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Alternating-Current a-C:H White Thin-Film Light-Emitting Diodes with Composition-Graded Carrier Injection Layers

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1. Introduction

Light-emitting devices based on condensed matters have been receiving considerable attentions since the demonstration of the first light-emitting diode (LED). Currently many researchers around the world are aggressively working toward developing a light source that could replace the traditional light sources, such as incandescent and fluorescent lamps, in general lighting applications. Owing to small size, high efficiency, long lifetime and without mercury pollution, LED which could emit white light has been considered a promising candidate not only economic but also environmental for future lighting applications. In recent years, alternating-current (AC) LEDs have been considered to be the more practical light sources because they are easy to be used and installed without additional accessory, can save more power consumption, and have a longer lifetime. A variety of organic molecules, conjugated polymers, and blends had been found to exhibit electroluminescence (EL) properties and demonstrated all the colors needed for display applications, and the symmetrically configured AC light-emitting devices based on these materials had been fabricated. Nevertheless, the brightness of device is only about 10 cd/m^2 at an applied voltage of 17.7 V [1]. Besides, the existing AC thin-film EL devices based on, e.g., Mn-doped ZnS, have considerable drawbacks, such as high fabrication cost and operating voltage [2]. In this study, a thin-film LED (TFLED) with a nearly symmetrical structure, which utilized the hydrogenated intrinsic amorphous carbon (i-a-C:H) film as luminescent layer and composition-graded (CG) hydrogenated intrinsic amorphous silicon germanium (i-a-SiGe:H, CG Ge) film as carrier injection layers, could emit white light with an EL spectrum spreading from 350 to 750 nm under either a direct-current (DC) forward or reverse bias or an AC voltage will be demonstrated.

2. Experimental

The schematic structure and employed source-gas flow-rates for each layer during deposition are shown in Fig. 1. The various amorphous films were deposited on the indium-tin-oxide (ITO)-coated glass substrate by utilizing a plasma-enhanced chemical vapor deposition (PECVD) system (ULVAC CPD 1108D) at a substrate temperature of 210 ^{0}C. The luminescent layer is i-a-C:H film. In-situ H_2-plasma treatment (H_2 flow-rate = 25 sccm, chamber pressure = 0.3 torr, RF power = 5 W, time = 30 min.) was adopted for i-a-C:H layer. Then, the top Al layer was deposited with a thermal coating system (ULVAC VTC-410) through a metal mask. Finally, the finished TFLED was put into a rapid thermal annealing system (RTA, JETFIRST PROCESSOR) and annealed in H_2 ambient at 240 ^{0}C for 10 min.. The device EL spectra were measured with a monochrometer (SPEX 270M) which was controlled by the DM 3000 spectrometer, and its EL brightness was measured by a photo-multiplier tube (ORIEL detection system 7070, PMT 70680) and a semiconductor parameter analyzer (HP 4145B).

3. Results and Discussion

Figure 2 shows the J (current density)-V (applied voltage) and B (brightness)-V curves of fabricated devices with and without CG Ge layers, respectively, measured under forward-bias mode (FBM: ITO-electrode was biased positively with respect to the Al-electrode) and reverse-bias mode (RBM: ITO-electrode was biased negatively with respect to the Al-electrode). As shown in Fig. 2, the EL threshold voltages (V_{th}s, defined as the x-axis intercept of straight line extrapolating from linear portion of B-V curve) of devices with and without CG Ge layers were 7.5 and 9 V under FBM, and were 7.8 and 10 V under RBM, respectively. The brightnesses of devices with and without CG Ge layers were about 1000 and 640 cd/m^2 under FBM, and were 560 and 390 cd/m^2 under RBM, respectively, at an injection current density of 300 mA/cm^2. Obviously, the performance of device with CG Ge layer was greatly enhanced no matter the device was operated under FBM or RBM. The improved EL performance would be due to the enhanced carrier injection efficiency resulting from the smoother energy barriers with CG technique. Figure 3 shows the EL spectra of devices with and without CG Ge layers, respectively, measured under FBM and RBM at 12 V. The peak wavelengths of devices with and without CG Ge layers were 520 and 505 nm under FBM, and were 515 and 515 nm under RBM, respectively. The full-widths at half maximum (FWHMs) of devices with and without CG Ge layers were around 200 and 220 nm under FBM, and were 250 and 250 nm under RBM, respectively. The EL spectra of devices with and without CG Ge carrier injection layers were qualitatively very similar and revealed close peak wavelength and broad FWHM. Figure 4 shows the EL spectra of relative intensity for device with CG Ge layer under 100, 1k, 10k, 20k, and 100k Hz sinusoidal voltages of 5 V rms, respectively. One could observe that the EL peak wavelength shift toward the longer one with frequency. Also, from the inset of Fig. 4, it could be found that the device EL intensity increased with the frequency of sinusoidal applied voltage up to 20 kHz and then decreased rather rapidly with the higher frequency. Finally, the intensity became very weak at about 100 kHz. The spectrum-shift phenomenon and frequency dependence of the EL intensity would be qualitatively explained with the mobility of charge carriers in amorphous layer. The mobility of carrier in amorphous material was low, especially for a-C:H film [3]. The reason for the spectrum-shift phenomenon was supposed to, with the increasing frequency, part of the carriers had no enough time to transport to the i-a-C:H luminescent layer and be recombined there to emit light with shorter wavelength. Hence the carrier recombination might occur mainly in the CG i-a-SiC:H or even i-a-SiGe:H layer and emit light of longer wavelength. Besides, the behavior of frequency-dependent EL intensity might be due to, in lower frequency range, the carrier injection and recombination would follow-up the AC bias, and this led to the EL intensity was increased with the increasing of frequency. At a much higher frequency, the EL started to lag the applied voltage, as in a simple RC circuit and the EL intensity decreased.

