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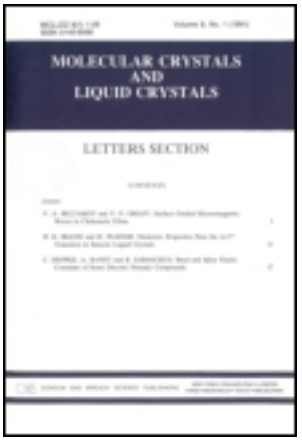

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Two Color Realization of Red and Blue by the Selective Deposition of a Red Light Emitter

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Two Color Realization of Red and Blue by the Selective Deposition of a Red Light Emitter

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From the basic structure of a red organic light-emitting device (OLED) with peak wavelength of 624 nm, blue emission with peak wavelength of 457 nm could be obtained by simply excluding an emissive layer of the red device. This technology makes it possible to fabricate two color OLEDs of red and blue simultaneously so that the manufacturing cost can be greatly reduced in the application devices due to simple structure and saving of the used materials. The experimental results showed the maximum current efficiencies of 16.7 cd/A and 4.8 cd/A and the luminance of 4600 cd/m^2 and 7300 cd/m^2 at 8V in the red and blue devices, respectively.

Keywords Current efficiency; exciplex; exciton; luminance; OLED; quantum efficiency

Introduction

Organic light-emitting devices (OLEDs) have several advantages for display and lighting applications such as low power consumption, wide viewing angle, fast response, and compactness. Over the past two decades, advances in the performance of OLED have been made through the synthesis of efficient lumophores, optimization of structure, and doping technology [1–3]. High efficiency OLEDs have a multilayer structure in which several layers are used for specific functions. To facilitate the movement of one type of carriers (holes and electrons), an injection and transport layer may be inserted between the emitter and the corresponding electrode. For OLED applications, three basic emissions of red, green and blue are needed. Different materials according to the emission color are generally used in the functional layers of OLED to optimize the electroluminescent characteristics of each device. Therefore, the process should be complicated and many kinds of organic materials are needed in the fabrication of the application devices with emission of more than two colors.

Two color emission of red and blue can be used in the lighting applications and medical instruments [4, 5]. For examples of biomedical applications, Papageorgiou *et al.* [6] have evaluated the effectiveness of blue light and a mixed blue and red light in acne

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treatments. Glickman *et al*. [7] have found that short wavelength light, especially, blue light, demonstrates positive influence for acute melatonin suppression, and Erdle *et al*. [8] have evaluated the wound healing effect of 670 nm- light on incisions and burn injuries and suggested that red light exposure may be helpful in postoperative wound repair.

In this study, a new technology which can simply realize two color emissions of red and blue without any additional steps from the process of a red emission device is introduced. By the selective deposition of an emissive layer (EML) in the structure of red OLED, two color OLEDs with emission of red and blue can be simultaneously made. With the use of this technology, the manufacturing cost can be greatly reduced in the fabrication of two color OLEDs due to simple process and saving of the used materials.

To obtain high luminance and quantum efficiency in the experimental devices, phosphorescent emission was used in the red device. Phosphorescent OLEDs based on phosphorescent dyes generally exhibit the improved electroluminescent characteristics in comparison with fluorescent OLEDs because both of singlets and triplets can be used for light emission [9, 10]. On the other hand, the blue device emits fluorescent light because it consisted of the remained three organic layers without an emissive layer of the red device.

