Available online at www.sciencedirect.com
ScienceDirect
Thin Solid Films 516 (2008) 496–499
thin solid films
www.elsevier.com/locate/tsf

Hot Wire CVD for thin film triple junction cells and for ultrafast deposition of the SiN passivation layer on polycrystalline Si solar cells

R.E.I. Schropp *, R.H. Franken, H.D. Goldbach, Z.S. Houweling, H. Li, J.K. Rath, J.W.A. Schüttauf, R.L. Stolk, V. Verlaan, C.H.M. van der Werf

Utrecht University, Faculty of Science, SID — Physics of Devices, P.O. Box 80.000, 3508 TA Utrecht, The Netherlands

Available online 15 June 2007

Abstract

We present recent progress on hot-wire deposited thin film solar cells and applications of silicon nitride. The cell efficiency reached for μc-Si:H n–i–p solar cells on textured Ag/ZnO presently is 8.5%, in line with the state-of-the-art level for μc-Si:H n–i–p's for *any* method of deposition. Such cells, used in triple junction cells together with hot-wire deposited proto-Si:H and plasma-deposited SiGe:H, have reached 10.5% efficiency. The single junction μc-Si:H n–i–p cell is entirely stable under prolonged light soaking. The triple junction cell, including protocrystalline i-layers, is within 3% stable, due to the limited thicknesses of the two top cells. The application of SiN_x:H at a deposition rate of 3 nm/s to polycrystalline Si wafer solar cells has led to cells with 15.7% efficiency. We have also achieved record high deposition rates of 7.3 nm/s for transparent and dense SiN_x;H. Hot-wire SiN_x:H is likely to be the first large commercial application of the Hot Wire CVD (Cat-CVD) technology.

Keywords: HWCVD; Solar cells; Multijunction; Efficiency; Stability; Silicon nitride

1. Introduction

The technology of Hot Wire Chemical Vapor Deposition or Catalytic CVD has made great progress during the last couple of years. Novel materials have been obtained with controlled properties and there is increasing evidence that large area continuous coating is feasible. This review discusses a number of examples of significant progress at our laboratory in the light of other achievements worldwide. Specifically, recent p–i–n and n–i–p solar cells are highlighted, as well as the application of silicon nitride (SiN_x:H) to polycrystalline solar cells.

The area of hot-wire deposited SiN_x:H has shown great progress and this material is likely to be the first to be commercially applied. Silicon nitride is used in many applications. The proceedings of this conference alone show the successful use of HW-SiN_x as encapsulation barrier against H_2O and O_2 (even on top of sensitive organic layers), as passivating dielectric in AlGaN/GaN high mobility FETs, as a mechanically strong material for microelectromechanical structures (MEMS), as a gate dielectric in TFTs, and as a passivating antireflective layer on polycrystalline solar cells.

2. Thin film a-Si:H p–i–n solar cells

Our 'standard' protocrystalline Si:H is deposited by HWCVD at a substrate temperature T_{sub} of 250 °C. We use Ta filaments at a temperature of 1850 °C, pure SiH_4 feed gas and a process pressure of 0.02 mbar, resulting in a deposition rate of 1 nm/s [1]. A fingerprint of the protocrystalline nature of this material is the narrow width of the first sharp peak in X-ray diffraction (XRD) [2]. For p–i–n type solar cells with a thickness of 300 nm, deposited on Asahi U-type SnO_2:F-coated glass, under AM1.5 light-soaking conditions a light-induced decrease in fill factor (FF) of less than 10% has been observed [3]. We incorporated 200-nm thick HW-deposited protocrystalline cells in top-cell limited micromorph tandem cells in order to study their stability against light-induced degradation. The results reflect the potential of top-cell limited multibandgap thin film silicon micromorph tandem cells, which is important for high-yield outdoor application (as expressed in kWh/kWp yr) [4]. In many

* Corresponding author.
E-mail address: r.e.i.schropp@phys.uu.nl (R.E.I. Schropp).

0040-6090/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.tsf.2007.06.052

Table 1
Performance of a 200 nm/1000 nm HWCVD proto-Si/HWCVD μc-Si:H superstrate p–i–n/p–i–n tandem cell on texture-etched ZnO (made at IPV Jülich) before and after light soaking

Thicknesses 200/1000 nm	V_{oc} (V)	J_{sc} (mA/cm2)	FF	η (%)
Initial	1.39	10.0	0.61	8.5
Stable (500 h)	1.39	10.1	0.60	8.5

regions of the world, a positive correlation between operation temperature and light intensity exists, which is advantageous for the daily and annual energy yield of the top cell, but adverse for that of the bottom cell. This is due to differences in the temperature coefficients for the performance of the top and bottom cell. Therefore, top cell limited micromorph tandem cells will provide more energy per annum than bottom cell limited tandem cells [5], but this imposes stringent stability requirements on the top cell. Table 1 shows the performance and stability of a top-cell limited p–i–n/p–i–n micromorph tandem cell on glass with texture-etched ZnO received from IPV Jülich. Both i-layers have been deposited by HWCVD. Between the short-circuit current densities generated by the two stacked cells a deliberate mismatch exists of 2.6 mA/cm^2. It is seen that this cell is perfectly stable even though the current-limiting amorphous Si cell dominates its fill factor (FF). The high stability is due to the protocrystalline nature of the active layer in the top cell.

