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Amorphous-SiC Thin Film Light Emitting Diode Using Quantum-Well-Injection Structures

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As an approach to improve the performance of hydrogenated amorphous silicon carbide (a–SiC:H) p–i–n thin–film light–emitting diodes (TFLED's), two quantum–well–injection (QWI) structures had been incorporated into the i–layer of p–i–n TFLED, at p–i and i–n interfaces individually. The electroluminescence (EL) intensity of the proposed QWI TFLED is about seven times higher than that of basic p–i–n TFLED at an injection current density of 2 A/cm^2, and its brightness is about 4 cd/m^2. For this QWI TFLED, a yellow–like light emission was observed by naked eyes experimentally.

1. INTRODUCTION

The development of a–SiC:H p–i–n TFLED's has a noticeable progress in recent years [1-6]. TFLED has several advantages as compared with a conventional crystal LED, such as accessible to large–area flat–panel displays, tunable color using integrated multilayer structures and low cost. However, to meet the requirements of practical applications, TFLED needs performance improvements, e.g. the increase of EL intensity and the enhanced emission of shorter wavelength light (green to blue). In this study, the a–SiC:H quantum–well–injection (QWI) structures are added at the p–i and i–n interfaces of basic a–SiC:H p–i–n TFLED, to increase its EL intensity and improve its shorter wavelength light emission.

2. DEVICE FABRICATION AND OPERATION

The schematic cross–section of a QWI TFLED is shown in Fig. 1(a), where the thickness of each layer is also indicated. The indium–tin–oxide (ITO) coated Corning 7059 glass was used as the substrate. After a standard cleaning process, it was put into the ULVAC CPD–1108D plasma–enhanced chemical vapor deposition (PECVD) system. In order to improve the contact performance between ITO electrode and p^+–type layer, a CF_4–O_2 plasma was used to bombard the ITO film prior to the deposition of the p^+–type a–SiC:H layer [7-8]. Then, the p^+–layer (150 Å), QWI structure (75 Å total, the SiH_4:C_2H_2 ratio is 1:9 in the barrier–layers and is 4:6 in the well–layer), i– layer (350 Å), QWI structure (75 Å total), and n^+– layer (300 Å) a–SiC:H were deposited sequentially. In order to obtain a higher optical gap (3.1 eV) for the barrier–layers of QWI structures, the carbon source used for a–SiC:H film was C_2H_2 rather than CH_4 [5]. The circular device area defined by the top *Al* electrode was 1.13×10^{-2} cm^2.

The schematic energy–band diagram under forward bias for a QWI TFLED is shown in Fig. 1(b). The current of an a–SiC:H p–i–n TFLED is determined by carriers tunneling through barriers at p–i and i–n interfaces and its emission of light is mainly based on the radiative recombination in the i–layer near p–i interface [1]. For QWI TFLED, the tunneling energy level could be increased by the QWI structures, which result in an improvement of shorter–wavelength light emission due to the recombinations of electrons and holes with a higher energy. Because most of the applied voltage drops at the QWI barrier layers due to the barrier layer has a higher energy–gap, the carrier tunneling–injection probability can be increased by this enhanced voltage drop and electric field in barrier layers [6], and then the EL intensity could be improved by use of these QWI structures.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The J (current density) vs. V (applied voltage) and B (EL intensity) vs. V curves of an a–SiC:H QWI TFLED are shown in Fig. 2. As can be seen from this figure, the tunneling current occurs at an applied voltage equal to 8 volts where the EL intensity begins to increase. This tunneling phenomenon was checked by the linear $\log(J/V^2)$ vs. $(1/V)$ relationship for $V \geq 8$ volts, following Fowler–Nordheim formula [9], where J is the current density and V is the applied voltage. If the injection efficiency of carriers can be enhanced, then the EL intensity can be improved. The QWI structures was employed to enhance the injection efficiency of electrons and holes, to obtain a higher EL intensity.

