

## A New Type of Thin-Film EL Cell Providing Continuous Tunable Color Emission

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A new type of ac thin-film electroluminescent(EL) device emitting an electrically tunable color from green to red spectra has been developed. The structure of the device consists of two cells of thin-film electroluminescence of the ZnS medium doped with  $TbF_3$  and  $SmF_3$ . By controlling the ac bias voltage applied across each cell, the emission spectrum can be tunable from green to red color with about 100 foot lambert(ft-L). A series of technical data on this new device are presented and discussed.

### §1. Introduction

Recently, much attention has been paid to ac thin-film electroluminescent(EL) device, for applications of wide-area flat-panel display. Quite recently, mass production of double-insulating ZnS:Mn orange-light-emitting devices has been initiated.<sup>1)</sup> As regards multi-coloring of EL device, a lot of R & D efforts have been made for the strong potential needs from wide application fields. Many kinds of luminescent centers, for example donor-acceptor pair type impurities, transition metal ions and rare-earth fluoride molecules, have been investigated elsewhere.<sup>2-5)</sup> Among these luminescent centers, rare-earth fluoride have at least two advantage in view of practical application. The first is comparatively high conversion efficiency due to the large ionization cross section of molecular centers.<sup>5)</sup> The second is their capability on a wide variation of the emission color by selecting appropriate molecular centers. High-brightness green-light-emitting ac thin-film EL device has been attained by using a construction of  $In_2O_3-Y_2O_3-ZnS:TbF_3-Y_2O_3-Al$ .<sup>6)</sup> Furthermore, by selecting luminescent centers and optimizing the fabrication conditions of the EL device, we have succeeded in developing EL device emitting green (doped with  $TbF_3$ ,  $ErF_3$  or  $HoF_3$ ), red(doped with  $SmF_3$ ), yellow (doped with  $DyF_3$ ), blue (doped with

$TmF_3$ ), orange (doped with  $NdF_3$ ) and whitish-green (doped with  $PrF_3$ ).<sup>7)</sup> As for three primary colors of light, the  $TbF_3$ - and  $SmF_3$ - doped devices provide relatively high brightness, but  $TmF_3$ -doped devices are about two orders of magnitude lower. Table I shows the presently obtained brightness level of these devices under 5 kHz sinusoidal excitation. Further study is required for bright blue-emitting device to realize the full-color display. On basis of these technologies, we have developed a new type of continuous tunable color emission EL device with stacked thin-film EL cells having different luminescent centers. We use the stacking structure, because (1) all films formed ac thin-film EL cells are transparent,

Table I The presently obtained brightness level of thin-film EL cells emitting three primary colors of light with the double insulated ac thin-film EL devices under 5 kHz sinusoidal voltage excitation, together with their dopant materials.

color	dopant	brightness
green	$TbF_3$	700 ft-L
red	$SmF_3$	170 ft-L
blue	$TmF_3$	3 ft-L

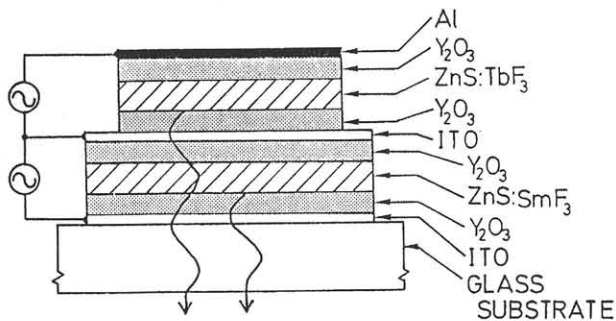


Fig. 1 Schematic illustration of the thin-film EL device consisting of two stacked cells with different color emission.

- (2) a horizontal separation between two stacked cells is no matter, since these films are thin,
- (3) various color can be realized with one address.

### §2. Device Fabrication

Figure 1 shows a schematic illustration of the proposed device structure. Two primary double insulated ac thin-film EL cells are stacked vertically on the commercial indium-tin-oxide (ITO)-coated glass. The back electrode was formed by Al evaporation. All other depositions were carried out by electron beam evaporation. The  $Y_2O_3$  films were adopted as the insulator layers. During the evaporation, the substrate temperature was kept about  $100^\circ C$  and the deposition rate was  $5 \text{ \AA}/\text{sec}$ . The ZnS was used as a host material of the phosphorus layer. The phosphorous layer was deposited at  $230^\circ C$  and the deposition rate was  $6\text{-}10 \text{ \AA}/\text{sec}$ . In this work,  $TbF_3$  and  $SmF_3$  were selected as the luminescent centers. The concentrations of the  $TbF_3$  and the  $SmF_3$  were 0.92 mol% and 0.24 mol%, respectively. The  $ZnS:TbF_3$  layer emits strong green light at 550 nm. On the other hand, the emission spectrum of the  $ZnS:SmF_3$  layer has three dominant lines at 649 nm, 600 nm and 565 nm. Intensities of these lines are dependent on the fabrication conditions, but the emission color is red. After the phosphorous films formation, the thermal treatment was made on the heater kept at  $500^\circ C$  for one hour in vacuum.