In the experiments, the red device has an organic structure of N,N′-diphenyl-N,N′-bis-[4-(phenyl-m-tolyl-amino)-phenyl]-biphenyl-4,4′-diamine (DNTPD)/ 1,1-bis-(di-4-polyaminophe nyl) cyclohexane (TAPC)/ bis(10-hydroxy-benzo[h]quinolinato)beryllium ($Bebq_2$) doped with 5 vol.% RP411 (red phosphorescent dye from SFC Co.)/ ET137 (electron transport material from SFC Co.). Here, the DNTPD and TAPC are used as a hole injection layer (HIL) and a hole transport layer (HTL), respectively. The use of DNTPD with a highest occupied molecular orbital (HOMO) level of 5.1 eV makes the hole injection easy from an anode of indium tin oxide (ITO). The TAPC as a HTL has a HOMO level of 5.3 eV and a lowest unoccupied molecular orbital (LUMO) level of 1.8 eV with the hole mobility of 0.01 cm^2/Vs[11]. Therefore, the TAPC can be used as a good hole transport material in the OLED due to the high hole mobility and a large LUMO barrier at the interface of TAPC and EML which can confine the electrons injected from a cathode in the region of emitter. The $Bebq_2$ has been used as a host material of red emission in the OLEDs because of its high electron mobility and good energy transfer [12]. The RP411 and ET137 are the proprietary materials from SFC Co., which are commercially provided as a red phosphorescent dye and an electron transport material, respectively, in the conventional OLED applications [13].

The blue device has an organic structure of DNTPD/TAPC/ET137 without an .EML of the red device. Here, the role of DNTPD is same with that in the red device. The TAPC as a HTL in the blue device has also a role of excited state complex (exciplex) prevention around the region of exciton formation. Exciplex can be formed in the case in which a dimer between two organic materials is formed[14]. When the exciplex returns to the ground state, its components dissociate and emit a light. The insertion of TAPC between DNTPD and ET137 is very important in the blue emission structure because an exciplex formation which creates an another emission of yellow light can occur in the double layers of DNTPD/ET137.

The ET137 is used as an EML as well as an electron transport layer (ETL) in the blue emission device. The zone of exciton formation is located in the ET137 near the interface with TAPC because the hole mobility in the HIL and HTL is higher than the electron mobility in the ETL. Therefore, the light emission in the structure of DNTPD/TAPC/ET137 is based on the singlets of ET137 which emits a blue light. The energy level diagram of the materials used in the experiments is shown in Fig. 1.

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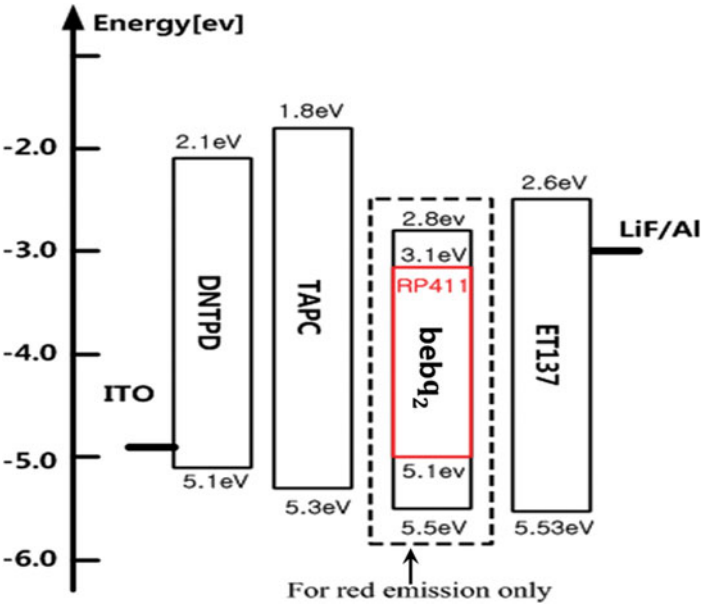

Figure 1. Energy level diagram of the materials used in the experiments.

Experimental Procedure

The substrates with an ITO anode of 12 Ω/sq on glass were cleaned by ultrasonic cleaning process with acetone and isopropyl alcohol. The remaining solvent was removed by soft-baking for 10 minutes at 100°C. To improve the surface morphology of anode, the plasma treatment was executed at 150 W for two minutes under 8 mTorr pressure of O_2/Ar. The plasma treatment before deposition of organic materials is expected to reduce the energy barrier for hole injection from anode and remove the surface contaminants. All organic layers and cathode were deposited by in-situ method under 5×10^{-8} Torr.

