Prediction and prevention of defective regions within thin-film silicon solar cells

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Abstract – **Previously developed growth model is used to simulate occurrence of defective regions within thin-film silicon solar cells. Such procedure enables expansion of optical optimization with prediction and prevention of defective regions, resulting in optimized textures generating high short-circuit current density (J_{SC}) while maintaining good electrical properties of the cell. The approach is applied on sinusoidal and semi-circular texture. Best predicted case for the analysed double junction thin-film silicon solar cell is the semi-circular texture with period of 1800 nm and height of 900 nm, where improvement in J_{SC} of 2 % and 85 % is expected for top and bottom cell, respectively.**

I. INTRODUCTION

Optical simulations play an important role in the process of optimization of thin-film silicon solar cells. The progress of modern computers in recent years makes fully 3-D optical simulations a viable tool for prediction of light propagation throughout the devices. With increasingly complicated structures forming solar cells, more and more effects must be taken in consideration in order to predict accurate trends and furthermore optimize devices.

Introduction of textures into thin-film silicon solar cell typically leads to higher short-circuit current density (J_{SC}), but can at same time also introduce defective regions in material, caused by the shading effect during deposition [1]. These regions are known to impair electrical properties of solar cell (open circuit voltage V_{OC} and fill factor FF). In order to predict occurrence of such regions, previously developed combined model of non-conformal layer growth [2] was expanded. This addition enables omission of detrimental textures in the phase of design. Such procedure enables expansion of optical optimization to find textures generating high J_{SC} while maintaining good electrical properties.

II. COMBINED GROWTH MODEL

Deposition of layers on textures using typically used processes causes the shape of the surface after deposition to differ from initial, underlying surface. Typically these changes were neglected in optical modelling. These changes can, however, significantly influence the result of simulations [2]. To be able to predict the change of morphology during the deposition of thin layers and as reported in this paper to predict and omit defect region formation within semiconductor layers, combined model of non-conformal layer growth was previously developed [2]. It combines two principles of growth: (I) ideal, conformal growth (in vertical direction), and (II) isotropic growth (in direction of normal in each point on initial surface). Both growths are combined considering a geometrical ratio, called growth parameter – g. The value of the g is determined empirically by fitting the model to cross–sectional images and can vary with material, deposition type and deposition conditions used, but not with different thickness of deposition or with underlying type of texture.

III. PREDICTION OF DEFECTIVE REGIONS

During the deposition of layers on textured initial surfaces, shadowing of elevated areas can lead to reduced density of deposited materials in regions in between [1]. Occurrence of these defective regions above V-shaped valleys is a known issue in design of high-efficiency thin-film solar cells, which deteriorates electrical properties of the device. Previous experiences show, that defective regions in thin-film silicon absorbers will form on top of valleys with opening angle (φ) bellow ~ 135° (180° being completely flat surface). Since morphology changes during the deposition, so do the opening angles on the surface. Since angles can also reduce, defective regions might occur later during deposition even if initial texture does not contain any opening angles bellow 135°.

Therefore, it is important to monitor the surface of the grown layer. Previously developed growth model was used in our approach to simulate growth of thin layers in several, incremental steps. In each step the opening angles were calculated along the entire surface. In this way we can detect occurrence of defective regions even later in deposition or even predict the maximum thickness of film that would

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still be composed of material without pronounced defective regions.

IV. APPLICATION

We applied our approach on 2-D sinusoidal texture and 2-D semi-circular texture since both are considered to have relatively smooth valleys (high opening angles throughout the surface). Example of opening angle (φ) calculation during the layer growth is shown in Fig. 1 (g parameter was set to 0.3 corresponding to the growth of μc-Si:H layer under certain deposition conditions). While low opening angle region is predicted within the sinusoidal cell, no significant reduction of angles is expected for the case of semi-circular texture for the selected period, height and thickness of the layer.

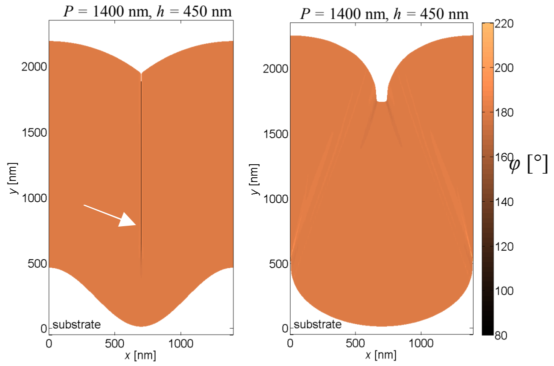

Fig 1. Calculated opening angles on top of sinusoidal (left) texture and semi-circular (right) texture. 10 nm incremental steps of growth were considered. For the case of sinusoidal texture a region of low opening angle appears (< 135 °, indicated by the arrow). No such region is present for semi-circular texture of same dimensions.

The presented approach was used to extend optical optimization (improve J_{SC}) of thin-film double junction micromorph (a-Si:H/μc-Si:H) solar cell (absorbers of 200 nm and 1200 nm for a-Si:H and μc-Si:H cell, respectively). Optical simulations were done in COMSOL Multiphysics [3] software, which uses finite element method of solving Maxwell equations to determine the propagation and absorption of light throughout the device.

Simulations of defective regions showed that for all analysed sinusoidal textures occurrence of defective regions is expected at some point (vertical position) within solar cell. Consequently impaired electrical properties of the device, would negate optical improvements achieved by the texturing, so no pronounced increase in efficiency is expected for these cases. Optical optimization is here therefore only presented for the case of semi-circular texture. In Fig. 2 J_{SC} of the bottom μc-Si:H cell is shown, while improvements in the top cell are relatively small and consistent for all analysed texture dimensions. For all texture sizes under the dashed line, no occurrence of defective regions is expected within the active layers of the cell. For the best case (P = 1800 nm and h = 900 nm) improvement in short-circuit current of 2 % for the top and of 85 % for the bottom cell is predicted in reference to flat cell.

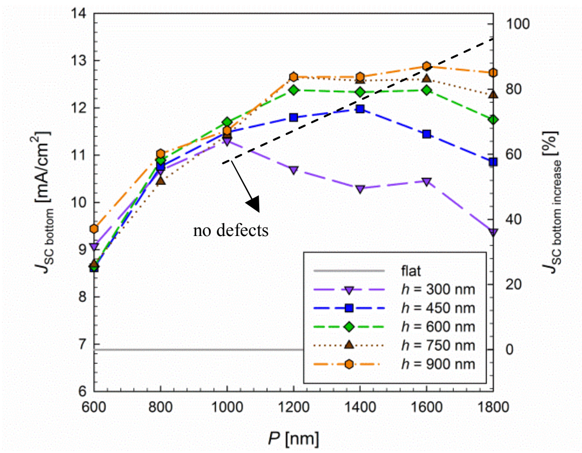

Fig 2. Generated short-circuit current density (J_{SC}) of the bottom μc-Si:H cell for semi-circular texture (Fig. 1 right side). Textures under the dashed line satisfy the condition for defectless growth of both, top a-Si:H and bottom μc-Si:H pin structures.

V. CONCLUSIONS

Previously developed growth model was used to simulate occurrence of defective regions within thin-film silicon solar cells deposited on top of different surface textures. Such procedure enables expansion of optical optimization to find textures generating high J_{SC} while maintaining good electrical properties. Best case was found to be a semi-circular texture with period of 1800 nm and height of 900 nm, where improvement in J_{SC} of 2 % and of 85 % is expected for top and bottom cell, respectively, in comparison to flat, non-textured cell.

ACKNOWLEDGEMENT

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