Effect of internal stress on the chemical texturing of sputtered Al:ZnO layers for light-trapping in thin film solar cells

S. Michotte, Q. Van Overmeere, E. Van Caloen, I. Sbille, R. Santoro, and J. Proost
Université catholique de Louvain, *Institute of Mechanics, Materials and Civil Engineering, Louvain-la-Neuve, Belgium*

1. Introduction

The main properties that Transparent Conducting Oxide (TCO) layers for solar cells need to possess are both high transparency and high conductivity. For thin film silicon solar cells, an additional requirement for the front TCO layer is that it must also scatter the light in order to increase the effective light path in the cell. The tandem cell made of amorphous and microcrystalline silicon as absorber is a good example where light trapping plays a decisive role for device performance. Understanding the key parameters controlling the TCO texturization is therefore crucial to create the proper roughness and features sizes that maximize large angle scattering of the visible as well as near infra-red light [1,2]. Besides the crystalline orientation of the TCO [3], its internal stress, originating from the deposition process itself as well as from differences in thermal expansion coefficient within the complete cell structure is another of those key parameters. Here we focus on aluminum doped zinc oxide (Al:ZnO) layers since this TCO is made only of abundant elements and it can be easily textured by a wet-chemical etching step.

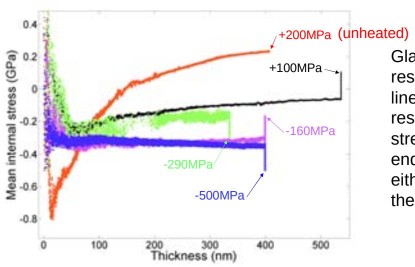
2. Experimental

Various Al:ZnO films were RF sputtered from a ZnO target doped with Al_2O_3. As evidenced by X-ray diffraction and scanning electron microscopy, the resulting wurtzite structure always presented a columnar structure with the c-axis perpendicular to the substrate. They differ however by the level of internal stress.

- The internal stress evolution is followed in-situ during the film growth
- The etching speed is recorded by ICP chemical analysis both ex and in-situ
- The resulting rugosity is observed by SEM
- The light scattering resulting from the texturation is measured optically

3. Stress evolution during Al:ZnO sputtering

The glass or Si/SiO_2 substrates were free to bend and (while rotating) their curvature evolution was monitored in-situ using a multi-beam optical stress sensor (MOSS) [5]. The curvature is indeed proportional to the stress-thickness product while the thickness was obtained independently with a quartz crystal microbalance. The internal stress evolution is thus recorded during RF sputtering of Al:ZnO films with optimum conditions (in term of electro-optical properties) of O_2/Ar ratio, and either unheated or with optimum substrate temperature (150°C). The heated samples have transparency above 90% in the visible and a resistivity of about 200μΩcm.

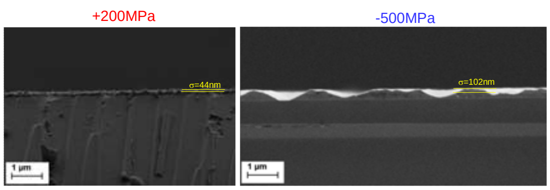


Glass and Si substrates having respectively larger and smaller linear expansion coefficient with respect to Al:ZnO, the thermal stress arising upon cooling at the end of the deposition add 180MPa either towards the compressive or the tensile direction

4. Etching step

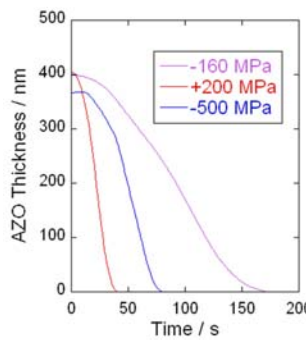
Various deposition conditions lead to different craters aspects and spacings [4].

