Revue des Energies Renouvelables Vol. 13 N°1 (2010) 179 – 186
DOI: https://doi.org/10.54966/jreen.v13i1.187

Optimization of the performance of micromorph tandem solar cell a-Si/µc-Si

Adnan Amin Boussettine[1], Béchir Dridi Rezgui[2], Abdelhalim Benmansour[1], Georges Bremond[2] and Mustapha Lemiti[2]

[1] Unité de Recherche Matériaux et Energies Renouvelables, URMER
Abou Bekr Belkaïd University, B.P. 119, Tlemcen, Algeria
[2] INL – UMR 5270, INSA of Lyon,
Blaise Pascal Building, 20 Av. A. Einstein, 69621 Villeurbanne Cedex, France

(reçu le 02 Décembre 2009 – Accepté le 27 Mars 2010)

Abstract - *We have performed a Computer modeling using AMPS 1D and AFORS-HET for optimizing a-Si:H/µc-Si:H tandem cells on p-i-n/p-i-n configuration. We investigated the influence of the substrate temperature for doped layer deposition technique in the top cell performances and the influence of the thickness of the bottom cell in the density of current that present a crucial parameter in the current matching between subcells. The simulation results demonstrate in one hand that a top cell a-Si with doped layers deposited by PECVD with 1000C substrate temperature provides a notable increase in the efficiency, and in the other hand a bottom cell µc-Si with 900nm thick intrinsic layer exhibit more density of current. The performances of micromorph cell obtained from simulation give a good agreement with experimental results and confirm the importance of the combination a-Si/µc-Si as a double junction solar cell.*

Résumé - *Nous avons effectué une modélisation informatique en utilisant AMPS 1D et AFORS-HET pour l'optimisation de a-Si:H/µc-Si:H cellules tandem pour la configuration p-i-n/p-i-n. Nous avons étudié l'influence de la température du substrat par la technique de déposition de la couche dopée sur les performances de la cellule face avant et l'influence de l'épaisseur de la cellule face arrière sur la densité de courant, qui présente un paramètre crucial dans le rapprochement en cours entre les sous-cellules. Les résultats de simulation démontrent que d'une part, la cellule haute a-Si dopé, avec des couches déposées par PECVD avec une température de 1000 °C du substrat, permet une augmentation notable de l'efficacité, et d'autre part la cellule basse µc-Si avec 900 nm présentent une épaisse couche intrinsèque avec en plus la densité de courant. Les performances de la cellule micromorphe obtenus par simulation donne un bon accord avec les résultats expérimentaux et de confirmer l'importance de la combinaison a-Si/µc-Si comme étant une double jonction de cellules solaires.*

Keywords: a-Si/µc-Si tandem solar cell - PECVD - AFORS-HET - AMPS 1D - µc-Si bottom cell.

1. INTRODUCTION

The thin film silicon technology is now already mastered and become one of the most promising branches in present photovoltaic industry. The actual aim of researchers is focusing to performing the efficiency of silicon solar cells based on amorphous materials. An important design that must give a good performance is the Tandem cell solar cell (double or triple junction).

First concept was a-Si/a-SiGe but, as the cost of the Ge precursors is high and the electronic quality of the a-SiGe:H layers is lower than for a-Si:H layers, a lot of effort is being done in replacing the a-SiGe:H part of the cell by other solutions like

microcrystalline Si [6]. This leads to the 'micromorph' cell concept combining an a-Si:H top cell with a microcrystalline Si bottom cell [1] as shown in Figure 1.

This concept was introduced by Neuchâtel University; the key element of this micromorph cell is the hydrogenated microcrystalline silicon bottom cell that opens a novel perspective for thin film silicon technology.

This cell is more stable, a relative efficiency loss is lower than 5 % versus 30 % in the case of single a-Si solar cell [2].

However, a-Si/µc-Si Tandem solar cell provides a good stability against light soaking and provides certainly a promising efficiency by the enhanced collection of photons having a low energy and respectively an important reduction of the thermalization photons energies exceeding the bandgap of the material. An efficiency limit of 35 % was obtained theoretically for a-Si/µc-Si solar cell [3].

