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Optimization of the antireflection coating of thin epitaxial crystalline silicon solar cells

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Abstract

In this work we use an effective weighting function to include the internal quantum efficiency (IQE) and the effective thickness, T_e, of the active cell layer in the optical modeling of the antireflection coating (ARC) of very thin crystalline silicon solar cells. The spectrum transmitted through the ARC is hence optimized for efficient use in the given cell structure and the solar cell performance can be improved. For a 2-µm thick crystalline silicon heterojunction solar cell the optimal thickness of the Indium Tin Oxide (ITO) ARC is reduced by ~8 nm when IQE data and effective thickness are taken into account compared to the standard ARC optimization, using the AM1.5 spectrum only. The reduced ARC thickness will shift the reflectance minima towards shorter wavelengths and hence better match the absorption of very thin cells, where the short wavelength range of the spectrum is relatively more important than the long, weakly absorbed wavelengths. For this cell, we find that the optimal thickness of the ITO starts at 63 nm for very thin (1 µm) active Si layer and then increase with increasing T_e until it saturates at 71 nm for $T_e > 30$ µm.

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Keywords: antireflection coating; epitaxial silicon solar cell

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1. Introduction

Reduction of the wafer thickness has so far been a significant factor driving cost reduction in silicon-based solar cells. However, moving beyond 100-µm will likely impose significant challenges related to handling [1] in addition to the relative increase in kerf losses [2]. Epitaxial silicon growth and layer transfer techniques provide ways to continue the trend of reduced silicon usage. Naturally, silicon provides the perfect seed for epitaxial growth, and various lift off techniques have been studied in order to reuse the expensive silicon substrate. Another approach is to use a low-cost substrate, such as display glass or metal foil, which remains attached to the solar cell. The realization of high quality crystalline silicon on such substrates requires a carefully chosen seed-layer for epitaxial growth. In this work we focus on tailoring the antireflective properties of the ARC to match the cell structure of an ultrathin, heterojunction, epitaxial crystalline silicon solar cell. A schematic view of the crystalline silicon heterojunction cell is shown in Figure 1. A variety of homo- and heteroepitaxial seeds on glass substrates [3,4] have been investigated, but for this particular study an n^+ Si wafer was used as the substrate for the epitaxial growth. For the thin heterojunction solar cells, the conductance in the doped a-Si:H layers is not high enough to allow for an efficient lateral collection. Transparent conductive oxides (TCOs) are often used to address this issue. The TCOs must also have a high transmittance in order to provide light to the active layer of the cell. As typical TCOs have refractive indices $n \approx 2$, such layers can also function as an anti-reflection coating for the solar cells.

For all crystalline Si thin film approaches, the combination of crystalline material and very thin active layers make light trapping a prerequisite to increase the current density. The aim of all light trapping approaches is to increase the average path length of the incoming photons. A 1-µm thick silicon layer with front side texture and rear reflector may therefore absorb the same amount of light as a flat 10-µm layer. It is therefore convenient to use the effective Si thickness, T_e, to account for arbitrary light trapping structures.

Efficient antireflection coatings (ARCs) are important to improve the light collection properties of solar cells of all thicknesses. Single layer ARCs for thick absorbers are well known and their only purpose is to reduce reflections without absorbing light in the ARC itself. Such ARCs are simply optimized for minimal integrated reflectance with respect to the AM1.5 spectrum. However, for very thin silicon solar cells, the cell thickness and structure will affect the properties of the optimal ARC to a larger extent. Although the improvement in current density after application of specific ARCs are commonly reported [6, 7], this does not implicate that the ARC is optimized with respect to the current density or cell structure. Modeling of the optical properties is predominantly performed using special purpose software and is hence normally separated from the electrical and structural modeling of the solar cell. In this work we use an effective weighting function to include the internal quantum efficiency (IQE) and the effective thickness of the active cell layer in the optical modeling. The spectrum transmitted through the ARC is hence optimized for efficient use in the given cell structure and the solar cell performance can be improved.

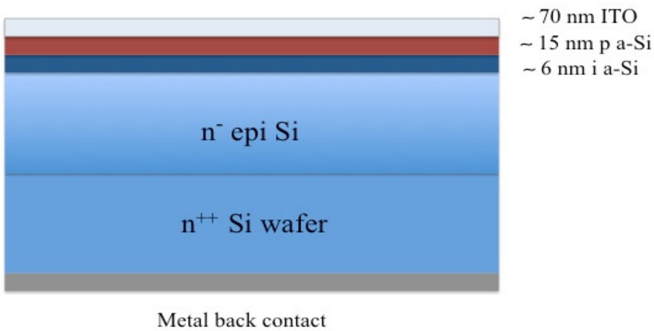

Fig. 1. The structure of the epitaxial crystalline silicon cell