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Optoelectronic characteristics of *a*-SiC:H-based *pin* thin film LEDs having a thin Mo buffer layer in contact with *p*-type *a*-Si:H

Yen-Ann Chen, Yung-Hung Wu, Wen-Chin Tsay, Li-Hong Laih, Jyh-Wong Hong and Chun-Yen Chang

To improve the electroluminescence (EL) properties of the *a*-SiC:H-based *pin* thin film light-emitting diodes (TFLEDs) with the promotion of hole injection efficiency, a thin Mo metal film was used as a buffer layer to prevent reactions between the ITO (indium-tin-oxide) electrode and the p^+-*a*-Si:H layer. With the formation of semi-transparent Mo silicide after annealing, a lower EL threshold voltage and a significantly higher brightness for a finished TFLED were achieved. The brightness of the obtained device was 1300cd/m² at an injection current density of 600mA/cm², and its EL threshold voltage was 14V.

Introduction: Owing to their high conductivity and transmittance coefficients for visible light, the indium-tin-oxide (ITO) and tin-oxide (TO) are usually used as the front electrode for optoelectronic devices. When these transparent electrodes are in contact with H_2-plasma, both physical and chemical reactions are initiated [1 – 3]. Usually, various amorphous films are deposited with a plasma-enhanced chemical vapour deposition (PECVD) system and their source gases are diluted in H_2, hence, these reactions take place during film deposition for device fabrication. These reactions cause the penetration of In and Sn into the consequently deposited p^+-*a*-Si:H layer. The p^+-*a*-Si:H film contaminated by Sn and In would possess more defect states and a lower concentration of free holes [4]. The injected holes from the external ITO electrode might easily be captured in the degraded p^+-*a*-Si:H layer. Moreover, the accumulation of holes in p^+-*a*-Si:H could build up a potential barrier to suppress the hole injection efficiency.

Several semi-transparent metals, such as thin Cr and Mo films, have been proposed for insertion between the ITO and p^+-*a*-Si:H as a buffer layer [3 – 5]. The thin Mo film has several advantages: it has a high visible-light transmittance and forms a stable Mo silicide with p^+-*a*-Si:H film. With a thin Mo film coated on the ITO, the migration of the Sn and In oxides in the ITO caused by the H_2-plasma would be suppressed and no oxidsed p^+-*a*-Si:H layer would be formed.

In this Letter, a 3nm Mo buffer layer [3, 6] inserted between the ITO and p^+-*a*-Si:H layers was adopted to improve the performances of a thin film light-emitting diode (TFLED). Moreover, as shown in Fig. 1, to reduce the effects of the notch barriers existing at the *pi* and *in* interfaces of a TFLED, a composition-dopant-graded (CDG) gap structure has been employed [7]. CDG1 could increase the hole injection efficiency. At the same time, CDG2 has an additional low-resistance *a*-SiCGe:H layer to further improve the electron injection efficiency [7].

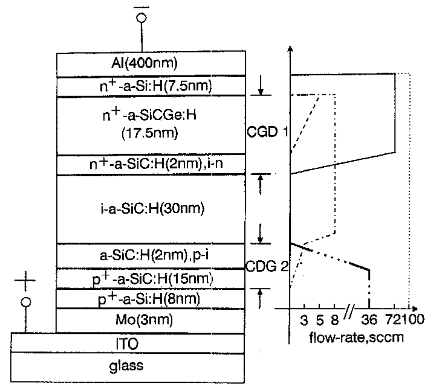

Fig. 1 *Schematic cross-section and flow-rates of source gases of obtained a-SiC:H-based TFLED*

—·—·— B_2H_6, 1% in H_2
——— PH_3, 1% in H_2
– · – · C_2H_2, pure
– – – – GeH_4, 10% in H_2
········· SiH_4, 4% in H_2

Fabrication of device: Fig. 1 shows a schematic cross-section of the fabricated device and the flow-rates of the source gases used in this study. After a dry cleaning process of ITO with a H_2-plasma, the ITO-coated-glass substrates were put into the chamber of a sputtering system equipped with an Mo target. A 3nm Mo layer was then deposited onto the ITO film. These Mo-coated samples were reloaded into the PECVD chamber to deposit the required amorphous films for a TFLED. The fabrication process is detailed in [7]. The Mo silicide is then formed during p^+-*a*-Si:H deposition and post-metallisation, annealing as will be mentioned in the following [3, 6].

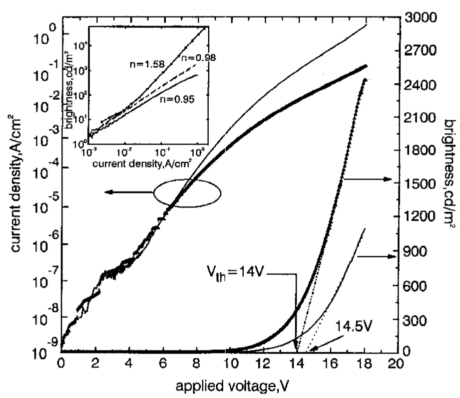

Fig. 2 *J-V and B-V characteristics of devices 1 (without Mo layer) and 2 (with Mo layer)*

Inset: curves of log(*B*) against log(*J*) for devices 1 and 2 and packaged HP HLMP-8405 high brightness orange LED
——— device 1
············ device 2
—●— HP HLMP-8405 orange LED

Results and discussions:

