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Optimisation of periodic surface textures in thin-film silicon solar cells using rigorous optical modelling by considering realistic layer growth

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Abstract

Rigorous optical simulations based on finite element method (Comsol simulator) were carried out in order to analyse the effect of different periodic substrate textures on short-circuit current density of a tandem micromorph solar cell. In our modelling an important aspect of non-conformal growth of the layers comprising the solar cell was considered. Optimisation shows that introducing 2-D textures into the substrate surface results in higher photocurrents than in the case of 1-D textures. The shape of initial sinusoidal textures was additionally altered to enable growth of layers of greater quality, thus improving electrical properties of the cell. Such textures were found to further improve optical properties as well, peaking at 98 % increase (ref. flat cell) of photocurrent of bottom cell, surpassing the photocurrent generated when introducing random textures.

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Keywords: Light trapping; Modelling; Simulation; Thin-Film Solar Cell

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1. Introduction

Conversion efficiencies of thin-film silicon solar cells can be improved by implementing light management techniques in solar cell structures. Solar cells, which are deposited on properly textured substrates/superstrates, exhibit increased scattering of light at interfaces and improved anti-reflective properties, both leading to augmented light confinement and absorption in the cell. Increased absorption in active layers leads to higher short-circuit current density (J_{SC}), which can translate directly to increased efficiency, if remaining electrical properties are preserved (V_{OC} and *FF*). Typically, substrate textures are of random nature, generated naturally e.g. by growth of transparent conductive oxides (TCO) such as SnO_2:F [1] or ZnO:B [2] or applying post etching process, as in case of magnetron sputtered ZnO:Al [3]. Recently it has been shown that optimised periodic textures can even surpass state-of-the-art optical properties of random textures [4]. Lately developed interference lithography in combination with thermoplastic and UV embossing presents a great opportunity for fabrication of advanced synthetic periodic structures in order to achieve much needed increase in conversion efficiencies [5,6]. However, textures need to be optimised.

In this paper we present results of rigorous optical simulations of a tandem micromorph (*a*-Si:H/*μc*-Si:H) solar cell with introduced 1-D and 2-D periodic textures on the substrate surface. Translation of the initial texture on subsequent internal interfaces was calculated using a model for prediction of realistic growth of thin layers within thin-film solar cells. Systematic optimisation and comparison between solar cells with implemented 1-D and 2-D textures was done. Initially, period and height of sinusoidal textures were varied then the shape of the textures was altered systematically in a way, which enables better light trapping and furthermore, higher quality of the deposited layers with less defective regions.

2. Models

Simulations were done using COMSOL optical simulation tool [7], which uses finite element method of solving Maxwell equations to rigorously simulate electromagnetic wave propagation throughout solar cells. Optimisation of 1-D periodic textures was done using 2-D optical modelling, while 2-D periodic textures were optimised utilizing 3-D optical modelling. Optimisation was done considering improvements of optical properties of solar cells and attention was paid to select textures which are expected to render less defective regions in semiconductor layers grown on these textures. For this reason, often discarded aspect of non-conformal growth was considered in our modelling. Recently we developed a model to predict how the morphology of the interfaces changes from the initial substrate texture with deposition of materials [8–11]. Consideration of this deformation significantly improves validity of the simulation results. We used the model for the layer growth with parameters fitted to real device cross-sectional SEM (scanning electron microscope) images. In general, the model combines two types of growth (a) conformal (occurring in vertical direction) and (b) isotropic (occurring in direction perpendicular to the local surface segment). A proper ratio of both growths, which is empirically deduced from SEM images, was considered.

Realistic complex wavelength-dependant refractive indices of different materials were used in optical simulations to describe material optical properties [12]. In calculations of short-circuit current density (J_{SC}) of the cells ideal extraction of charge carriers from absorber layers (i-*a*-Si:H and i-*μc*-Si:H) was assumed, while contributions from p- and n- doped layers were neglected as this is close to actual condition in state-of-the-art devices [13]. AM1.5G solar spectrum was used as illumination.

Our optimisation study was done on a micromorph (*a*-Si:H/*μc*-Si:H) solar cell, which has a great potential for high efficiency thin-film silicon solar cell. Substrate configuration enables roll-to-roll fabrication on flexible substrates, which offers relatively simple integration of textures on the plastic or steel foil. The structure of the cell used in 2-D and 3-D modelling is shown in Figure 1. To reduce the size of the model, only a half of the period is used in simulations in both dimensions and symmetry boundary conditions are applied to side borders.