Correlation between EL Characteristics and Substrate Surface Roughness in Top-Emission Powder EL Devices

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ABSTRACT

Powder electroluminescent (EL) devices are planar light-emitting devices that can be fabricated on paper substrates using a simple printing process. In this study, to clarify the effects of surface roughness to the EL characteristics, we fabricated the EL devices with a top-emission structure on emery papers.

1 Introduction

Powder electroluminescent (EL) devices with electric-field-type excitation are planar light-emitting devices that can be fabricated on paper substrates using a simple printing process. Powder EL devices have a high potential for commercial applications because they are flat light emitting devices and require only simple printing processes with a low cost of production and without semiconductor processes using vacuum and plasma. Powder EL has mainly been used for auxiliary light sources, such as backlights for mobile phones and dials of table clocks. However, many researchers have re-evaluated a powder EL device as a planar light-emitting device with excellent environmental resistance, owing to the durability of the device against bending and stretching [1] and the self-healing property of the light-emitting layer. [2]

By exploiting their excellent environmental resistance, new functionalities that are difficult to achieve with conventional light-emitting devices have been realized. For example, a stretchable sound-in-display that synchronizes light and sound can be fabricated by sandwiching phosphor and dielectric elastomers between stretchable electrodes. [3] EL devices can be used for detecting carbon dioxide [4] and ammonia [5] by measuring the changes in the EL intensity using electrodes whose electrical resistance changes as the gas molecules are adsorbed. In addition, a novel sensing device can be fabricated by measuring the changes in EL intensity generated by changes in pressure, temperature, and sodium ion concentration on a skin surface. These variations can be expressed as the impedance variations of the skin surface by using the skin surface as a floating electrode. [6] The development of a transparent high-dielectric-constant polymer has enabled low voltage driving and has achieved EL emission with wireless power transfer. [7] Because of the ability to realize such unique functionalities, powder EL devices are a candidate for wearable next-generation digital signage. Many such novel applications have been proposed. [8] However, a problem that limits their application is their low brightness.

To solve this issue, various researchers have realized high brightness EL devices by improving and modifying EL phosphor, [9] a highly dielectric polymer, [7] and device structure. [10] In a previous study, we focused on the surface roughness of the paper substrate and found that the planarization of the substrate is effective in achieving high luminescence from a bottom emission-type powder EL device. [11] Therefore, the luminance of EL devices can potentially be improved by modifying the properties of the film substrates. In addition, we demonstrated that high luminescence can be obtained when cellulose nanofiber films with low surface roughness and high transmittance are used as a base material for bottom-emission powder EL devices. [12] However, the effect of both the surface roughness and transmittance of the substrate on EL properties could not be evaluated separately. This is because EL luminance is affected by multiple factors in a complicated manner, such as applied voltage and frequency. To understand the effects of surface roughness alone, we used emery paper as the EL substrate, studied the changes with various surface roughnesses, and fabricated a top-emission powder EL that was not affected by substrate transmission.

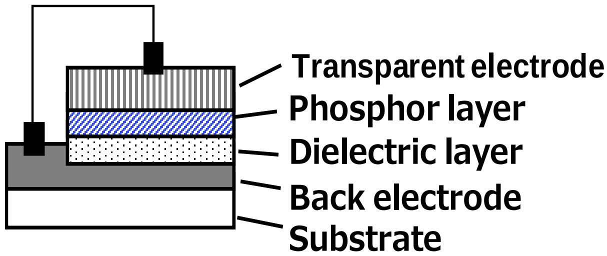

Fig. 1 Cross-sectional view of the top-emission type powder EL device

2 Experiment

Based on previous studies, [13] top-emission powder EL devices were fabricated. Emily paper (11–40 μm^2) was purchased from Yeanda Ltd (Table 1). Poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate) (PEDOT: PSS), a conductive polymer, was purchased from Sigma-Aldrich Co. Zinc-sulfide (ZnS)-type particles (GG64), used as phosphor layers, were purchased from OSRAM SYLVANIA. Barium titanium oxide ($BaTiO_3$) used as the dielectric layer, was purchased from KANTO CHEMICAL Co., Inc. Ag paste, used as the back electrode, was purchased from MINO GROUP Co., Ltd. Cyanoresin (CR-V), used as a high dielectric polymer, was purchased from SHINETSU Chemical Co., Ltd., and cyclohexanone and the solvent were purchased from FUJIFILM Wako Pure Chemical Co. Top-emission devices were fabricated by layering the aforementioned materials on each substrate, as shown in Fig. 1, using an automatic screen printer (TU2020-C: Seritech Corporation). Each sample was dried at 80 °C for 45 min in an air-blast constant-temperature incubator (DKN402; Yamato Scientific Co. Ltd.). The voltage dependences of the current and luminance of the samples were measured using an EL characteristic measurement system (SX-1152, Iwasaki Tsushinki Co., Ltd.). A spectrometer (USB2000, Ocean Insights Ltd.) was used to obtain the EL spectra.

