LATEST DEVELOPMENTS ON MICROMORPH TANDEM CELLS AT IMT

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ABSTRACT

The latest developments on micromorph tandem cells in small area laboratory and large area industrial PE-CVD systems are reviewed. We report on a 13.3% initial efficiency micromorph tandem cell deposited in our small area system. The development of an in-situ silicon oxide based intermediate reflector layer (SOIR) was essential in order to achieve such high efficiencies. We describe its detailed material structure and discuss optical management aspects for different cell configurations. In our large area industrial R&D reactor the highest efficiency so far obtained is a 11.0% initial efficiency micromorph tandem cell. We discuss in detail the role of pressure and silane depletion on the cell parameters of single junction microcrystalline cells and present efficiency trends decreasing from 8.2% to 7.0% with deposition rates increasing from 0.3 nm/s to 1.2 nm/s.

1. EXPERIMENTAL

P-i-n micromorph and microcrystalline single junction solar cells are deposited on surface textured ZnO transparent conductive oxide grown by low-pressure chemical vapour deposition (LPCVD). Its surface roughness can be tuned using a plasma post-treatment applied to the ZnO layer. All silicon containing films are deposited by very-high frequency plasma enhanced chemical vapour deposition (VHF-PECVD) at frequencies larger than 70 MHz in the small area laboratory system and at 40.68 MHz in the large area industrial R&D system. The small scale system is a dual chamber deposition system, whereas all layers are deposited in a single chamber process in the large area system. The current-voltage curves are measured using a dual lamp sun simulator in standard test conditions and calibrated with the current density value from the EQE measurements. The material properties of the SOIR are characterized by different techniques including Transmission Electron Microscopy (TEM), Rutherford Backscattering Spectroscopy (RBS) and X-ray diffraction (XRD).

2. RESULTS

The material properties of doped SOIR deposited in situ with plasma enhanced chemical vapor deposition systems have been investigated. The challenge in the development of these layers is to lower the refractive index without compromising the electrical conductivity. The SOIR is used in micromorph tandem cells to increase the current density in thin top amorphous cells. Low refractive indices are therefore desirable because the reflectivity of the layer depends on the index step between silicon oxide and silicon.

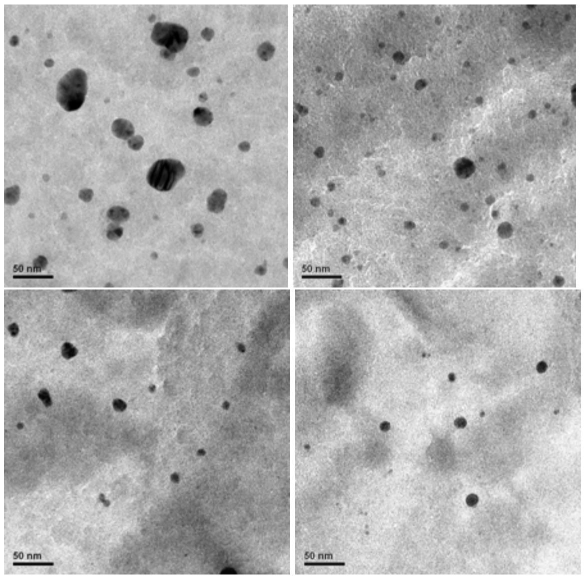

Figure 1: TEM top-view images of ~ 100 nm thick nc-SiO_x layers with different refractive index. Refractive index is decreasing from top left to bottom right figure.

In order to better understand the trade-off between optical and electrical requirements of the SOIR, the structure of the layers was analyzed with bright field TEM images. In the images of Figure 1, silicon nanocrystals embedded in an amorphous silicon oxide matrix can be seen. For decreasing refractive index the silicon nanocrystals are reduced in number and in size. Accordingly, the conductivity of the layers decreases (not shown). This correlation suggests that the conductive properties of doped SOIR are associated with the presence of densely distributed and large silicon nanocrystals that, most likely, are the conductive channels through which the current flows.

XRD and RBS measurements confirm that a silicon crystalline phase is present in the layers and that the refractive index is directly related to the oxygen content of the layer [1].

In order to assess the SOIR functionality in a tandem cell and to improve the understanding of the optical device properties, the effectiveness of this layer in increasing the photo-carrier generation in the a-Si:H top absorber was compared for p-i-n devices deposited on different rough, highly transparent, front ZnO layers. Low doping level and high haze for the front ZnO strongly enhance the current density (J_{sc}) in the mc-Si:H bottom cell whereas J_{sc} in the top cell is influenced by the angular distribution of the transmitted light related to different surface morphologies and by the reflectivity of the SOIR [2].

