THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI.
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N^0. 4 – 2011, ISSN 1453 – 083X

IMPROVEMENT OF PHOTOVOLTAIC CELLS EFFICIENCY BY REDUCING CONTAMINATION IN SINGLE CHAMBER PECVD SYSTEM BY PASSIVATION WITH a-Si:H AND μc-Si:H THIN FILMS*

B. DIACONU[1], A. VICENTE[2], V. MUSAT[1] AND R. MARTINS[2]
[1]Centre of Nanostructures and Functional Materials-CNMF, “Dunărea de Jos” University of Galaţi, Romania
[2]CENIMAT-I3N, Departamento de Ciência dos Materiais, and CEMOP-UNINOVA,
Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa, Portugal

ABSTRACT

High performance solar cells, deposited in a single chamber, can be obtained when low levels of contamination exists for the p-,i-,n- layers. This is a recurrent problem not only in the laboratories, but also in the industrial single chamber plasma enhanced chemical vapour deposition (PECVD) systems. In this paper an effective method of reducing the impurities, through the passivation with amorphous and nano/microcrystalline silicon thin film of the PECVD chamber walls, before and during the deposition of the solar cell layers is described.

KEYWORDS: a-Si:H, μc-Si:H, PECVD, contamination, solar cell

1. Introduction

The economically advantage of depositing solar cells in a single chamber PECVD system is obvious comparing to the multi-chamber system. The problem is the contamination during the deposition of different doped layers and this must be very seriously taken in consideration [1]. There are several causes which can lead to contamination and they can be related not only to cross contamination of p-, i-layer [2], but also due to impurities that are on the chamber walls from previous depositions or as a result of technical issues [3]. Even if the layers of the solar cells are optimized and theoretically they should lead to an efficiently working device, the contamination is a factor that can drastically reduce the performance of the solar cell. There are different methods of passivating the chamber, using different types of gases, but there is still a lot of potential for reducing the level of contamination.

Hydrogenated amorphous silicon (a-Si:H) and hydrogenated microcrystalline silicon (μc-Si:H) are intrinsic materials which bring their separate advantages for using as passivation layers [4].

2. Experimental results

The experiments took place in a single chamber PECVD system [5]. The configuration of the solar cell used for comparing the pasivation methods was glass/ZnO NW/GZO/p/i/n/Al. The passivating materials, hydrogenated amorphous silicon (a-Si:H) and hydrogenated microcrystalline silicon (μc-Si:H), were deposited using SiH_4 and H_2 gases. The choosed conditions for pasivating the PECVD chamber walls were at low pressure and low power, using hydrogen diluted silane, for the intrinsic a-Si:H material and at high pressure and high power using highly diluted silane with hydrogen, for the μc-Si:H material, to have stable materials. The intrinsic materials were deposited using VHF (27 MHz) at a substrate temperature of 200^{o}C. The deposited layers were characterized by spectroscopic ellipsometry (SE), using a Jobin Yvon UVISEL DH 10 ellipsometer and the data was simulated using Tauc-Lorentz dispersion model [6] and BEMA. The solar cells were characterized with current density versus voltage (J-V) measurements under an AM1.5 solar simulator at room temperature.

---

*Paper presented at the Symposium ***"The Impact of Nanotechnologies and Nanomaterials on Industrial Development and Quality of Life",*** Galati, May 19, 2011, organized by the Center for Nanostructures and Functional Materials (CNMF), Faculty of Metallurgy, Materials Sciences and Environment, “Dunarea de Jos” University of Galati

3. Results and discussion

Intrinsic a-Si:H layers deposited by pure silane SiH_4 in PECVD show high defect densities due to the short-range order at the atomic length scale[7]. These defects can be reduced to some extent if SiH4 is diluted with an optimum level of hydrogen (H_2).
An important objective is to have short passivation time deposition of intrinsic layer material, therefore is needed to obtain deposition conditions with high deposition rate while maintaining the quality of the films. It becomes difficult to achieve this objective due to the large number of parameters (pressure, substrate temperature, VHF power, frequency, etc.) that have to be optimized to obtain such conditions.

Figure 1 shows the experimental data of the growth rate for the a-Si:H films deposited using VHF SiH_4/H_2 discharges as a function of H_2 dilution.

