DISCUSSION

PCBM was doped with various concentrations to change the position of the emitting layer by controlling the distribution of electrons and holes. There were three factors that influenced the color range characteristics of a device according to doping. The first factor is the difference in hole mobility of green QD according to PCBM doping. In the double EML structure where PCBM is not doped with a low concentration of PCBM doping, most of the ETL is recombination, and the red QD emits light, but PCBM doping allows more holes to be distributed in the VBM of the green QD, increasing the recombination in the green QD. As a result, the green spectrum increased. This is because when the hole mobility of green QD decreases, the number of holes that can be distributed in VBM of red QD passing through VBM of green QD is reduced. In order to confirm the decrease in hole mobility by concentration, a Hole Only Device (HOD) by concentration was manufactured as shown in Figure 6, and the current density by voltage was measured. As the concentration of PCBM doped in green QD increased, the value of the current density decreased. The difference in current density by the concentration at the same voltage after the ohmic contact region is more than twice as much as each other, and as the doping concentration increases, the hole mobility decreases. The second factor is the difference in the work function of green QD according to doping on PCBM. At concentrations above 0.3w%, the turn-on voltage of the device decreased by 1V. This is because the gap between the Homo level of PVK and VBM of Green QD, which affects when the hole moves due to the increase in the work function of green QD, is lowered. In Figure 6, in the J-V graph of 0.3w% HOD, the voltage at the inflection point at which the slope changes was 1.5V different from the graph of other doping devices. It was indirectly confirmed that the gap difference between the Homo level of PVK and the VBM of green QD was reduced because a large amount of holes reached the green QD at low voltage. At low voltages, the probability that electrons exist in the CBM of red QD is higher than that of the CBM of green QD, so the more holes are distributed in red at low voltages, the greater the amount of radiative recombination in red QDs. Due to this phenomenon, at a concentration of 0.3w% or more, the amount of red QD emission increases compared to a device doped with a lower concentration of PCBM. The last factor is the difference in efficiency caused by interfering with radiative recombination of green

QD as the doping concentration of PCBM increases. As the PCBM doped increases, the purity of the green QD decreases and the luminous efficiency decreases. The reason why the current density is higher and the EQE is lowered is that non-radiative recombination increases, which makes electron and hole recombination smoother than other devices, but the amount of light emission decreases.

5 CONCLUSIONS

In this paper, the distribution of electrons and holes was controlled through PCBM doping on green QD. With this characteristic, it is possible to control the color emitted by voltage. By controlling the doping concentration, two different characteristics were expressed. Through two characteristics, it was possible to change the position of the layer mainly emitted from the device. The non-doped device, which emits mostly red QD, due to the decrease in hole mobility, which is a characteristic of low-concentration PCBM doping, allows green QD to emit light. As a characteristic of the medium concentration of PCBM doping, the band gap of green QD is maintained, but the difference with the HOMO level of PVK is decreased due to the increase of VBM. Due to this characteristic, the turn-on voltage was lowered, and the red QD recombination was increased at a low voltage, thereby increasing the amount of red QD emission. However, in the doping device having a certain concentration or higher, the green QD purity was decreased, increasing non-radiative recombination, and thus the luminance of light emission decreased. A device capable of color-tunable by concentration/voltage was manufactured by reducing the hole mobility of QD and increasing the work function, but doping with a high concentration decreases the efficiency of the device, so it is necessary to fabricate the device with an appropriate doping concentration.

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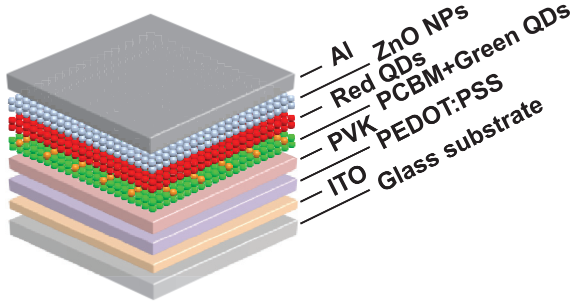

Fig. 1 Schematic of the layer structure for the color-tunable double EML QD-LED doped PCBM.

