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A-SiC:H p-i-n Thin-Film Light-Emitting Diodes with Barrier Layers Inserted at p-i Interface

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To improve the electroluminescence (EL) intensity of the hydrogenated amorphous silicon carbide (a–SiC:H) p–i–n thin–film light–emitting diode (TFLED), the barrier layers (BLs) had been inserted at its p–i interface to enhance the hole injection under forward–biased operation. The obtained brightness for a single BL TFLED (device I) is higher and has a value of 342 cd/m^2 at an injection current density of 600 mA/cm^2. Also, a brightness of 197 cd/m^2 at 600 mA/cm^2 for a double BL TFLED (device II) is obtainable.

1. INTRODUCTION

Since Pankove *et al.* reported an infra–red EL in a–Si:H p–i–n junction at low temperature in 1976 [1], the development of a–SiC:H p–i–n TFLEDs has progressed markedly [2]–[6]. However, to improve the applicability of TFLED, the increase of its EL intensity and the lowering of its EL threshold–voltage are desirable. In 1989, Hamakawa *et al.* employed hot–carrier tunneling injection (HTI) layers to improve the luminosity of the a–SiC:H TFLED [4]. They obtained a brightness of 20 cd/m^2 at an injection current density of 1 A/cm^2. In this study, a single barrier (25 Å) (device I) or a double–barrier structure of barrier(10Å)/well(10Å)/barrier(10Å) (device II), was inserted at the p–i interface of an a–SiC:H p–i–n TFLED to improve its EL intensity and lower its EL threshold voltage.

2. DEVICE FABRICATION AND OPERATION

Fig. 1 shows basically the schematic cross–section of an a–SiC:H p–i–n TFLED with inserted BL. The indium tin oxide (ITO)– coated Corning 7059 glass was used as a substrate. After cleaning, it was put into the plasma–enhanced chemical vapor deposition (PECVD, ULVAC CPD–1108) system. In order to reduce the contact resistance between the ITO electrode and the p$^+$–layer, H_2–plasma was used to bombard the ITO film prior to the deposition of the p$^+$– type a–SiC:H layer [7]. The a–SiC:H p$^+$ (optical gap, E_{opt}, is equal to 2.40 eV), BL (E_{opt} = 2.65 eV), i (E_{opt} = 2.47 eV for device I , E_{opt} = 2.50 eV for device II), and n$^+$ (E_{opt} = 2.40 eV for device II) layers were then deposited consecutively, at a substrate temperature of 180 ^{0}C and a RF power density of 16 mW/cm^2. For better interface properties, all of the amorphous layers were deposited continuously without interrupting the RF power [5]. The n$^+$– layer of device II is a 300 Å a–SiC:H film. Whereas, the n$^+$– layer of device I contains is a graded– composition structure: after a 20 Å n$^+$–a–SiC:H film was grown, the C_2H_2 carbon–source was decreased to zero gradually at a rate of –1 sccm/min to form a graded–composition structure and then a 100 Å n$^+$–a–Si:H (E_{opt} = 1.8 eV) film was deposited. Total thickness of n$^+$– layer is about 300 Å. The circular device area defined by the thermally evaporated Al top electrode was 2.26 × 10^{-2} cm^2. Finally, both devices were annealed at 300 ^{0}C for 30

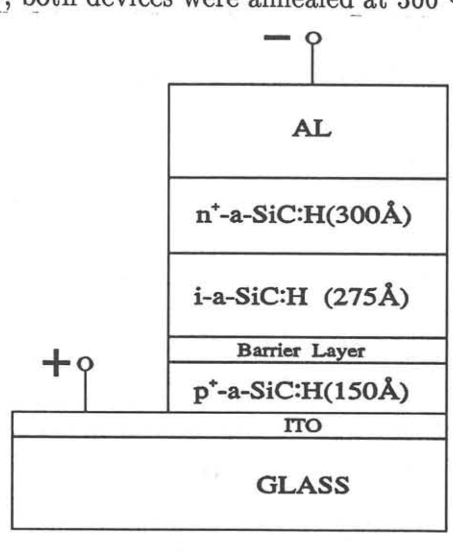

Fig. 1 The schematic cross–section for the a–SiC:H p–i–n TFLED with the inserted BL.

seconds initially and then at 150 ^0C for 30 minutes consecutively in H_2 ambient at a pressure of 110 torr, to improve the ohmic contact of *Al* electrode to the n^+–layer.

The current of an a–SiC:H p–i–n TFLED is determined by carriers crossing the barriers at p–i and i–n interfaces, and its light emission is mainly based on the radiative recombination in the i–layer, especially near the p–i interface [3]. Therefore, the enhancement of carrier–injection efficiencies can improve the EL intensity of the TFLED [4]. The BLs have a higher optical–gap, so most of the applied bias drops on these layers. This results in a higher electric field in the BL, which can be used to improve the hole injection efficiency [4]. In addition, the BL structure can increase the recombination energy of carriers and cause a blue–shift of light emission [3].