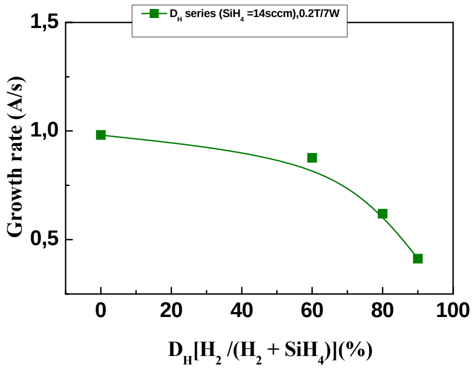

Fig 1. *The growth rate of thin films vs H_2 dilution.*

It is observable that by keeping the pressure and power constant, the growth rate predictably decreases with an increase in the H_2 dilution. This fact can be explained by the following reasons. First, the increase in H_2 leads to the displacement of plasma chemistry in favour of more atomic hydrogen as compared to reactive silicon precursors, and decreased formation of a-Si:H. Secondly, the higher amount of available H-ions creates an etching effect on the film surface. Lastly, a higher H dilution leads to lowering of electron temperature, decreasing the formation of a-Si:H. Thus, it is desirable to keep the dilution ratio at an optimum level.

The optical parameters obtained by SE provide information about the physical structure of the material [8]. The Tauc-Lorentz model was fitted to the experimental data ($\chi^2 < 1$) using a layer sample model, the AF45 glass, the bulk layer (pure a-Si:H film) and a surface layer (x% a-Si:H + y% voids). The effect of hydrogen dilution on the optical parameters for all the D_H series of samples are shown in Figure 2.

In Figure 2 one can see the evolution of the physical density parameter (A) with the D_H. This parameter A relates to the film density, thus higher the value of A, the denser (or less porous) is the material. The D_H series depicted in this plot shows a smooth increase in the A value with increasing D_H up to a certain level, while at higher dilutions (~90%), A decreases.

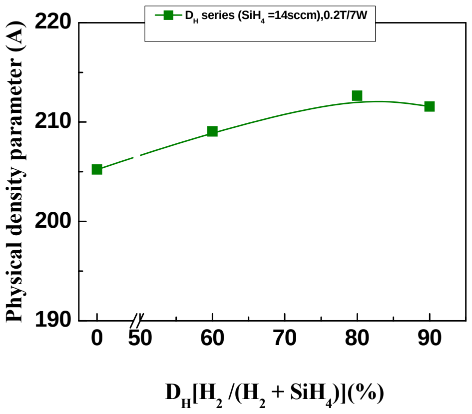

Fig 2. *Physical density parameter (A) as a function of D_H for the deposited silicon films.*

The disorder parameter in Figure 3 shows that it does not vary significantly with rise in power. For the majority of the depositions conditions, the C value stays ranges within 2.1 – 2.2, which corresponds to pure amorphous material.

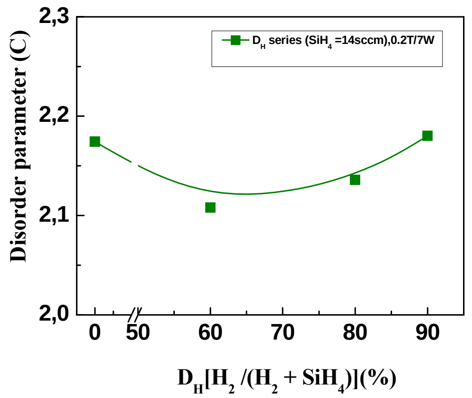

Fig 3. *The disorder parameter (C) as a function of D_H for all the deposited samples.*

μc-Si:H is a versatile material having a complex microstructure given by the effect of hydrogen dilution on the growth of microcrystalline network which is of prime importance.

In the deposition of μc-Si:H using silane diluted by H_2, a certain threshold value of the dilution ratio exists, where μc-Si:H nucleation occurs [9].

Lowering the partial pressure of silane leads to an increase in the atomic hydrogen flux density on the growing surface.

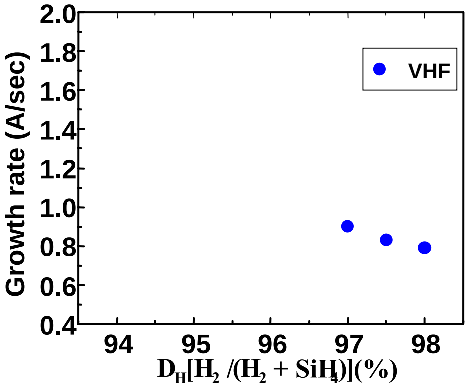

Fig 4. *Experimental results of the growth rate as a function of H_2 dilution of the films deposited from VHF at 97%, 97.5% and 98% deposition of μc-Si:H intrinsic layer.*

Thus, high hydrogen dilution or silane depletion enhances micro or nano crystalline growth. The consumption of silane exceeds the silane supply in the high power regime, and silane depletion leads to μc-Si:H growth. Thus, the atomic hydrogen density is the most crucial factor for the deposition of μc-Si:H, the optimization of which allows rapid optimization of the microstructure of the μc-Si:H material.

