Dynamic deposition of microcrystalline silicon

Thomas Zimmermann, Tsvetelina Merdzhanova,
Matthias Meier, and Aad Gordijn

Combining linear plasma sources and high-frequency plasma deposition on moving substrates may reduce manufacturing costs for thin-film silicon solar cells.

The first solar cells made of microcrystalline silicon (μc-Si:H) were successfully deposited in 1994.\textsuperscript{1} Since then, single-junction p-i-n solar cells made with this particular material have achieved efficiencies of greater than 10%\textsuperscript{2}. To compete with other photovoltaic technologies, however, the microcrystalline silicon cell is often combined with an amorphous silicon (a-Si:H) cell in an a-Si:H/μc-Si:H tandem junction device. This improves the conversion efficiency of the cell, and therefore the voltage of the device, compared with single-junction solar cells.

Amorphous and microcrystalline silicon layers are typically deposited using plasma-enhanced chemical vapor deposition (PECVD). The μc-Si:H absorber layer represents about 80% of the total silicon layer thickness of an a-Si:H/μc-Si:H tandem solar cell. As a result, its deposition rate has a significant influence on the throughput of the PECVD equipment and the manufacturing costs. Therefore, research into thin-film silicon growth aims to achieve high deposition rates for μc-Si:H.

Developers have found that microcrystalline silicon solar cells deposited by radio-frequency (RF) and very-high frequency (VHF) PECVD processes both obtain efficiencies of about 9–10%. However, RF-PECVD processes are carried out at deposition rates of 0.5 nm/s to maintain good material quality.\textsuperscript{3} In contrast, VHF-PECVD processes can be conducted at deposition rates up to about 2.5 nm/s with little influence on the solar cell performance.\textsuperscript{4} While very high frequencies are beneficial for the quality of μc-Si:H grown at high rates, they have a negative influence on the homogeneity of the deposition process when using large/industrial-scale electrodes. Developers have proposed various solutions to this problem,\textsuperscript{5–7} all of them targeting static deposition processes, where the substrate remains stationary in front of the electrode during deposition.

Our approach combines linear plasma sources and VHF-PECVD for the dynamic deposition of thin-film silicon on moving substrates. By scaling the electrode in only one dimension, linear plasma sources\textsuperscript{8} enable the use of very-high frequencies without compromising on the cell’s homogeneity. Because of the elongated electrode shape, the substrate has to pass by the electrode at a fixed speed to ensure a homogeneous deposition in both substrate dimensions (see Figure 1). Ultimately, we can use this technique to deposit continuously on plastic or metal foils in a roll-to-roll process, further reducing manufacturing costs.

Earlier work demonstrated that we can deposit state-of-the-art a-Si:H solar cells by dynamic VHF-PECVD.\textsuperscript{9} Our current study focuses on deposition of microcrystalline silicon, since its properties are more sensitive to changing deposition

Continued on next page
conditions during material growth. The specific gas distribution system we chose alters the gas composition along the width of the electrode.\textsuperscript{10} As a result, static $\mu$c-Si:H deposition processes tend to exhibit some inhomogeneity in gas flow direction (see Figure 2).

By adapting the deposition conditions it is possible to deposit $\mu$c-Si:H statically at growth rates up to 1.4nm/s with little influence on the solar cell efficiency (see Figure 3). Therefore, we conclude that the combination of linear plasma sources and VHF-PECVD has similar limitations to other VHF-PECVD systems when considering static deposition. As we move from static to dynamic processes, the substrate encounters changing deposition conditions during material growth. Figure 3 shows that the efficiency of solar cells with dynamically deposited intrinsic layers is slightly lower than for cells where the layers are deposited statically. The changing conditions during the dynamic deposition process appear to affect the quality of microcrystalline silicon negatively.

At present, the results indicate that changing deposition conditions during the growth of $\mu$c-Si:H can result in a slight decrease in the solar cell efficiency. However, earlier studies show that by keeping the deposition conditions constant (especially the gas composition), it is possible to improve the efficiency of $\mu$c-Si:H solar cells deposited dynamically.\textsuperscript{11, 12} Therefore, we plan to study the effects of dynamic deposition on $\mu$c-Si:H in more detail. Our aim is to close the gap between static and dynamic processes in terms of material quality and growth rate to take advantage of the dynamic VHF-PECVD technique.

This work was carried out under the FP7-framework project ‘Fast Track’, funded by the European Commission under grant 283501.

**Figure 2.** Efficiencies of $\mu$c-Si:H solar cells as a function of the distance to the gas feed for an exemplary static deposition process. Note, that the electrode extends from $x = 5$cm to $x = 25$cm.

**Figure 3.** Efficiencies of $\mu$c-Si:H solar cells for static and dynamic VHF-PECVD processes as a function of the deposition rate of the intrinsic layer. Note that average growth rates are given for dynamic deposition processes.

**Author Information**

Thomas Zimmermann
BATOP GmbH
Jena, Germany

Tsvetelina Merdzhanova, Matthias Meier, and Aad Gordijn
Institute of Energy and Climate Research (IEK5-Photovoltaik)
Forschungszentrum Jülich GmbH
Jülich, Germany

**References**


7. T. Takagi, M. Ueda, N. Ito, Y. Watabe, and M. Kondo, Microcrystalline silicon solar cells fabricated using array-antenna-type very high frequency plasma-enhanced chem-