As a sequence of process in the fabrication of the devices, the DNTPD with thickness of 500 Å was firstly deposited as a HIL. And then, the 300 Å -thick film of TAPC was formed as

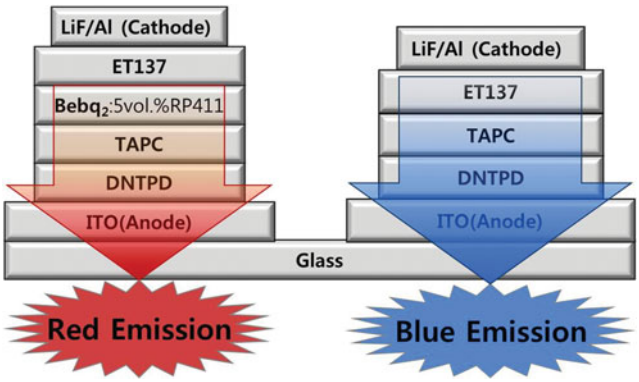

Figure 2. Device structures of red and blue emission.

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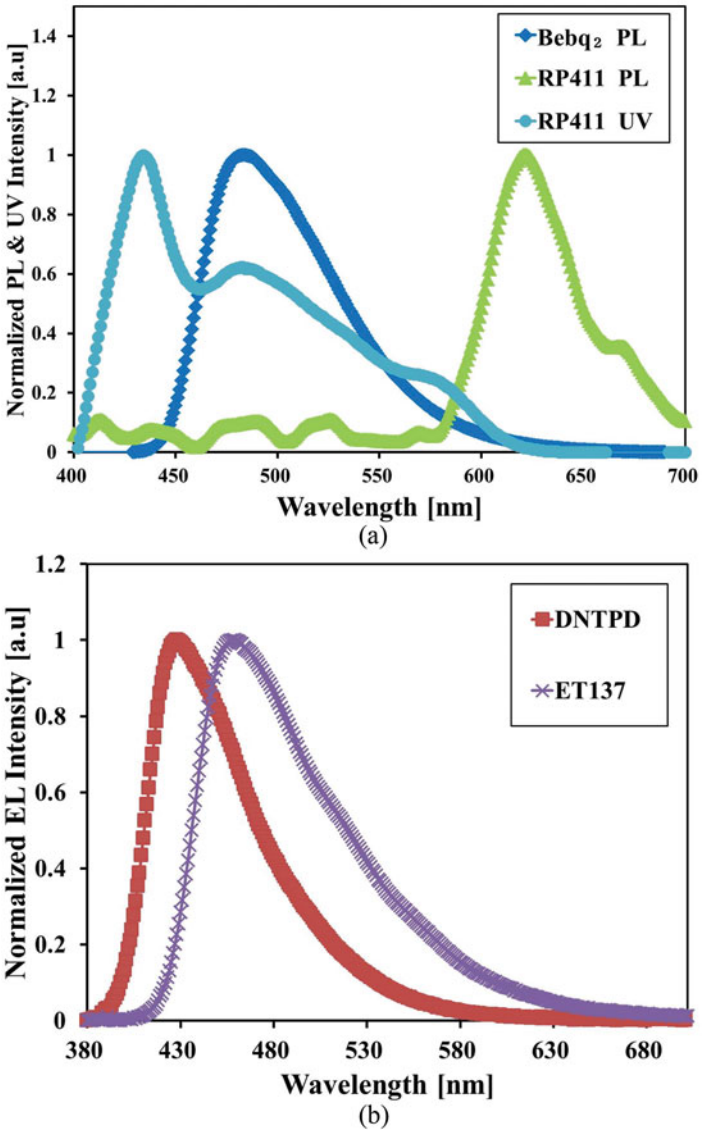

Figure 3. PL, UV-vis absorption spectra, and EL spectra of the used materials: (a) PL spectra of $Bebq_2$ and UV-vis absorption & PL spectra of RP411, (b) EL spectra of DNTPD and ET137.

a HTL. In the formation of EML for red emission, the 300 Å-thick film of $Bebq_2$ doped with 5 vol.% RP411 was selectively deposited only in the red device. Next, the layer of ET137 with thickness of 500 Å was deposited. as an ETL for the red device and an EML&ETL for the blue device. Finally, the 10 Å -thick LiF and 1200 Å -thick Al were successively deposited to form an electrode of cathode. The structures of the fabricated devices are shown in Fig. 2. The electroluminescent characteristics such as current density, luminance, luminous efficiency, electroluminescence spectra, and CIE color coordinates were measured with a Polaronix M6100 test system (McScience) and a CS-1000 spectroradiometer (Konica Minolta) in a dark condition.

