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Multi-Color Organic Light Emitting Panels Using Self-Aligned Ink-Jet Printing Technology

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We have investigated multi-color organic light emitting panels using a self-aligned (SA) ink-jet printing (IJP) technology. Emission ink with phosphorescent materials of an iridium(III) bis(2-(2′-benzothienyl) pyridinato-N,C3′) (acetylacetonate) ($Btp_2Ir(acac)$) for red, an fac-tris(2-(p-tolyl)-pyridine)iridium ($Ir(tpy)_3$ for green, and an iridium(III) bis(2-(4,6-difluorophenyl) pyridinato-N,C2′) picolinate (FIrpic) for blue were printed on an indium-zinc-oxide (IZO) coated glass substrate covered with an insulating poly-methylmethacrylate (PMMA) layer. The PMMA was dissolved in a solvent of ink, then, emission region was formed at the same position as that of the ink-jet-printed region. The device structure was IZO/PEDOT/PMMA (30 nm)←Ink/BCP (20 nm)/LiF (1 nm)/Al (70 nm). Luminescence of the device with red, green and blue emission materials, were 655 2,640 and 857 cd/m^2, respectively. We have also demonstrated 150 ppi resolution of multi-color light emitting panels using the self-aligned IJP method.

Keywords: ink-jet printing method; light emitting logo panels; organic phosphorescent device; self-alignment technology; small molecular solution-process

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1. INTRODUCTION

Organic light-emitting devices (OLEDs) have merits of bright emission, high efficiency and fast response; these merits are advantageous for next-generation flat-panel displays. One of the issues in the fabrication of large-area OLEDs is the patterning technique of emission area. Recently the drop-on-demand system of the ink-jet printing (IJP) method has attracted considerable attention [1]. For fabricating OLEDs using the ink jet printing method, bank formation is commonly used to prevent shorting of the device. Shimoda *et al*. reported a prototype OLED panel fabricated using the IJP method [2]. The IJP method requires bank formation and entails a high cost and difficulty in precise alignment control. Therefore, a new fabrication process not beset by these problems was desired. In order to satisfy these subject, we have proposed and investigate the self-aligned (SA) bank formation of OLEDs using the ink jet printing method, in which an insulating material is formed and a mixture of organic materials mixed with host and emission materials is ink-jet-printed on a substrate, where these ink get printed regions become emission regions [3]. In this device fabrication, we selected low-molecular-weight organic phosphorescent material for solution-process because we can realize an equivalent performance and reliability to those of evaporated OLED [4]. We also demonstrated top-emission SA OLED, which is interesting for use in active matrix displays with higher aperture ratios [5]. In this study, we demonstrate multi-color OLED panels using SA IJP using phosphorescent materials.

2. DESCRIPTION OF PROPOSED SELF-ALIGNMENT PROCESS

The steps in the self-alignment device fabrication are shown in Figure 1. An insulating film was formed on an anode of an indium-zinc-oxide (IZO) coated glass substrate. It is necessary for this insulating material to be soluble in an organic solvent and to exhibit good insulating characteristics. Then, the solution with dissolved organic host and emission materials was ink-jet-printed. Here, the insulating layer was dissolved in the solvent and an emission layer was formed alternately, that is, self-alignment OLED fabrication was carried out. Finally, a cathode layer was evaporated onto the organic layer in a manner similar to that used in conventional OLED processes [3,5].

The merits of the self-aligned fabrication process are as follows: First, the fabrication process is simple. For prototype panels the patterning of a polyimide bank and the precise position control of