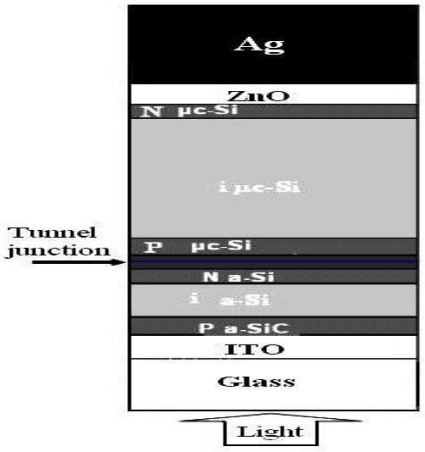

Fig. 1: Schematic view of the typical Micromorph tandem solar cell

2. MODELING OF MICROMORPH TANDEM SOLAR CELL

2.1 General conditions of simulation

During our simulation under AMPS 1D [4] and AFORSHET [5], we have take fixed conditions of illumination 'One Sun' with the standard AM1.5G and the ambient temperature of 300 K. The model DOS (density of states) is used for the modelling of the amorphous materials which possess a strong density of defects such as the amorphous silicon and the microcrystalline silicon. We did not take into account the defects at the interfaces between various materials.

2.2 Optimization of single junction a-Si used as top component in tandem micromorph cell

2.2.1 Optimization of intrinsic layer thickness

In a tandem configuration, the current matching is a crucial parameter. Truthfully, the top cell should not be made thicker than about 250 nm, otherwise, insufficient light reach the bottom cell and the Steabler-Wronski effect will be considerable [6].

In tandem applications, we have chosen a-Si top cell with 250 nm thick intrinsic layer. The complete structure is formed by Figure 2:

- 80 nm thick TCO (Transparent Conductive Oxide), ITO is favorable for a front contact
- Thinner layer a-Si doped p (L = 10 nm)
- Intrinsic layer a-Si, the thickness is 250 nm
- Thinner layer a-Si :H doped n (L' = 20 nm)
- TCO of 80 nm thickness based on ZnO
- 1 µm of Ag.

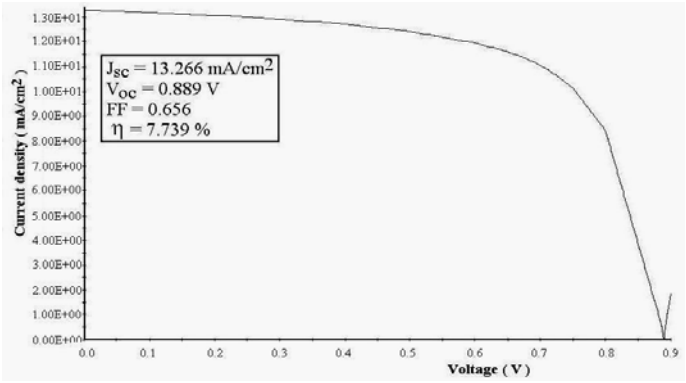

Fig. 2: The illuminated J-V characteristic

2.2.2 Optimization of doped layers substrate temperature

Generally, at the time of deposition of a-Si:H material doped p and doped n by PECVD process, the substrate temperature was adjusted between 100 °C et 350 °C. For this reason in this work we attempt to define the value of temperature correspond to optimal performances of p-i-n a-Si:H solar cell.

We are interested in three values of substrate temperature T = 100 °C, 140 °C and 210 °C. Figure 3 and figure 4 show respectively the J-V characteristic and the quantum efficiency of the a-Si solar cell.