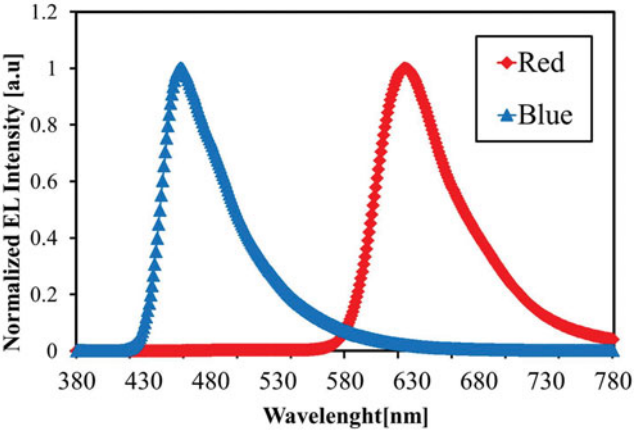

Figure 4. EL spectra of the fabricated devices at an applied voltage of 8 V.

Results and Discussion

Photoluminescence (PL) spectra of $Bebq_2$ and UV-vis absorption & PL spectra of RP411 are shown in Fig. 3(a), and the EL spectra of DNTPD and ET137 are shown in Fig. 3(b). As shown in Fig. 3(a), the wide overlap between PL spectra of $Bebq_2$ and UV-vis absorption spectra of RP411 makes it possible for the $Bebq_2$:RP411 to be a good host-dopant system for a red emission. The peak wavelengths of PL were 484 nm for the $Bebq_2$, 622 nm for the RP411, and the peak wavelengths of EL were 427 nm for the DNTPD and 458 nm for the ET137.

Electroluminescence (EL) spectra of the fabricated devices at an applied bias of 8V are shown in Fig. 4. The peak wavelengths of EL spectra were 624 nm for the red device and 457 nm for the blue device. The peak wavelength of EL for the red device is similar to that of PL for the RP411, and the peak wavelength of EL for the blue device is similar to that of EL for the ET137. This means that light emission of the red device comes from

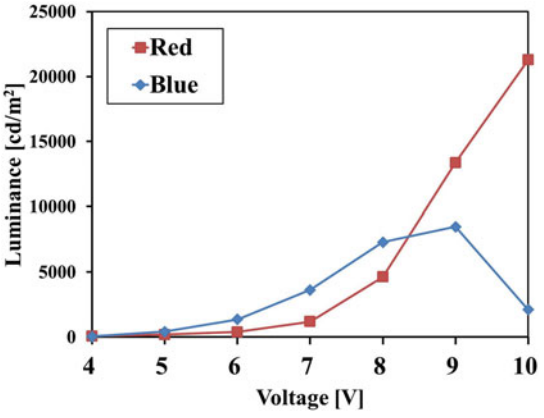

Figure 5. Luminance-voltage characteristics of the fabricated devices.

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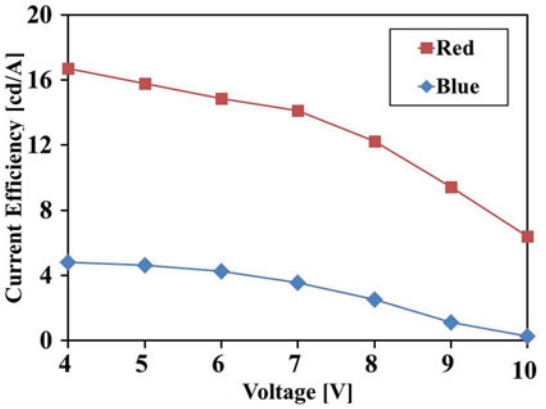

Figure 6. Current efficiency–voltage characteristics of the fabricated devices.

energy release of RP411 triplets and light emission of the blue device from energy release of ET137 singlets.

