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HYDROGENATED AMORPHOUS SILICON-CARBIDE THIN-FILM LIGHT-EMITTING DIODE WITH QUANTUM-WELL-INJECTION STRUCTURE

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Indexing terms: Light-emitting diodes, Thin-film devices

To improve the electroluminescence (EL) intensity of the hydrogenated amorphous silicon carbide (*a*-SiC : H) *pin* thin-film light-emitting diode (TFLED), a quantum-well-injection (QWI) structure has been incorporated into the *i*-layer of an *a*-SiC : H *pin* TFLED at the *p–i* interface. The obtained brightness of this QWI TFLED is 256 cd/m^2 at an injection current density of 800 mA/cm^2, which is about three orders of magnitude higher than the brightness of an *a*-SiC : H *pin* TFLED. Also, a comparatively lower EL threshold voltage of 6 V was observed for this *a*-SiC : H QWI TFLED.

Since Pankove *et al.* reported an infra-red EL in an *a*-SiC : H *pin* junction at low temperature in 1976 [1], the development of *a*-SiC : H *pin* TFLEDs has progressed markedly [2–5]. However, for practical applications of TFLEDs, the increase of EL intensity and the lowering of EL threshold voltage are desirable. In 1989, Hamakawa *et al.* employed hot-carrier tunnelling injection (HTI) layers to improve the luminosity of the *a*-SiC : H TFLED [4]. They obtained an EL intensity of 20 cd/m^2 at an injection current density of 1 A/cm^2. In this Letter, a QWI structure was inserted at the *p–i* interface of an *a*-SiC : H *pin* TFLED to improve the EL intensity and lower the EL threshold voltage.

The schematic cross-section of an *a*-SiC : H QWI TFLED is shown in Fig. 1. Indium tin oxide (ITO) coated Corning 7059 glass was used as the subtrate. After cleaning, it was put into the plasma-enhanced chemical vapour deposition (PECVD, ULVAC CPD-1108) system. 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^+-*a*-SiC : H layer [6]. The *a*-SiC : H p^+-, QWI structure-, *i*-, and n^+-films were then deposited consecutively, at a substrate temperature of 180°C and an RF power density of 16 mW/cm^2. The thickness and optical gap (E_{opt}) of each layer are also indicated in Fig. 1. For better interface properties, the p^+-layer, QWI structure and *i*-layer were deposited continuously without interrupting the RF power [5]. Details of the deposition conditions can be found in Reference 5. The circular device area defined by the thermally evaporated top Al electrode was 2·26 × 10^{-2} cm^2. Finally, the device was annealed at 300°C for 30 s initially and then at 150°C for 30 min consecutively in H_2 ambient at a pressure of 110 torr, to improve the contact of the Al electrode to the n^+-layer.

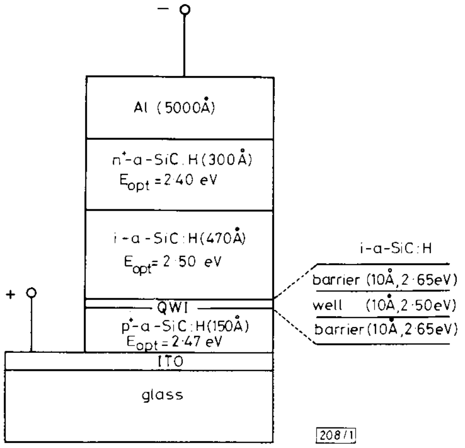

Fig. 1 *Schematic cross-section for a-SiC: H QWI TFLED*

The light emission of the *a*-SiC : H *pin* TFLED is mainly based on the carriers injected into and radiatively recombined 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 QWI structure added at the *p–i* interface could be used to improve the hole injection efficiency because most of the applied voltage drops across this structure, and thus higher electric fields exist in the barrier layers with a higher optical gap [4].

Fig. 2 illustrates the comparison of brightness against injection current density for the *a*-SiC : H QWI TFLED, single (*p–i*) graded-gap TFLED [5] and HP (Hewlett Packard) HLMP-8405 high brightness orange LED. The EL intensity of each LED was measured by placing the LED in front of a photomultiplier tube (PMT, ORIEL 7070) when the LED was driven by an HP 4145B semiconductor parameter analyser, and the brightness was obtained by calibrating the measured EL intensity using an optometer (UDT S370). The brightness of the *a*-SiC : H QWI TFLED is 256 cd/m^2 at an injection current density of 800 mA/cm^2, and 197 cd/m^2 at 600 mA/cm^2. This brightness is more than 10 times higher than that of a

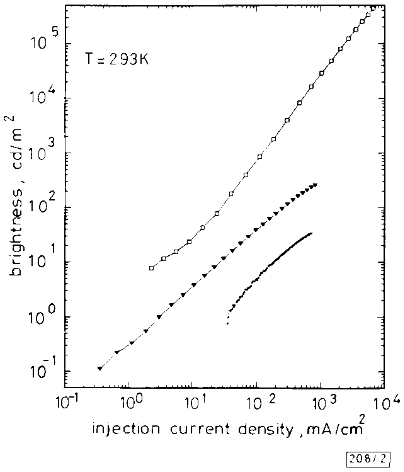

Fig. 2 *Log–log plots of brightness against injection current density for a-SiC: H QWI TFLED, single (p–i) graded-gap a-SiC: H TFLED [5] and HP HLMP-8405 orange LED*

