Evaluation of Distributed Inorganic Electroluminescence (EL) Devices with Comb Electrodes

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Distributed inorganic electroluminescence (EL) devices comprise a metal electrode, and can be fabricated at a low cost using coating processes. In this study, we deposited comb electrodes with narrow gaps between the teeth on a glass substrate, thus realizing a high electric field intensity that cannot be achieved with conventional structures. Au electrodes are deposited to form a comb shape and then spin-coated with a phosphor layer obtained by mixing ZnS phosphor particles with resins at a certain ratio. An AC voltage was applied to the gaps between the teeth of the comb electrode to emit light, from which the luminance was measured for different electric field intensities. The luminances measured from the glass substrate side (the bottom of the device) were low for a device with a Au comb electrodes (Au electrodes) when the electric field intensity was 5 V/μm. However, the luminances measured from the phosphor layer side (the top of the device) for the device with the Au electrodes were high. In contrast, the luminance measured from the phosphor layer side for the device with the Au electrodes 1.5-fold higher than that measured from the glass substrate side. This was because the luminance was not affected by the transmittance of the electrodes themselves when measured from the phosphor layer side. Therefore, it may be possible to produce a display that does not require transparent electrodes by using the phosphor layer side of a device with comb electrodes made of metals, such as Au, for the front side of the display.

Key words: Comb electrode, Inorganic EL, Electric field

1. INTRODUCTION

Electroluminescence (EL) is a phenomenon in which phosphors emit light upon the application of an electric field [1-8]. Depending on the structure and operation mode, inorganic EL devices are classified into four groups. Specifically, there are different structures depending on whether a thin film [9-19] or distributed powder [20-24] is used, each of which has two operation modes for emission, i.e., DC and AC operation modes. Among them, AC-operating EL devices have been confirmed to operate particularly stably for both distributed-powder and thin-film structures.

The improvement of luminance for thin-film EL devices has already been reported [25-32]. In particular, EL devices using high-lumiance blue-emitting phosphors have achieved a high luminance and a long lifetime, and have been examined for application to full-color displays using a technique for displaying the three primary colors through color conversion [33]. Moreover, the matrixing of distributed EL devices, which has been proposed for use in the mass production of simple-pattern devices, has also been reported [34].

On the other hand, distributed inorganic EL devices can be fabricated using simple coating processes [35], such as screen printing, and have been developed for use in backlight panels. However, their performance characteristics are unsatisfactory for practical application with several points requiring improvement. Cost-effective techniques for producing phosphor particles [36], as well as those for improving the luminescence characteristics by mixing phosphor particles and organic dyes, have been studied [37,38]. In addition, research on distributing carbon nanotubes (CNTs) in binders for phosphor layers has been carried out [39].

As shown in Fig. 1, general distributed inorganic EL devices comprise a metal electrode, a dielectric, a phosphor layer, a transparent electrode, and a glass substrate from top to bottom, and can be produced at a low cost using coating processes. However, there is an upper limit to the intensity of the electric field achieved by thinning the phosphor layer because the phosphor layer cannot be thinner than the diameter of the phosphor particles.

The purpose of this study is to realize a device with a high electric field intensity that cannot be achieved with conventional structures by forming comb electrodes on a glass substrate. The structure with the comb electrodes is simple, consisting of a phosphor layer, electrodes, and a glass substrate from top to bottom, and in the future this structure may be thinner and more cost-effective than conventional structures.

Although there has recently been a problem of the limited availability of In, an element in indium tin oxide
(ITO) [40], homogeneous luminescence sources may be obtained using a metal as a material for comb electrodes. In this experiment, we fabricated Au and ITO comb electrodes, and compared their luminescence characteristics.

![Cross-sectional diagram of standard distributed-type inorganic EL panel.](image)

Fig. 1 Cross-sectional diagram of standard distributed-type inorganic EL panel.

2. EXPERIMENTAL DETAILS

2-1. Comb-type electrode

A distributed inorganic EL device was fabricated by depositing ITO comb electrodes on a glass substrate as shown in Fig. 2(a). Specifically, the electrodes were deposited to form a comb shape on the same plane of the glass substrate, and the gap between the teeth was kept smaller than the diameter of phosphor particles. Thus, we attempted to realize higher electric field intensities and higher luminance due to the high electric field than those that can be achieved with conventional structures. Figure 2(b) shows the cross-sectional structure of the comb electrodes.

