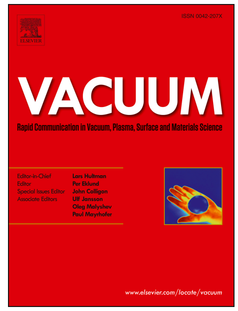
Accepted Manuscript



Development of amorphous silicon solar cells with plasmonic light scattering

L.J. Crudgington, T. Rahman, S.A. Boden

PII: S0042-207X(16)31024-7

DOI: 10.1016/j.vacuum.2016.12.026

Reference: VAC 7246

To appear in: *Vacuum*

Received Date: 21 June 2016

Revised Date: 8 December 2016

Accepted Date: 16 December 2016

Please cite this article as: Crudgington LJ, Rahman T, Boden SA, Development of amorphous silicon solar cells with plasmonic light scattering, *Vacuum* (2017), doi: 10.1016/j.vacuum.2016.12.026.

Development of Amorphous Silicon Solar Cells with Plasmonic Light Scattering

L. J. Crudgington, T. Rahman, and S. A. Boden.*

***Abstract*— This paper reports the result of simulation and fabrication of the optical effects of metallic nano-particle arrays within amorphous silicon thin-films. A finite-difference time domain approach is used to design and model nano-particle arrays within opto-electronic models of thin-film amorphous silicon. An increase in optical scattering and localized surface plasmon resonance is observed, resulting in an increase in power absorption within the material active region and a reduction in optical reflection from the film surface. It is shown that this enhancement in optical performance depends on the particle size, shape, position within the structure and proximity to the metallic back reflector. Process development of metal-island films on silicon and glass, followed by the fabrication and measurement of amorphous silicon P-I-N devices featuring plasmonic nano-particles is demonstrated; showing an enhancement in-keeping with results achieved using simulation.**

***Index Terms*— PECVD, Amorphous, plasmonic, nano-particles.**

I. Introduction

In depth understanding of the effects of optical light scattering technologies is essential when designing thin film silicon photovoltaic devices [1]. Despite their reduced energy conversion efficiencies compared to single-crystal silicon based cells, amorphous silicon (a-Si:H) thin film solar cells are a significantly cheaper technology with greater fabrication flexibility due to the reduction of silicon material usage by a factor of ten or more. The ability to deposit on inexpensive, flexible substrates over large areas such as glass or plastic [2] and the possibility of integration into architectural facades [3] further adds to the appeal of thin film silicon.

In order for this technology to achieve significant market share, their energy conversion efficiency values must be increased using an equally inexpensive technique compatible with their fabrication processes. Optical methods of scattering and trapping incident light within the devices have been extensively researched, which conventionally consist of deposition on to textured substrate materials [4], using dielectric confinement to trap light [5] and more recently, the use of self-organised plasmonic nano-particle layers within the device window layer or back reflector, [6-10] using the deposition and subsequent annealing of thin metal films.

Whilst these techniques often yield favourable results, the accurate tailoring of periodic nano-particle arrays to the absorption characteristics of the amorphous silicon material are expected to yield greater increases in performance compared to the randomised particles.

In the second section of this work, the Lumerical FDTD Solutions TCAD package is used to model the interaction of incident light with nano-particle arrays incorporated in thin-film hydrogenated amorphous silicon (a-Si:H) materials. The parameter space is fully explored over a wide range of shapes, dimensions, positions within the structure, constituent materials, and proximity to reflective surfaces, and these variations are used to demonstrate the effects of plasmonic nano-particle arrays on device performance.

In the third section, process development is undertaken to determine the fabrication conditions that result in the optimum particle dimensions corresponding to the simulation results. Conditions including deposited metal thickness, anneal temperature and anneal duration are varied and the results are investigated using scanning electron microscopy (SEM). An a-Si:H solar cell is fabricated, whose conditions have been optimised as published elsewhere [11], and the nano-particle arrays are applied to the back reflector of these devices in order to observe if the performance is enhanced.

II. Simulation

A. Set-up

The simulation model is shown in figure 1, and is constructed to follow the structure of the optimum amorphous P-I-N silicon devices fabricated in previous published work [11]. It consists of the following optical topography:

- Glass Substrate, SiO_2 Palik model [14] – Perfectly Matched Layer (PML), 625nm simulation boundaries.
- Amorphous Silicon, sampled data model [11] - 400nm.
- Indium Tin Oxide, FDTD model [13] - 200nm.
- Al / Ag Back Reflector, Palik model [14] - 300nm.

This work was supported in part by the Engineering and Physical Sciences Research Council. The authors are with the School of Electronics and Computer Science, University of Southampton, SO17 1BJ, U.K. (e-mail: ljc1g09@ecs.soton.ac.uk*; T.Rahman@soton.ac.uk,; sb1@ecs.soton.ac.uk).