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UV and Visible range Electroluminescence from MOS Devices Fabricated by Spin-Coating of Gd/Dy Organic Compound Films on Silicon

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Abstract

UV and visible range EL from MOS devices with spin-coated Gd silicate-related oxide having additive elements of Dy is presented. The devices emitted UV and visible wavelength range EL, which originated from the intrashell transitions in Gd^{3+} and Dy^{3+}, respectively. The surface silicate layer is analyzed by the XPS depth profiles and an EL mechanism is discussed.

1. Introduction

Si-based light-emitting devices, which have superior process compatibility to Si metal-oxide-semiconductor (MOS) LSIs, are very attractive for realizing microdisplays in portable systems as well as optical interconnections reducing metal wire delay. Recently, EL in ultraviolet (UV) through IR range from MOS devices with rare-earth elements were reported [1,2]. MOS devices fabricated with the spin-coated organic compound films of Tb/Eu showed the green and red EL [3,4].

In this study, we demonstrate UV and visible range EL from MOS devices with spin-coated gadolinium (Gd) silicate-related oxide having additive elements of dysprosium (Dy). The surface silicate layer is analyzed by the X-ray photoelectron spectroscopy (XPS) depth profiles and a model of photoemission mechanism is also discussed.

2. MOS EL Devices and Measurement Setup

Fig. 1(a) shows a schematic cross section of a MOS device with a [Gd/(Gd+Dy)-Si-O] layer. Organic compound liquids of Gd and Dy were spin-coated on n^+-Si. Device #1 was fabricated with a single liquid source of Gd. The atomic ratios (Gd : Dy) in mixture liquids for device #2 was prepared to be (10 : 1), where Gd and (Gd : Dy) mixture liquids were two fold diluted with the thinner liquid. The fabrication process steps are shown in Fig.2 (b).

The EL spectra were measured by a back-illuminated CCD camera stabilized at -70 °C with a monochromator under a constant current supply. The wavelength range from 290 to 1000 nm can be detected at once [3,4].

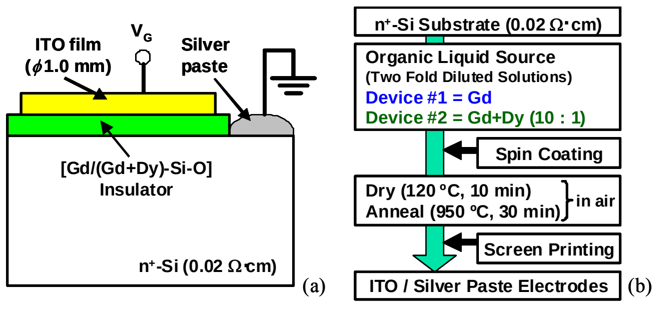


Fig. 1 (a) A schematic cross section of a MOS device and (b) fabrication process steps.

3. Results and Discussion

Fig. 2(a) shows the forward $+I_G$ vs $+V_G$ characteristics. The rising voltage $+V_R$, where $+I_G$ increased steeply, was about +11 V for both devices #1 and #2. The linear relation of the Fowler-Nordheim (FN) plot in Fig. 2(b) confirms the FN tunnel current and the injection of hot electrons into the insulator from Si substrate.

Fig. 3 shows microphotographs of (a) an ITO electrode in #2, and (b) an EL color image of devices #2. Since EL could not be observed from the devices with the single element liquid source of Dy, the devices with strong white EL were realized by mixing the Gd solution with the Dy solutions.

Fig. 4 shows EL spectra of #1 and #2 in the wavelength range of (a) 300 ~ 1000 nm and (b) 300 ~ 330 nm (UV range). Device #2 emitted strong visible light with narrow peaks but less UV light. Device #1 had smaller visible components, which contained the broad peaks superimposed on narrow peaks.

