MICROCRYSTALLINE SILICON SOLAR CELLS: EFFECT OF SUBSTRATE TEMPERATURE ON CRACKS

Martin Python, Didier Dominé, Fanny Meillaud, Christophe Ballif
Institute of Microtechnology (IMT), Thin Film silicon and photovoltaics Laboratory, Rue Breguet 2, 2000 Neuchatel, Switzerland

ABSTRACT

Single junction microcrystalline silicon solar cells presently reach confirmed efficiencies up to 10.1%. Further improvement on device quality is now necessary to continuously increase the electrical performances of the solar cells. Zones of porous material, called "cracks", appear when the substrate, such as glass covered with zinc oxide (ZnO), is too "rough". Previous works have demonstrated that these cracks have mainly detrimental effects on the Fill Factor (FF), and act as bad diodes with a high reverse saturation current. The number of cracks can be decreased with appropriate surface treatment, but then, the light scattering is reduced (lower roughness). This study presents an alternative/complementary way to decrease crack density by increasing the substrate temperature during deposition, which leads to an increase of FF.

1. INTRODUCTION

Microcrystalline silicon (μc-Si:H) is widely used for single junction thin film solar cells in laboratories. The highest confirmed efficiency is 10.1% [1]. This material is also used in micromorph tandem cells, which consist in a stack of amorphous and microcrystalline cells [2]. In single junction μc-Si:H, zones of porous material, called cracks, typically appear when the device is deposited on substrates with V-shape morphology (i.e. sharp and steep valleys) [3]. In Neuchâtel, μc-Si:H p-i-n solar cells are deposited on glass covered by low pressure chemical vapor deposition zinc oxide (LPCVD ZnO), which possesses such a as-grown V-shape morphology (pyramids). Performances of μc-Si:H solar cells are very sensitive to cracks that may appear in the intrinsic layer because of the morphology of the substrate surface, shadowing effect and low diffusion of precursors during growth. A Scanning Electron Micrscopy (SEM) micrograph of cracks in μc-Si:H is presented in Fig.1.

As already demonstrated in previous papers [4, 5], these cracks can indeed be directly related to a decrease of fill factor (FF) and open-circuit voltage (V_{oc}). These zones of low material density act as bad diodes with a high reverse saturation current.

An existing approach to decrease crack density is to modify the surface morphology from V-shape to U-shape by applying a surface treatment [3]. However, the surface treatment decreases the light scattering capabilities of the LPCVD ZnO since it reduces the roughness of the ZnO surface.

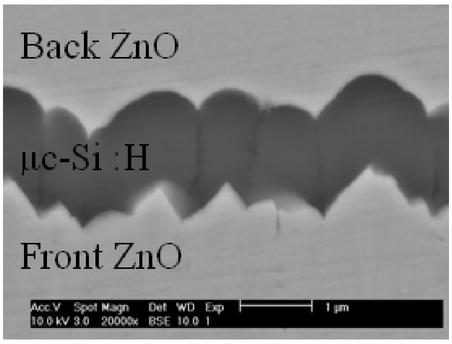

Figure 1 SEM micrograph (Electron Backscattered detector) on solar cell cross-section: μc-Si:H appears grey between front and back ZnO (light gray). Cracks appear as darker lines in silicon.

In this work, we show that an increased substrate temperature during the deposition of the intrinsic layer can improve its density. The increase of substrate temperature enhances the diffusion of precursors at the surface of the growing layer. The shadowing effect due to surface morphology is then lowered, because the particles can more easily reach the bottom of the pyramids. This effect thus helps to decrease the cracks density. The influence of substrate temperature on μc-Si:H was partially studied in [6], but the mechanisms were not completely established. In this paper, a substrate temperature series for i-layer (p and n layer were deposited at the same temperature) was prepared on identical ZnO layers. An extensive characterization was performed with help of electrical and optical characterizations, as well as microscopy tools.

2. EXPERIMENTAL PROCEDURE

The substrates were prepared by depositing a 5 μm thick LPCVD-ZnO layer, from a vapor-gas mixture of water, diethyl-zinc and diborane, on AF45 glass substrates from Schott. The surface morphology was subsequently modified by applying a plasma surface treatment (as in [3]) on the ZnO layers for 40 min and 60 min (ZnO40 and ZnO60). As previously mentioned, this treatment allows for morphologies ranging from V-shape (initial) to U-shape (with treatment). μc-Si:H single junction solar cells were deposited on these substrates in a small area plasma-enhanced chemical vapor deposition (PECVD) reactor, working at very-

high excitation frequency (VHF) [3]. The thickness of the μc-Si:H intrinsic layer is approximately 1.8 μm. The deposition of μc-Si:H was performed in p-i-n structure with the same p-layer and n-layer for every cell and i-layers were deposited at different substrate temperatures (controlled by the electrode temperature) from 170°C to 270°C.
The SEM observations were carried out with a Philips XL-30 ESEM microscope. The Backscattered electrons (BSE) can originate from a depth between 10-1000 nm [7]. Then, the contrast obtained in BSE micrographs is sensitive to the surface and to possible sub-surface structures. The lateral resolution is around 50 nm. A linear cracks density (cracks/micron) is estimated by counting the number of cracks along the substrate plane on SEM micrographs (as presented in Fig. 1).

