

**Amorphous silicon thin film solar cells deposited entirely by Hot-Wire Chemical  
Vapour Deposition at low temperature (<150 °C)**

Fernando Villar, Aldrin Antony\*, Jordi Escarré, Daniel Ibarz, Rubén Roldán, Marco

Stella, Delfina Muñoz, José Miguel Asensi and Joan Bertomeu

Departament de Física Aplicada i Òptica, Universitat de Barcelona, Martí i Franquès 1-11,  
E08028-Barcelona, Spain.

\*aldrinantony@ub.edu

**Abstract**

Amorphous silicon n-i-p solar cells have been fabricated entirely by Hot-Wire Chemical Vapour Deposition (HW-CVD) at low process temperature <150 °C. A textured-Ag/ZnO back reflector deposited on Corning 1737F by rf magnetron sputtering was used as the substrate. Doped layers with very good conductivity and a very less defective intrinsic a-Si:H layer were used for the cell fabrication. A double n-layer ( $\mu\text{c-Si:H/a-Si:H}$ ) and  $\mu\text{c-Si:H}$  p-layer were used for the cell. In this paper, we report the characterization of these layers and the integration of these layers to fabricate solar cell at low process temperature. An initial efficiency of 4.62% has been achieved for the n-i-p cell deposited at temperatures below 150 °C over glass/Ag/ZnO textured back reflector.

**Keywords**

Hot-wire deposition; Amorphous materials; Solar cells

**1. Introduction**

Thin film silicon solar cells on polymeric substrates have gained interest among the photovoltaic research due to their light weight, flexibility, low cost, easiness in roll-to-roll production, and possibility for the monolithic series interconnection. The critical parameter in the fabrication of silicon thin film solar cells on polymeric substrates is the temperature. On one hand it should be high enough to guarantee good quality layers, and on the other side it should be less than the stability temperature limit of the polymer. In the case of amorphous silicon thin films, it has been reported that, the films deposited at substrate temperatures lower than 200 °C possess structural disorder and defects in the material [1]. Hence, the substrate temperature is a critical factor with regard to the material quality. HW-CVD technique has demonstrated to be a good alternative to deposit device quality intrinsic amorphous silicon thin films at low temperature. In a previous work, we have reported the deposition of nanocrystalline silicon thin films on polyethylene naphthalate (PEN) substrates by the HW-CVD technique [2]. Even though, there are reports on the low temperature fabrication of a-Si:H thin film solar cells below 150 °C by HW-CVD, those groups have used PECVD to deposit the doped layers [3,4]. Here we present the first results of an a-Si:H solar cell fabricated below 150 °C with the entire n-i-p structure deposited by HW-CVD.

## **2. Experimental**

The details of the HW-CVD system for the silicon thin film deposition are explained elsewhere [5]. Two parallel and straight tantalum wires of 0.5 mm diameter 7 cm length, connected in series were used as the catalyser. The separation between the two filaments was 3.5 cm and the distance between the filaments to the substrate distance was fixed as 4

cm.  $\text{PH}_3$  and  $\text{B}_2\text{H}_6$  were used as the dopant gases for n and p-layer respectively. The intrinsic and doped layers were deposited at pre-heated substrate temperature of  $100\text{ }^\circ\text{C}$ . Figure 1 shows the increase in substrate temperature due to the irradiation of the filament during deposition. In the case of intrinsic a-Si:H thin film deposition with a set substrate temperature of  $100\text{ }^\circ\text{C}$  and a filament current of 10.5 A, the effective substrate temperature is always less than  $120\text{ }^\circ\text{C}$ . In the case of doped layers, the filament current was 12.9 A and the deposition time was always less than 7 min, and the effective substrate temperature was below  $150\text{ }^\circ\text{C}$ . The textured silver back reflector was deposited by rf magnetron sputtering onto Corning 1317F glass substrates at a substrate temperature of  $450\text{ }^\circ\text{C}$ . Indium doped tin oxide (ITO) was used as the front contact, which was deposited by rf magnetron sputtering at room temperature. The 80nm thick ITO layer showed a sheet resistance of was  $55\Omega/\square$  and  $>90\%$  transmission in the visible region. The temperature dependence of electrical conductivity of the samples was measured in vacuum by two probe method with evaporated aluminium contacts, in the temperature range 30 to  $100\text{ }^\circ\text{C}$ . The thickness of the samples was measured using a thickness profilometer. The crystalline fraction of the samples was estimated from the Raman spectroscopy. Fourier transform infrared (FTIR) spectroscopy was used to analyse the quality of the material by evaluating the microstructure factor ( $R^*$ ) and the hydrogen content in the film. Spectroscopic ellipsometry (SE) was used to assess the disorder in the material.