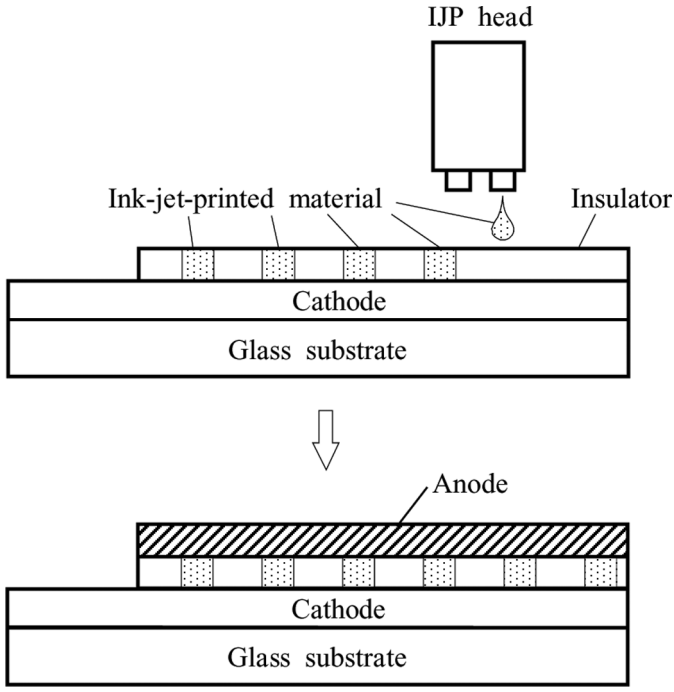

FIGURE 1 Process step of self-aligned ink-jet-printed OLED and organic materials under study.

ink-jet-printed dots are necessary. Using this self-aligned process, the lithographic process of bank formation becomes unnecessary. Second, free pattern formation without constraint is possible. This may be advantageous for the fabrication of high-resolution and large-area emission poster displays. Third, a device with a higher optical confinement will be possible with higher and lower refractive indices of the emission and insulating materials, respectively. This third aspect is desired in high-efficiency OLEDs.

3. EXPERIMENT

Figure 2 show organic materials under study. The details of the fabrication process are as follows: After ultraviolet ozone treatment, the conducting polymer poly-(ethylenedioxythiophene)/poly(styrenesulfonate) (PEDOT) was spin-coated on an IZO-coated glass substrate, which was then baked at 200°C for 5 min in air. Next, the insulating material poly(methylmetacrylate) (PMMA) was spin-coated on the

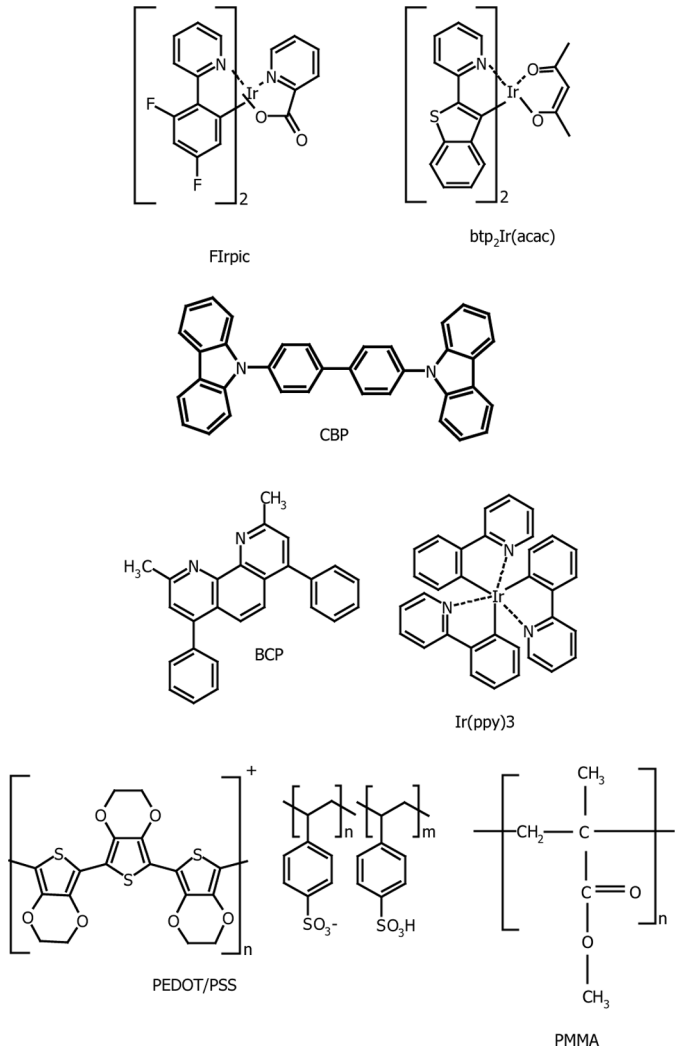

FIGURE 2 Organic materials under study.