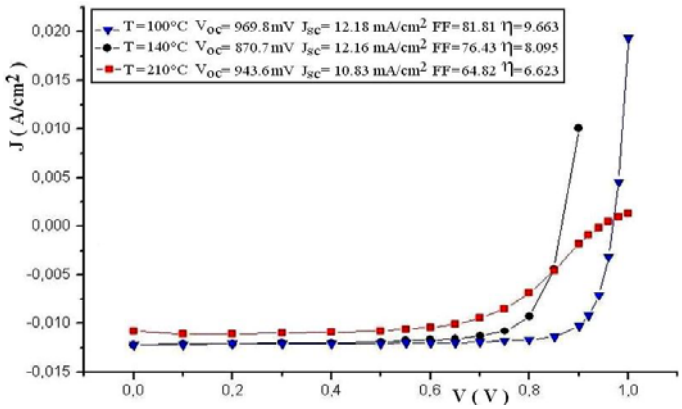

Fig. 3: Illuminated J-V characteristic of a-Si solar cell
for different substrate temperature T = 100 °C, 140 °C et 210 °C

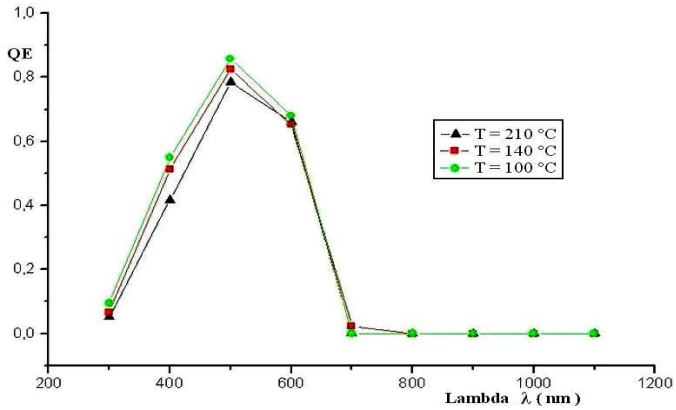

Fig. 4: Quantum efficiency of a-Si solar cell at T = 100 °C, 140 °C and 210 °C

From this figures, it is clear that a temperature of 100 °C offer the best efficiency. However, when the substrate temperature decrease more hydrogen atom are included in the film (suitable case for the passivation of dangling bonds), thus the bandgap of doped materials increase.

Therefore, the quantum efficiency for a short wavelength (< 600 nm) is improved accompanied with a raise in the current density value (from 10.83 mA/cm^2 for T = 210 °C to 12.18 mA/cm^2 for T = 100 °C)

Another advantage of low substrate temperature deposition T = 100 °C is the reduction of light-soaking effect [7].

2.2.3 Optimization of single junction µc-Si used as bottom cell in micromorph structure

The quality of the intrinsic layer called also absorbent layer represents a very important parameter in the photovoltaic conversion. However the profile of the internal electric field which has to facilitate the separation of the pair of electron-hole and the diffusion of charge carrier towards the doped regions is strongly affected by the quality of this layer. This internal electric field is not uniform in the intrinsic layer and it is altered by the density of defects.

The microcrystalline cell is mainly constituted by:

1. A film µc-Si doped p of thickness of the order of 30 nm with Eg = 1.4 eV
2. An intrinsic µc-Si film with Eg = 1.4 eV
3. A material µc-Si doped n of thickness of 30 nm approximately Eg = 1.4eV.

To obtain a best performance, the µc-Si bottom cell according to its indirect gap must have the most important density of current so to maintain a matching of current between the components. This last one has to present a density of current approximately twice as big with regard to the top cell (i.e. $J_{sc}(a-Si)$ = 13 mA/cm^2 we have $J_{sc}(\mu c-Si)$ = 26 mA/cm^2) [8].

For that presented simulation, we have chosen a range of thicknesses between 500 nm to 1200 nm. The figure 5 schematizes the illuminated characteristics J-V of µc-Si cell. According to these results, we notice a maximal density of current (21.040 mA/cm^2) for a value of the thickness of the intrinsic layer d = 900 nm.

One of the problems of the microcrystalline cells for the obtaining an efficient conversion of the solar spectrum is the weak value of the open circuit voltage V_{oc}, which is remarkable in the figure 5.