### **3. Results and Discussion**

#### *3.1. The back reflector*

The textured silver back reflectors consists of a  $\sim 750\text{ nm}$  silver layer deposited over corning 1737F glass substrates by rf magnetron sputtering at  $450\text{ }^\circ\text{C}$ . The process

conditions were optimised to get the desired roughness. A very thin layer of 15 nm Chromium was deposited over glass substrates for the better adhesion of the silver to the glass. ZnO:Al of 70 nm was deposited over the textured silver at 100 °C to complete the back reflector structure. The layer morphology has been studied by AFM (Fig. 2) and the measured RMS roughness of the back reflector used for the solar cell deposition was around 47 nm. The average feature height (174 nm) and the mean period between peaks (1.2  $\mu\text{m}$ ) were also calculated for this texture by the method discussed by Terrazoni et.al. [6]. The ratio between these average feature height and the period between the peaks was 0.14. All these results indicate that an acceptable light trapping can be achieved with this back reflector to use as the substrate for a-Si:H solar cells.

### 3.2. The a-Si:H intrinsic layer

Different depositions of the intrinsic a-Si:H were done on glass substrates either without any intentional substrate heating or at a substrate temperature of 200 °C. Compact materials with a low  $R^*$  values were obtained for the depositions done in a pressure range  $2 \times 10^{-2}$  to  $10^{-1}$  mbar as shown in figure 3. The intrinsic a-Si:H used for the cell was deposited at a pressure of  $3 \times 10^{-2}$  mbar with a silane dilution ratio ( $\text{SiH}_4/[\text{SiH}_4+\text{H}_2]$ ) of 5%. The thickness of this intrinsic layer was 250 nm. The microstructure factor and the hydrogen content in the film were evaluated from this FTIR spectrum [7]. The film showed a high hydrogen content ( $C_{\text{H}} \sim 15\%$ ), which might be due to the growth at low substrate temperature [8]. The low microstructure value of 0.03 of this film indicates a very compact structure. The activation energy obtained from the temperature dependant conductivity measurement was 0.81 eV. The dark conductivity at room temperature was found to be  $10^{-10}$  S/cm and the ratio of photoconductivity to the dark conductivity was  $10^4$ . The spectroscopic ellipsometry measurements showed a high signal corresponding to a

dense and compact amorphous material. From the fittings following the Tauc-Lorentz model, we have extracted the material parameters (disorder factor  $C= 206$  eV, density factor  $A= 182$  eV, and the optical band gap=  $1.67$  eV) [9]. They are in good agreement with the values for the device quality films deposited by PECVD [4].

### *3.3. The doped layers*

A double n-layer with a thin microcrystalline bottom layer (10nm) and a top amorphous layer (25nm) was used for the cell. This combination allows in having better contact interface between the n and the intrinsic layer. The activation energy of this double n-layer was found to be  $0.23$  eV with a dark conductivity of  $3.6 \times 10^{-3}$  S/cm. The individual layers have activation energies of  $0.04$  eV and  $0.329$  eV for the microcrystalline and amorphous n-layer respectively. The p-layer was deposited at a process pressure of  $1.4 \times 10^{-2}$  mbar and the thickness was  $30$  nm. The activation energy of this layer was found to be  $0.27$  eV with a room temperature dark conductivity of  $4.5 \times 10^{-2}$  S/cm.

