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Invited

Recent Trends and Challenges in EL-QD Display Technologies

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ABSTRACT

In this report, recent R&D trends will be reviewed of EL-QD materials, devices, and patterning methods, as well as display panels, demonstrated by panel makers. As well, major technological challenges will be discussed, which remains for mass production of the EL-QD display.

1 Introduction

Quantum dot (QD), which is a semiconductor nanoparticle, has attracted many researchers, because of its high color purity, photochemical stability, and high quantum yield, originated from its inorganic nature and tunable bandgap energy by its size.[1] Because QD can converts blue light to red and green lights with very narrow bandwidths, it is widely used in display applications [2]

EL-QD is a self-emissive display which utilizes the QDs as emitters. It has a similar device structure as OLED, except it uses QDs as emitters (Figure 1). It is an ideal display technology, because of its high efficiency, color purity, long lifetime as well as low-cost fabrication by using inkjet printing process.[3] However, an inherent nature of QDs, different from organic emitters, introduces technical challenges to be overcome in order for improving efficiency and lifetime, as well as reliable pixel patterning by using inkjet printing process.

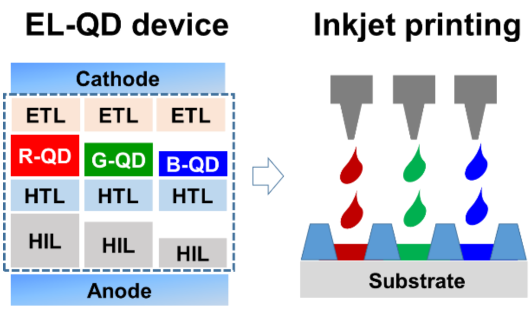

Figure 1. Inkjet-printed EL-QD device

In this report, recent R&D trends will be reviewed and major technological obstacles will be discussed, which must be solved for mass production of the EL-QD display.

2 Current Status of EL-QD Display Technology

2-1 Cd-free QDs

Even though Cd-based EL-QD devices have made a great progress in quantum efficiency and lifetime,[4] it is highly requested to replace Cd-based QD to Cd-free QD for display applications, because of RoHS regulation which limits the use of hazardous substances in electronic devices.

Figure 2 and 3 show recent progress of Cd-free EL-QD device performances.[3] It is clearly seen that Cd-free EL-QD devices performances have been rapidly enhanced over the decade. Especially, red EL-QD devices reached EQE over 20% and T50 lifetime of over 1 million hours at 100nit.[5,6] As well, blue EL-QD also achieved EQE over 20% and T50 lifetime of over 15,000 hours at 100nit.[7] It is expected to reach EQE 20% and T50 lifetime of 1 million hours at 100nit for all three colors within a couple of years, if this fast improvement continues.

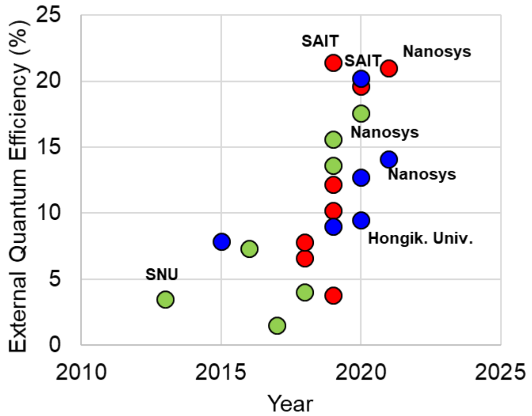

Figure 2. Progress of Cd-free EL-QD efficiency

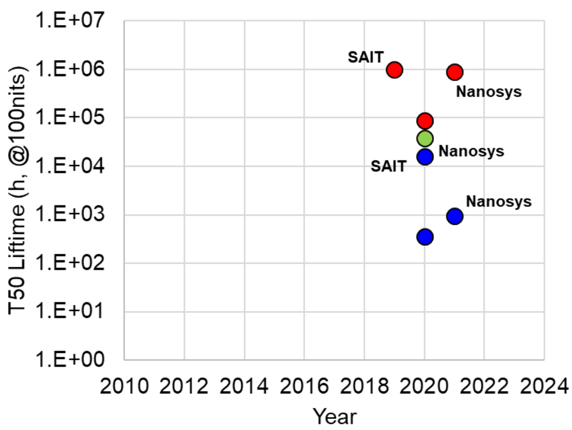

Figure 3. Progress of Cd-free EL-QD lifetime

2-2 Inkjet Printing

Inkjet printing is believed to be the most feasible tool of patterning full color EL-QD display for mass production, because EL-QD and CTL (charge transport layer) are solution-state materials and the inkjet printing technology including inkjet printers and ink materials are pretty matured.[8]

Figure 4 compares EL-QD demo panels from several panel makers, with commercially available display applications, in terms of panel size and pixel resolution. It is obvious that the panel makers are developing the EL-QD display for large-sized applications like TV and monitor. Because of the resolution limit of inkjet printing, it seems that the EL-QD is not possible to be utilized for mobile applications.

