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Materials for thin film silicon solar cells

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1. Introduction

The aim of the thin film silicon solar cell industry for production capacities of several Gigawatt in recent years is strongly related to the impressive development of microcrystalline silicon (µc-Si:H). The application of µc-Si:H as absorber layer in stacked solar cell devices has given new hope for highly stabilized efficiencies of thin film silicon solar modules. The quality and process technology of µc-Si:H have made considerable progress. As the µc-Si:H gets more advanced, new and old interest is in high efficiency & stable amorphous silicon (a-Si:H) material for top cells.

Also any means which allow reducing the thickness of the top cell while still delivering sufficient current to match with the bottom cell are investigated. Apparently all kinds of optical manipulations are of interest here unless one wants to reduce the total cell thickness and sacrifice some maximum efficiency against stability and production cost.

We will present our latest developments in thin film silicon solar cells with new types of window layers, intermediate reflectors, anti-reflective coatings, all in connection with our high quality a-Si:H and µc-Si:H absorber layer materials.

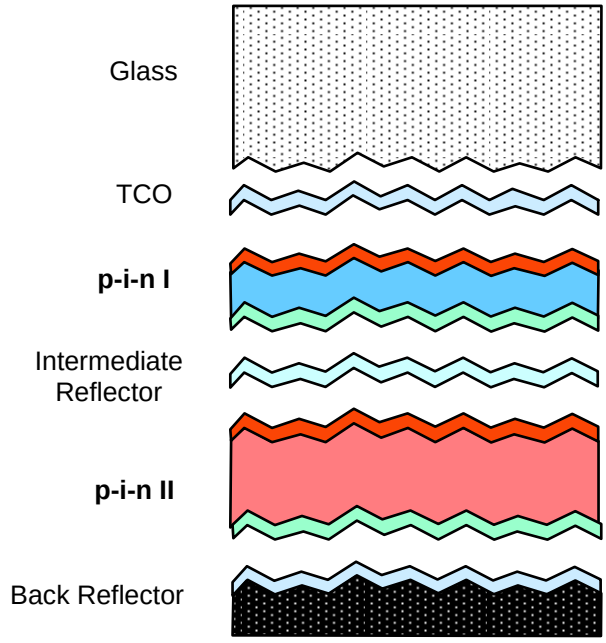

Fig. 1 Schematic cross section of a tandem thin film silicon solar cell layer stack.

2. Experiments

The thin film silicon and silicon alloy materials are prepared from the gas phase with Plasma Enhanced Chemical Vapor Deposition (PECVD) or Hot Wire Chemical Vapor Deposition (HWCVD) at temperatures typically around 200°C. PECVD processes are run at standard excitation frequencies of 13.56 MHz as well as at frequencies in the VHF range (80 – 100 MHz). For HWCVD processes filament materials such as tungsten (W), tantalum (Ta), and rhenium (Re) are used. Tandem solar cells on the base of such materials consist of a layer stack of typically ten different layers including a Transparent Conductive Oxide (TCO) front contact and a metallic back reflector back contact (Fig. 1).

Materials and solar cells are developed on 10 × 10 cm² glass substrates. For solar cells chemical texture etched ZnO:Al prepared by reactive sputtering is used as transparent conductive oxide (TCO). Alternatively a commercial SnO_2:F TCO is used. The cells are grown in pin/pin configuration with a-Si:H and µc-Si:H as absorber layer in the top and bottom cells, respectively. The <p> and <n> layers are amorphous or microcrystalline depending on their position and function in the layer stack.

µc-SiC:H alloys to be used as highly transparent doped layer are developed using the HWCVD process with rhenium (Re) filaments and a gas mixture of monomethylsilane diluted in hydrogen and trimethylaluminium as a p-doping gas source.

Microcrystalline silicon oxide (µc-SiO_x:H) also for application as highly transparent doped layer and as intermediate reflector between top and bottom cell are prepared with PECVD from gas mixtures of silane, carbon dioxide and hydrogen. Phosphin and trimethylboron are used for n- and p-type doping, respectively.

The optical, structural and electrical properties of the layers were investigated by optical transmission and reflection spectroscopy, photo thermal deflection spectroscopy (PDS), Raman spectroscopy, Rutherford back scattering (RBS), infrared spectroscopy, transmission electron microscopy and electric conductivity measurements.