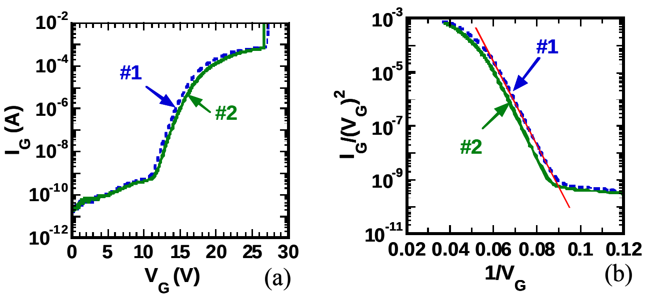


Fig. 2 (a) $+I_G$ vs $+V_G$ characteristics and (b) FN plot.

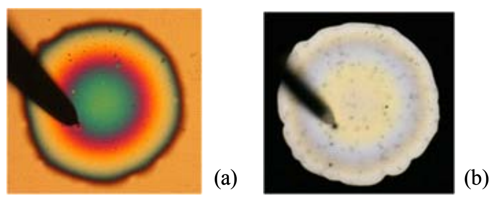
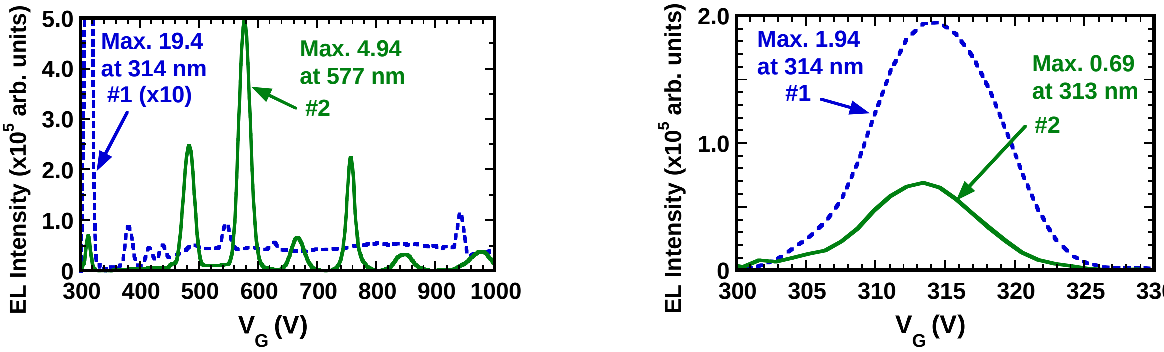


Fig. 3 Microphotographs of (a) an ITO electrode in #2, and (b) an EL color image of devices #2.



(a) (b)

Fig. 4 EL spectra of #1 and #2 in the wavelength range of (a) 300 ~ 1000 nm and (b) 300 ~ 330 nm (UV range).

Fig. 5 shows the extraction of Gaussian distribution functions G_i for EL of #2. The spectra are normalized to the maximum intensity and fitted to the following equation: $G_i = M_i \exp[- (E - E_i)^2/2(\sigma_i)^2]$, where M_i, E_i, and σ_i are the maximum EL intensity, the center energy, and the standard deviation, respectively. E_4 in #2 is the intrashell transitions of $^6P_{7/2} - {}^8S_{7/2}$ [3.97 eV] in Gd^{3+} ions [1]. Energy levels E_1~ E_3, and E_5 observed in #2 correspond well to the intrashell transitions of $^4F_{9/2}$ - $^6H_{J/2}$ (J = 13, 15, 9, and 11) in the Dy^{3+} ions [2]. E_6 and E_7 appear to correspond to the transitions of $^4F_{9/2}$ - $^6H_{J/2}$ (J = 5 and 7) in Dy^{3+}. The higher energy electrons accelerated by the electric fields in #2 are transferred to the Gd^{3+} ions and excite the state from the $^8S_{7/2}$ to $^6P_{7/2}$. Then, the electron energy is transferred from Gd^{3+} to Dy^{3+}, followed by the radiative transitions from $^4F_{9/2}$ to $^6H_{J/2}$ in the Dy^{3+} ions. As for #1, the peak around 310 nm corresponds to the transition in Gd^{3+}. The origins of the other peaks in the visible range, which may be related to Gd and/or defects in the oxide, are not clear as of now.

