Double Graded-Gap a-SiC:H P-I-N Thin-Film LED with Composition-Graded N-Layer and Carbon-Increasing P-Layer

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An a-SiC:H p-i-n thin-film LED's (TFLED's), having the composition-graded n-layer and carbon-increasing p-layer used to replace the constant optical-gap p⁺-a-SiC:H and n⁺-a-SiC:H layers employed by the previously reported double graded-gap (DG) TFLED[1], which contains dopant-graded p⁺-i and i-n⁺ junction, was successfully fabricated to improve the electroluminescence(EL) of TFLED. This device had an obtainable brightness of 400 cd/m² at an injection current density of 600 mA/cm² and its EL threshold voltage (V_{th}) was 9.9 V only. The device EL spectrum peaked at 586 nm wavelength and emitted orange-yellowish light as observed by the naked eyes. The optimum condition of rapid thermal annealing (RTA), which improved the ohmic contact between the device thin film layer and external electrode, was suggested to be 5 min at 300 °C, in a 250 torr H₂ ambient.

1. INTRODUCTION

The development of p-i-n TFLED's especially those made of a-SiC:H has progressed significantily[1-8]. By tunning the carbon source gas (e.g. C_2H_2) fraction during deposition of amorphous film, the optical-gap of the a-SiC:H could be easily adjusted from 1.8 to more than 3.5 eV, so the EL spectrum of a-SiC:H would range from infrared to visible and even to ultra violet region theoretically.

The a-SiC:H p-i-n TFLED's have several potential advantages as compared to the crystalline LED's, since it could be employed to make large flat-panel displays and deposited onto any cheap substrate. But they usually have a higher V_{th} and lower brightness than those of the crystalline LED and further improvements are needed to meet the requirement for practical application. In this paper, the composition-graded n-layer and carbon-increasing p-layer were used to further improve the EL properties of the a-SiC:H p-i-n TFLED.

2. DEVICE FABRICATION

Fig. 1. depicts the schematic cross-section and the optical-gap diagrams of the proposed a-SiC:H p-i-n TFLED. As shown in Fig. 1(a), the used substrate was indium-tin-oxide (ITO)-coated Corning 7059 glass, and after cleaning it was loaded into the reaction chamber of an plasma-enhanced chemical vapor deposition(PECVD ULVAC CPD-1108D) system. Then, a H₂-plasma bombarding to the ITO surface was followed, which could reduce the contact resistance between ITO electrode and p⁺ layer[6-8][10]. Then, the p⁺-, i- and n⁺-a-SiC:H layers were deposited onto glass substrate consequently without interrupting the RF power[6-9]. The carbon-increasing

p⁺-a-SiC:H layer was fabricated by gradually increasing the flow-rate of C2H2 source gas. On the other hand, by gradually decreasing the flow-rate of C₂H₂ source gas, the composition-graded n⁺-a-SiC:H layer, which inclded a thin n⁺-a-Si:H film, could be similarly fabricated. The deposition processes of the dopant-graded p-i and i-n junctions were described elswhere[1]. Finally, the top Al film was obtained by thermal evaporation, through a metal mask which defined a circular device area of 1.13*10⁻². cm², by using an ULVAC MB62-4502 ultra-high vacuum coater and at a substrate temperature of 150 °C. To reduce the contact resistance between the electrode and p+- or n+post-metallization-annealing (PMA) was layer, a performed with a rapid thermal annealing (RTA) system. The film deposition conditions of various amorphous layers used in proposed device were listed in Table 1.



Fig. 1(a). The schematic cross-section of the proposed a-SiC:H p-i-n TFLED.



K−150 Å → K−−300 Å → K−−250Å →

Fig. 1(b). The schematic optical-gap diagram of the proposed TFLED under forward-bias.