In accord with the importance which must be taken to the density of current in a tandem cell, in the follow work of simulation we have taken 900 nm thick intrinsic layer of the bottom cell.

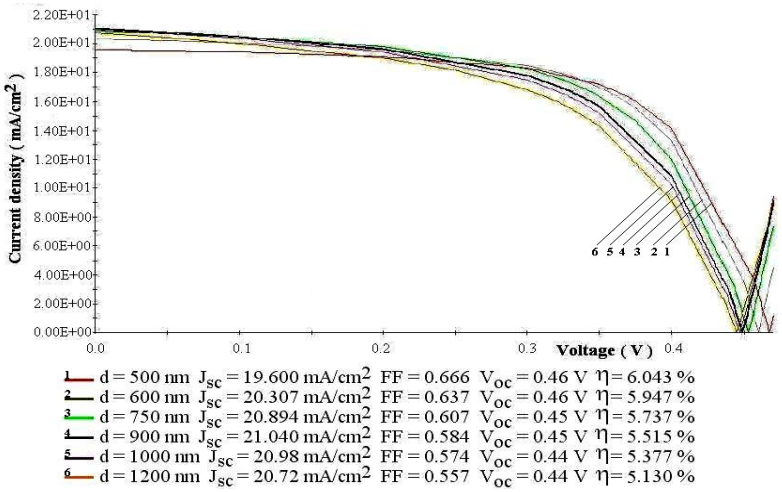

Fig. 5: Influence of intrinsic layer thickness in the performance of µc-Si solar cell

2.2.4 Modelling of tandem micromorph cell a-Si/µc-Si

The schematic structure of tandem cell a-Si/µc-Si is represented in figure 6. However, the tunnel junction performs an important role in the transport of charge carrier between the components by tunnel/recombination effect.

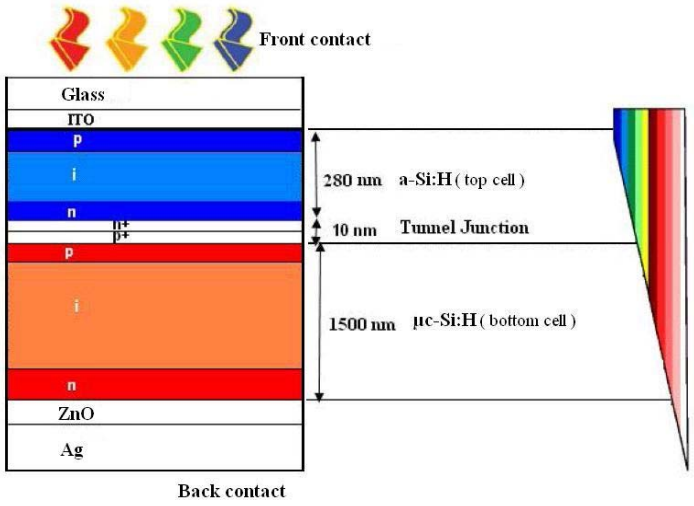

Fig. 6: Schematic structure of micromorph tandem cell in superstrate configuration

In our simulation we have utilize this diode made up microcrystalline material due to its slightly high mobility compared to the mobility of a-Si:H.

The figure 7 illustrates the quantum efficiency of the a-Si, as well as of the µc-Si. The bottom cell presents the better quantum efficiency with a density of current J_{sc} =22.252 mA/cm^2 in comparison with the top cell J_{sc} =12.592 mA/cm^2.

This result demonstrates the concern of cell stacking and the photo-generation enhancement for the narrow bandgaps photons.

After the steps of optimization, we have made the interconnection between the top and the bottom cell. Figure 8 shows the band diagram of the tandem cell in thermodynamic equilibrium. We can notice the important role of the tunnel junction in the carriers transport between the components.

