Preliminary results on a-SiC:H based thin film light emitting p–i–n diode by hot wire CVD

Samadhan B. Patil, Alka A. Kumbhar, Shweta Saraswat, R.O. Dusane*

Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology, Mumbai 400076, India

Abstract

Preliminary results on the first hot wire deposited a-SiC:H based thin film light emitting p–i–n diode having the structure glass/TCO(SnO$_2$:F)/p-a-SiC:H/i-SiC:H/n-a-SiC:H/Al are reported. The paper discusses the results of our attempts to optimize the p-, i- and the n-layers for the desired electrical and optical properties. The optimized p-layers have a bandgap $E_g \approx 2$ eV and conductivity a little lower than $10^{-3}$ (Ω cm)$^{-1}$. On the other hand, the optimized n-type a-SiC:H show a conductivity of $\approx 10^{-4}$ (Ω cm)$^{-1}$ with bandgap 2.06 eV. The highest bandgap of the intrinsic layer is approximately 3.4 eV and shows room temperature photoluminescence peak at approximately 2.21 eV. Thin film p–i–n diodes having i-layers with $E_g$ from 2.7 to 3.4 eV show white light emission at room temperature under forward bias of >5 V. However, the 50-nm thick devices show appreciable reverse leakage current and a low emission intensity, which we attribute to the contamination across the p–i interface since these devices are made in a single chamber with the same filament.

Keywords: Thin film light emitting diode; a-SiC:H; Hot wire CVD

1. Introduction

Thin film light emitting diodes (TFLEDs) using a-SiC:H open up possibilities for realizing a robust display technology. Moreover, the amorphous nature and the large area deposition enable uniformity of the displays. One of the first a-SiC:H TFLED was fabricated by Kruangam et al. [1,2]. These devices had the structure glass/TCO/p-a-SiC:H/i-a-SiC:H/n-a-SiC:H/Al with a-SiC:H layer deposited by the RF glow discharge and showed a rather low light emission. The light emission is governed by tunneling across the barrier at the p–i and i–n interfaces. The notch barriers at these interfaces were later modified by the insertion of a very thin layer of a-SiN:H [3]. This lowered the tunneling width for the carriers leading to an increased recombination and hence enhanced the light emission. In another attempt to improve the light emission Hong et al. proposed a graded p–i junction [4–6]. In the above devices, all layers were deposited by plasma enhanced chemical vapor deposition (PECVD). The undesirable effects of PECVD such as bombardment-induced damage to the interface and etching are well known. The hot wire chemical vapor deposition (HWCVD) is much simpler compared to PECVD where the plasma-induced damage at the interface could be avoided.

We have fabricated a-SiC:H p–i–n, TFLED in a single chamber HWCVD apparatus with a tungsten filament. Three different layers of the device, i.e. p-type a-SiC:H, intrinsic a-SiC:H and n-type a-SiC:H were optimized separately, before the final device was attempted.

2. Experimental

2.1. p-Layer deposition

Source gases used for the deposition of p-layer are SiH$_4$, C$_2$H$_2$ and B$_2$H$_6$. With C$_2$H$_2$ as source gas the maximum conductivity achieved was $\sim 10^{-4}$ (Ω cm)$^{-1}$. Variation of bandgap ($E_g$) and conductivity as a function of the C$_2$H$_2$ flow is shown in Fig. 1. Later CH$_4$ was also used as the carbon source in place of C$_2$H$_2$ to get a higher conductivity but with the same bandgap $\sim$ 2.0 eV. Maximum conductivity achieved with CH$_4$ is of the order of $10^{-5}$ (Ω cm)$^{-1}$. Thus an improvement of almost one order was noted with change of source gas from C$_2$H$_2$ to CH$_4$. 
2.2. n-Layer deposition

Gases used for the deposition of n-layer are SiH₄, C₂H₂ and PH₃. Conductivity in the range 10⁻⁴–10⁻⁵ (Ω cm)⁻¹ is observed for films with a bandgap ~2.06 eV. Fig. 2 shows variation in conductivity and bandgap of the n-type a-SiC:H films as a function of the PH₃ flow. Here C₂H₂ flow was kept constant at 0.75 since the desired bandgap of 2 eV was achieved. It was easier to deposit high conductivity n-type a-SiC:H with bandgap ~2.0 eV than p-type a-SiC:H with similar requirement. This may be due to the inherent higher efficiency of the phosphorus doping.