For solar cells current-voltage curves are measured using a double source (Class A) AM 1.5 sun simulator to

determine fill factor (FF), short circuit current density (jsc) and open circuit voltage (Voc). To measure the current density of the component cells a quantum efficiency set-up was used.

2. Results

The quantum efficiencies and solar cell parameters for a solar cells with a µc-SiC:H window layer compared to a record cell with a conventional µc-Si:H window are shown in Fig. 2. We observe a much improved QE with considerably enhanced short circuit current densities using the µc-SiC:H window.

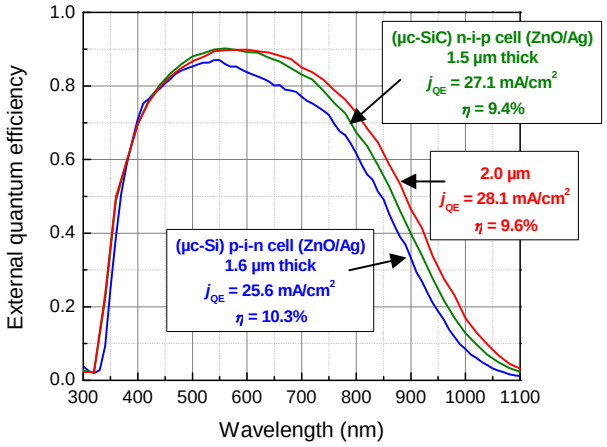

Fig. 2 Quantum efficiencies, current densities and total conversion efficiencies of µc-Si:H solar cells with µc-SiC:H window layers compared to a cell with a µc-Si:H window layer.

The effect of an intermediate µc-Si:O_x:H reflector in a tandem cell is demonstrated in Fig. 3. It shows how by introduction of the intermediate reflector total current contributions are shifted from the bottom to the top cells. This allows a reduction of the top cell thickness without losses in total current at the benefit of improved stability and higher voltages.

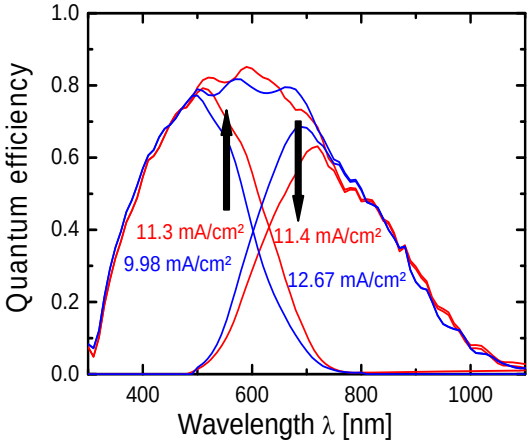

Fig. 3 Quantum efficiencies of a a-Si:H/µc-Si:H tandem cell with and without µc-SiO_x:H intermediate reflector.

A summary of improved material properties for the newly developed microcrystalline silicon alloys with oxygen and carbon is shown is Fig. 4. This diagram is used as a figure of merit for development of doped window layers in thin film solar cells. Such layers have to have a high transparency, equivalent to a large optical gap and a high dark conductivity at the same time. Using µc-SiC:H and µc-SiO_x:H much improved combinations of high band gap at high conductivity are available.

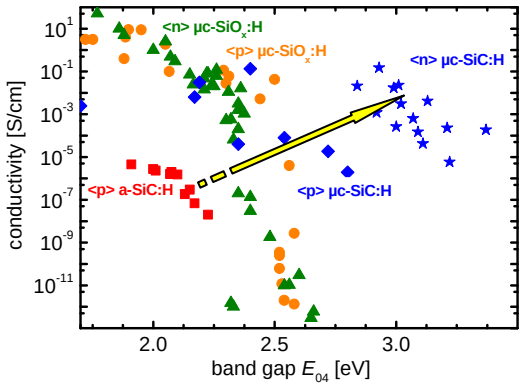

Fig. 4 Dark conductivity vs. optical band gap of µc-SiC:H and µc-SiO_x:H alloys with n- and p-type doping. The arrow indicates the improvement of high conductivities at high optical band gaps.

3. Conclusions

Material development for application in thin film silicon tandem solar cell has a high potential to further improve the performance of these devices. Efficiencies of 14.5% for small area cells and 12% for large area modules are realistic targets already with the existing technology taking advantage of the improved properties of the new materials.

Acknowledgements

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