3. EXPERIMENTAL RESULTS

The J (current density) vs. V (applied voltage) and B (brightness) vs. V curves for these two a–SiC:H TFLEDs are shown in Fig. 2. The EL intensity of each TFLED was measured by placing the TFLED in front of a photomultiplier tube (PMT, ORIEL 70680) when the TFLED was driven by an HP 4145B semiconductor parameter analyzer, and the brightness was obtained by calibrating the measured EL intensity using an optometer (UDT S370). As shown in the figure, the currents of both TFLEDs increase rapidly for V increasing from 0 to 1.6 volts, this is probably due to the 1.6 eV difference of the electro–chemical potentials of the n^+– and p^+– regions. While 1.6 volts < V < 4 volts, the flat–band condition could be achieved and the injection current becomes space–charge–limited–current (SCLC) with trap [8]. For V $\geq$ 4 volts, the trap–filled limit could be reached, then the current rises rapidly, similar the trap–free SCLC [8]. The details of its conduction mechanism is still under investigation. The EL threshold voltage, V_{th}, is defined by a voltage at which the EL level can be detected by a PMT. Device I has a V_{th} of 5.2 volts and device II has a V_{th} of 6 volts. These V_{th} are much lower than that of an single graded–gap a–SiC:H TFLED with a V_{th} of 28 volts [5]. This V_{th} lowering could be attributed to the BL structure benefits the hole injection current.

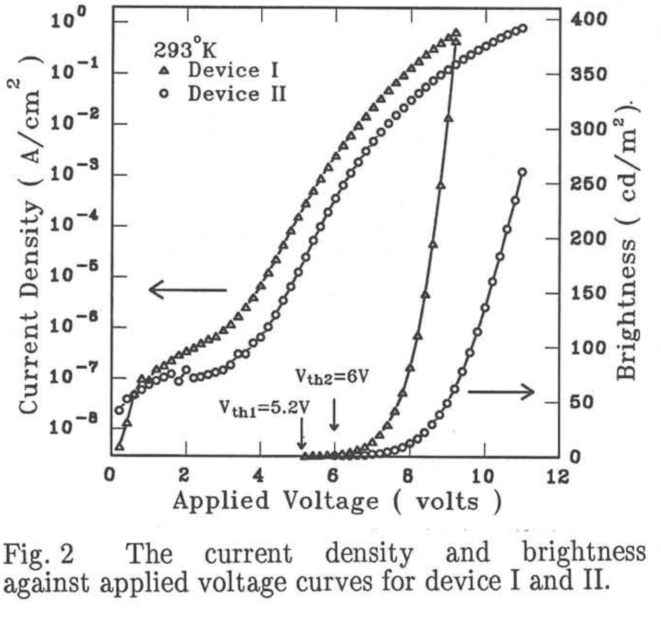

Fig. 2 The current density and brightness against applied voltage curves for device I and II.

Fig. 3 shows the EL spectra of device I under different bias voltages (200 Hz, 50% duty cycle). The EL spectrum was measured by using a monochrometer (ORIEL 77200), a PMT and a lock–in amplifier (PARC 5210). The EL spectra of device II can be found in ref. 6. As observed by the naked eyes, an yellowish light emission was detected for device I, while the device II emits an orange light. On the other hand, a basic a–SiC:H p–i–n TFLED without the BL structure, emits red light even it has an i–layer with E_{opt} equal to 2.58 eV [2]. Therefore, the EL intensity within the shorter wavelength range is enhanced by the BL structure, which could be ascribed to the higher electric fields in the barriers which allow carriers to be injected into the i– layer with a higher energy level [3],[4]. The peak–wavelength of the spectrum decreases from 650 to 620 nm as the applied voltage is increasing from 6 to 7.2 volts. This could be caused by a higher applied voltage inducing carriers to be injected into the i–layer with a higher energy.

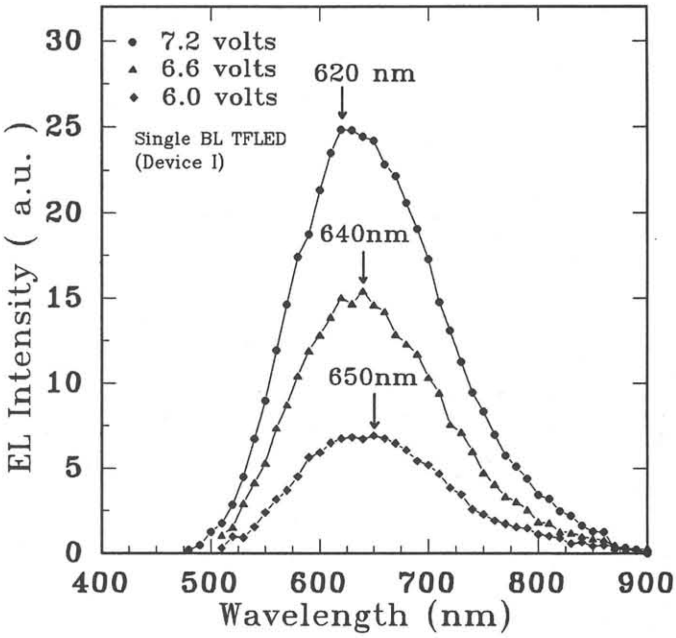

Fig. 3 The EL spectra of the a–SiC:H TFLED with single BL under different bias voltages.

