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Improvement of Current Injection of Porous Silicon

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We used n-i-p-n amorphous silicon (a-Si:H) layer to improve the current injection of porous silicon(PS)-based light-emitting diode(LED). And the photoluminescence (PL) signal of the as-anodized PS would show the reason why the PS-based LED could emit visible light ranging from red to blue light. The current conduction mechanism of the proposed device was also studied in this paper.

1. Introduction

The c-Si has a very poor radiative recombination efficiency, since it has an indirect 1.12 eV bandgap which corresponds to an infrared emission. With the processes of anodization, the PS can be formed on c-Si wafer and it has a strong visible PL signal[1-5]. With this characteristics, the PS-based light-emitting diodes (LED's) could even emit various visible lights ranging from red to blue. However, the brightnesses of these PS-based LED's were low due to, possibly, the low current-injection efficiency. So, in this paper, the additional n-i-p-n amorphous silicon (a-Si:H) layers deposited onto the PS were used to improve the conduction current of PS-based LED. Beside, in this paper, the PL signal of PS, excited by He-Cd laser, could be the powerful evidence to explain the reason why the PS-based LED could emit red, green and blue light.

2. Device Structure and Fabrication

The schematic cross-section of the proposed PSLED is shown in Fig. 1. The employed Si wafer (p on p^+, [100], 5~9 ohm-cm) was put into an E-gun evaporation system to deposit a 300 nm Al layer on its backside. Then the Si wafer was annealed at 300 °C in N_2 for 3 min. to obtain a better ohmic contact between the Al and p^+-Si wafer. The annealed Si wafer was then cut into 2 x 2 cm^2 square, and the square was loaded into a vertical anodization apparatus to form the PS layer. The deposited Al on the backside of c-Si square served as the anode. A platinum sheet served as the cathode. A current density of 1.492 mA/cm^2 was applied for 5 min. and the used electrolyte was an 1:2 mixture of HF ($49\%_{wgt}$) and methanol. The obtained PS sample had a thickness of 1.2 μm and a PL spectrum peaked at about 675 nm as measured with an Argon laser. Then the n-, i-, p- and n-type amorphous silicon (a-Si:H) layers were deposited onto the PS layer with a photo-CVD system (SAMCO, UVD-10) consequently. After the deposition of a-Si:H layers, Al (4 nm) and Au (12 nm) were evaporated onto the n-a-Si:H layer with an E-gun system to form the semi-transparent electrode with an area of 0.785 cm^2. Then a thicker Au (100 nm) layer with an area of 0.045 cm^2 was evaporated onto part of device to provide a probing pad. Lastly, the sample was annealed at 300 °C in N_2 for 5 min. to improve the ohmic contact between the Al (4 nm) and n-a-Si:H layer.

3. Results and Discussions

Fig. 2(a) and (b) illustrates the J(current density) vs. V (applied voltage) characteristics of PS-based LED with n-i-p-n a-Si:H layers, and without a-Si:H layer. It was obvious that the PS-based LED with n-i-p-n a-Si:H layers had a substantially (about 6 orders of magnitude) higher current density than that of PS without any a-Si:H layer. The reason for this increase of injection current density might be due to the n-i-p-n a-Si:H layers could form a high electric field in the i-a-Si:H layer when the PS-based LED was under forward bias. This high electric field, hence, would increase the probability of electron tunneling into the a-Si:H and PS layers. Besides, the n-a-Si:H layer used to contact the Al electrode might have a lower work-function difference than that between the Al electrode and PS, that would also result in an increase of injection current density. Those electrons with higher injection energy would also have a higher probability to be injected into the energy states of PS.

The PL spectra of as-anodized PS, excited by a He-Cd laser, was demonstrated in Fig. 3. There were evidently three PL peaks at 660, 464 and 405 nm respectively, corresponding to the wavelengths of red, green and blue lights. So, one might conjecture there were at least three energy states existed in as-anodized PS, and these energy states might be related to the visible light emissions.

Fig. 4 shows the plot of log(J) vs. log(V) for the proposed PS-based LED under different higher temperatures. We used analytic model to fit the log(J)-log(V) curves in order to find the current-conduction mechanism of device. As shown in this figure, when the device was under a lower applied voltage, the Poole-Frenkel current[6] was dominant, however, when under a higher applied voltage, the tunneling current[6] was the main mechanism. When the device was under a lower applied voltage, electrons could be excited from the traps of a-Si:H films and inject into PS layer to form current. This mechanism is Poole-Frenkel current. However, when the device was under a higher applied voltage, electrons would have higher energy to tunnel the barrier between Al electrode and n-a-Si:H film and to inject into PS layer to form current. The current is called tunneling current.

4. Conclusions

In conclusion, n-i-p-n a-Si:H layers could efficiently increase the conduction current density in PS-based LED, and hence possibly could improve its brightness and threshold voltage. And from PL experimental results, we gave another evidence to prove that there were at least three energy states existed in PS, that made it possible for PS to emit visible light ranging from red to blue light. At last, we found the Poole-Frenkel and tunneling current were the main current-conduction mechanisms when the device was under a lower and higher applied voltage, respectively.