□ HP HLMP-8405 orange LED
▼ single QWI TFLED
● single graded-gap TFLED [5]

TFLED with HTI structures [4], about 6·6 times higher than that of single graded-gap TFLED (with a brightness of 30 cd/m^2 at 600 mA/cm^2) [5], and about three orders of magnitude higher than that of the basic *pin* TFLED (with a brightness of 0·13 cd/m^2 at 200 mA/cm^2) [2]. Besides, the single QWI TFLED has a lower threshold voltage, V_{th}, defined at a voltage at which the EL level can be detected by a PMT, of 6 V as compared to 28 V for the single graded-gap TFLED [5], as indicated in Fig. 3. This lowering of V_{th} could be attributed to a large part of applied voltage being distributed over the barrier layers of QWI structure, which benefits carrier injection.

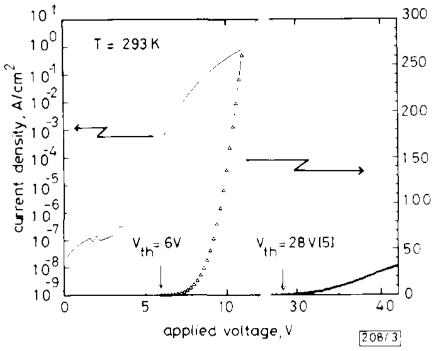

Fig. 3 *Current density against applied voltage and brightness against applied voltage a-SiC: H QWI TFLED*

The brightness against applied voltage curve for single graded-gap *a*-SiC : H TFLED is also shown [5]

Fig. 4 shows the EL spectra of the *a*-SiC : H QWI TFLED under various bias voltages (200 Hz, 50% duty cycle), measured by using a monochrometer (ORIEL 77200), a PMT and a lock-in amplifier (PARC 5210). It is evident that about one third of the EL emission lies in the infra-red region which is not observable. For this TFLED, orange light emission was observed by the naked eye. On the other hand, the basic *a*-SiC : H *pin* TFLED with the optical gap of the *i*-layer equal to 2·58 eV, without the QWI structure, emits red light [2]. Therefore the EL intensity within the shorter wavelength range can be enhanced by the QWI structure, which could be ascribed to the higher electric fields in the barriers which allows carriers to be injected into the intrinsic layer with a higher energy level [3, 4]. Also, the peak wavelength of the emitting spectrum reduces from 750 to 730 nm as the applied voltage is increased from 8 to 10 V. This could be due to the higher applied voltage inducing carriers to be injected into the *i*-layer with a higher energy.

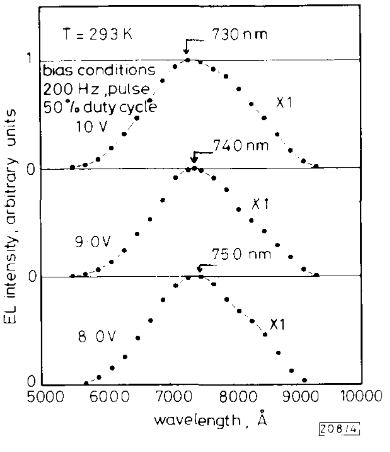

Fig. 4 *EL spectra of a-SiC: H QWI TFLED under various bias voltages*

In conclusion, the EL intensity of the *a*-SiC : H *pin* TFLED had been improved significantly by using the proposed QWI structure inserted at the *p*–*i* interface. This phenomenon could be ascribed to the enhanced carrier injection efficiencies due to the QWI structure. In addition, the EL threshold voltage of the *a*-SiC : H QWI TFLED is substantially lower than those of the basic *pin* and single-graded-gap *a*-SiC : H TFLEDs. These improved EL intensities, enhanced light emission within the shorter wavelength range, and the lowering of the EL threshold voltage strongly suggest the potential for practical applications of *a*-SiC : H TFLEDs.

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DETERMINATION OF DEPTH OF PROTON EXCHANGED LAYER IN $LiNbO_3$ FROM LASER INDUCED PYROELECTRIC SIGNALS

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Indexing terms: Integrated optics, Optical waveguides, Acoustic waveguides, Laser applications

A new nondestructive technique for the determination of the depth of the proton exchanged (PE) layer in $LiNbO_3$ is reported. The techniques relies on the difference in phase of measured pyroelectric voltages, induced by a modulated laser beam incident on the exchanged and unexchanged regions. Measurements of PE layer thickness in a Z-cut $LiNbO_3$ sample have been corroborated by prevalent, more elaborate, optical characterisation techniques.

Introduction: Proton exchanged (PE) optical and acoustic waveguides [1] have been receiving considerable attention lately, with both PE $LiNbO_3$ and $LiTaO_3$ being the subject of detailed modelling and characterisation [2–5].

One of the critical parameters of such optical and acoustic waveguides is their exchange depth, which determines the number of propagating modes. This depth is generally estimated from relatively involved techniques such as optical characterisation techniques [6], Rutherford backscattering spectrometry (RBS) and nuclear reactions [2].

This Letter presents a new method for experimentally determining the exchange depth by means of phase measurement of laser induced pyroelectric signals. The PE layer forms a thin insulating overlay on the surface of $LiNbO_3$ and $LiTaO_3$ substrates, which also happen to be pyroelectric materials. A