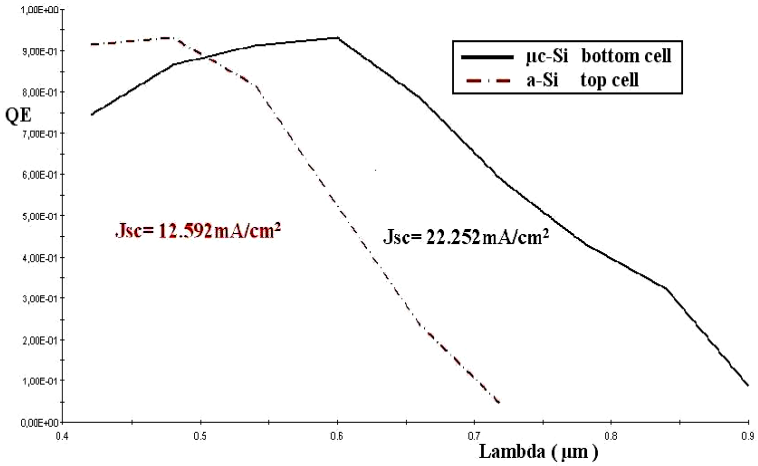

Fig. 7: Spectral response curves of the tandem micromorph cell

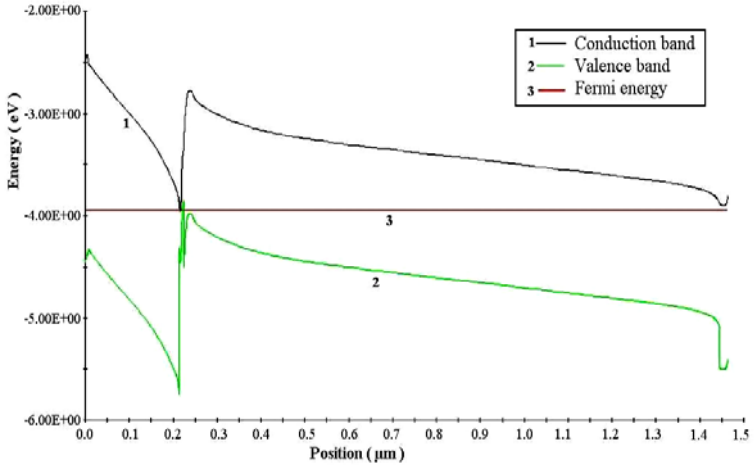

Fig. 8: Band diagram of the tandem cell a-Si/µc-Si in the thermodynamic equilibrium

3. SIMULATION RESULTS

The characteristic J-V of the double junction a-Si/µc- Si under AM1.5G illumination is represented in Figure 9.

The corresponding performances are:

J_{sc} = 10.992 mA/cm^2 , FF = 77.1 % , V_{oc} = 1.546 V , η = 13.098 %.

From these results, we can see in one hand the main cell stacking effect expressed by the boost in the V_{co} by summing the V_{co} of each component, and in the other hand the problem of current matching related to disagreement between the components and the resistive losses in the tunnel junction.

Our cell performances are in a good agreement with another work [9, 10].

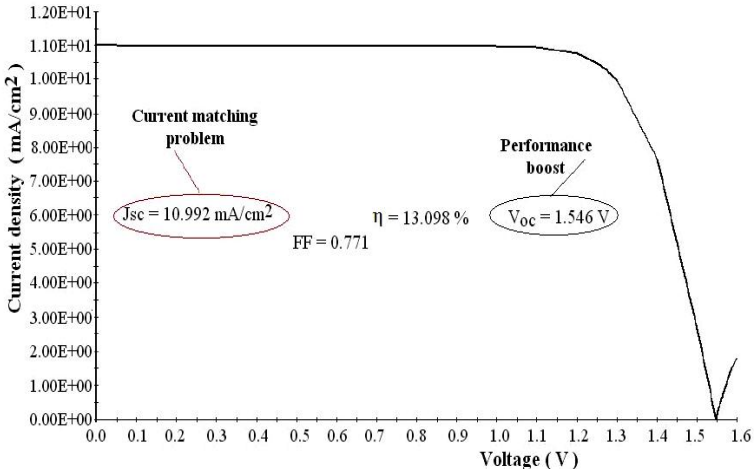

Fig. 9: Illuminated J-V characteristic of micromorph tandem cell

4. CONCLUSION

One-dimensional device modelling of tandem a-Si/µc-Si solar cell has been investigated with taking into account the disorder in structure of the amorphous materials by an appropriate model.