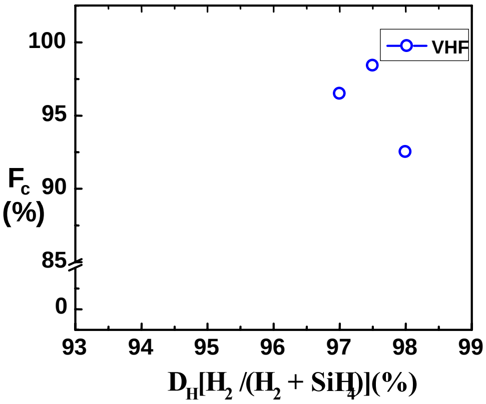

Fig 5. *Experimental results of the crystalline fraction (F_C) as a function of H_2 dilution of the films deposited from VHF.*

The chosen conditions for passivation process where:

- Intrinsic a-Si:H film was deposited using VHF (27.12 MHz) plasma decomposition of SiH_4, at a substrate temperature (Ts) of 200˚C, Pressure (P_{gas}) of 0.2 Torr, H_2 dilution ($D_H=H_2/(H_2 + SiH_4)$) of 0% and Power (P_{vhf}) of 7 W.

- Intrinsic μc-Si:H film was deposited at P_{gas} of 2 Torr, D_H of 98% and P_{VHF} of 50W.

The growth rates of the a-Si:H and μc-Si:H layer are 0.982 Å/s and 0.792 Å/s respectively, so the time for obtaining the desired passivation thickness is comparable.

The layers deposited for passivation were a-Si:H and μc-Si:H with different thicknesses, depending on the growth time. To estimate the passivation effect of these layers on the efficiency of photovoltaic cell, two groups of cells were deposited. For the first solar cells group, the passivation was done depositing first 10 minutes of a-Si:H and then 10 minutes of μc-Si:H thin films. For the second solar cells group, the depositing time for a-Si:H was 30 minutes and for μc-Si:H was 30 minutes. All solar cells have been deposited with a pre-hydrogen glow [10], using the same p-i-n configuration with the same layers compositions. The other parameters were kept constant.

The functional characteristics for two of the deposited photovoltaic cells, belonging to each group, were measured after an annealing treatment at 150°C, and the results are shown in Figures 6-7.

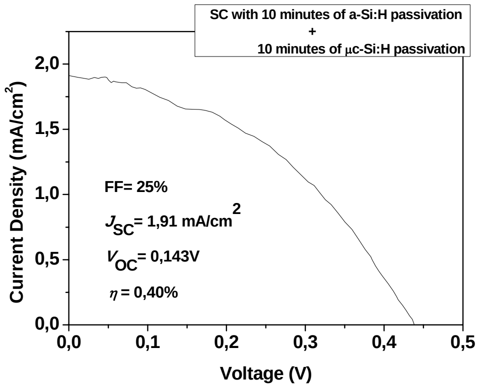

Fig 6. *I-V Curve of the photovoltaic solar cell obtained with 10 minutes a-Si:H + 10 minutes μc-Si:H passivation (first group).*

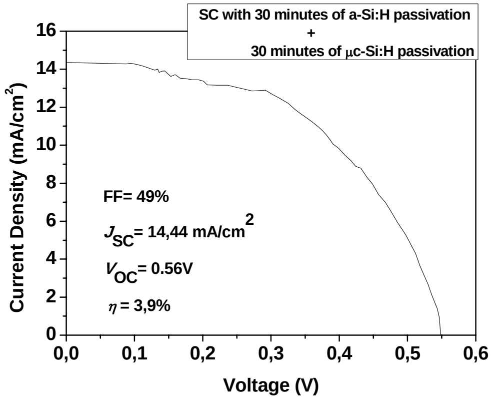

Fig 7. *I-V Curve of the photovoltaic solar cell obtained with 30 minutes a-Si:H + 30 minutes μc-Si:H passivation (second group).*

The cell obtained after the total passivation of 60 minutes (second group) has an efficiency of 3.9%, which is much better than the solar cell obtained with only a total passivation of 20 minutes. The variations of filling factor (FF), the short-circuit current (J_{SC}) and the open-circuit voltage (V_{OC}) follow the same improvement in the case of the cells deposited according to the second passivation procedure. This shows that one of the key factors for improving the efficiencies of the solar cells is the thickness of passivation layers, a-Si:H and μc-Si:H, correlated with the quality of these layers given by C (disorder) and A (compactness) parameters.

