

# Powder electroluminescent device based on paper substrate for designing multi-functional digital signage

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## ABSTRACT

We demonstrated the emissions of multi-colored light from a powder electroluminescent device using a thermochromic material through a temperature control. At room temperature, the emission of a sapphire blue light from the device was observed under the application of an alternative current voltage. With an increase in the temperature, the color of the thermochromic materials changed from orange to white, leading to sky blue emissions from the device owing to the decrease in energy transfer from the excited state of the phosphor to the thermochromic material.

## 1. INTRODUCTION

To realize a Super Smart Society, namely, Society 5.0, many different types of electronic devices must be connected to the global network at any time and in any location. In such a society, the devices must not only achieve flexibility with the ability to easily attach to the surface of a curved object such as paper, they must also have a workability allowing them to be cut into an arbitrarily shape. Display devices with a human machine interface also require such functionalities. However, a conventional liquid crystal display device uses a hard glass substrate and a light-emitting diode backlight. In addition, an organic electroluminescent (EL) display device must block the oxygen and water to prevent an unfavorable reaction. Thus, such displays cannot achieve the above requirements.

To overcome this, we focused on a powder EL device that achieves numerous advantages, including a high throughput, workability, weatherability, and stable bendability. With regard to the bending durability, we demonstrated powder EL devices on an Ag grid laminated with Poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS) that achieves a successfully demented bending durability of 20,000 cycles [1, 2]. Despite such advantages, the commercial applications of this device remain a niche market in its present state. To realize new applications, a powder EL device with a multiple functionalities should be achieved. For this reason, we introduced a thermochromic (TC) material that can enable a reversible color change in a powder EL device through an external heat stimulus, thereby achieving a novel powder EL device that exhibits multi-color light emissions from a change in temperature. In this study, we introduced a TC layer that enables a color change in a device from orange to white at 40 °C, and evaluate the electrical and optical behaviors.

## 2. EXPERIMENTAL

### 2.1 Materials

Tracing paper applied as a substrate was purchased from Sakae Technical Paper Co., Ltd. Zinc sulfide (ZnS)-type particles (GG65) used as a phosphor layer were purchased from Osram Sylvania. Barium titanium oxide (BaTiO<sub>3</sub>) utilized as a dielectric layer was purchased from Kishida Chemical Co., Ltd. Cyanoresin (CR-V) applied as a high dielectric polymer was purchased from Shinetsu Chemical Co., Ltd. Cyclohexanone used as a solvent was purchased from Fujifilm Wako Pure Chemical Co. PEDOT:PSS applied as a transparent electrode was purchased from Sigma-Aldrich Co., LLC. The encapsulated TC materials utilized as a TC layer were purchased in a slurry form from Kirokusozai Co., Ltd. Finally, Ag-paste for application as a back electrode was purchased from Mino Group Co., Ltd.

### 2.2 Preparation of the EL devices

The high-dielectric polymer paste was prepared by mixing cyanoresin and cyclohexanone at a weight ratio of 3:7. The phosphor particles and BaTiO<sub>3</sub> were dispersed in a high-dielectric polymer paste at a weight ratio of 4:6. These functional materials were laminated using an automatic screen printing machine (TU2020-C, Seritech Co., Ltd.) (Fig. 1). Each material was sintered in a constant-temperature oven (FS-405, Yamato Scientific Co., Ltd.) at 150 °C for 6 min. The transparent electrode was sintered for 40 min.

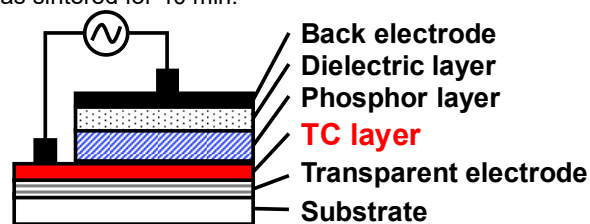


Fig. 1 Structure of powder EL devices

### 2.3 Photophysical and EL measurements

Ultraviolet-visible (UV-vis) absorption spectra of the films were measured using a spectrophotometer (OP-TR/RF-GONIO-MN, Ocean Photonics). Photoluminescence spectra were obtained using a spectrofluorometer (FluoroMax-3, Horiba). The excitation wavelength of the films was 350 nm. The voltage dependences of the current and the luminance of the prepared devices were measured using an EL measurement system (SX-1152, Iwatsu Electric CO., Ltd.).