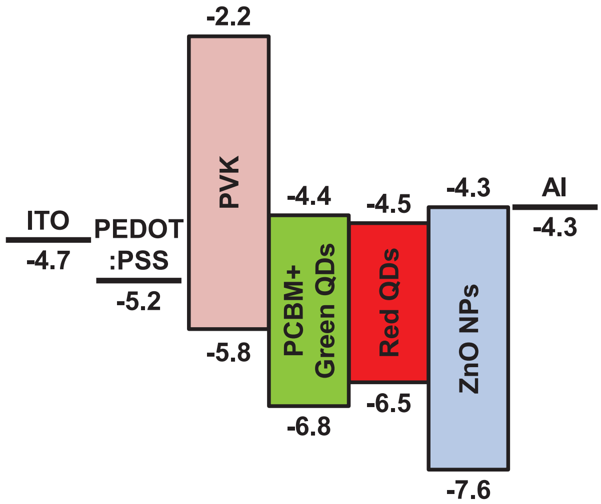

Fig. 2 Energy level diagram of the color-tunable double EML QD-LED doped PCBM.

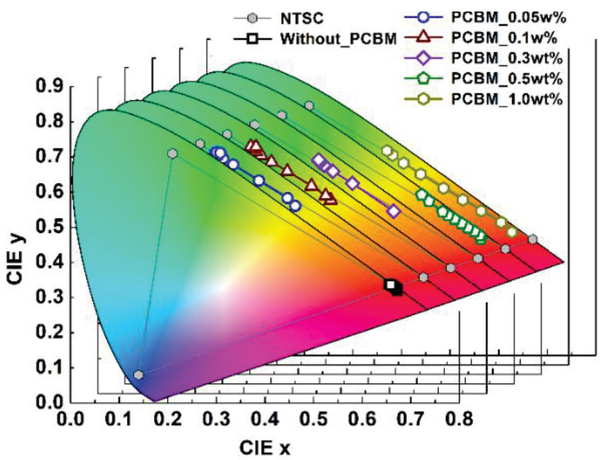

Fig. 3 CIE color coordinates of the color-tunable double EML QD-LED doped PCBM by concentration.

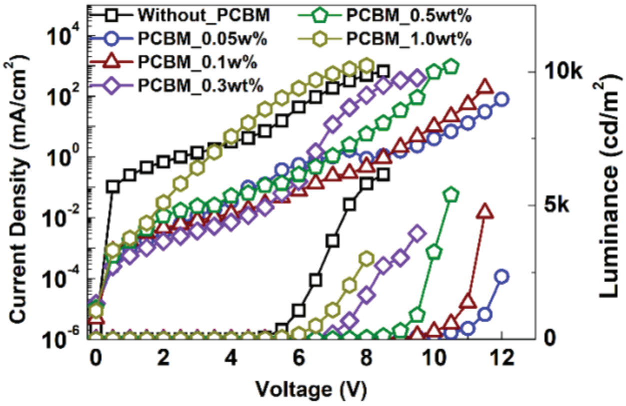

Fig. 4 Current density-voltage-luminance (J-V-L) characteristics of the color-tunable double EML QD-LED doped PCBM by concentration.

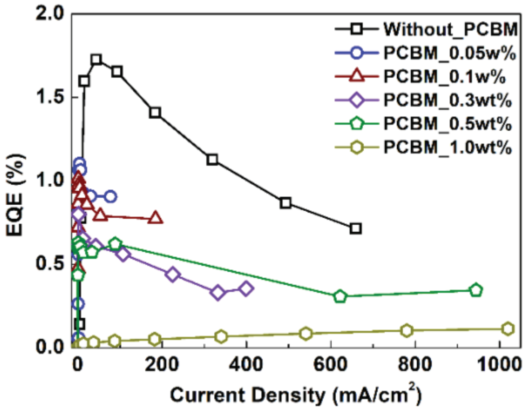

Fig. 5 EQE of the color-tunable double EML QD-LED doped PCBM by concentration.

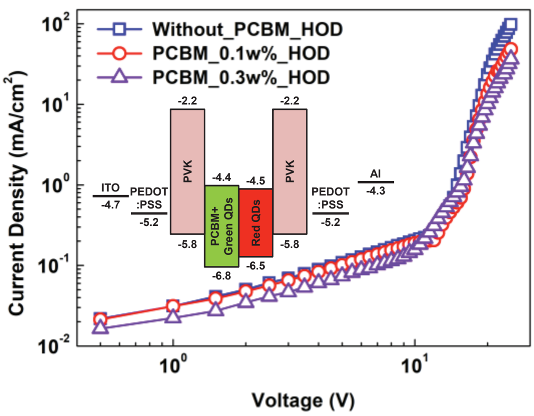

Fig. 6 J-V characteristics of HODs with 0.1w%-, 0.3w% PCBM doping, and without PCBM doping. (inset) Energy level diagram of the HOD with PCBM doping.