Thin Film Silicon Solar Cell on Highly Textured Substrates for High Conversion Efficiency

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The development of high-efficiency thin-film silicon solar cells requires a cell design allowing for a high light trapping while maintaining optimum cell electrical properties. Light scattering at highly textured interfaces is first a decisive feature to improve the light management in the cells [1–3]. In the superstrate configuration, efficient light trapping can be realized with the use of zinc-oxide (ZnO) front electrode textured as grown via low-pressure chemical vapor deposition (LP-CVD). The control of the ZnO growth modes allows for the design of front electrodes with varying surface morphologies [4] (Fig. 1), so that layers can be developed with different haze in transmission, angle of light diffusion and free carrier absorption. Studies presented led to the development of low free-carrier absorption TCO allowing for a high total short circuit current of 28 mA/cm^2 in micromorph (hydrogenated amorphous silicon / microcrystalline silicon tandem) solar cells.

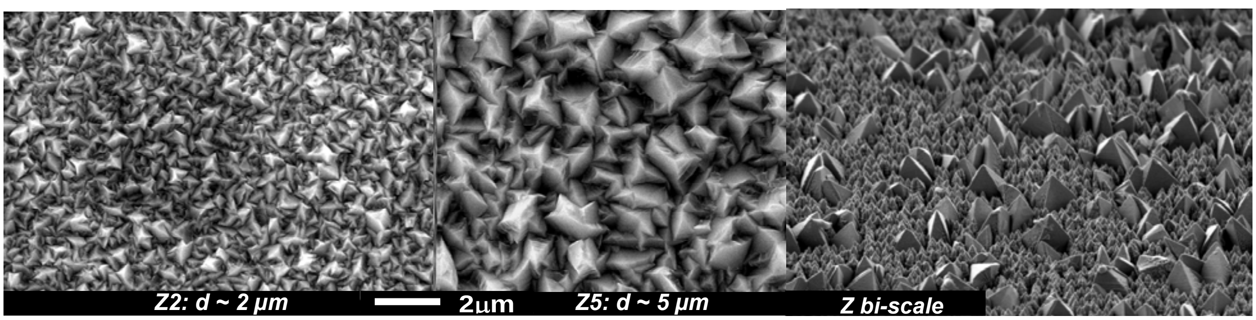

Figure 1.SEM top view of different ZnO front electrodes grown by LPCVD, from standard pyramidal layers to controlled growth layers demonstrating multi-scale texturing.

In combination to an efficient light scattering at the interfaces, light trapping can be improved in the top cell of a micromorph solar cell by the use of an intermediate reflector layer (IRL), realized here as a silicon oxide matrix incorporating silicon nano-crystals [5], developed in semi-industrial reactor with an index of refraction down to 1.7 at 600 nm wavelength. The combination of such IRL with a multi-scale textured ZnO front electrode (Fig. 1) with quasi-lambertian light diffusion potential permitted to reach a short circuit current density approaching 15 mA/cm^2 in a 250 nm a-Si:H top cell. This demonstrates the importance of the angular diffusion of the scattered light to reach a high current in the top cell and therefore to improve stabilized efficiencies of micromorph solar cells. The light management approach developed for micromorph solar cells in the substrate configuration will also be presented. The use of a periodic sinusoidal structured substrate and of a textured asymmetric IRL permitted the development in this configuration of micromorph cells with up to 12.5 mA/cm^2 matched current [6].

A possible limitation to the development of thin film silicon solar cells onto substrates with higher light trapping potential can originate from local variations of the silicon layers when grown on rough surfaces, with potential local variations of the material and diode quality. A rough substrate can lead to the creation of undesired local current drains, degrading performance and reliability of the cells [7-8].

The optimization of the cell processing and of the cell design can first lead to an improvement of the electrical properties of cells grown on highly textured substrates. An improved microcrystalline silicon deposition process is shown to lead to a single junction cell with an initial efficiency of 9.5 % fully developed in a KAI large-area reactor, and to allow for the development of a micromorph cell with 13 % initial efficiency while incorporating reasonable junction thicknesses (250 nm a-Si:H cell and 1.8 µm µC-Si:H cell). Moreover, the incorporation of a thin resistive interlayer is shown to allow for a quenching of the cells leakage current, improving the electrical properties of a-Si:H single junction solar cells developed onto highly textured substrates [9].

Advanced concepts are still required to continue improving the thin film silicon solar cell efficiency. In the substrate configuration, silver nanoparticles embedded in a dielectric material have strong scattering properties, due to localized surface plasmons, and were studied as back reflector. In order to achieve high light trapping, the concept of a-Si:H solar cells deposited on nanorods was also studied and preliminary results are presented demonstrating the high potential of such solution, also applicable for the superstrate configuration. An alternative approach to improve micromorph solar cell performance is also reported, with the possible surface morphology adaptation at the IRL in the superstrate configuration, allowing for the growth of a microcrystalline bottom cell with improved electrical properties, and possibly leading to an asymmetric intermediate reflector design (Figure 2).

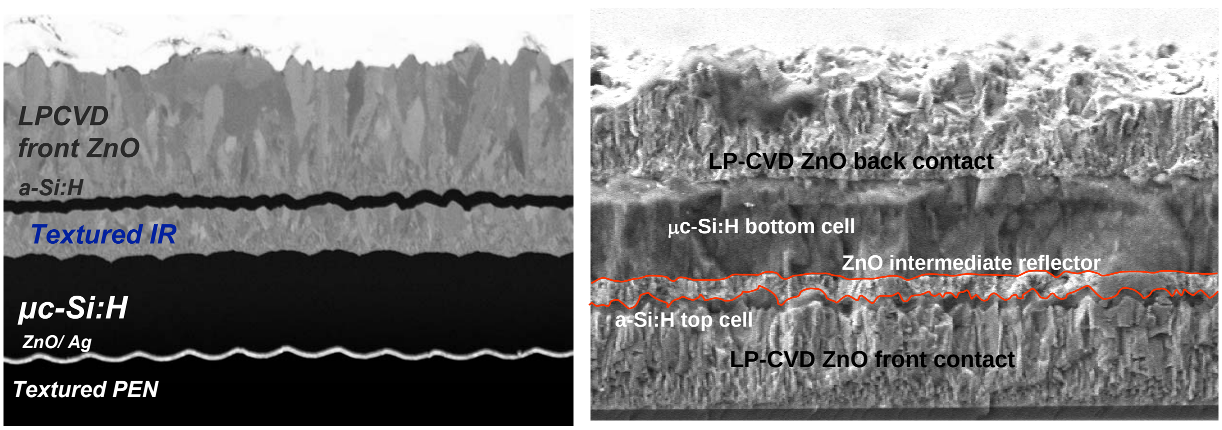

Figure 2.SEM cross-section of a micromorph solar cell in the substrate configuration (n-i-p, left), and in a superstrate configuration (p-i-n, right) with a surface morphology adaptation at the intermediate reflector layer, here realized with ZnO.

Advanced concepts were studied to improve the light trapping of thin film silicon solar cells and are presented. The impact of the proposed cell design onto the cell electrical properties could be mitigated by optimization of the cell structure. The presented advancements should allow for an increase of thin-film silicon solar cells stabilized efficiency in a near future.

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