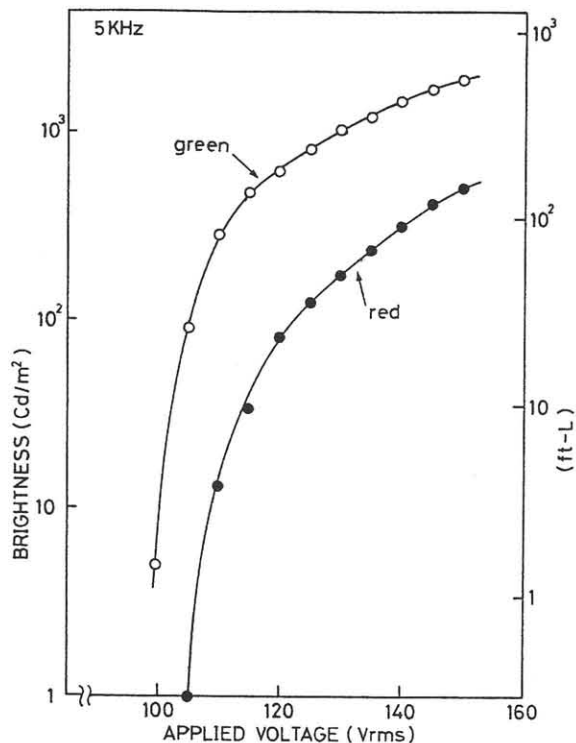


Fig. 2 The brightness versus applied voltage characteristics of the EL device providing continuous tunable color emission. Open and closed circles denote the result of  $ZnS:TbF_3$  cell and  $ZnS:SmF_3$  cell, respectively.

### §3. Characteristics of Tunable Color Emission

Figure 2 shows the typical brightness versus applied voltage (B-V) characteristics of the green-light-emitting ( $ZnS:TbF_3$ ) cell and the red-light-emitting ( $ZnS:SmF_3$ ) cell of this type of devices under sinusoidal voltage excitation at 5 kHz. The brightness of the devices was measured by luminescence meter (TOPCON, BM-3), after an aging treatment of 2 hours. The B-V curves of the two cells shown in Fig. 2 was measured separately, that is, the driving voltage was applied to either front or back electrode. As can be seen in Fig. 2, for both cells, the threshold voltage for EL emission is about 100 volts, the brightness increases rapidly with applied voltage of 110-120 volts and tends to saturate above about 130 volts.

The emission spectra of the device were measured under the 5 kHz sinusoidal voltage excitation by optical multichannel analyzer (PAR, MODEL 1215). The driving voltage was applied to both the front and back electrodes through the

middle ITO of the common electrode. The emission spectrum changes with the voltage applied to each cell layer, as can be seen in Fig. 3. When the voltage applied to green-light-emitting cell ( $V_g$ ) is 113 volts and that applied to the red-light-emitting cell ( $V_r$ ) is 110 volts (lower than the threshold voltage for EL emission), only green emission can be observed, as is shown in Fig. 3(a). Contrary to this, when the  $V_g$  is 90 volts (lower than the threshold voltage for EL emission) and the  $V_r$  is 135 volts, then red emission is observed, as can be seen in Fig. 3(d). Furthermore, when both  $V_g$  and  $V_r$  become higher than the threshold voltages of each cell, green and red emissions were mixed. In the case of (b), the green emission intensity is superior to red one, then the emission color looks yellow-green. In the case of (c), the emission looks yellow. In the case of (d), the red emission is dominant, and so the mixed color looks orange. Consequently, any color between green to red is observed by changing the applied voltage of each cell about 30 volts. Stable emission of about 100 ft-L is observed in this device.

There is difference in the maximum brightness between green emission and red emission, as can be seen in Fig. 2. For good color mixing, the red-light-emitting cell was driven near the brightness-saturating region, but the green-light-emitting cell was driven at the brightness-increasing region to get the same brightness as the red-light-emitting cell. In this work, the amplitude modulation was selected in driving method, but uniform emission could not be obtained near the threshold voltage in such driving method. Another modulation method should be employed to get various colors with wide dynamic range of brightness and is under consideration.

#### §4. Summary

The emission characteristics of the new type of EL device providing continuous tunable color emission have been investigated. The results for these devices are summarized as follows:

- (1) A new type of EL device emitting tunable color from green to red has been developed by stacking vertically double structures of double

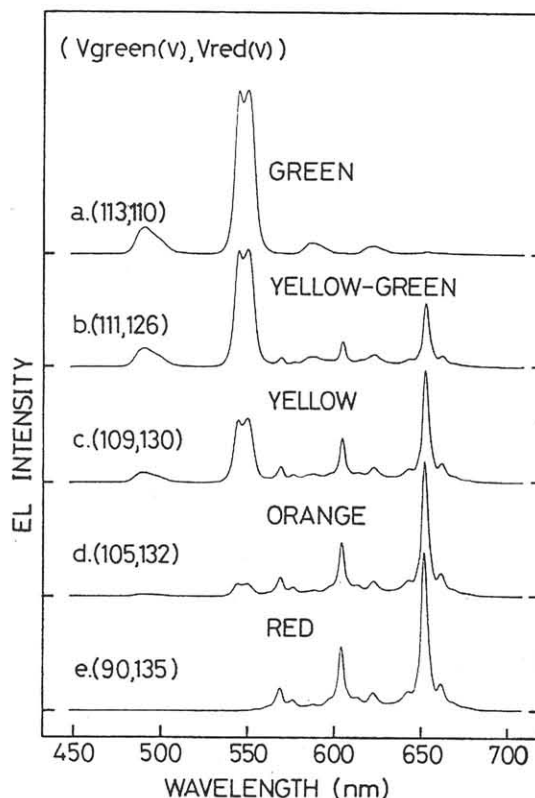


Fig. 3 The emission spectra of the EL device as a parameter of driving voltage applied to each cells. Any color between green and red can be obtained with changing the driving voltage of each cell about 30 volts.

insulated ac EL cells.

- (2) Any color between green and red can be observed with changing the driving voltage of each cell about in the range of 30 volts.
- (3) For any color between green and red, about 100 ft-L brightness could be realized in this device.

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