

Optical and Electrical Properties of Thin Film Electroluminescent Devices with SrS:Cu, Ag Phosphor Layer

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Abstract: The SrS:Cu, Ag thin film electroluminescent devices were fabricated on AlTiO₃/ITO/glass substrates by electron-beam evaporation. The emission spectrum of the device was about 460 nm with $x=0.20$, $y=0.29$ in the CIE color coordinator. It was found that the emission spectrum was saturated to pure blue color when Ag sensitizer was doped in SrS:CuCl phosphors. The luminance of the device was increased by increasing the sulfur pressure. The measured luminance was saturated with 430 cd/m² at the applied voltage of 90 V and the maximum luminance was 580 cd/m² at 110 V. The polarization charge and conduction charge of the devices were found to be about 3.5 $\mu\text{C}/\text{cm}^2$ and 7.4 $\mu\text{C}/\text{cm}^2$, respectively.

Keywords: Electroluminescent, SrS:Cu, Ag phosphors, Emission spectrum, Electrical charge, Capacitance

1. Introduction

The thin film electroluminescent (TFEL) devices have been attracted much attention for the application of the full color flat panel display and back light for the liquid crystal display (LCD)^{1,2}. The TFEL devices are all solid and self emissive display with good features such as fast response time, wide viewing angle and the capability for a high resolution. The recent challenge for the thin film EL and organic light emitted diodes (OLED) technologies is focussed on the producing of the multi-color as well as full color displays³⁻⁶. The first multi-color thin film electroluminescent devices using inorganic phosphors were based on the patterned color filtered out from yellow emitting phosphors. However, the luminance of blue color and driving voltage should be improved for practical display application^{7,8}. The TFEL emission mechanism is characterized by high field assisted tunneling and a field induced ionization of luminescent centers^{9,10}. In this work, the SrS:Cu,Ag TFEL devices were fabricated on ATO (AlTiO₃)/ITO/glass substrates by the electron beam evaporation method. The optical and electrical proper-

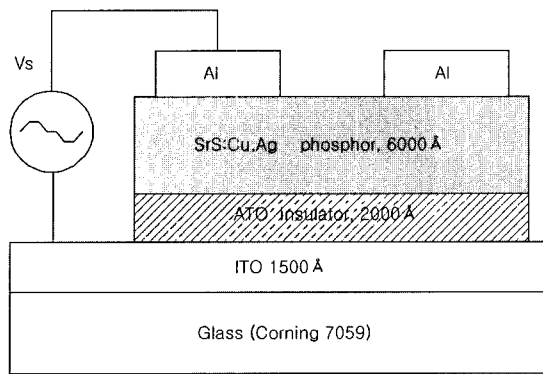
ties were investigated by applying sinusoidal voltages at the frequency of 1 kHz.

2. Experimental

The TFEL devices¹ were fabricated on ATO(AlTiO₃)/ITO/glass substrate using SrS:Cu,Ag phosphors by the electron beam evaporation method. The SrS and CuCl powder pellets were used as the host materials and AgCl powders were added with a ratio of 0.4 at % as the sensitizer material to improve the luminance and color purity. The evaporation pressure and the substrate temperature were about 6.5×10^{-6} Torr and 400°C, respectively. The deposition rate was about 7 Å/sec and the thickness of phosphor layer was formed to be about 600 nm. In order to compensate the deficiency of sulfur in the phosphor layer during evaporation, the sulfur powders were evaporated separately from a Knudsen cell. After the deposition of phosphors on the substrates, the TFEL devices were annealed at the temperatures ranging from 600°C to 800°C for 3 minutes under N₂ ambient by the rapid thermal annealing (RTA) system in order to improve the crystallinity. Finally, Al

Table 1. The deposition conditions of SrS:Cu, Ag base TFEL devices by the electron beam evaporation

Items	Conditions
• Base pressure	• 6.0×10^{-6} Torr
• Sulfur pressure	• 8.0×10^{-6} - 3.5×10^{-5} Torr
• Source materials	• SrS, CuCl, S and Ag
• Substrate	• ITO/Glass
• Substrate temperature	• 400°C
• Deposition rate	• about $7 \text{ \AA}/\text{sec}$
• Thickness of phosphor	• about 600 nm