![Cross-sectional structure of comb electrodes.](image)

Fig. 2 (a) comb-shaped electrode on the substrate, (b) Cross section of distributed-type inorganic EL device with comb-type Electrode.

2-2. Phosphor particles

Next, the method of fabricating the inorganic EL device with comb electrodes is described. The comb electrodes deposited on the glass substrate were spin-coated with a phosphor layer. Spin coating was performed at a speed of 500 rpm for 10 s in the first step and at a speed of 2000 rpm for 20 s in the second step. The phosphor layer was obtained by mixing polymer-type cyanoresins (CR-S and CR-V, Shin-Etsu Chemical Co., Ltd.) and phosphor particles (gg45, Osram Sylvania) at a certain ratio.

![Distribution of phosphor particle size.](image)

Fig. 3 (a) SEM image of phosphor particles (b), distribution of grain size of gg45 phosphor particles (c), photoluminescence spectra of inorganic phosphor layer.

Figure 3(a) shows a scanning electron microscopy (SEM) image of the phosphor particles used in this experiment. The diameter of the phosphor particles was 15-35 μm. Figure 3(b) shows the distribution of the grain size obtained from the SEM image. Phosphor particles with a diameter of 21-30 μm account for the largest percentage (55.6%). Because some particles had a diameter as large as 50 μm, the phosphor layer in a conventional structure would have been thick.

Figure 3(c) shows the spectrofluorometric characteristics (photoluminescence spectra) of the phosphor particles obtained using a spectro fluorophotometer (F-2700, Hitachi High were irradiated with an excitation light with a wavelength of 370 nm, the emission of light with a wavelength of 485 nm was observed. This indicates that gg45 emits blue-green light.
3. Results and Discussion

3-1. Cross-sectional observation with SEM

Figure 4(a) shows cross-sectional SEM images of the distributed inorganic EL device used in the experiment. A phosphor layer in which the phosphor particles are distributed, a BaTiO₃ dielectric layer, and an Ag back electrode were formed on a glass substrate from bottom to top. Figure 4(b) shows an enlargement of the phosphor layer in Fig. 4(a). It was observed that the phosphor particles are distributed on the glass substrate.

Fig. 4 Cross sectional SEM picture of EL device. (a) whole image, (b) enlargement of phosphor layer.

3-2. Observation of emission from glass substrate side (bottom of device)

When a voltage is applied to the comb electrodes, an electric field is generated in each gap between adjacent teeth, and the phosphor particles in the gaps are excited by the electric fields to emit light. The narrower the gap, the higher the electric field intensity, because the electric field intensity is inversely proportional to the distance between the electrodes. Moreover, emission mainly occurs in and around the gaps between the teeth. A large amount of emitted light is transmitted through the ITO electrodes because of their high transmittance.

Figure 5(a) shows an optical microscopy image of a device with two ITO electrodes observed from the glass substrate side (the bottom of the device) when no voltage was applied. At the center of the device is a gap of 10 μm between the ITO electrodes. Figure 5(b) shows the emission observed when an AC voltage of 150 V with a frequency of 1.8 kHz was applied to the device in Fig. 5(a). The result revealed that not only the gap but also the surrounding area, with a total width of 150 μm, exhibited a very high luminance.

The luminance for a different gap width between the ITO electrodes was examined [Figs. 5(c) and 5(d)]. In Fig. 5(c), the gap width, observed at the center of the device, is 50 μm, which is fivefold greater than that in

Fig. 5 Images showing luminance of distributed type inorganic EL panel with emission from bottom side. (a) No applied voltage (b), voltage applied to ITO electrodes with a gap of 10 μm. (c) No applied voltage (d), and voltage applied to ITO electrodes with a gap of 50 μm. (e) No applied voltage (f) voltage applied to ITO with comb-type electrodes with a gap of 10 μm.
Figs. 5(a) and 5(b) (10 μm). Figure 5(d) shows the emission observed when an AC voltage of 150 V with a frequency of 1.8 kHz was applied to the device in Fig. 5(c). It was confirmed that the device with an interelectrode gap width of 50 μm [Fig. 5(d)] also emits light, although its luminance is lower than that of the device with a gap width of 10 μm [Fig. 5(b)]. The width of the emission area is approximately 150 μm. The comparison of Figs. 5(b) and 5(d) reveals that the gap width between the ITO electrodes significantly affects the luminance.