Figure 5 shows luminance-voltage (L-V) characteristics of the fabricated devices. The luminance increased exponentially according to the applied voltages below a critical voltage because OLED as a diode is driven by current injection. The blue device has a critical voltage of 8 V above which the increase rate of luminance begins to reduce and the device can be even destroyed at a higher voltage. The relatively low critical voltage of the blue device compared to that of the red device seems to be due to the thinning of total thickness by removing a layer of $Bebq_2$:RP411. The luminance at an applied voltage of 8V were 4600 cd/m^2 for the red device and 7.300 cd/m^2 for the blue device.

Luminous efficiencies such as current efficiency and quantum efficiency are very important parameters to evaluate the electroluminescent characteristics of light emitting

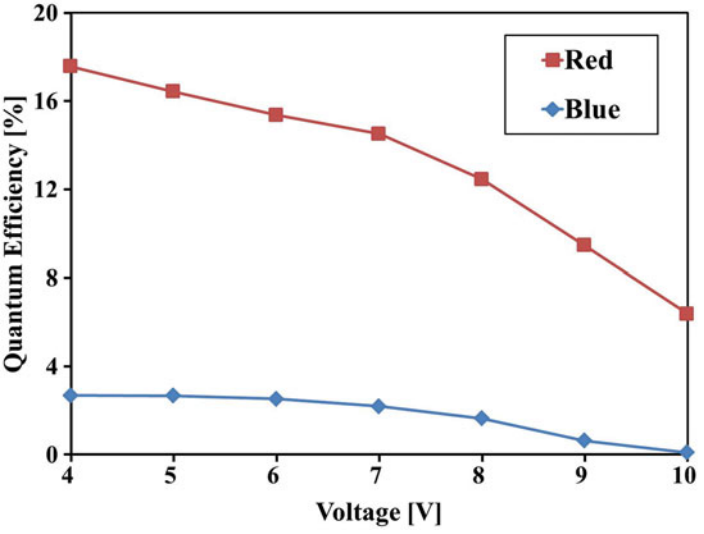

Figure 7. Quantum efficiency–voltage characteristics of the fabricated devices.

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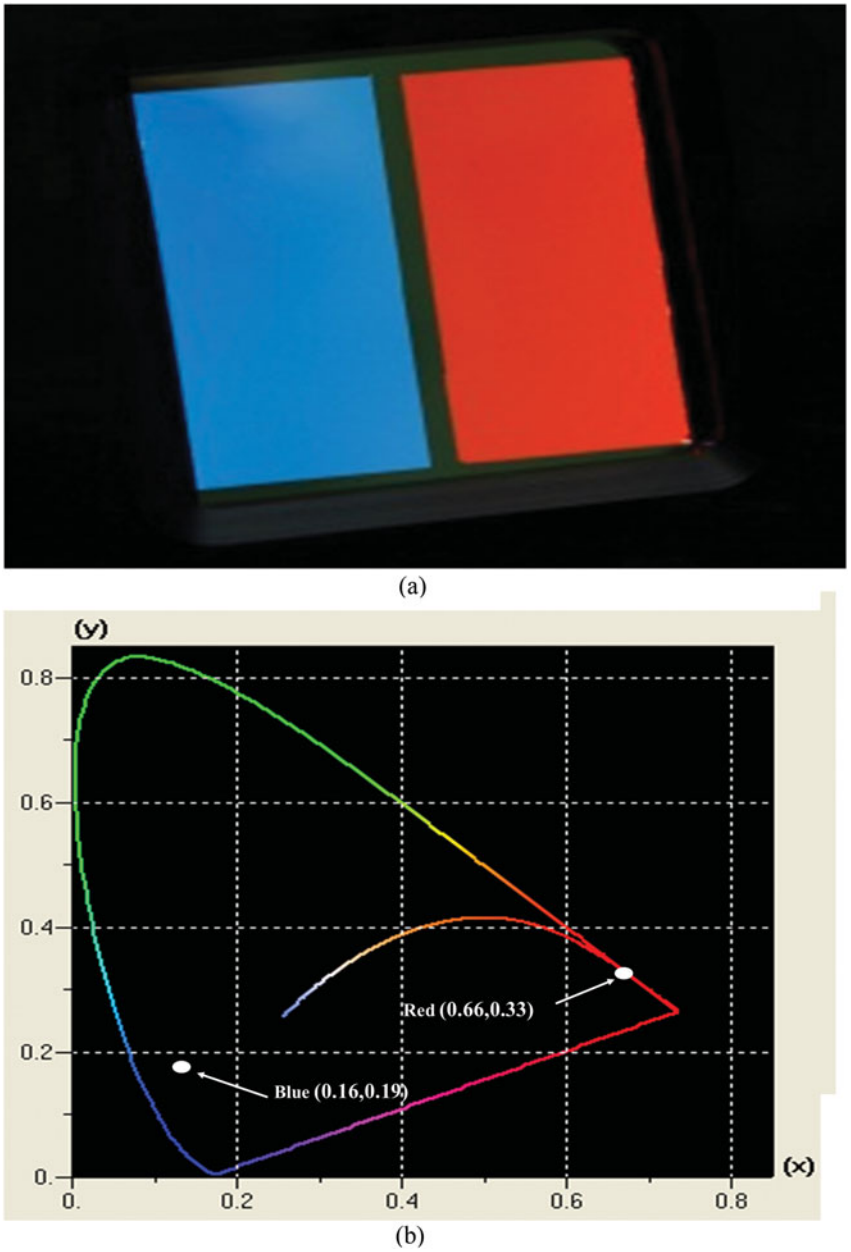