Table 1 Abrasive particle size of the emery papers used.

Japanese industrial standard	
Type	Abrasive particle size of emery paper (μm)
P400	40
P600	28
P800	20
P1000	16
P1500	11

3 Results

The EL spectra of the devices were investigated to ascertain the effect of the substrates on EL emission under an AC voltage of 170 V at 1.2 kHz.EL intensity increased with decreasing abrasive particle size; devices with P1500 substrates exhibited an intensity approximately 1.7 times higher than that exhibited by devices with P400-substrate. As shown in the inset of Fig. 2, an emission peak of an EL band was observed at a wavelength of 490 nm, which was almost identical to that observed in previous devices. [13] [14]

As shown in Fig. 3, under an AC voltage of ±300 V at 1 kHz, the current density decreased exponentially as the abrasive particle size of the substrate film increased. A plot of the current density concerning an abrasive particle size at ±300 V and 1 kHz AC voltage is shown in Fig. 4. The current density decreased exponentially with increasing abrasive particle size. This indicates that the current density of dispersive EL can be improved exponentially by smoothing the substrate surface.

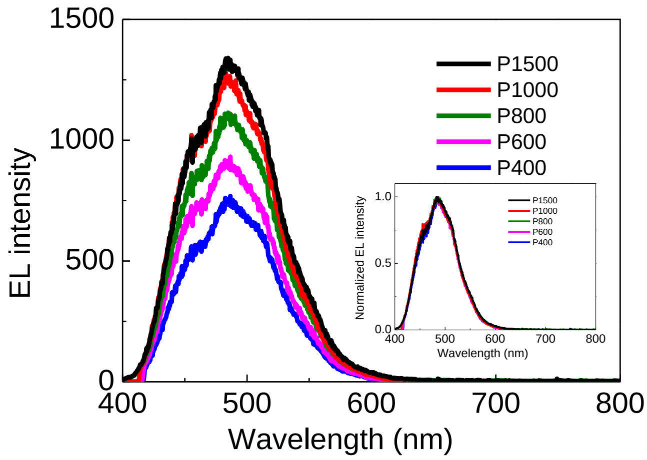

Fig. 2 EL spectra of the devices with different substrates under the application of an AC voltage of 170 V at 1.2 kHz

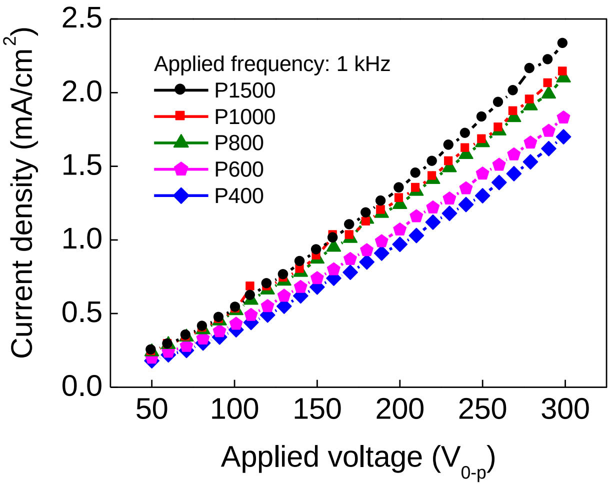

Fig. 3 I-V characteristics of powder EL devices

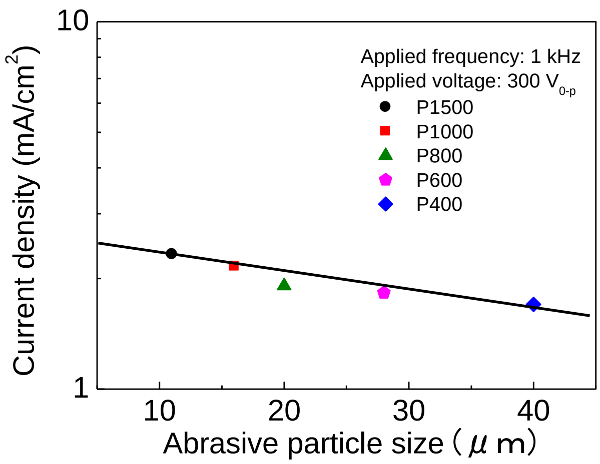

Fig. 4 Current density according to abrasive particle size of substrate

Based on previous studies, [9] [10] thermographic temperatures were measured under an AC voltage of ±170 V at 1.2 kHz applied to all devices for 100 s. The relationship between the maximum temperature and the current density obtained from this measurement is illustrated in Fig. 5. The amount of heat generated by the powder-EL device was exponentially related to the current density.