Figure 5(e) shows the structure in which ITO comb electrodes are formed. Figure 5(f) shows the emission observed when an AC voltage of 150 V with a frequency of 1.8 kHz was applied to the device in Fig. 5(e). Light was uniformly emitted from the entire region by forming the ITO electrodes in a comb shape.

3.3 Comparison between ITO and Au comb electrodes

We examined the luminance characteristics of two devices with different electrodes, i.e., ITO and Au comb electrodes. The width of the gap between the teeth of the comb electrodes was 10 μm, and both comb electrodes were spin-coated with a single phosphor layer. In this examination, we compared the luminance measured from the glass substrate side (the bottom of the device) with that measured from the phosphor layer side (the top of the device). First, the luminance was measured from the glass substrate side [Fig. 6(a)]. Only a phosphor layer (without a dielectric layer) was deposited by spin coating on the glass substrate with the ITO comb electrodes, on which an upper electrode was deposited. An AC voltage with a frequency of 1.8 kHz was applied. In the graph in Fig. 6(a), the abscissa represents the electric field intensity and the ordinate represents the luminance measured from the glass substrate side. When the electric field intensity was 15 V/μm (applied voltage, 150 V), the luminance for the device with the ITO electrodes was 96.6 cd/m², whereas that for the device with the Au electrodes was 58.7 cd/m².

This indicates that the device with the ITO electrodes exhibits a higher luminance than the device with the Au electrodes because of the leakage of light passing through the ITO electrodes.

Next, the luminance was measured from the phosphor layer side [Fig. 6(b)] for the same devices. An AC voltage with a frequency of 1.8 kHz was applied. In the graph in Fig. 6(b), the abscissa represents the electric field intensity and the ordinate represents the luminance measured from the phosphor layer side. When the electric field intensity was 15 V/μm (applied voltage, 150 V), the luminances were 91.6 and 111.4 cd/m² for the devices with ITO and Au electrodes, respectively. In the measurement from the phosphor layer side, the reflectance of the electrodes themselves is more important than their transmittance. For the device with the Au electrodes, the luminance measured from the phosphor layer side was 1.9-fold higher than that measured from the glass substrate side. One possible reason for the luminance of the device with the Au electrodes being higher than that of the device with the ITO electrodes is that the Au electrodes have a higher reflectance than the ITO electrodes. According to the above findings, displays can be fabricated without using ITO transparent electrodes when the phosphor layer side of devices with Au comb electrodes is used for the front side of displays.

Figure 7(a) shows the luminance measured from the glass substrate side for different gap widths between the teeth. The luminance for the devices with the ITO electrodes with a high transmittance was higher than that for the device with the Au electrodes for all the gap widths examined, particularly for gap widths below 50 μm. In contrast, the luminance measured from the phosphor layer side for the device with the Au electrodes was higher than that for the device with the ITO electrodes, as shown in Fig. 7(b). The device with the Au electrodes exhibited a high luminance, particularly for gap widths below 100 μm. This may be because the Au electrodes have a higher reflectance than the ITO electrodes.

Fig. 6 Luminance-voltage characteristics of distributed type inorganic EL panel. (a) Emission from bottom side; (b) emission from top side.
The capacitance of each electrode along the direction which corresponds to the applied electric field was estimated. It noted that the substrate plays a very important role without dielectric materials. The capacitance of comb-electrodes for two electrodes gaps are 86 pF (L/S=5 μm) without dielectric materials. It could be seen that capacitance increases as electrodes gap reduces. If both combs have interdigitated electrodes with the same shape, the structure can be acceptably approximated to the proposing results of capacitance. It could be significantly reduced in order to decrease material costs.

4. Conclusion
We confirmed that our devices, in which comb electrodes are formed and coated with a phosphor layer obtained by mixing phosphor particles with resins, emitted light upon the application of a voltage. The luminance was 100.7 cd/m² for the device coated with a single phosphor layer (We also confirmed that the luminance increased to 181.6 cd/m² when the particle density was increased.). We also compared ITO electrodes with Au electrodes by measuring the luminance from the top and bottom of devices in which a single phosphor layer was deposited on the comb electrodes with a gap of 10 μm between the teeth. The luminances measured from the glass substrate (the bottom of the device) were 96.6 and 58.7 cd/m² for the devices with ITO and Au electrodes, respectively, when the electric field intensity was 15 V/μm. The luminances measured from the phosphor layer side (the top of the device) were 91.6 cd/m² for the device with the ITO electrodes and as high as 111.4 cd/m² for the device with the Au electrodes when the electric field intensity was 15 V/μm.

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5. References
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