It has been found that the substrate temperature in the PECVD process and the thicknesses of intrinsic layer are of great importance. It is also found that the micromorph tandem cell correspond to a good combination of double junction solar cells.

REFERENCES

[1] H. Keppner, U. Kroll, P. Torres, J. Meier, R. Platz, D. Fischer, N. Beck, S. Dubail, J.A. Anna Selvan, N. Pellaton Vaucher, M. Goerlitzer, Y. Ziegler, R. Tscharner, Ch. Hof, M. Goetz, P. Pernet, N. Wyrsch, J. Vuille, J. Cuperus, A. Shah and J. Pohl, '*The "Micromorph" Cell: a New Way to High-Efficiency-Low-Temperature Crystalline Silicon Thin-Film Cell Manufacturing ?*', AIP Conference Proceedings, C.E. Witt, M. Al-Jassim, J.M. Gee,

NREL/SNL PV Program Review Meeting, Lakewood, CO, Vol. 394, N°1, pp. 271 - 281, November 1996.

[2] F. Sculati-Meillaud, '*Microcrystalline Silicon Solar Cells: Theory, Diagnosis and Stability*', Thèse de Doctorat, Université de Neuchâtel, 183 p., 2006.

[3] F. Meillaud, A. Shah, C. Droz, E. Vallat-Sauvin and C. Miaza, '*Efficiency Limits for Single-Junction and Tandem Solar Cells*', Solar Energy Materials and Solar Cells, Vol. 90, N°18-19, pp. 2952 – 2959, 2006.

[4] H. Zhu, A.K. Kalkan, J. Hou, S.J. Fonash, '*Applications of AMPS-1D for Solar Cell Simulation*', National Center for Photovoltaics (NCPV), 15th Program Review Meeting, AIP Conference Proceedings,Vol. 462, pp. 309 – 314, 1999.

[5] R. Stangl, M. Kriegel, K.V. Maydell, L. Korte, M. Schmidt and W. Fuhs, '*AFORS-HET an Open-Source on Demand Numerical PC Program for Simulation of (Thin Film) Heterojunction Solar Cells, Version 1.2*', IEEE Trans. Hahn-Meitner Institut Berlin, Conference Record IEEE Photovoltaic Specialists conference, 2005, Vol. 31, pp. 1556 – 1559, 2005.

[6] J. Poortman and V. Arkhipov, '*Thin Film Solar Cells Fabrication, Characterization and Applications*', John Wiley & Sons, England, 2006.

[7] C. Droz, '*Thin Film Microcrystalline Silicon Layers and Solar Cells: Microstructure and Electrical Performances*', Thèse de Doctorat, Université de Neuchâtel, 161 p., 2003.

[8] A. Luque and S. Hegedus, '*Handbook of Photovoltaic Science and Engineering*', John Wiley & Sons, England, 2002.

[9] M. Vanecek, J. Springer, A. Poruba, O. Kluth, T. Repmann, B. Rech, N. Wyrsh, J. Meier and A. Shah, '*Light Trapping and Optical Losses in Microcrystalline Si and Micromorph Solar Cells*', Proceedings of 3rd World Conference on Photovoltaic Energy Conversion, Vol. 2, pp. 1527 – 1532, May 12-16, 2003 Osaka, Japan.

[10] H. Keppner, J. Meier, P. Torres, D. Fischer and A. Shah, '*Microcrystalline Silicon and Micromorph Tandem Solar Cells: Thin Film Solar Cells*', Applied Physics A, Materials Science & Processing, Vol. 69, N°2, pp. 169 – 177, 1999.