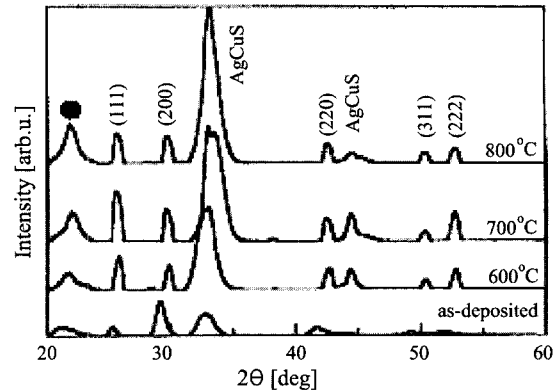
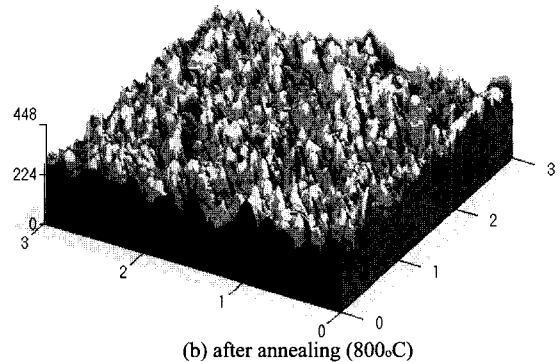
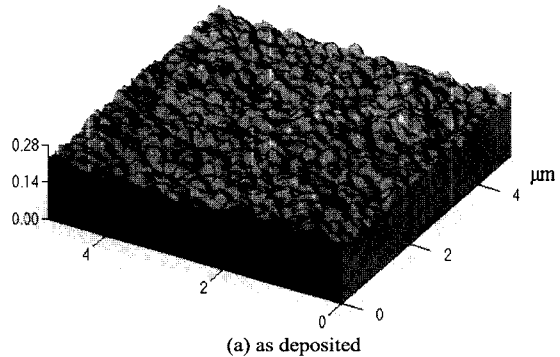
**Fig. 1.** Cross sectional structure of SrS:Cu, Ag TFEL device.

electrodes were deposited onto the phosphor layer by the thermal evaporation. The crystalline structures and surface morphologies of the phosphors were examined by the X-ray diffraction (XRD) analysis and the atomic force microscopy (AFM). The emission spectra of the devices were evaluated by the optical spectra multi-channel analyzer (OSMA) and the luminances were measured using the chroma meter. The electrical charges versus voltage characteristics were analysed by the sawyer-tower circuit. Table 1 shows the deposition conditions of SrS:Cu, Ag base TFEL devices by electron beam evaporation.

Figure 1 shows the schematic cross sectional structure of the TFEL device.

3. Results and Discussion

Figure 2 shows the XRD patterns of SrS:Cu, Ag TFEL devices as a function of RTA annealing temper-

**Fig. 2.** XRD pattern of SrS:Cu, Ag thin-film (●: unknown peaks).**Fig. 3.** AFM images of SrS:Cu, Ag films of the (a) as-deposited and the (b) annealed film at 800°C .

atures. The TFEL devices were exhibited randomly oriented crystal structures with main peaks of SrS phase.

The peak intensities were increased slightly with increasing the annealing temperatures from 600°C to 800°C . The XRD patterns revealed that the phases of AgCuS and unknown SrS compound were also appeared. These compounds were originated from

insufficient crystallization and may be affected to the color purity and luminance of TFEL devices.

To investigate the crystallinity of the devices, the full width at half maximum (FWHM) values were observed. The FWHM value of (200) reflection peak of the device annealed at 600°C was about 3.2° (degree) and decreased to 2.8° for the sample annealed at 800°C, suggesting the improvement of the crystallinity.

Figure 3 shows the AFM images of the (a) as-deposited phosphor film and the (b) annealed at 800°C. AFM images indicate that the surface roughness of phosphor layers was affected by the post-annealing. The R_{rms} value of the as-deposited film was 1.7 nm with relatively smooth surface. Whereas, the R_{rms} values were increased from 3.8 nm to 9.0 nm as the annealing temperature increased from 600°C to 800°C. The increase of R_{rms} values may be attributed to the conglomeration of the phosphor particles due to a high temperature annealing.

