Optics Communications 331 (2014) 325–329

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Anodic aluminum oxide nanograting for back light trapping in thin c-Si solar cells

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ARTICLE INFO

Article history:
Received 7 May 2014
Received in revised form
31 May 2014
Accepted 24 June 2014
Available online 3 July 2014

Keywords:
Solar cell
Anodic aluminum oxide
Light trapping structure
Finite difference time domain
Surface oxidation

ABSTRACT

Enhanced absorption of near infrared light in silicon solar cells is important for achieving high conversion efficiencies while reducing the solar cell's thickness. In our work, a light trapping structure combined with anodic aluminum oxide (AAO) nanograting and Ag thin layer was proposed. The finite difference time domain (FDTD) method was used to study the relationship between AAO's geometrical parameters and light absorption character of thin Si solar cells. Simulation results show that the optimum AAO parameter is 0.75 for the duty circle, 380 nm for period and 90 nm for thickness. Absorption spectrum shows that, AAO in optimum structure can highly increase light absorption for Si solar cell in wavelength from 500 to 1100 nm. Parameter tolerance analyzing of AAO shows that, choosing AAO as a back light trapping structure allows a tolerance more than $\pm 10\%$ for period and about -5% to 20% for thickness.

1. Introduction

Nowadays, the trend of making solar cells with Si material is to further reduce the thickness of absorption layer, so that the manufacturing cost can be saved as much as possible. But the light absorption becomes lower and light easily overflows before it is absorbed when the Si active layer is not thick enough [1,2]. For example, the penetration depth of photons in the wavelength range between 900 and 1100 nm is up to 3 mm and therefore exceeds typical crystalline silicon solar cell thicknesses of about 180 μm. So one of the foremost challenges in designing silicon solar cells is devising an efficient light-trapping scheme while reducing the thickness of Si. Traditional approaches to light trapping enhancement in solar cells rely on controlling light paths through geometrical optics [3]. Several analytical and numerical investigations indicated that diffractive structures on the backside of solar cells can achieve efficient light trapping [4–6]. Among these, subwavelength grating with metal reflectors [7–10] are the most common light trapping structures. As shown in Fig. 1(a), the metal layer can reflect the light in near-infrared range to prevent its leakage through the backside, while the subwavelength grating can diffract the incident light into oblique angles to significantly increase the optics path. But this method has its own limitation since photolithography and other cleanroom facilities are required to fabricate the subwavelength gratings [11]. To overcome this, some easily fabricated photonic crystals structures are introduced to replace the grating [12].

Anodic aluminum oxide (AAO) template was first reported by a Japanese scientist Masuda [13]. Due to its periodic array structure, it has been intensively investigated as a template to prepare nanomaterials [14,15]. Nowadays, AAO is treated as a photonic crystal to design light trapping structure. For example, Hnida once fabricated a distributed Bragg reflector (DBR) with stromatolithic AAO [16]. Xing designed a back light trapping structure using AAO and DBR [17]. However, in the present work, systematic analysis for the influence of AAO's geometrical parameters and parameter tolerance on light trapping is barely reported.

In this paper, we proposed a light trapping structure combined of AAO nanograting and Ag thin layer. FDTD software was used to systematically study how the AAO's thickness, duty circle, period and structure tolerance affect solar cell's short current density (J_{sc}) character. Fig. 1(b) illustrates the schematic of Si solar cell with AAO. Simulation results show that, a J_{sc} of 55.49 mA/cm^2 was produced by AAO in optimum parameters. Using AAO as the back light trapping structure can increase the light absorption by 22.85% in the wavelength from 280 to 1100 nm. Parameter tolerance analyzing shows that AAO allows a higher parameter tolerance in light trapping. This makes AAO a more potential candidate of 2-D grating structure for light trapping of Si solar cells.

2. Simulation model and AAO parameter setting

In the simulation, a commercial FDTD software package, FDTD Solutions, provided by Lumerical Solutions was used. The simulation model is shown in Fig. 2. AAO of different sizes was put on the backside of a 1000 nm thick Si active layer, and a 50 nm thickness