By increasing the filament temperature, we investigated by how much the deposition rate r_d for a-Si:H could be further increased in order to take advantage of the high deposition rate capability of HWCVD. Special precautions were taken to protect the Asahi SnO_2:F coated substrates onto which the cells were deposited [1]. While the cells deposited at 1 nm/s reached an initial efficiency of 8.9% (0.88 V, 14.2 mA/cm^2, FF = 0.71), we achieved 8.5% at an r_d of 1.6 nm/s, 8.1% efficiency at an r_d of 2.1 nm/s, and at an r_d of 3.2 nm/s still a high efficiency of 7.5% was obtained. The i-layer deposition time under the last conditions is only 3–4 min. Up to an r_d of 2.2 nm/s the cells behave quite stable: for cells with i-layers thinner than 300 nm (as in tandem cells) the degradation in FF is less than 10%.

Table 2
Present status of single junction HWCVD μc-Si:H n–i–p solar cells at various laboratories

Laboratory [ref]	V_{oc} (V)	J_{sc} (mA/cm^2)	FF	η (%)
Utrecht [present work]	0.545	23.39	0.668	8.52
Jülich [8]	0.542	19.9	0.69	7.5
Kaiserslautern [9]	0.522	21.6	0.66	7.3
Ecole Polytechnique [10]	0.42	20.7	0.59	5.1
Gifu [11]	0.550	11.32	0.56	3.49
Unisolar [12] (non HWCVD)	0.568	23.59	0.671	8.99

3. Thin film μc-Si:H n–i–p cells and triple cells

To enhance the efficiency in the n–i–p configuration, we developed textured Ag/ZnO back reflector layers on stainless steel substrates, using rf magnetron sputtering. An example of the surface morphology as observed with Scanning Electron Microscopy (SEM) is shown in Fig. 1. The μc-Si:H i-layer is deposited at 270 °C by HWCVD. We use Ta filaments at a temperature of 1850 °C, a SiH_4/H_2 gas mixture at a flow ratio of 5/100, and a pressure of 0.05 mbar, resulting in a deposition rate of 0.21 nm/s. The Raman ratio of crystallinity for this material is 40% and the crystallites have 10–20 nm sizes [6]. Further, we optimized the μc-Si:H n-type doped layer and the n/i interface, and in addition we used H_2/SiH_4 ratio profiling during i-layer deposition [7]. Table 2 shows the present results in comparison with other data obtained on single junction μc-Si:H n–i–p type cells on various substrates [8–12]. In our case, mainly due to the textured back reflector on stainless steel, the short-circuit current J_{sc} went up from the value of 15.2 mA/cm^2 obtained on plain stainless steel to 23.4 mA/cm^2 on textured Ag/ZnO. The spectral response curve is shown in Fig. 2. For comparison, Table 2 includes the latest best results obtained at United Solar Ovonic, LLC, for this type of cell as obtained using their ‘modified VHF’ technique. We believe that the obtained efficiency of 8.5% is a record value for hot-wire deposited μc-Si:H

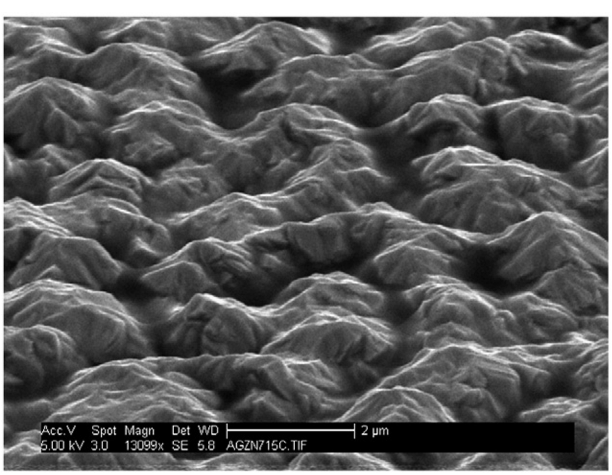

Fig. 1. The SEM morphology of an rf magnetron sputtered Ag/ZnO textured back reflector.

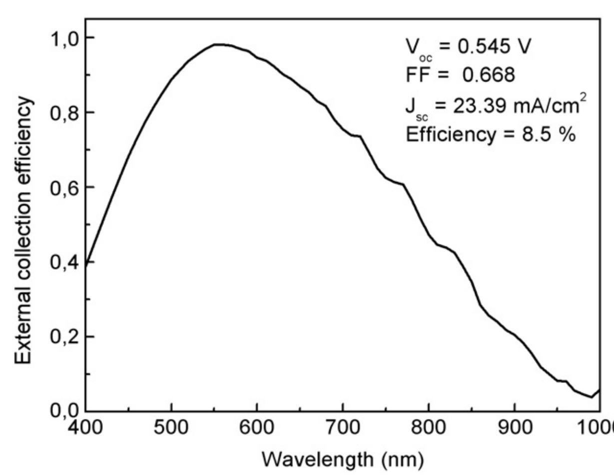

Fig. 2. Spectral response at 0 V of a 2-μm thick μc-Si:H nip solar cell on textured Ag/ZnO. The AM1.5 cell parameters of the cell are listed.