(i) *J-V and B-V characteristics:* Fig. 2 depicts the J-V and B (brightness)-V characteristics of devices 1 (without an Mo layer) and 2 (with an Mo layer). As can easily be seen, device 2 had a lower electroluminescence (EL) threshold voltage, V_{th} = 14V, and a higher current density under the same applied voltage as compared to device 1 for which V_{th} = 14.5V. Device 2 also had a brightness as high as 1300cd/m² while for device 1 it is only 620cd/m² for the same current density of 600mAcm². Thus, the stable Mo silicide was able to improve the brightness of a TFLED. Conversely, the inset of Fig. 2 shows the curves of log(*B*) against log(J) for device 1, device 2 and a packaged HP HLMP-8405 high orange brightness LED. The brightness of device 2 was 1300cd/m^2 which was ~10 times less than that of the HP HLMP-8405 orange LED and ~2 times higher than that (620cd/m^2) of device 1, at a current density of 600mA/cm^2. The mechanism of radiative recombination for a TFLED could be determined from the slope, n, of the log(B) against log(J) curve. As is shown in this inset, the values of n for devices 1 and 2 were very close to 1, so the radiation mechanism of a TFLED was considered to be monomolecular and/or tail-to-tail state recombinations [8]. As can be observed from the inset plot, the larger the n value, the higher the brightness of devices, and the n value for device 2 was slightly greater than that of device 1. So it was believed that the higher brightness of device 2 was due to an improvement in the quality of the interface between p^+-a-Si:H and ITO with a thin Mo layer.

(ii) *EL spectrum:* As is shown in Fig. 3, the EL spectra of devices 1 and 2 peaked at wavelengths of 670 and 620nm, respectively. The peak wavelength of the emitted light may be related to the energy level of the injected carriers, as can be observed from the inset plot of Fig. 3 which depicts the EL spectra of device 2 under various applied voltages. Device 2 had a shorter peak wavelength as compared to that of device 1 at the same applied voltage. Moreover, in Fig. 3, the full-width at half maximum (FWHM) of the EL spectrum was 200nm for device 1 while that of device 2 is 160nm. These values provide evidence that the injected holes in device 2 had a higher energy level and a narrower energy distribution, due to the thin Mo layer employed.

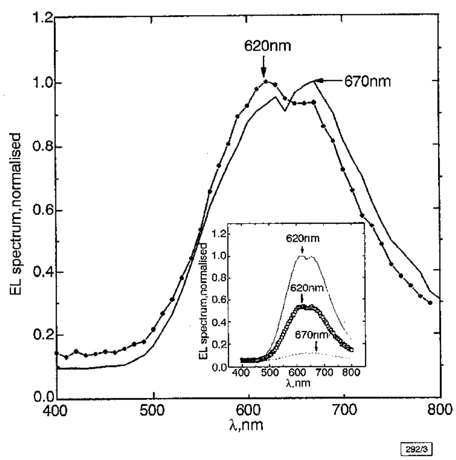

Fig. 3 *EL spectra of devices 1 (without Mo layer) and 2 (with Mo layer) under applied voltage of 15 V*

Applied voltage = 15V
——— device 1
—●— device 2
Inset: EL spectra of device 2 under various applied voltages
——— 19V
- -□- - 17V
.... 15V

(iii) *Effects of annealing:* The qualities of the amorphous films in the device and the ohmic contacts between the external electrode (ITO/Mo or Al,) and the contacted layer (p-a-Si:H or n-a-Si:H) could be improved by the technique of rapid-thermal-annealing (RTA) in an H_2 ambient. Device 2 was annealed with a temperature of between 260 and 320°C for 10min. The lowest average value of V_{th} and highest average value of B for TFLEDs were obtained at an annealing temperature of 280°C. An annealing temperature of 300°C was considered as a critical temperature at which the hydrogen started to diffuse out of the amorphous materials [9]. So, the devices that were annealed at a temperature of >300°C showed poor performances. To find the best time duration of rapid thermal annealing (RTA) for device 2, various RTA time durations, 8, 10, 12, and 14min, were tried, while the temperature was kept at 280°C. It was found that the best RTA time-duration was 10min. Hence, the optimal conditions of RTA for device 2 were 10 min duration at 280°C in an H_2 ambient.

Conclusion: From the results of this study, it was obvious that the thin Mo buffer layer inserted between the ITO and p^+-a-Si:H layers could be used to improve the optoelectronic performances of TFLEDs. The TFLED with (without) an Mo layer had a lower (higher) device resistance, a lower (higher) EL threshold voltage of 14V (14.5V), a higher (lower) brightness of 1300cd/m^2 (620cd/m^2) at J = 600mA/cm^2, a shorter (longer) EL peak wavelength of 620nm (670nm), and better (poorer) EL stability. The optimal conditions of annealing for the proposed TFLED with a thin Mo layer were 10 min duration at 280°C in an H_2 ambient.

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Picosecond switching due to electron tunnelling and avalanche in GaAs/Al_xGa_{1-x}As diode

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A new semiconductor heterostrostructure diode with an S-type current-voltage characteristic that can be used for high-speed voltage switching is proposed and demonstrated. This behaviour is caused by the electrons tunnelling through the potential barrier and initiating avalanche multiplication in a small energy gap base region.

Introduction: Two-terminal semiconductor devices with nonlinear current-voltage (I-V) characteristics are widely used in various ultrafast signal shaping and switching applications. Two extreme cases of such nonlinearity are I-V characteristics corresponding to N-type negative differential conductivity (N-NDC) and to S-type NDC (S-NDC). Devices exhibiting N-NDC are more numerous; Gunn diodes, tunnelling diodes and resonant tunnelling diodes are the best known examples. In contrast, the development of semiconductor diodes with S-NDC was less successful, although the S-NDC effect is preferable to N-NDC for high-power switching and tunable high frequency generation applications.