3. RESULTS

For both ZnO series (ZnO40 and ZnO60), the increase of substrate temperature is shown to decrease the cracks density as presented in Fig. 2. The cracks density decreases from 0.23 cracks/microns for deposition of i-layer at 170 °C to 0.13 cracks/microns at 270 °C for μc-Si:H solar cells on ZnO40. The same behavior is observed for solar cells deposited on ZnO60: here the density of cracks decreases from 0.16 to 0.02 cracks/microns. The density of cracks is higher on ZnO40, because the pyramids are less treated and the precursors reach the bottoms of the valleys with more difficulty due to shadowing of pyramids. The fill factor (not presented here) increases from 68 to 70 % for the cells deposited with substrate temperature from 170°C to 230°C. The electrical parameters of the cells deposited at 270°C drop off, probably due to diffusion of boron from the p layer into the i-layer.

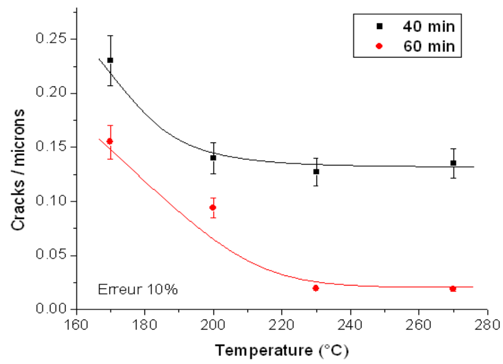

Figure 2 Decrease of crack density with the increase of substrate temperature on ZnO treated 40 and 60 minutes. (Lines are guide for the eyes).

4. DISCUSSION

The substrate temperature has a strong influence on the microcrystalline growth for thin film deposited with PECVD. As already discussed in previous papers and confirmed here, the treatment of the surface of the substrate facilitates a decrease of the number of cracks. Indeed, the shadowing effect decreases with U-shape morphology as compared to V-shape. For this reason, the solar cells deposited on ZnO60 have less cracks that on ZnO40. Moreover, it is seen here that the number of cracks can also be decreased by increasing the substrate temperature during i-layer deposition. As seen in Fig. 2, the cracks density decreases strongly between 170 °C and 270°C. However, too high temperature (270 °C) leads to i-layer contamination from the doped layers and, hence, bad electrical solar cell performances. For 170 °C, 200 °C and 230 °C, the increase of FF can be linked to a decrease in crack density.

5. CONCLUSION

The decrease in cracks density is a key point for developing high efficiency thin film μc-Si:H solar cells. To increase the density of μc-Si:H material, one way is to modify the substrate morphology from V-shape to U-shape but this will influence the scattering of light, and hence, the short-circuit current density of the solar cells. In this paper, we show that by varying the substrate temperature during i-layer deposition, crack density can be further decreased, without any influence on the scattering of the light, because the surface morphology of the substrate is not changed.
Large substrate temperatures would be an issue in case of micromorph tandem (a-Si:H + μc-Si:H), since in p-i-n configuration, amorphous silicon is deposited first and the high substrate temperature for i-layer of microcrystalline cell may lead to an annealing of already-deposited amorphous cell leading to dopant contamination by diffusion. On the contrary, in n-i-p configuration, high temperature could be successfully applied since μc-Si:H is deposited first.

6. ACKNOLEDGMENT

The authors acknowledge support by the Swiss National Science Foundation under grant SNSF 200020-116630 and by the Swiss Federal Office of Energy under contract 101191.

7. REFERENCES

[1] K. Yamamoto, M. Toshimi, T. Suzuki, Y. Tawada, T. Okamoto, A. Nakajima, *MRS Spring Meeting*, (1998)
[2] J. Meier et al.. *Proceedings of the 13th EC Photovoltaic Solar Energy Conference*, pp. 1445-1450 (1995)
[3] J. Bailat et al., *Proceedings of the 4th WCPEC Conference*, (2006), pp. 1533-1536
[4] M. Python, E. Vallat-Sauvain, J. Bailat, D. Dominé, L. Fesquet, A. Shah, C. Ballif, *Journal of Non-Crystalline Solids,* **354**, 19-25, 2008
[5] M. Python, O. Madani, D. Dominé, F. Meillaud, E. Vallat-Sauvain, C. Ballif, in submission, 2008.
[6] P. Delli Veneri, L. V. Mercaldo, E. Bobeico, P. Spinillo, C. Privato, *19th European Photovoltaic Solar Energy Conference*, Paris (2004)
[7] J. Goldstein, D. E. Newbury, P. Echlin, C. E. Lyman, D. C. Joy, E. Lifshin, L. C. Sawyer, J. R. Michael, ISBN 0306472929, 9780306472923, Published by Springer, 2003