Figure 8. Emission photograph and CIE color coordinates at an applied voltage of 8 V: (a) Emission photograph, (b) CIE color coordinates.

devices. Current and quantum efficiency of the fabricated devices are shown in Fig. 6 and Fig. 7, respectively. We can calculate the current efficiency by an equation of L/J if current density(J)-voltage(V)-luminance(L) relationship is known. In Fig. 6 and Fig. 7, Maximum current efficiency and quantum efficiency of the red device were 16.7 cd/A and 17.6% for the red device and 4.8 cd/A and 2.7% for the blue device, respectively. Current and

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quantum efficiencies of the fabricated devices at 8V were 12.2 cd/A and 12.5% for the red device and 2.5 cd/A and 1.6% for the blue device, respectively. The roll-off characteristics of current and quantum efficiencies according to the increase of voltage may be attributed to the luminescence quenching at high current density.

Electroluminescent characteristics of the blue device are inferior to those of the red device because the blue emission is a kind of fluorescent light and the red emission is a phosphorescent light. Considering the simple structure of blue emission, however, luminance and current efficiency of the blue device obtained in our experiments are not low in comparison with those of other fluorescent blue OLEDs with more complicated structures reported so far [15, 16].

Emission photograph and CIE color coordinates of the fabricated devices are shown in Fig. 8. The simultaneous emission of pure red and light blue under an applied voltage of 8V is seen in the photograph of Fig. 8(a). The color coordinates on the CIE chart were (0.66, 0.33) for red device and (0.16, 0.19) for the blue device in Fig. 8(b). Color purities were 94% for the red emission and 77 % for the blue emission.

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Conclusions

A red OLED with peak wavelength of 624 nm and a blue OLED with peak wavelength of 457 nm were simultaneously fabricated on the same substrate without any additional steps from the fabrication process of the red device. The blue light-emitting device could be simply obtained by excluding the red emissive layer of $Bebq_2$:RP411 in the fabrication of the devices.

The experimental results showed maximum current efficiency of 16.7 cd/A and luminance of 4,600 cd/m^2 at 8V in the red device and maximum current efficiency of 4.8 cd/A and luminance of 7,300 cd/m^2 at 8V in the blue device. The color coordinates on the CIE chart were (0.66, 0.33) and (0.16, 0.19) of pure red and light blue for the red and blue devices, respectively.

Though luminance and current efficiency of the blue device are not sufficiently high, electroluminescent characteristics of the blue device obtained in our experiments can be evaluated to be good in consideration of simple structure and fluorescent emission. The technology in this study makes it possible to fabricate two color OLEDs of red and blue simultaneously on the same substrate with the advantages of simple process and saving of materials.

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