Advanced light management for thin film silicon solar cells on foil

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Short introductive summary
We present different new concepts to improve the light trapping in thin film silicon solar cells on steel foil. One of these concepts is to incorporate a textured back reflector, where the light scattering texture is made by Nano-Imprint Lithography (NIL). In this concept, we imprint a texture in a UV-hardening lacquer that has been applied on the steel foil. This texture then is covered by a silver layer, serving as a reflector and a back contact. Any arbitrary texture can be imprinted, and we will present results for random and periodic textures showing that we can obtain short circuit currents (Jsc) of more than 24 mA/cm2 for cells with a nc-Si absorber layer of only 1 micron. Another approach is to replace this silver layer by a white back reflector (WBR). Since, in contrast to the common utilization of a WBR in superstrate cells, in substrate-type n-i-p cells the WBR has to undergo all the different steps of the cell processing, there are strict requirements to the material of the WBR, in terms of degasing and temperature stability. We have identified suitable materials and applied these in a-Si solar cells. The Jsc values of these cells were even slightly higher than those of cells with a NIL back reflector. To our knowledge this is the first application of a WBR in substrate-type cells. Application of WBR in single junction nc-Si cells and in tandem cells is ongoing and the results will be presented at the conference. Finally, we will also present a-Si/nc-Si tandem cells on foil in which we combine these back reflector concepts with implementation of an intermediate reflector (IR) based on doped SiOx.

Purpose of the work
In order to tailor the light management for various cell concepts and optical properties of all cell components a flexible light management strategy is highly desired. UV NIL texturization offers this flexibility since virtually all imaginable textures can be made by this technology and it is upscalable to large area processing. Good light trapping requires strong scattering AND high reflection at the rear side of the cell. Silver is an excellent reflector but is expensive. We present a white back reflector for use in n-i-p type cells, in combination with a TCO layer as a technologically superior, and economically attractive alternative.

Approach
The back reflector experiments were carried out on our lab scale equipment for NIL on sizes of 10x10 cm2. On these substrates we made dozens of smaller cells by RF-PECVD, and the characterization was done with a dual source solar simulator to determine Voc and FF of the cells and with a spectral response setup to determine the Jsc accurately.

Scientific innovation and relevance
The main scientific innovations of this work are the application of NIL for textured back reflectors, and white back reflectors in thin film silicon cells on steel foil. Due to the opaqueness of the foil, common technologies for NIL cannot be applied since the UV irradiation cannot occur through the substrate but has to occur through the stamp. WBRs are commonly applied in p-i-n Si solar cell configurations on glass but there they are applied at the end of the cell processing. In our processing on steel foil, the WBR has to be compatible with the entire cell process chain, which has been achieved in this work.

Results
Application of NIL and white back reflectors results in excellent light trapping in a-Si and nc-Si cells on steel foil. Applying these concepts we managed to achieve back reflectors with a Haze factor of more than 95% for the entire visible wavelength regime. We made nc-Si and a-Si cells on these back reflectors and Jsc’s of more than 24 mA/cm2 for nc-Si cells with an absorber layer thickness of just 1000 nm.

Conclusions
Superior light management in thin film solar cells can be achieved by nano imprint lithography of light-scattering textures in combination with white back reflectors. In our contribution we show the application of these concepts in combination with intermediate reflectors in thin film silicon tandem solar cells on steel foil.