Acknowledgements

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References

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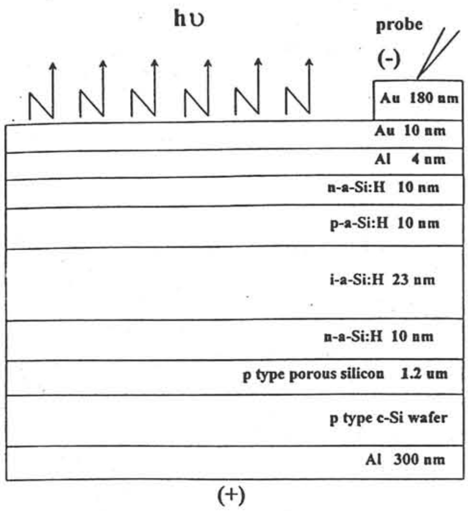

Fig. 1 The schematic cross-section of the proposed PSLED

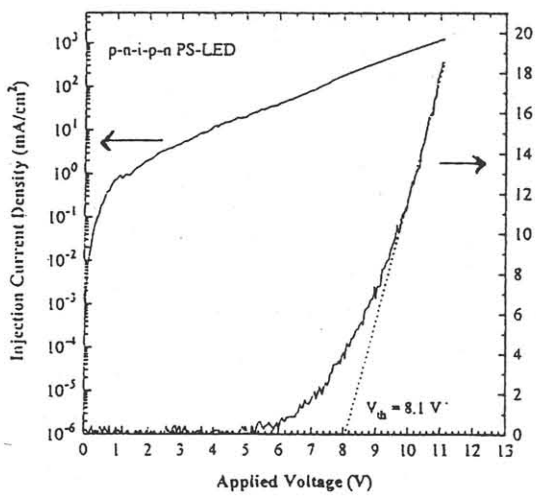

Fig. 2(a) The current density and brightness vs. applied voltage for the proposed PS-based LED.

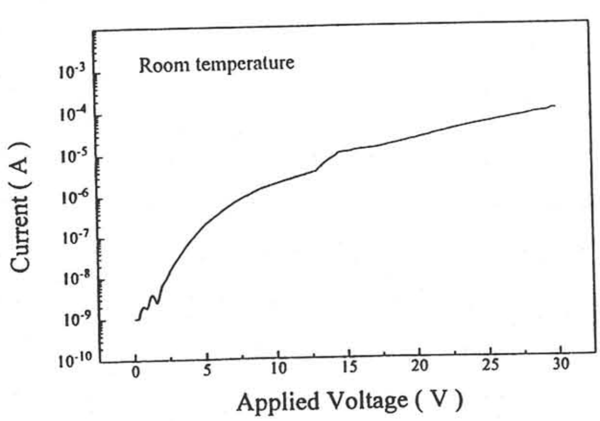

Fig. 2(b) The current density vs. applied voltage characteristics of the proposed PS-based LED without a-Si:H layer.

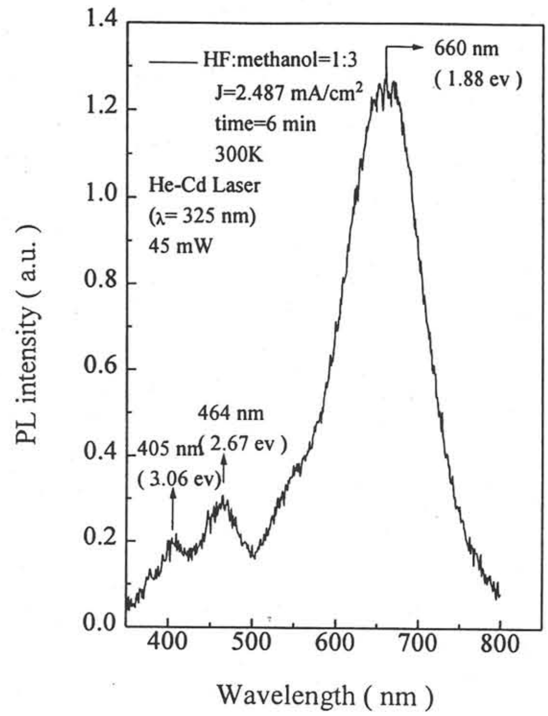

Fig. 3 The PL spectrum of the as-anodized PS.

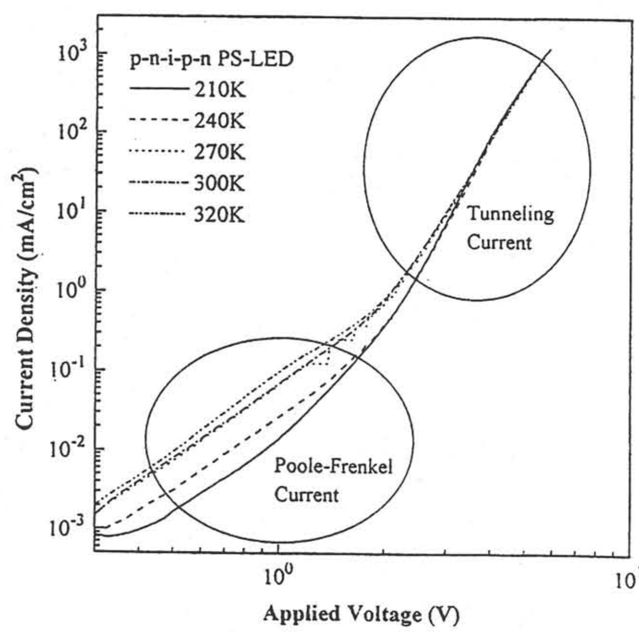

Fig. 4 The plot log(J) vs. log(V) for the proposed PS-based LED under different temperatures.