Table 1. Deposition conditions of a-SiC:H films

Layer	Gas flow-rate (sccm)	Pressure (Torr)	G.R.* (Å/sec)	E _{opt} (eV)
Р	$SiH_4: C_2H_2: B_2H_6$ = 100 : 4.6 : 36	0.38	0.64	2.00
i (SienCen)	$SiH_4 : C_2H_2$ = 100 : 9.2	0.33	0.65	2.43
n	SiH ₄ : C ₂ H ₂ : PH ₃ = 100 : 4.6 : 72	0.49	0.28	2.40
÷	SiH₄ : C2H2 : PH ₃ = 100 : 0 : 72	0.46	0.13	1.40

R.F. power = 5 Watts R.F. power density = 7 mW/cm² Substrate temperature = 180 °C * : Growth rate

Process gases :

1. SiH₄: 4 % SiH₄ + 96 % H₂

2. B₂H₆: 1 % B₂H₆ + 99 % H₂

3. PH₃ : 1 % PH₃ + 99 % H₂

4. C₂H₂: 50 % C₂H₂ + 50 % H₂

3. BRIGHTNESS & J-V CURVES

Fig. 2 illustrates the J (current density)-V and B(brightness)-V characteristics of the proposed device and double graded-gap (DG) TFLED[1]. The proposed one had a composition-graded n^+ layer and carbon-increasing p-layer, but the DG TFLED had the constant optical-gap p^+ and n^+ a-SiC:H layers[1]. As could be seen from this figure, the proposed TFLED had a V_{th} of 9.9 V which was

much lower than that (13.8 V) of the DG one. This could be caused by the employed compositiom-graded n-layer and carbon-increasing p-layer which decrease the series and contact resistances of the device. These two layers would reduce the notch barriers at p^+ and n^+ contacts. So, for V > 6V, the proposed device had a significantly higher current density than that of the DG TFLED[1].

As exhibited in Fig. 1(b), the proposed TFLED had a much higher brightness than that of DG one[1]. This could be primarily due to the improvement of carrier injection and hence the radiative recombination probability around the p-i interface. The proposed TFLED had an obtainable brightness of 400 cd/m² at a J=600 mA/cm². This brightness was significantly higher than 207 cd/m² of the DG TFLED[1], and 342 cd/m² of TFLED with a n⁺-a-SiC:H composition-graded layer andd a thin i-a-SiC:H barrier inserted at the p-i interface.



Fig. 2. The characteristics of current density and brightness vs. applied voltage for the proposed TFLED and the previously reported double graded-gap TFLED[1].

4. EL SPECTRUM

The EL spectra of the proposed device and DG one[1] are illustrated in Fig. 3. For the DG TFLED, the EL spectrum peaked at 700 nm and was with a full-width-at-half-maxmum (FWHM) of 190 nm. Also, it emitted red light as observed by the naked eyes. But, the proposed device had an EL spectrum peaked at 586 nm and with a FWHM of 140 nm. The proposed device emitted a orange-yellowish light. This might be due to the employed carbon-increasing p^+ -a-SiC:H layer would enhance the hole tunneling into the tail-states, which had a higher energy, of i-a-SiC:H layer having a higher optical-gap.



Fig. 3. A comparison of EL spectra for the proposed TFLED and the previously reported double graded-gap TFLED[1].

5. PMA

Fig. 4 shows the effect of PMA time on V_{th} of the proposed device. The PMA could be used to improve the ohmic contact between the p⁺- or n⁺- layer and external electrode. This figure indicated a 5-min 300 °C annealing in 250 torr H₂ ambient was suitable.



Fig. 4. The effect of annealing temperature on EL threshold voltage (V_{th}) of the proposed TFLED.

6. CONCLUSION

As an alternative approach to improve the EL intensity of a-SiC:H TFLED, the composition-graded n-layer and carbon-increasing p-layer were used to improve the p⁺-i and i⁺-n interface, electron and hole injection efficiencies and hence EL intensity significantly. This increase of brightness could be ascribed to the reduced interface states by using the continuous deposition technique[6-9], (composition) graded-gap junctions, carbon-increasing layer, and the lowered contact resistance due to PMA. An achievable brightness of 400 cd/m² at an injection current density of 600 mA/cm² and a low EL V_{th} of 9.9 V were obtained for the proposed TFLED.

8. ACKNOWLEDGEMENT

This work was supported by National Science Council of R.O.C. under contract NSC83-0417-E008-014.

9. REFERENCES

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