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Towards Perfect Anti-Reflection and Absorption for Nanodome-Array Thin Film Silicon Solar Cell

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Abstract

In this study, a novel nanodome array structure for thin film silicon solar cell is proposed and systematically simulated. This design not only reduces surface recombination, but also achieves a high broadband absorption regardless of the polarisation and incident angles of light, by taking advantage of almost perfect anti-reflection, Mie scattering and Fabry-Perot resonance. The fabrication of such a nanodome structure is technically feasible and the proposed approach is also applicable to other solar cell materials.

Keywords: Nanodome; antireflection; solar cell; resonance; light absorption

1. Introduction

Photovoltaic is a promising source for future renewable energy. Currently, the commercial market is dominated by crystalline silicon (Si) due to its abundance, nontoxicity and mature technology. However, due to the poor light absorption in Si, an absorbing layer over 200 μm is required to effectively absorb the sunlight, which accounts for the high cost of Si solar cell [1]. In contrast, thin film solar cells provide an economical alternative by greatly reducing the material required and hence the manufacturing cost. However, it is crucial to improve the photon management ability of thin film solar cells so that high

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power conversion efficiency (PCE) can be achieved. Many studies have focused on incorporating Si nanostructures, like nanowire [2], nanocone [3], and nanopillar [4] arrays, into Si solar cells to enhance light harvesting. They have demonstrated a much reduced light reflection and strong light trapping ability. When the sunlight with a wavelength comparable with the dimension of the nanostructure, strong scattering is induced which effectively prolongates the sunlight optical path length [2-4]. Nevertheless, the large surface area associated with these nanostructures aggravates the surface recombination loss, which in turn substantially degrades the carrier collection efficiency [5]. To address this issue, low aspect ratio nanodome and nano-pyramid Si solar cell structures have been proposed to achieve both efficient light absorption and carrier collection [6-10]. Such structures can improve the device performance by reducing light reflection while enhancing absorption by coupling most of the incident sunlight into the low aspect ratio nanostructures. Furthermore, as the roughness factor, defined as the ratio between the actual surface area and geometric surface area of the structure, is much smaller than that of nanowire, the surface recombination is significantly reduced. Besides, due to the more planar surface, conformal deposition of top electrode can be achieved in contrast to Si nanowires based cells. The nanodome structure has been successfully fabricated and demonstrated the highest short circuit current ever reported among nanostructure based solar cells [7]. Therefore, the novel low aspect ratio nanostructure is a promising and practical approach for light management to boost the PCE of solar cells.

In this paper, we systematically investigate the absorption enhancement mechanisms for poly-Si nanodome structure incorporated with both top amorphous silicon nitride (Si_3N_4) antireflection coating (ARC) and back silver (Ag) reflector. The top Si_3N_4 also functions as surface passivation layer to lower carrier recombination. Our simulation results show that the proposed structure can achieve almost perfect antireflection and broadband absorption for both TE and TM polarisations and moreover the performance depends little on the illumination angle.

2. Simulation details

High Frequency Structure Simulator (HFSS) [11] has been used to carry out three-dimensional (3D) Finite Element Method (FEM) simulations to determine the absorption in the nanodome array structure. The basic structure of the nanodome is shown in Fig. 1 with both 3D schematic and cross-sectional views. The structure periodicity is set as P. The thickness of the thin film (T_2) is fixed at 1 μm. On top of device is a thin layer of Si_3N_4 having a thickness of T_{Si3N4}, acting as an antireflective layer and passivation layer to reduce the surface recombination. The bottom electrode is 200 nm (T_3) thick silver. The light absorbing Si thin film is sandwiched between the two layers. Due to the periodicity, only one unit cell incorporated with periodical boundary conditions is simulated. The top and bottom of the structure are bounded by the

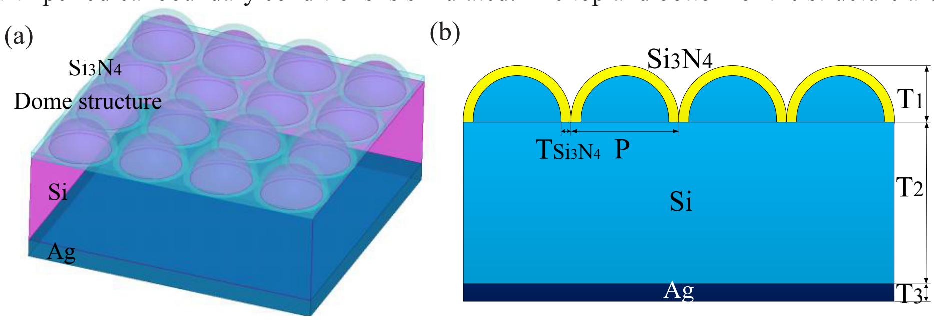

Fig. 1. The simulated nanodome thin film solar cell structure. (a) 3D schematic and (b) cross-sectional view of the nanodome structure.