Optik 127 (2016) 1003–1006

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Effect of nanopits size and spacing on the light absorption in silicon thin film solar cells

Haoshi Wang, Fei Gao*, Yi Wu, Fuxian Li, Songjie Zhou, Huijun Wu, Xiaoyao Zheng, Shengzhong Liu*

School of Materials Science and Engineering, Shaanxi Normal University, West Chang'an Street 620, Xi'an 710119, Shaanxi, China

ARTICLE INFO

Article history:
Received 4 February 2015
Accepted 29 October 2015

Keywords:
Light trapping
Light absorption
Periodic nanopits
a-Si thin film solar cell
FDTD

ABSTRACT

Periodic nanopits texture has been shown to demonstrate light trapping properties and promising potential for Si thin film solar cell. In this work, the effect of size and spacing of periodic nanopits texture on the light absorption in amorphous silicon (a-Si) thin film solar cells was studied using finite difference time domain (FDTD) method. The results show that, in most cases, there is a bigger light absorption in a-Si thin film cells for larger nanopits size (≥200 nm), and the light absorption decreases with increasing nanopits spacing. A total absorptivity maximum of 70.7%, 70.8%, and 69.0% of a-Si thin film solar cell with a 300 nm thick a-Si active layer are achieved for nanopits size/spacing ratio of 400 nm/0.4, 500 nm/0, and 600 nm/0.2, respectively. The electric field intensity distribution of the a-Si thin film solar cell with periodic nanopits texture was also evaluated to offer further physical insight into their light trapping properties.

1. Introduction

Silicon (Si) thin film solar cells have attracted growing attention due to the reduced costs of raw materials and processing. However, there is a poor light absorption in Si thin film solar cell for their excessively thin active layers. Therefore, a careful design of Si thin film solar cell is crucial for improving light absorption. One way to enhance light absorption and thus improve the efficiency of Si thin film cell is to implement light trapping techniques to reduce light reflection and prolong the light paths in the cell [1–3].

Light trapping can be implemented by adding a scattering texture to one or several of the interfaces in the Si thin film solar cells. Various light trapping structures have been researched and developed. These structures contain the multilayer antireflection (AR) coatings [4,5], dielectric nanopillars [6,7], metallic nanoparticles [8,9], nanovoids [10], and nanogratings [11,12]. As was recently shown by Sai et al. [13,14], a self ordered periodic Al nanopits texture which was used as back reflector in μc-Si thin film solar cell could increase the short circuit current density from 18.6 mA/cm^2 to 24.3 mA/cm^2. They fabricated the periodic nanopits texture on the Al back reflector using anodic oxidation and chemical etching. Surface profile of the nanopits is an important factor which affects the light absorption in the Si thin film cells.

In this paper, the effects of the size and spacing of periodic nanopits on the Al back reflector on the light absorption in a-Si thin film solar cell were systematically studied using finite-difference time-domain (FDTD). We found that both the sizes and the spacing of the nanopits have considerable effects on the light trapping property of the a-Si thin film cells, and an optimal size and spacing of the Al nanopits has been obtained.

2. Optical simulation model

a-Si thin film solar cell with a substrate configuration was used in this study, as shown in Fig. 1. The cell consists of a 80 nm thick Al doped zinc oxide (ZnO:Al) front contact layer, followed by a 300 nm a-Si active layer, a 40 nm thick ZnO:Al layer, a 200 nm thick Ag layer, and a thick Al foil with periodic hemispherical nanopits on it, which can be realized and controlled by the experiments [13–15]. All of these layers are textured by the periodic nanopit array of the Al foil, which resulted in the same size and spacing of the nanopits for each layer. The effect of Al periodic nanopits on the light absorption in a-Si thin film solar cells were studied by calculating the optical wave propagation and absorption in the a-Si thin film cells with different nanopits sizes (*d*) and spacing (*s*). Three dimensional optical wave propagation and absorption in the a-Si cells was investigated by rigorously solving Maxwell's equations using finite

* Corresponding authors. Tel.: +86 29 81530709; fax: +86 29 81530702.
E-mail addresses: feigao@snnu.edu.cn (F. Gao), liusz@snnu.edu.cn (S. Liu).

http://dx.doi.org/10.1016/j.ijleo.2015.10.209

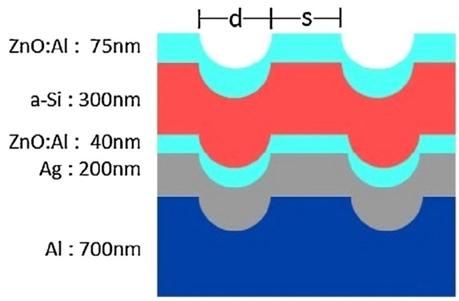

Fig. 1. Structure of a-Si thin film solar cell with conformal periodic nanopits textures with size *d* and spacing *s*.