### 3. RESULTS AND DISCUSSION

Fig. 2 shows the normalized photoluminescence (PL) spectrum of the phosphor layer and the absorbance spectra of the TC layer in the initial and heated states. The PL spectrum of the phosphor showed a peak at 450 nm. By heating the TC layer to 40 °C, the absorbance within the visible light region was decreased. This change in the absorbance band in the TC layer and the PL spectrum of the phosphor overlap well. Such an overlap with the absorption and emission bands facilitates an energy transfers between the phosphor and TC layers.

Fig. 3 shows the current and luminescence dependence of the voltage in powder EL devices with/without a TC layer at room temperature. With the introduction of the TC layer, the current of the powder EL device decreased to 0.36 mA, which is 0.45-times lower than that of the powder EL device without a TC layer (0.80 mA). Corresponding to this result, the luminescence is also lower. It is thought that the electrode distance increases by the introduction of the TC layer.

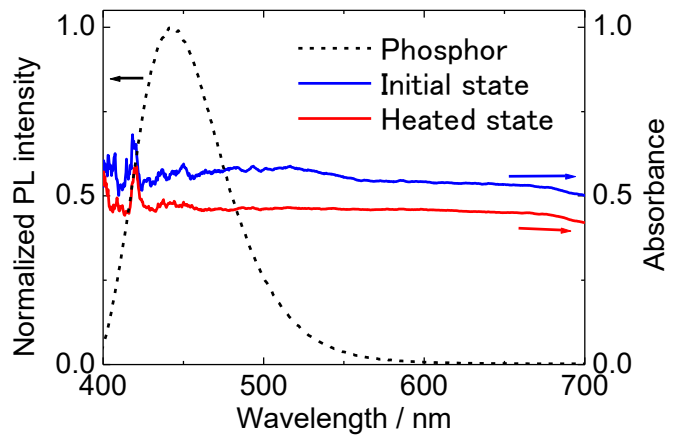
To demonstrate the multi-color EL by utilizing a change in the external temperature, we measured the EL spectra of the device in the initial and heated states under the application of an AC voltage of  $\pm 170$  V at 1.2 kHz (Fig. 4). In the initial state, a sapphire blue EL band with three emission peaks at 450, 490, and 550 nm was observed because the device was in a colored state. By contrast, in a heated state, the color of the device changed from orange to white, and the sky blue EL band with an emission peak 450 nm is almost identical to that of the PL spectrum (Fig. 2). The intensity at 450 nm of the device in a heated state was 2.5-times higher than that in the initial state. These results indicate that the EL color of the EL device can be controlled through the energy transfer between these materials.

### 5. ACKNOWLEDGMENTS

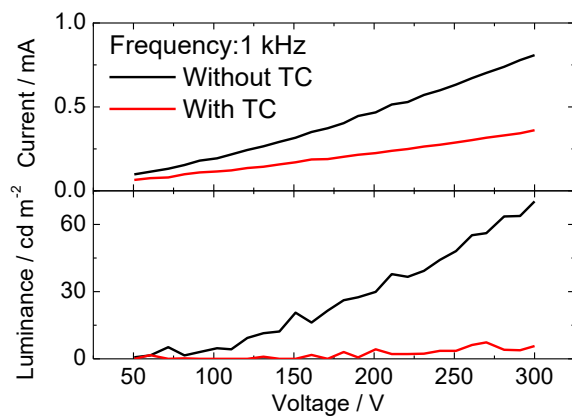
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### 6. REFERENCES

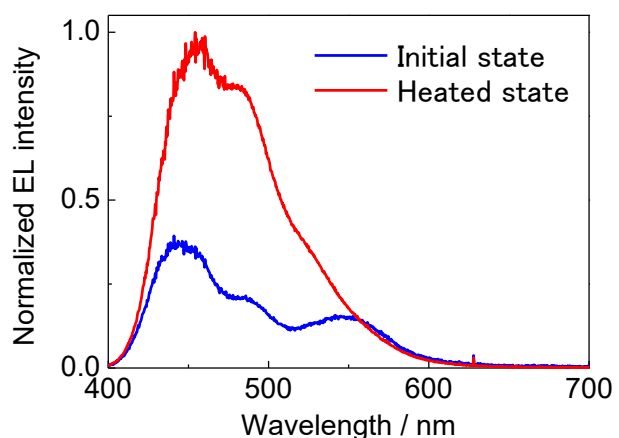
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**Fig. 2 PL spectrum of the phosphor layer and absorbance spectra of the TC layer in the initial/heated states**



**Fig. 3 Current (top) and luminescence (bottom) dependence of the voltage in powder EL devices with/without TC layer**



**Fig. 4 Normalized EL spectra of the device in the initial/heated states under the application of  $\pm 170$  V at AC voltage of 1.2 kHz**