The dependence of the luminance of the EL devices on applied voltage is shown in Fig. 6 for each substrate. Under applied voltages within 50–300 V, the luminance of all devices increased as the applied voltage increased. The luminance increased as the abrasive particle size decreased. At ±300 V, the device with P400 substrate exhibited a luminance of approximately 460 cd/m^2, whereas the luminance exhibited by the device with P1500 substrate was approximately 640 cd/m^2: an increase of 1.4 times.

To elucidate the relationship between the substrate characteristics and luminance quantitatively, a plot of EL luminance concerning the abrasive particle size of the film substrates under an AC voltage of ±300 V at 1 kHz is shown in Fig. 7. The luminance linearly increased as the abrasive particle size decreased, similarly to the behavior of current density (Fig. 4). Thus, the current density can be increased by increasing the abrasive particle size of the substrates, which leads to high luminance in powder EL devices. These results indicate that the surface roughness of the substrate determines not only the current density but also luminance.

4 Conclusions

In this study, top-emission powder EL devices were constructed using emery paper with various abrasive particle sizes, and the relationship between the particle size and EL properties was quantitatively evaluated.

The current density and luminance of the device using emery paper with a particle size of 40 μm were approximately 1.7 mA/cm^2 and 460 cd/m^2, respectively, at ±300 V and 1 kHz, whereas those of the device with a substrate particle size of 11 μm were approximately 2.3 mA/cm^2 and 640 cd/m^2, respectively. Both values were improved by a factor of 1.4. Furthermore, the current density and luminance decreased exponentially with increasing abrasive particle size.

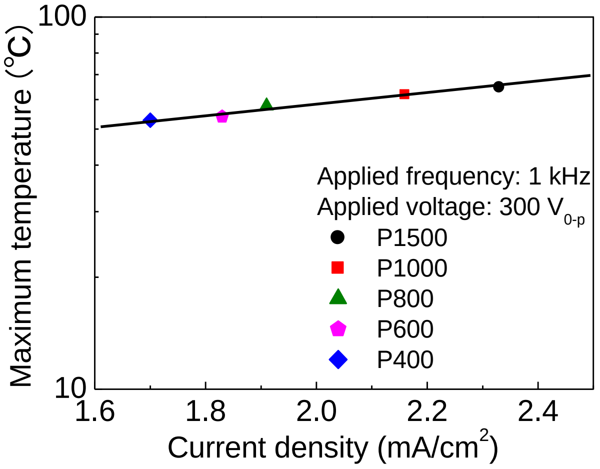

Fig. 5 Maximum temperature according to the current density of powder EL devices

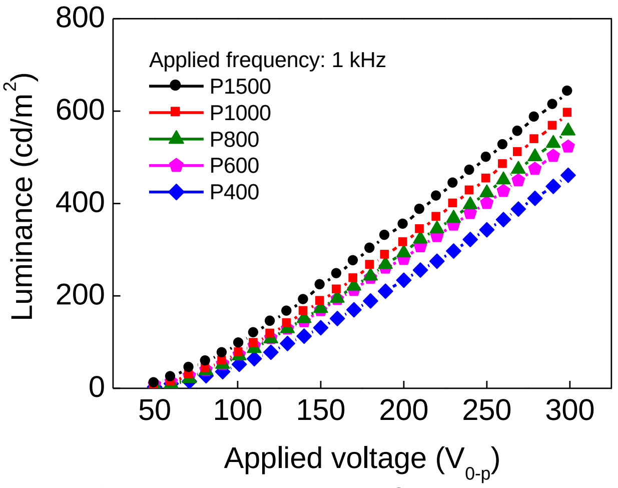

Fig. 6 L-V characteristics of powder EL

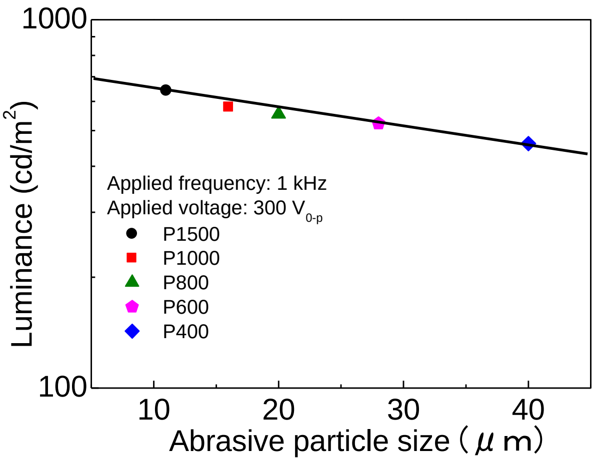

Fig. 7 Luminance according to the abrasive particle size of the substrates

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