The emission spectra of SrS:CuCl and SrS:Cu, Ag

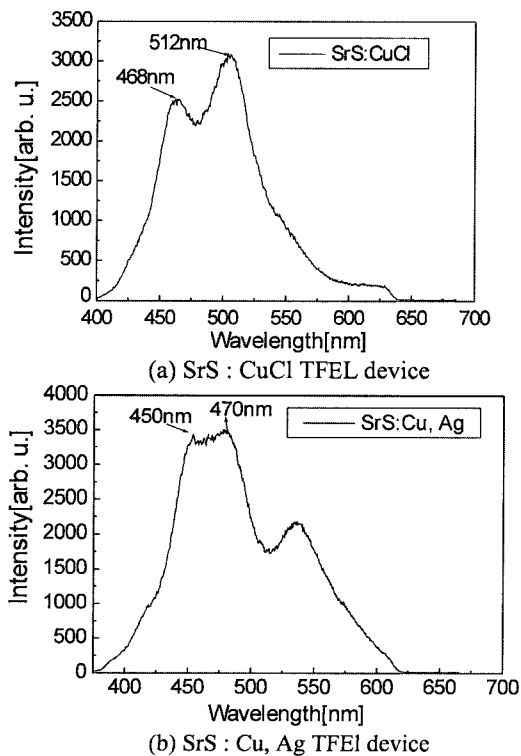


Fig. 4. Emission spectra of (a) SrS:CuCl device and (b) SrS:Cu, Ag TFEL device.

TFEL devices are shown in figure 4. In the case of SrS:CuCl device, the maximum emission peak exhibited at the wavelength of 512 nm with the CIE color coordinate of $x=0.21, y=0.33$. In contrast, the maximum emission spectrum of SrS:Cu, Ag TFEL devices was about 460 nm with $x=0.20, y=0.29$ in the CIE color chart. As a result, the emission spectrum showed the saturation to blue color when Ag sensitizer was doped in SrS:CuCl phosphors. The improvement of color purity by the addition of Ag sensitizer may be ascribed to the increase of trapped electron energy in Ag dimer centers.

Figure 5 shows the luminance of SrS:Cu, Ag TFEL devices as a function of the applied voltage at a different sulfur pressures. It was shown that the luminance was dependent on the sulfur pressures. The luminance was increased from 110 cd/m^2 to 300 cd/m^2 at 80 V

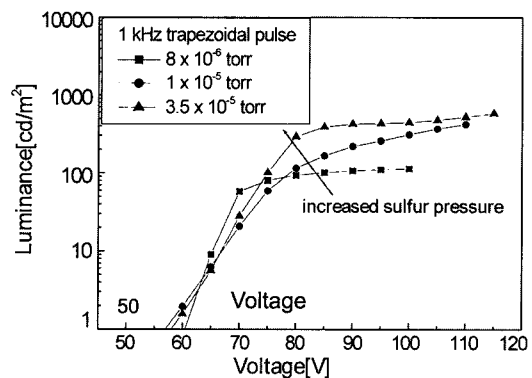


Fig. 5. Luminance of SrS:Cu, Ag TFEL devices as a function of the applied voltage at various sulfur pressures.

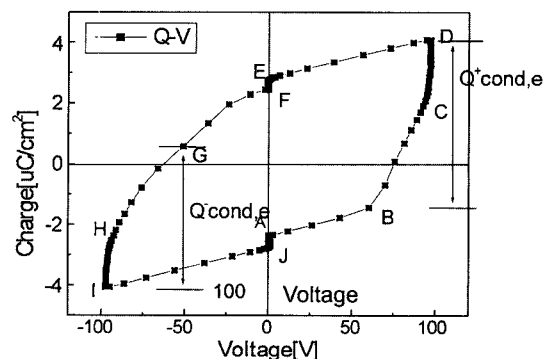


Fig. 6. Electrical charge versus voltage characteristic of SrS:Cu, Ag TFEL device.

with increasing the sulfur pressure from 8.0×10^{-6} Torr to 3.5×10^{-5} Torr. The measured luminance was saturated with 430 cd/m^2 at the applied voltage of 90 V and the threshold voltage was 60 V. The maximum luminance of 580 cd/m^2 was obtained at the applied voltage of 110 V under the sulfur pressure of 3.5×10^{-5} Torr. As a result, it is useful to note that the maintaining of high sulfur pressure over 3.5×10^{-5} Torr during evaporation is one of the important factors for the high luminance blue emission in SrS:Cu, Ag TFEL devices.