Optimization of the micromorph device was obtained by choosing the best plasma post-treatment for the front ZnO [3] in terms of high open circuit voltages and short current values and adapting the thicknesses of the SOIR. To reach initial conversion efficiencies above 13%, top and bottom cell thickness had to be increased to 340 nm and 3.5 µm, respectively, while the SOIR had a thickness of 150 nm. Tailoring all these cell parameters, the highest initial efficiency obtained was 13.3% (V_{oc}=1.36V, FF=70.8%, J_{sc}=13.8mA/cm^2) and the highest stable efficiency was 11.2% (V_{oc}=1.32V, FF=66.8%, J_{sc}=12.7mA/cm^2).

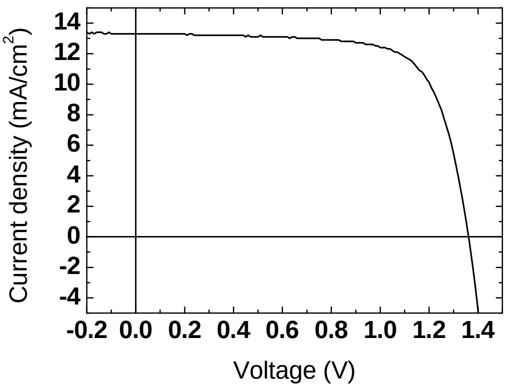

Figure 2: J-V curve of a 13.3% efficient micromorph cell on LPCVD-ZnO measured in its initial state.

In large area reactors an important part of the micromorph development has been dedicated to the characterization of single junction microcrystalline p-i-n devices. Cells were prepared with an intrinsic layer deposited at different pressures between 1.2 and 4.5 mbar near the transition region, in variable silane depletion regimes. For similar crystallinities, it is observed that solar cells prepared at higher pressures and in higher silane depletion conditions exhibit significantly higher performances. Silane depletion greatly affects solar cell efficiencies at lower pressures, whereas at higher pressure values its impact is diminished. FTPS measurements of µc-Si:H intrinsic layers included in the solar cells concur with this observation: with increasing pressure and silane depletion the defect density is significantly lowered. Simple calculations of the ion energy impinging on the substrate suggest that reduced ion bombardment is responsible for the improvements for increasing pressure [4]. Higher silane depletion conditions favour low ion bombardment, too. However chemical aspects, such as gas phase reactions and type of silane radicals are likely to play a role as well. A correlation between increasing growth rate and decreasing solar cell efficiency appears from our data leading to a decrease from 8.2% to 7.0% with deposition rates increasing from 0.3 nm/s to 1.2 nm/s.

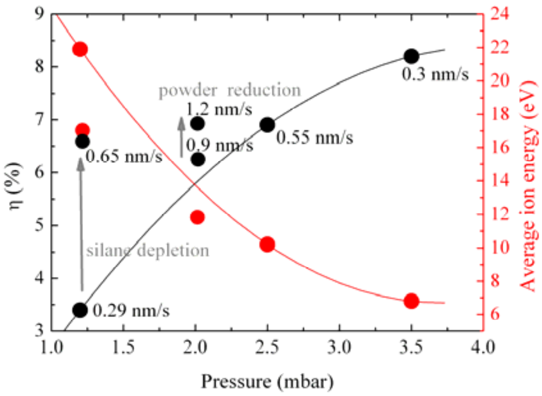

Fig. 3: Solar cell efficiencies as a function of the deposition pressure and silane depletion (black). The mean ion energy was calculated for each deposition regime (red). The lines are a guide to the eye.

Using the best microcrystalline single junction cell developed in a large area PECVD system, an 11.0% initial efficiency micromorph tandem cell could be obtained so far (V_{oc}=1.36V, FF=70.5%, J_{sc}=11.5mA/cm^2).

3. CONCLUSIONS

The development of a two-phase silicon oxide intermediate reflector allowed a significant increase of short circuit current and efficiency of micromorph cells deposited in small scale reactors up to 13.3%, for cells deposited on large grain LPCVD-ZnO. In large area reactors the effect of ion bombardment and silane depletion was investigated and single junction microcrystalline efficiencies up to 8.2% were achieved.

REFERENCES

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