### *3.4. Amorphous silicon nip solar cell*

The amorphous silicon nip solar cell was fabricated over the textured silver back reflector on glass, entirely by HW-CVD. Before the p-layer deposition, there was an air break to fix the masks to eliminate the probable chance of mixing of doped layers. The process temperatures during the deposition of thin film silicon n-i-p layers were below  $150$  °C. The ITO top contacts were done by rf magnetron sputtering without any substrate heating. The effective area of the cell was  $0.196$  cm<sup>2</sup>. The solar cell was characterised using Newport solar simulator with AM 1.5 filters. The I-V characteristic of the cell is show in figure 4. The cell showed an initial efficiency of  $4.62\%$  with a  $V_{oc}=0.69$ V,  $J_{sc}=11.02$  mA/cm<sup>2</sup> and  $FF=0.61$ . The estimated crystalline fraction of the p-layer from the Raman spectra was  $8\%$ .

The spectroscopic ellipsometry measurement of the doped layers showed lower signals indicating porosity as confirmed by the values of the fittings with a 10% of void fraction when using the Bruggeman model [10]. The comparatively low  $V_{oc}$  for the device might be due to the poor quality of the p-layer.

#### **4. Conclusion**

An amorphous silicon thin film solar cell in the n-i-p configuration was fabricated on glass substrates at low temperatures compatible for the polymeric substrates (<150 °C). We report an initial efficiency of 4.62%. To our knowledge, this is the best cell efficiency reported for an a-Si:H solar cell fabricated at low substrate temperature entirely by HW-CVD. The intrinsic a-Si:H material has a dense and ordered structure, whereas the poor quality of the p-layers limited the  $V_{oc}$  value resulting in a reduced efficiency.

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## Figure captions

Fig. 1 The increase in substrate temperature with time due to the irradiation from the hot filament

Fig. 2 The AFM image of the textured silver substrate with RMS roughness = 47nm

Fig. 3 The microstructure value estimated from the FTIR spectrum of different intrinsic a-Si:H thin films deposited either without any intentional heating of the substrate or with a substrate temperature of 200 °C.

Fig. 4 I-V characteristics of the a-Si:H n-i-p solar cells deposited entirely by HW-CVD at temperatures <150 °C on textured Ag back reflector.