4. Conclusion

The electroluminescence characteristics of a TFLED based on i-a-C:H layer had been demonstrated. It was found that the CG Ge carrier injection layers could be used to increase the EL brightness and intensity, and reduce the V_{th} of the device. The greatly enhanced performance would encourage the practical application of AC LEDs based on i-a-C:H film.

References

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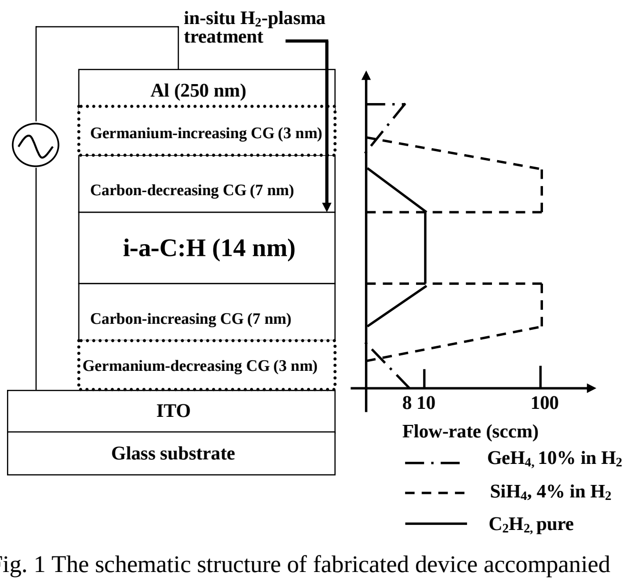

Fig. 1 The schematic structure of fabricated device accompanied with flow-rates of used source gases.

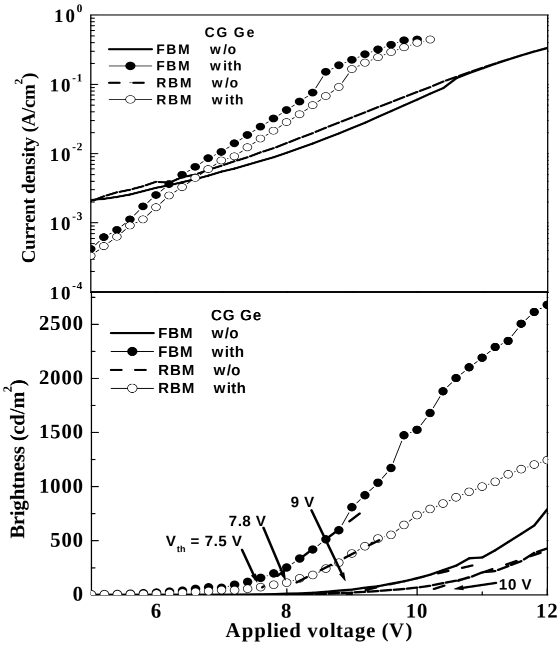

Fig. 2 The J-V and B-V curves of fabricated devices with and without CG Ge layers.

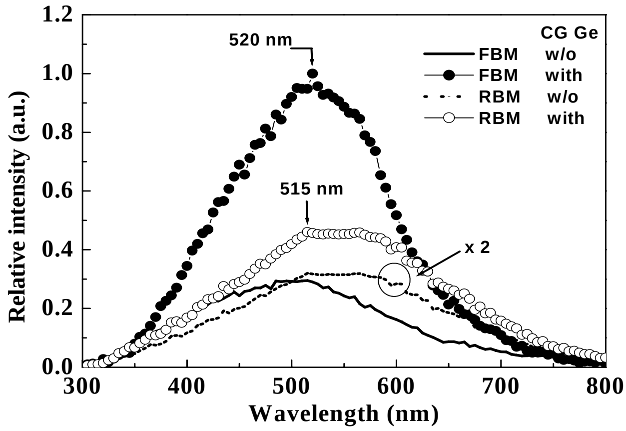

Fig. 3 The EL spectra of fabricated devices with and without CG Ge layers.

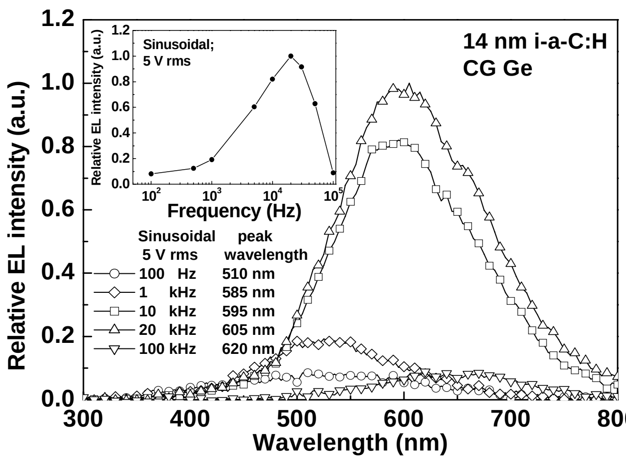

Fig. 4 The EL spectra of relative intensity for device with CG Ge carrier injection layers operated under sinusoidal voltages of various frequencies and at 5 V rms. The inset shows the frequency-dependence of EL intensity of the device.