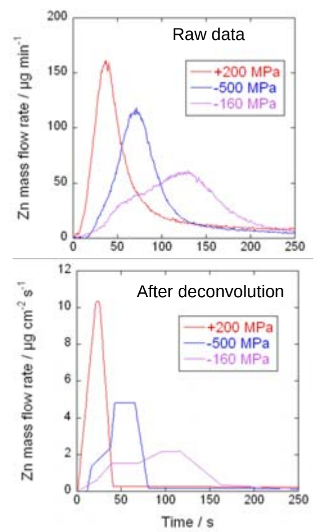
With such a crystalline orientation, the subsequent etching step, which consists of a wet-etching by HCl 0.4%, gives various crater-like surface textures. A cross section of such a texture is shown here



5. ICP analysis in-situ

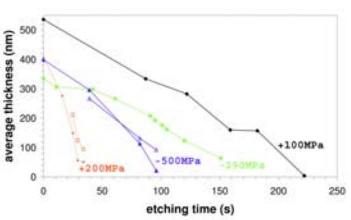
in-line chemical analysis performed with inductively coupled plasma optical emission spectrometry [6] was also performed :

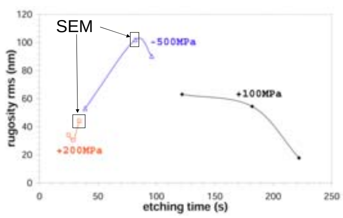




The formation of a large rugosity is manifested by a speed-up of the etching rate

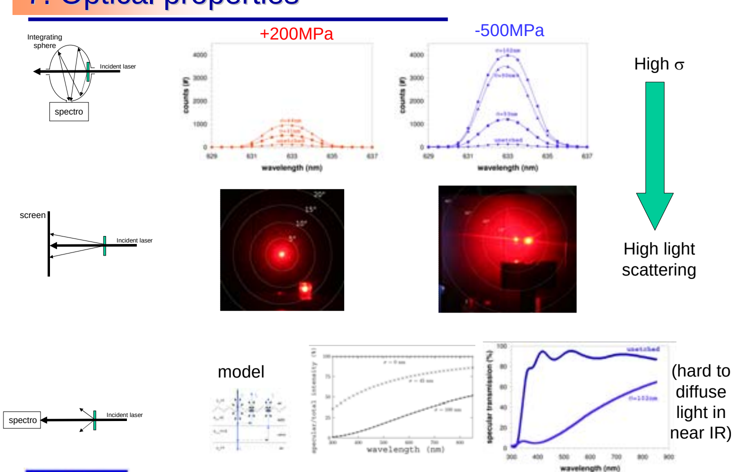
6. ICP ex-situ + SEM





- Al:ZnO with large tension (unheated) is etched very rapidly but only leads to moderate rugosity
- Al:ZnO with low internal stress is etched slowly with moderate rugosity
- Al:ZnO with large compressive stress is etched rapidly with a high rugosity

7. Optical properties



8. Conclusions

- Beyond the cristalline orientation, which was here kept constant, the internal stress level has a strong influence on the etching mechanism.
- To obtain highly textured layers i.e. high rugosity, high level of internal compressive stress is favourable.
- in-situ ICP chemical analysis during the etching step is a powerful tool to follow the texturation step. A large and sudden increase in the etching rate is indicative for the formation of a high rugosity.

9. References

[1] J. Muller, B. Rech, J. Springer, M. Vanecek, Solar Energy 77 (2004) 917.
[2] O. Isabella, J. Krc, M. Zeman, Applied Physics Letters 97 (2010) 101106
[3] Y.-H. Hu, Y.-C. Chen, H.-J. Xu, H. Gao, W.-H. Jiang, F. Hu, Y.-X. Wang, Engineering 2 (2010) 973.
[4] J. Hupkes, B. Rech, O. Kluth, T. Repmann, B. Zwaygardt, J. Muller, R. Drese, W. Wuttig, Solar Energy Materials & Solar Cells 90 (2006) 3054.
[5] J.A. Floro, S.J. Hearne, J.A. Hunter, P. Kotula, E. Chason, S.C. Seel and C.V. Thompson, Journal of Applied Physics 89 (2001) 4886.
[6] D. Mercier, Q.Van Overmeere, R. Santoro, J. Proost, Electrochimica Acta 56 (2011) 1329.

Le Fonds Européen de Développement Régional et la Wallonie investissent dans votre avenir. This work was supported by the UE and Walloon Region FEDER grant ECP12020011678F.