4. Conclusions

Hydrogenated amorphous silicon and hydrogenated microcrystalline silicon materials, with good stability related to growth rates, have been obtain and used as passivation layers.

The thickness of the passivation layer is an important factor for isolating the impurities that are on the walls of the single chamber PECVD system.

Photovoltaic cells with good efficiency have been developed, due to reducing contamination of PECVD chamber.

References

[1]. R. Martins, I. Ferreira, H. Águas, V. Silva, E. Fortunato, L. Guimarães - *Engineering of a-Si:H device stability by suitable design of interfaces*, Solar Energy Materials and Solar Cells, Volume 73, Issue 1, May 2002, Pages 39-49, 10.1016/S0927-0248(01)00109-X.

[2]. L. Raniero, S. Zhang, H. Águas, I. Ferreira, R. Igreja, E. Fortunato, R. Martins - *Role of buffer layer on the performances of amorphous silicon solar cells with incorporated nanoparticles produced by plasma enhanced chemical vapor deposition at 27.12 MHz*, Thin Solid Films, Volume 487, Issues 1-2, 1 September 2005, Pages 170-173, 10.1016/j.tsf.2005.01.059.

[3]. X. D. Zhang, F. H. Sun, G. H. Wang, S. Z. Xu, C. C. Wei, G. F. Hou, J. Sun, S. Z. Xiong, X. H. Geng,and Y. Zhao - *Effect of high crystalline p/i interface layer on the performance of microcrystalline silicon solar cells deposited in a single chamber system*, Phys. Status Solidi C 7, No. 3–4, 1116–1119 (2010) / DOI 10.1002/pssc.200982764.

[4]. Wang Guang-Hong, Zhang Xiao-Dan, Xu Sheng-Zhi, Zheng Xin-Xia, Wei Chang-Chun, Sun Jian, Xiong Shao-Zhen, Geng Xin-Hua, and Zhao Ying, *Reduction of the phosphorus contamination for plasma deposition of p i n microcrystalline silicon solar cells in a single chamber*, Chin. Phys. B Vol. 19, No. 9 (2010) 098102.

[5]. L. Raniero - *Produção e caracterização de células fotovoltaicas de silício nano-estruturado produzido por plasma de 27,12 MHz*, Pages 92-94 PhD thesis, Universidade Nova de Lisboa, Faculdade de Ciências e Tecnologia, Lisboa (2006).

[6]. Hiroyuki Fujiwara - *Spectroscopic Ellipsometry Principles and Applications*, Pages 170-172, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England (2007)

[7]. R. C. Chittick, J. H. Alexander, and H. F. Sterling - The Preparation and Properties of Amorphous Silicon, J. Electrochem. Soc. 116, 77 (1969).

[8]. J. Müllerová, P. Šutta, G. van Elzakker, M. Zeman, M. Mikula - *Microstructure of hydrogenated silicon thin films prepared from silane diluted with hydrogen,* Applied Surface Science, Volume 254, Issue 12, 15 April 2008, Pages 3690-3695, 10.1016/j.apsusc.2007.10.069.

[9]. R.E.I. Schropp, J.K. Rath, H. Li - *Growth mechanism of nanocrystalline silicon at the phase transition and its application in thin film solar cells*, Journal of Crystal Growth, Volume 311, Issue 3, 15 January 2009, Pages 760-764, 10.1016/j.jcrysgro.2008.09.155.

[10]. Xiaodan Zhang, Guanghong Wang, Xinxia Zheng, Changchun Wei, Xinhua Geng, Shaozhen Xiong, Ying Zhao - *A pre-hydrogen glow method to improve the reproducibility of intrinsic microcrystalline silicon thin film depositions in a single-chamber system*, Solar Energy Materials and Solar Cells, Volume 95, Issue 8, August 2011, Pages 2448-2453.