2.3. i-Layer deposition

In an earlier publication [8], we have demonstrated that use of C₂H₂ in the HWCVD facilitates the deposition of a-SiC:H with $E_g$ as high as 3.6 eV and conductivity ~10⁻¹² (Ω cm)⁻¹. These films also showed PL at room temperature. A 500 Å thick layer of the a-SiC:H material with $E_g$ = 3.4 eV was incorporated in the LED structure.

3. Fabrication and characterization of LEDs

LEDs were fabricated on TCO (SnO₂:F) coated glass with 20% haze (Asahi Japan). TCO with haze is observed to yield a better electro-luminescence intensity [2,9]. p-a-SiC:H ($\sigma = 10^{-6}$ (Ω cm)⁻¹, $E_g$ = 2 eV) with thickness 200 Å was deposited as top window, followed by a 300–1000 Å intrinsic a-SiC:H ($E_g$ = 3.0–3.3 eV) active layer. On top of this intrinsic layer, a n-type a-SiC:H injector ($\sigma = 10^{-4}$ (Ω cm)⁻¹, $E_g$ = 2 eV) with thickness 250 Å was deposited. The device was completed by depositing Al dots of 1 mm diameter. Fig. 3 shows a schematic of such a device with the corresponding band diagram shown in Fig. 4 [3]. Difference in the bandgap of p-layer and i-layer is responsible for the notch barrier formed at the p–i interface. This notch barrier at p–i interface is called valence band discontinuity ($\Delta E_v$). Similarly the barrier at i–n interface is called conduction band discontinuity ($\Delta E_c$). These band discontinuities have values of $\Delta E_v = 1.05$ eV and $\Delta E_c = 0.35$ eV, respectively [3], calculated from empirical formulae $\Delta E_v = 0.75\Delta E_g$ and $\Delta E_c = 0.25\Delta E_g$. Under application of electric field, carriers tunnel through the
4. LED characteristics

Fig. 5 shows the $I-V$ characteristics of the TFLEDs fabricated with i-layer thickness $\sim 900$ and $\sim 1000$ Å. It is observed that, the threshold voltage increases with increase in thickness of i-layer, since increase in thickness requires a higher voltage to induce a sufficiently high field for tunneling. Considering the Fowler–Nordheim [3] tunneling, given by the following expression

$$J \alpha E^2 \exp\left[-\frac{4\sqrt{(2m^*)}}{\phi_h}\frac{1}{3q\hbar E}\right]$$

where, $J$ is the junction current, $E$ is the applied electric field, $m^*$ is the effective mass of carrier, $q$ the electron charge and $\phi_h$ is the barrier height. We expect a straight

line plot of $\log(J/V^2) \, \text{vs.} \, 1/V$ in the tunneling regime. Our diodes start emitting light above 4 V, and, as can be seen from Fig. 6, one indeed observes a straight line beyond 4 V, confirming the tunneling behavior. Fig. 7 shows light emission from two TFLEDs having i-layer with bandgap 3 and 3.3 eV. The emission from both the diodes is very broad with a shift towards white for the higher bandgap device.

5. Conclusion

For the first time a HWCVD based TFLED has been realized, which emits light in the visible region. Though the intensity of the emission is very low, what we want to emphasize is that the HWCVD has the potential of yielding a large $E_a$ a-Si:C:H material having good electronic properties. One of the reasons for the low emission efficiency could be the fact that the devices are
made in a single chamber and the same filament deposit all the layers.

**Acknowledgments**

The work was carried out with the financial aid from Board of Research in Nuclear Sciences, Govt. of India. One of the authors S.B. Patil acknowledges Council of Scientific Research (CSIR), Govt. of India for financial support.

**References**