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http://dx.doi.org/10.1016/j.optcom.2014.06.049
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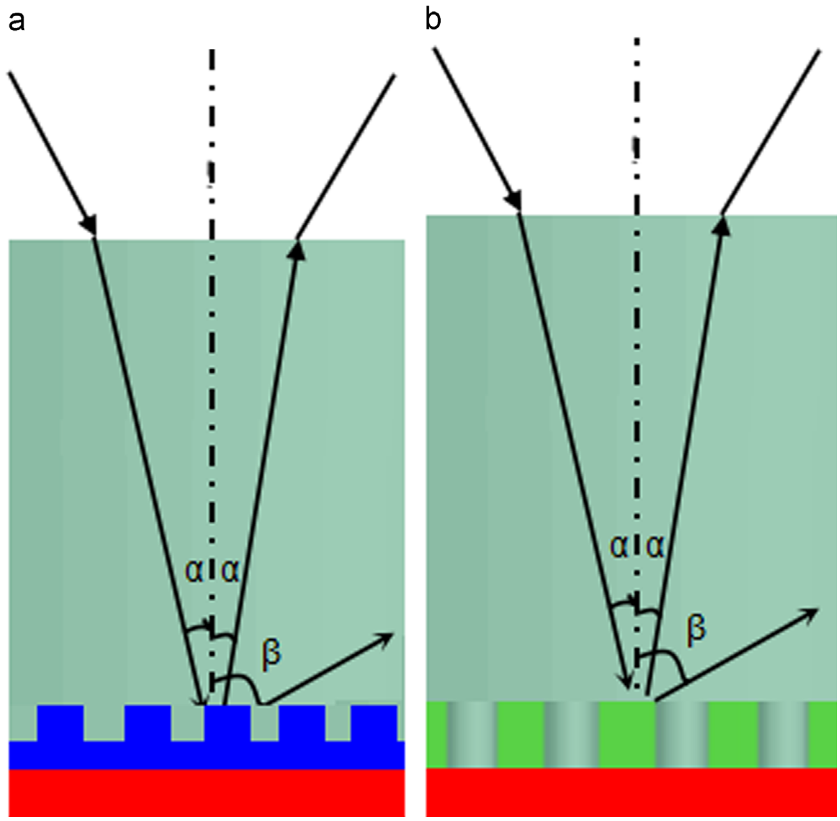

Fig. 1. Illustration of thin Si solar cells with two back light trapping designs: (a) a design with a perfect metal backing and subwavelength grating, (b) a design with a perfect metal backing and 2-D AAO nanograting, perfect metal is in red, periodic grating is in blue and 2-D AAO is in green, the else is c-Si. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

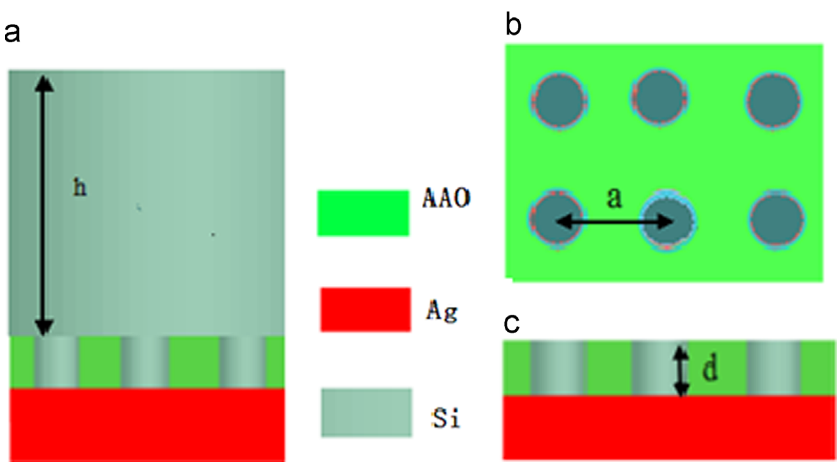

Fig. 2. Simulation model: d is the thickness of AAO, a is the distance between the AAO holes and h is the height of Si active layer.

Ag was set as a light reflector on the back of Si. The AAO parameters comprise: AAO thickness d, AAO period a, and AAO duty circle f (defined as the radio for the AAO diameter in one period). Period boundary was used in x and y axes, and perfectly matched layer (PML) boundary condition was used in the z axis. A plane-wave light source ranging from 280 to 1100 nm is used to illuminate the structure at normal incidence. To calculate the short current density of the solar cells with AAO, FDTD Solutions is applied to find out the values of reflectance $R(\lambda)$ and transmittance $T(\lambda)$. The absorptance $A(\lambda)$ is therefore determined by $A(\lambda)=1-T(\lambda)-R(\lambda)$, and the J_{sc} can be calculated by [18]

$$J_{sc}=e\eta\int_{280}^{1100} A(\lambda)I_{AM1.5}\, d\lambda \tag{1}$$

where e is the electron charge, $I_{AM1.5}$ stands for the solar intensity per wavelength interval, $A(\lambda)$ is the absorptance, η is the carrier collection efficiency which depends on the surface recombination and material quality (here we simply assume it is 100% for simplification). The solar spectrum and intensity was after the standard $AM_{1.5}$ Direct+Circumsolar spectrum.