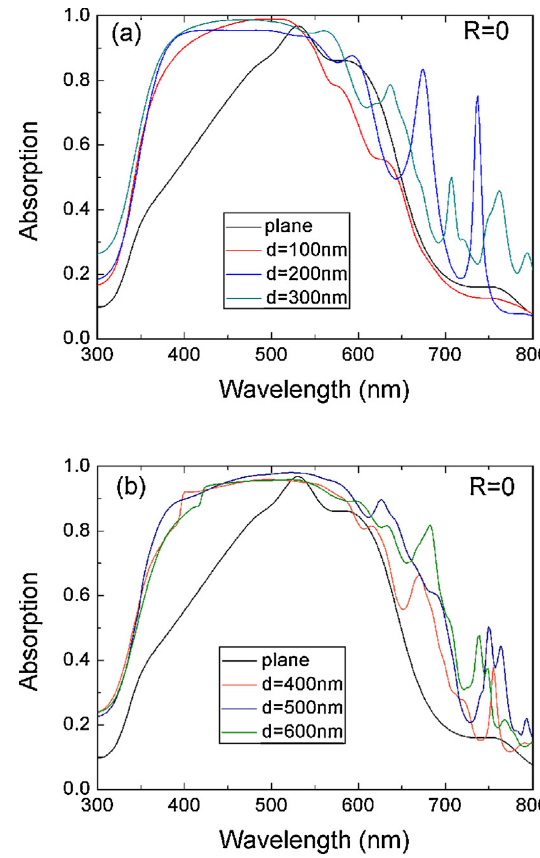

Fig. 2. Absorption spectra of a-Si layer in a-Si thin film cells with different nanopit sizes *d* and $R=0$ (i.e. zero spacing): (a) $d=100$, 200, and 300 nm; and (b) $d=400$, 500, and 600 nm.

difference time domain (FDTD) algorithm (FDTD Solutions 8.7.1, Lumerical Inc.).

The a-Si thin film cells were illuminated by a TM polarized (with the electric field parallel to the incident plane), normally incident plane wave with wavelength range from 300 to 800 nm, covering most of the useful solar spectrum for a-Si thin film solar cells. Perfectly matched layer boundary conditions were used in the light incident direction to prevent interference effect, and periodic boundary conditions were used in the lateral direction to simulate ordered array of nanopits. Optical constants of Al, Ag and a-Si were taken from Palik [16] and ZnO:Al was taken from Ref. [17]. For simplicity, effect of doping on the absorption of a-Si layer was neglected.

3. Results and discussion

Fig. 2 shows the wavelength dependence of absorption spectra of a-Si layer in the a-Si thin film cells with varying nanopit size *d* for $R=0$ (i.e. zero spacing between the nanopits), *R* is the ratios of nanopits spacing *s* to the nanopits size *d*: $R=s/d$. The absorption spectrum of a-Si thin film cell with plane interfaces is also shown for reference. It can be seen that there is a large light absorption improvement in the nanopits textured a-Si thin film cells in the wavelength from 300 nm to 550 nm, comparing with that of the plane a-Si thin film cell, such as the light absorption increases from 55% to 95% for 400 nm wavelength. The similar phenomenon was also reported before [18,19]. This absorption improvement is because of introducing nanopits in cells, which resulted in a decrease of light reflection on the surface of the cells, and increase of light diffraction and interference in the cells. The reason of reflection decrease can be explained as follows: the upper surface region containing nanopits and adjacent air can be seen as several plane layers with different air content, which makes the equivalent effective refractive index of each layer continuous changing from all air region to all solid film region, and suppresses light reflection [20].

For the cell with nanopits size of 100 nm, when the wavelength is larger than 550 nm, the absorption of a-Si layer decreases slightly compared with that of the plane a-Si cell. However for cells with nanopits size larger than 200 nm, when the wavelength is larger than 550 nm, the absorption curves appear several interference peaks, which resulted in the increase of light absorption in the cells.

Fig. 3 shows the absorption spectra of a-Si layer in the a-Si thin film cells with varying spacing ratio *R* for 500 nm nanopits texture. It can be seen that light absorption in the a-Si layer decreases with increasing nanopits spacing in the wavelength range from 300 to 550 nm. When the wavelength is larger than 550 nm, for $R=0$ to 0.4, there is a slight increase in the absorption of a-Si layer, but for $R=0.6$ to 1, the absorption of a-Si layer decreases slightly. These results suggest that the change of nanopits spacing mainly affects light absorption in shorter wavelength region.

To compare the light trapping properties of the a-Si thin film cell with different nanopit size and spacing, total absorptivity is introduced to evaluate. Total absorptivity *A* is defined as the ratio of the light power absorbed in the a-Si layer to the total incident light power that was incident on the cells over the whole wavelength range [21]:

$$A = \frac{\int_{300\,\text{nm}}^{800\,\text{nm}} a(\lambda)S(\lambda)\,\mathrm{d}\lambda}{\int_{300\,\text{nm}}^{800\,\text{nm}} S(\lambda)\,\mathrm{d}\lambda} \qquad (1)$$

where $\alpha(\lambda)$ is the absorption spectrum of the a-Si layer, and $S(\lambda)$ is AM1.5 solar spectrum [22]. The total light absorptivity *A* as a function of nanopit size *d* for different spacing ratio *R* is shown in Fig. 4.

In Fig. 4, it can be seen that for nanopits size larger than 200 nm, there is a bigger total light absorptivity. Tsao et al. also found that there is bigger absorption in a-Si layer with nanopit size between 430 and 700 nm in their experiment [23]. The total absorptivity maximum of 70.7%, 70.8%, and 69.0% are achieved for d/R of 400 nm/0.4, 500 nm/0, and 600 nm/0.2, respectively. However, in most cases, total light absorptivity decreases with increasing nanopit spacing ratio *R* for different nanopits size *d*.

To further understand the mechanism behind the improved light absorption in a-Si layer by appropriate selection of *d* and *R*, the electric field intensity distribution of light wave was computed at a wavelength of 750 nm, which is a resonance wavelength for $d=500$ nm and $R=0$, as shown in Fig. 2. Fig. 5 compares the electric