Fig. 6 shows the atomic concentration profiles of Gd, O and Si in addition to (a) C for #1, (b) Dy for #2 analyzed by XPS. The Gd concentration became the highest around 3 nm from the surface, and then gradually decreased toward the Si substrate. The profile of Dy was similar to that of Gd. Inside the cross point of Gd and Si concentrations, the Si/O ratios of about 1/2 suggested that the layers were SiO_x rich oxides with the Gd and/or Dy composites. The schematic cross sections of the devices estimated from XPS spectrum analyses are shown in Fig. 7. The first surface 6 nm thick layer consists of [Gd_2O_3/(DyO_x) and Gd/(Gd+Dy)-Si-O]. The second 23 nm thick layer is the SiO_x rich oxides with the Gd and/or Dy composites.

4. Conclusions

UV and visible range EL characteristics are reported for (ITO)/[(Gd/(Gd+Dy)-Si-O] insulator/n^+-Si substrate MOS devices, which were fabricated from the spin-coated films with organic liquid sources of (Gd) or (Gd+Dy). The devices with (Gd+Dy) emitted UV and visible wavelength range EL, which originated from the intrashell transitions in Gd^{3+} and Dy^{3+}, respectively. The insulator films consist of [Gd_2O_3/(DyO_x) and Gd/(Gd+Dy)-Si-O], and the SiO_x rich oxide with the Gd and/or Dy composites.

References

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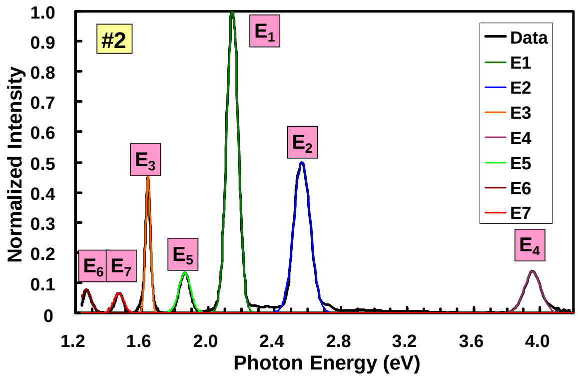
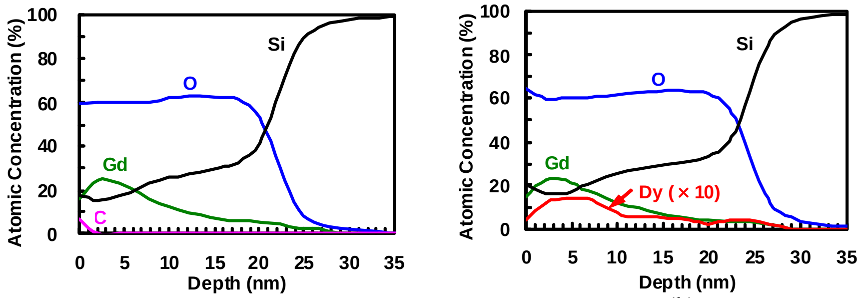


Fig. 5 Extraction of Gaussian distribution functions G_i for EL of #2



(a) (b)

Fig. 6 Atomic concentration profiles of Gd, O, Si, (a) C for #1, (b) Dy for #2.

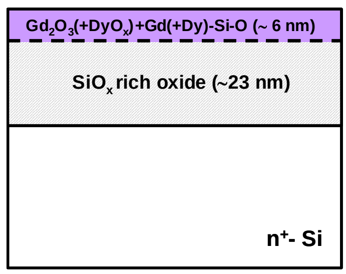


Fig. 7 Estimated schematic cross sections of #1/#2.