Fig. 3 shows the EL spectra of an a–SiC:H p–i–n QWI TFLED under various bias voltages (200 Hz, 50% duty cycle). The EL spectra were measured by using a monochrometer (ORIEL 77200), a photomutiplier (ORIEL 7070) and a lock–in amplifier. It is evident about one–half of the EL emission lays in the infrared region and is not observable by naked eyes. For this QWI TFLED, a yellow–like light emission was observed by naked eyes. On the other hand, the basic a–SiC:H p–i–n TFLED without QWI is a red one (peak is around 750 nm and full width half maximum is about 190 nm). The EL intensity within the shorter wavelength range is enhanced by the QWI structures espically at high applied bias voltage, this could be ascribed to the higher electric field in the barrier layers which allow carriers to be injected into the i–layer with a higher energy level.

Fig.4 shows the summary of EL intensities of an a–SiC:H basic p–i–n TFLED, a QWI TFLED, a conventional green LED and a conventional orange LED. The EL intensity of the TFLED was measured by placing the TFLED in front of a photomultiplier and the TFLED was driven by an HP 4145B semiconductor parameter analyzer. As can be seen from the figure, the EL intensity of a QWI TFLED is seven times higher than that of a basic p–i–n TFLED, at an injection current density equal to 2 A/cm^2.

4. CONCLUSION

A improved TFLED has been developed by inserting QWI structures at p–i and i–n interfaces, respectively. The carrier transport of a QWI TFLED is mainly based on the injection mechanism of electrons and holes at n–i and p–i interfaces through the notch barriers. The EL intensity is dependent on the radiative recombination in the various layers. In this study, the obtained brightness of QWI TFLED is about 4 cd/m^2 at an injection current density of 2 A/cm^2 as calibrated by an optometer (UDT S370). The emission light of the a–SiC:H QWI TFLED, as detected by human eyes, is a yellow–like one.

ACKNOWLEDGEMENT

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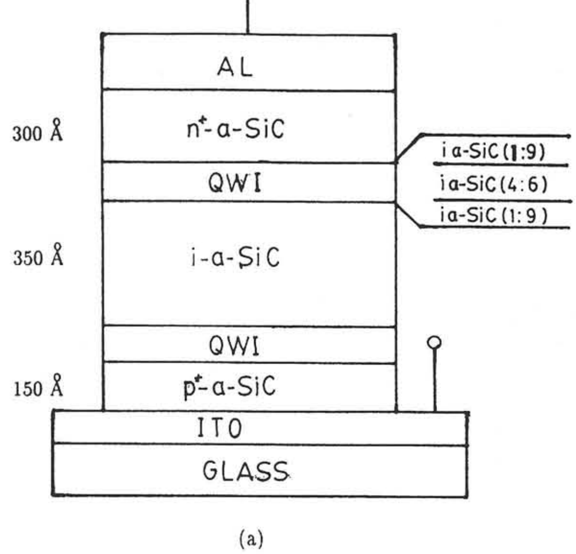
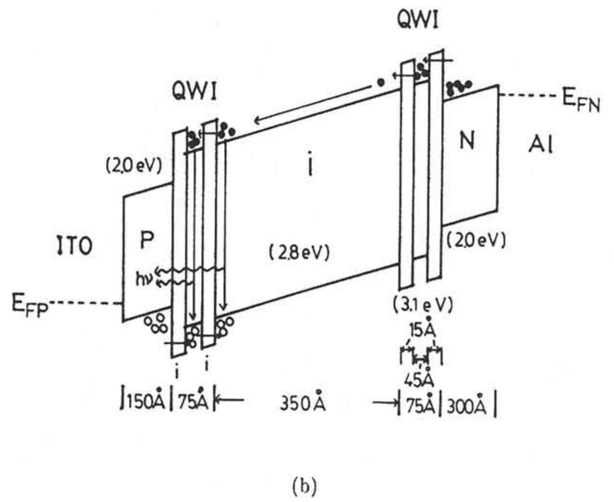


(a)

Fig. 1 a)Schematic cross–section of an a–SiC:H QWI TFLED, b) energy band diagram of an a–SiC:H QWI TFLED under forward bias.