substrate. Phosphorescent materials of iridium(III) bis(2-(2′-benzothienyl) pyridinato-N,C3′) (acetylacetonate) ($btp_2Ir(acac)$) for red, *fac*-tris(2-(*p*-tolyl)-pyridine)iridium ($Ir(tpy)_3$) for green, and an iridium(III) bis(2-(4,6-difluorophenyl) pyridinato-N,C2′) picolinate (FIrpic) for blue were used for emission center. The emission inks was mixed with host material of 4,4′-bis(9-carbazolyl)-biphenyl (CBP). The emission ink

was printed on an indium–tin–oxide coated glass substrate covered with PMMA layer. The PMMA was dissolved in a solvent, then, emission region was formed at the same position as that of the ink-jet-printed region which was then baked at 60°C for 1 hour in vacuum. Finally, a hole-blocking layer of bathocuproine (BCP) and a stacking layer of cathode LiF/Al were evaporated.

The device structure was IZO/PEDOT/PMMA (30 nm) ← Ink/BCP (20 nm)/LiF (1 nm)/Al (70 nm). The ink was composed for red (CBP: $btp_2Ir(acac)$ = 120: 2, 0.5 wt% chloroform solution), green (TPD: CBP: $Ir(tpy)_3$ = 5: 95: 5, 0.5 wt% chloroform solution) and blue (CBP: FIrpic = 120: 20, 0.5 wt% chloroform solution).

4. RESULTS AND DISCUSSIONS

In order to optimize the luminance, the ink was dropped on the same point. For the device at the one shot condition, the through-hole for the emission material cannot well connected to the entire thickness. Therefore, the luminance was lower than that of optimum condition. On the other hand, in three shot condition, thickness of the emission zone was thinner than that of optimum condition. As a result, number of the ink-jet printed dots at same point was optimized as 2. In this situation, fraction ratio of emission material and PMMA at emission zone and thickness of the emission zone were changed, as in a similar to Ref. 5.

Figures 3 and 4 show the comparisons of current density versus applied voltage (*J*-V) and luminance versus current density (*L*-*J*) characteristics, respectively. The maximum luminescence of the device with red, green and blue emission materials was 655, 2,640 and 857 cd/m^2, respectively. At 7 V, the brightness was 2,043 cd/m^2 ($J = 75.7\,mA/cm^2$) in green ink, and 636 ($J = 309\,mA/cm^2$) in blue, and 294 ($J = 53.5\,mA/cm^2$) in red emission materials. The electroluminescent spectrum of the red, green and blue emission peaks at 618, 512 and 475 nm, respectively. In red and blue devices, the luminance is lower than that of green device. One of the reason of difference in luminance is that photoluminescence efficiency $btp_2Ir(acac)$ and FIrpic are around 21 and 55%, respectively, in which efficiency is lower than the green phosphorescent material ($Ir(ppy)_3$) [$\sim$100%] [6,7,8]. In Addition, it is difficult to obtain high luminous efficiency in FIrpic device because of large triplet energy of FIrpic in comparison with CBP host [8]. To obtain a good color balances, control of emission size for overlapping the droplet position and introducing the new materials are effective. Another control method of emission intensity is the pulse width modulation of the passive or active matrix scheme.

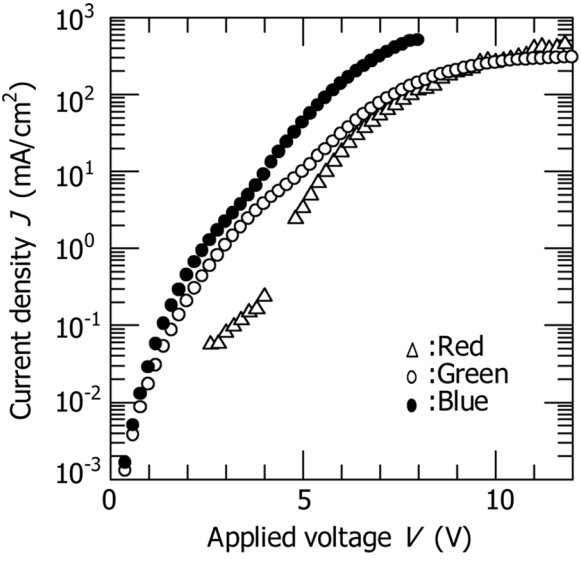

FIGURE 3 Current density vs. voltage characteristics of SA IJP OLED.