Fig.4 illustrates a comparison of brightnesses vs. injection current density for device I, device II and an HP (Hewlett Packard) HLMP–8405 high brightness orange LED. The brightness of the device I is 342 cd/m^2 at an injection current density of 600 mA/cm^2, the device II achieves a brightness of 197 cd/m^2 at 600 mA/cm^2. These brightness are more than 10 times higher than that of a TFLED with the HTI layers which has a brightness of 20 cd/m^2 at 1 A/cm^2 [4], and about three orders of magnitude higher than that of the basic p–i–n TFLED which has a brightness of 0.13 cd/m^2 at 200 mA/cm^2 [2].

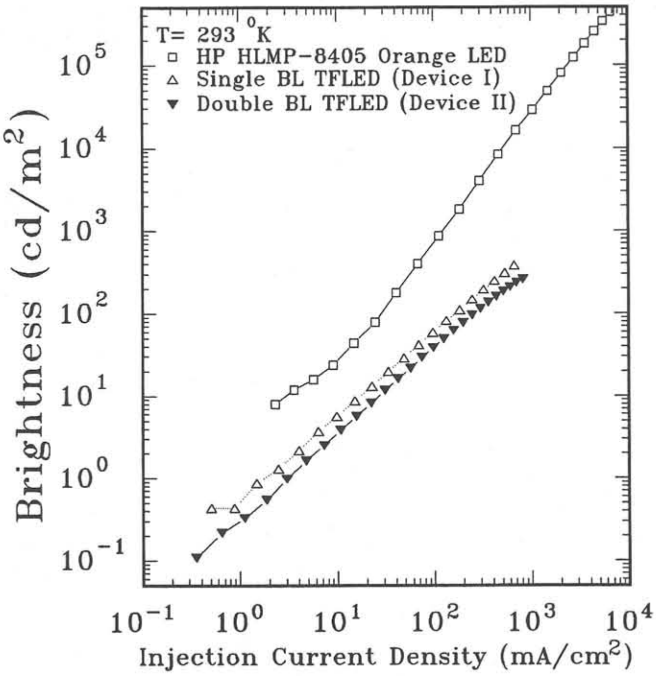

Fig. 4 The log–log plots of brightnesses versus injection current density for device I , device II and an HP HLMP–8405 orange LED.

Fig. 5 shows the curves of brightness vs. injection density under various temperatures for device II. The inset in Fig. 5 shows the EL intensity decreases with increasing temperature under the same injection current density. This means that the emission efficiency increases with decreasing temperature due to the less effectiveness of phonon scattering.

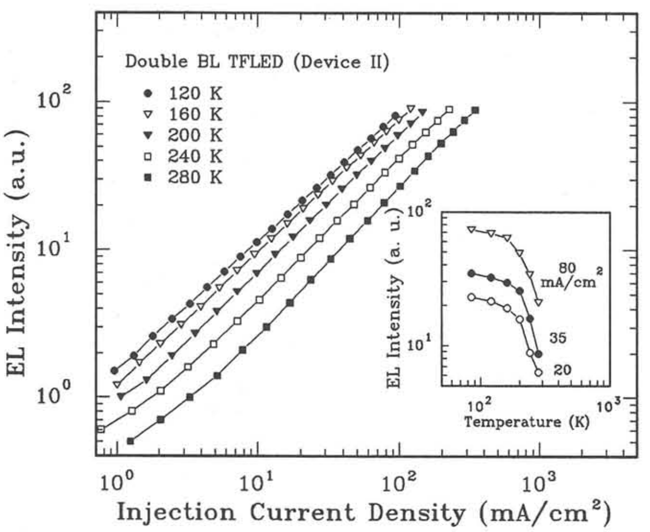

Fig. 5 The curves of brightness versus injection density under various temperatures for device II. The inset shows the curve of EL intensity versus temperature at different current densities.

4. CONCLUSION

In conclusion, the EL intensity of an a–SiC:H p–i–n TFLED had been improved significantly by using the proposed BL structures inserted at p–i interface. This phenomenon could be ascribed to the enhanced hole injection efficiency by using the BL structures. In addition, the EL threshold voltage of a–SiC:H BL TFLED is substantially lower than those of the basic p–i–n and graded–gap a–SiC:H TFLEDs [2],[5]. These improved EL intensity, enhanced light emission within the shorter wavelength range, and lowering of the EL threshold voltage strongly reveal the potential of applicability of a–SiC:H TFLED.

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