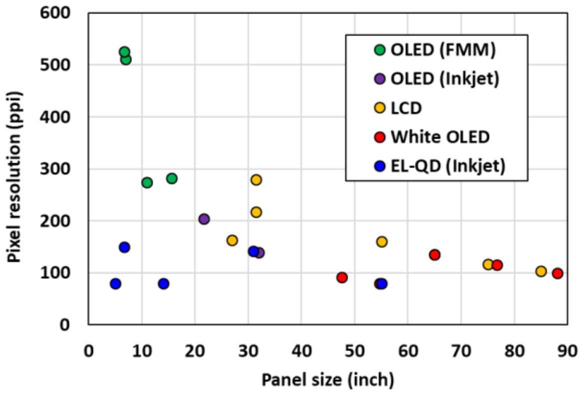

Figure 4. Panel size vs. pixel resolution according to display technology. EL-QD demo panels are publicly announced in conferences [9, 10,11]

3 Key Issues in EL-QD Display Technology

3-1 Ligand Engineering

Ligands which bind the surface of the QD play a role to stabilize the QD from each other through the steric hindrance of the ligands, as well as to electronically passivate the surface trap states of the QD, which induces a non-radiative decay of excitons. The long alkyl-chain ligand such as oleic acid is commonly used for stabilizing QDs in a solution, however, it disturbs the injection of charges into QD, because of its highly insulating nature.

To solve this problem, alternative ligands, such as short alkyl acid, halogen anion, or conjugated acid have been proposed and successfully proved to reduce the injection barrier.[5,7,12] But, these ligands can't provide the colloidal stability, enough to prevent a nozzle clogging problem, which happens when solute forms aggregates in ink, because they can't make a steric repulsion between QDs. This issue must be solved in order to improve the device performances of inkjet-printed device to a level of spun-coat device.

3-2 Alternative for Positive Aging

Positive aging means the quantum efficiency and lifetime becomes improved during storage, after EL-QD device is encapsulated with UV resin.[13] This phenomenon has been explained to occur because the surface defects of ZnO ETL nanoparticles are passivated by the chemical reaction with acidic components of UV resin and the electric currents increase during the aging process, which is attributed by the interfacial reaction between Al electrode and ZnO.[14,15] Because quantum efficiency and T50 lifetime of EL-QD is improved by 1.4 and 6.0 fold, respectively after positive aging process, it is essential to use UV resin for improving EL-QD device performances. [13]

However, it is not suitable for mass production of EL-QD display panels, because very small amount of acidic components need to be uniformly distributed onto the large glass substrate. Fundamental solution must be to develop inorganic ETL with reduced surface traps without the acidic treatment on the device.

4 Inkjet-printed Cd-free EL-QD Display Panel

Recently, we successfully fabricated 6.95" 217 ppi Cd-free EL-QD display panel (Figure 5). RGB EL-QD devices with top emission architecture has been developed and inkjet printing process has been established with specially designed colloidal inks with surface ligands.

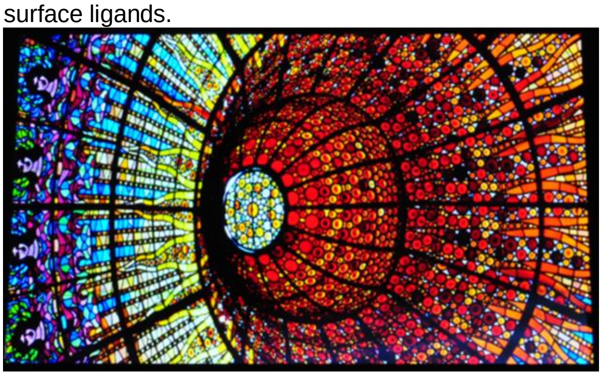

Figure 5. 6.95" 217 ppi inkjet-printed Cd-free EL-QD

5 Conclusions

Current status of inkjet-printed EL-QD technology are reviewed and key technological challenges for mass production are discussed. The world first Cd-free full color EL-QD display panel with 217 ppi was fabricated by utilizing RGB top emission EL-QD device. If the progress continues, it will be possible to develop the EL-QD technology which can be used for mass production.

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