Figure1

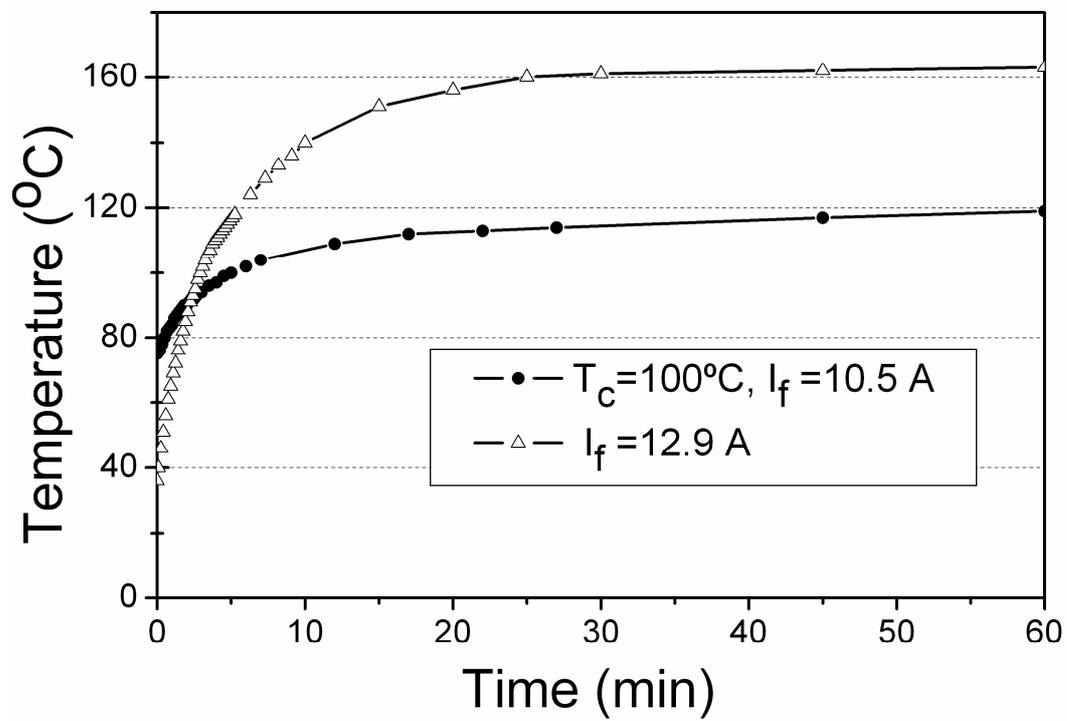


Figure 2

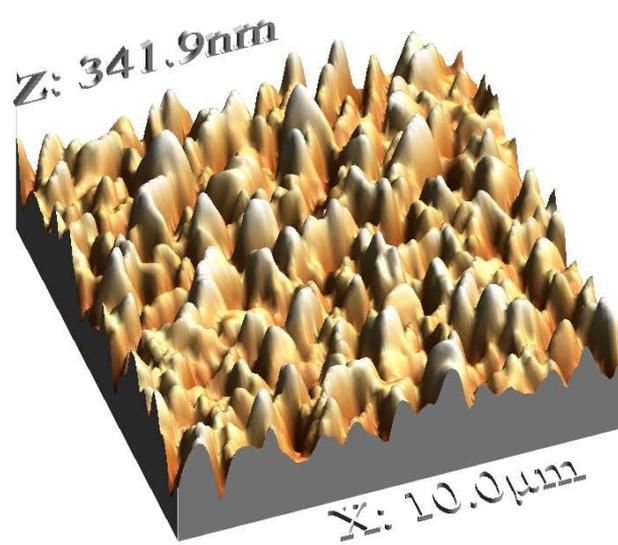


Figure 3

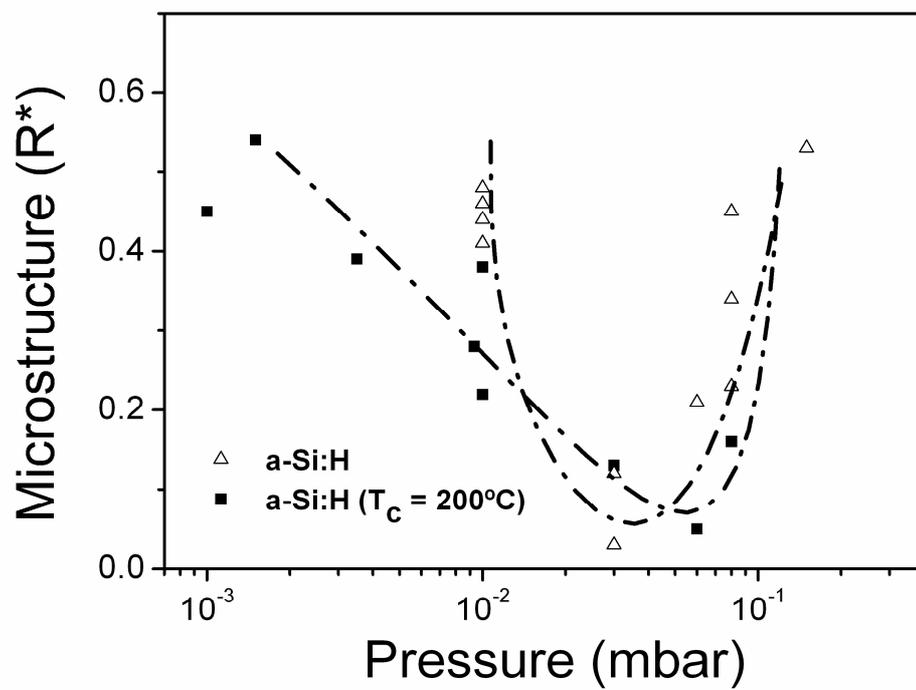


Figure 4