It is well known that the luminance of TFEL devices is affected by the electrical charges in the phosphor layer at a given applied voltage.

Figure 6 shows the electrical charges-voltage (Q-V) characteristics of SrS:Cu, Ag TFEL devices at the applied voltage of 90 V and 1 kHz frequency. It was shown that there were two steps of the charge slope

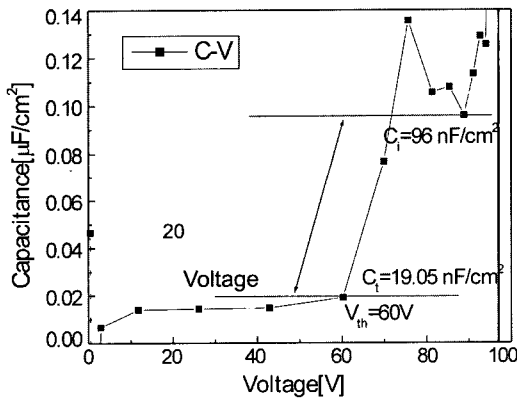


Fig. 7. Capacitance versus voltage characteristic of SrS:Cu, Ag TFEL device.

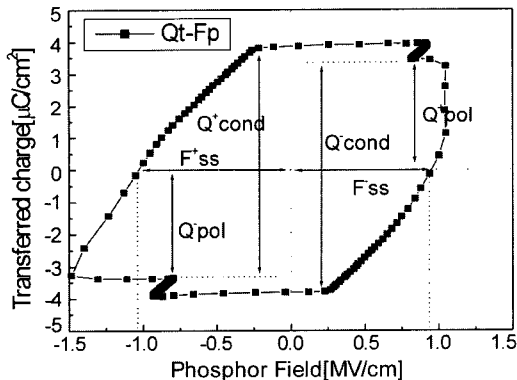


Fig. 8. Qt-Fp characteristic of SrS:Cu, Ag TFEL device.

according to applied voltages. From Q-V curve in figure 6, the abrupt change of the slope at the voltage around 60 V seems like to be threshold voltage (V_{th}) of the devices. The dependence of capacitance on the applied voltage (C-V) are shown in figure 7. The capacitance of TFEL devices can be obtained from the sum of the insulator capacitance (C_i) and phosphor capacitances (C_p) below the V_{th} value as the double layer film structure with insulator and phosphor. While, only the C_i should be accounted over the V_{th} due to the breakdown of phosphors. The capacitance was about 19 nF/cm^2 at the threshold voltage of 60 V and sharply increased up to 75 V, which resulted from the space charges in the phosphor. The capacitance was decreased to 96 nF/cm^2 at the applied voltage of 85 V.

Figure 8 shows the transferred charge density (Q_t) of the TFEL devices as a function of applied electric field (F_p). It was found that the value of the conduction charge, which contribute the phosphor emission, was $7.4 \text{ } \mu\text{C/cm}^2$.

The leak charge density was $0.4 \text{ } \mu\text{C/cm}^2$ at zero biased voltage. The polarization charge (Q_{pol}) of the device, indicating the trapped electron charges at the interface between insulator and phosphor layer, was found to be $3.5 \text{ } \mu\text{C/cm}^2$. It was also observed that the breakdown electric field (F_{ss}) of the phosphor layer was lower than 0.9 MV/cm .

For the high luminance, it is necessary to maintain high conduction and polarization charges in the phosphor layer. As a results, it seems possible to use SrS:Cu, Ag as a good quality blue phosphor for TFEL devices by optimizing the device structure.

4. Conclusions

The SrS:Cu,Ag TFEL devices were fabricated on ATO(AlTiO_3)/ITO/glass substrates by the electron-beam evaporation, and the optical and electrical characteristics were measured. The emission spectrum of the device was about 460 nm with $x=0.20$, $y=0.29$ in the CIE color coordinator. The emission spectrum showed the saturation to pure blue color when Ag sensitizer was doped in SrS:CuCl phosphors. It was observed that the luminance of SrS:Cu, Ag TFEL was increased with evaporation pressure of sulfur. The

breakdown electric field was 0.9 MV/cm. The polarization charge and the conduction charge of TFEL devices were found to be about $3.5 \mu\text{C}/\text{cm}^2$ and $7.4 \mu\text{C}/\text{cm}^2$, respectively. It can be concluded that the emission intensity of the device may be increased by the increasing of the conduction charge.

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