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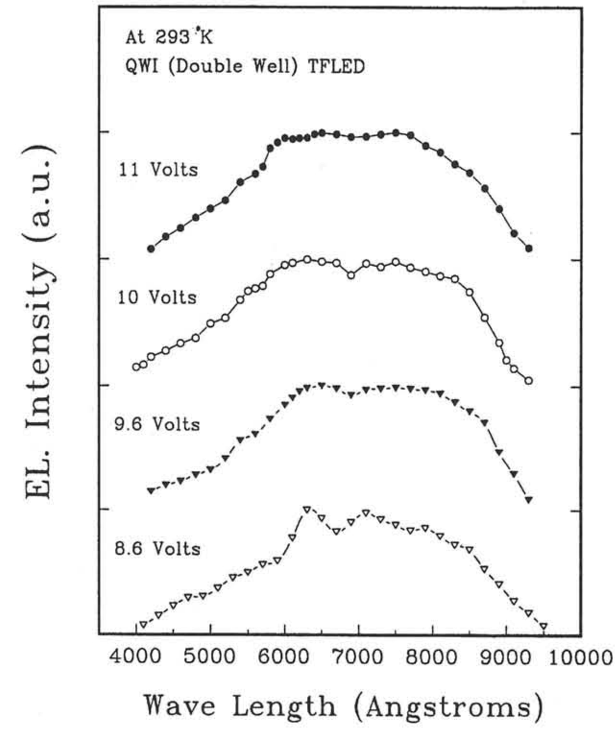

Fig. 3 The EL spectra of an a–SiC:H QWI TFLED.

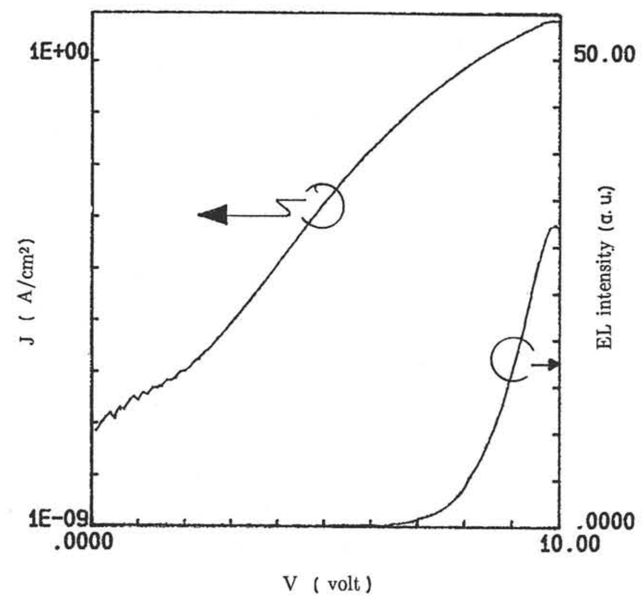

Fig. 2 The J (current density) – V and B (EL intensity) – V curves for an a–SiC:H QWI TFLED.

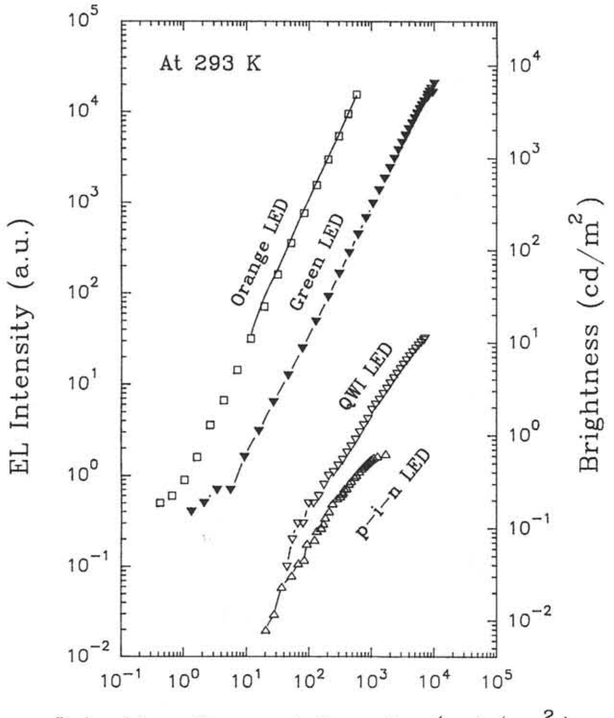

Fig. 4 The log–log plot of EL intensity versus injection current density for (a) basic p–i–n TFLED, (b) QWI TFLED, (c) conventional green LED and (d) conventional orange LED.