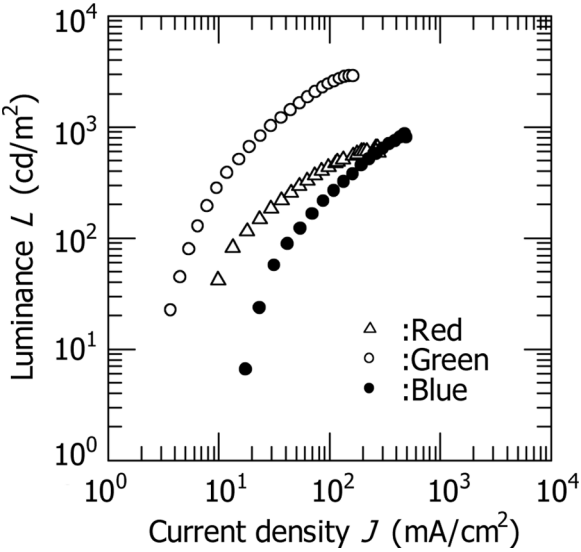

FIGURE 4 Luminance vs. current density characteristics of SA IJP OLED.

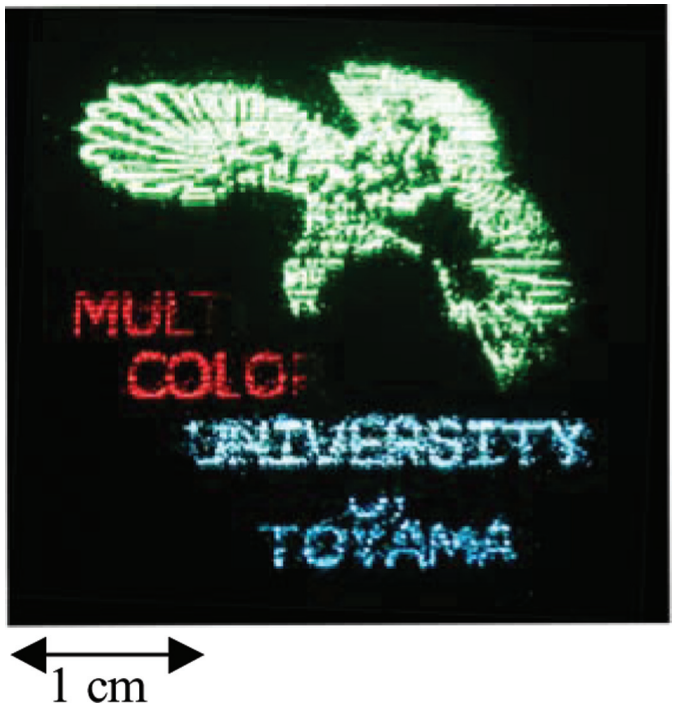

FIGURE 5 Photograph of multi-color panel with emission size of $30 \times 30\,mm^2$ and resolution of 150 ppi. (See COLOR PLATE IV)

Using above fabrication technique, we have demonstrated prototype multi-color display panel. The panel size was $30 \times 30\,mm^2$ and the panel resolution was 150 ppi. Figure 5 shows an example of pattern emission "ptarmigan" of a symbol bird of Toyama prefecture and character images. The operation voltage of 5.0 V is applied to the panel. As a result, clear emission pattern was achieved.

5. CONCLUSIONS

We had investigated fabrication of multi-color organic light emitting panel with ink-jet printed SA emission zone. Applying this fabrication technique, we have demonstrated the prototype panel with size of $30 \times 30\,mm^2$ and resolution of 150 ppi. The SA-IJP technology can easily control the position of emission dot. Therefore, this merit can be applicable for full-color "*Emission Poster*".

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