Multiple-level Grating Used for Nanostructured Thin Film Solar Cells

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***Abstract*-Surface recombination plays a key role in hign efficiency nanostructured thin film solar cells. How to reduce the recombination in a nanostructured cell or further increase absorption without increase of surface recombination is meaningful in solar cell design. We further increases light absorption without increase of surface recombination, and the extra light absorption contribute to the device efficiency. This concept of multiple-level grating shows significant importance in effective nanostructure light trapping.**

Keywords- solar cell; Nanophotonics; light trapping;

I. Introduction

Recently, significant research has been conducted on thin film solar cells for their advantages of reducing material cost and improving carrier collection efficiency compared with their wafer-based counterparts. Unfortunately, poor absorption of the incident light is consequent on the reduction of active layer thickness, especially close to the ban gap of the active material, which deteriorates the devices efficiency greatly. Various photon management schemes for thin film solar cells have been explored. Anti-reflection coatings (ARC) based on transparent conductive oxides (TCOs) and other low index dielectric materials have drawn considerable attention due to optical interface effect. Nano light trapping methods outperform traditional gratings and textures as they can exceed ray limits. Metallic grating and particles have also been studied for their ability of exciting SPPs, which leads to electric field confinement and benefits total absorption. Incorporating these features could benefits the cells by increase the number, spectral density and coupling of the modes in the active layer. The configurations of the structures vary from triangular to honeycomb, even in every kind of the common simple structures. However, the most optimal one among the innumerable light trapping structures is still inconclusive. It is demonstrated in [1] that intrinsic semiconductor gratings precede their low-index and metallic counterparts. Nevertheless, the increase of surface recombination is not evaluated in the total device efficiency. Yun Da et al.[2] investigated nanostructured silicon thin film solar cells and demonstrated surface recombination increase has a great impact on the efficiency numerically. It is of significant value to reduce the surface recombination and further increase absorption without surface recombination increase.

Here we further increase light trapping efficiency with multiple-level grating without the increase of surface recombination and discussed its influence on the absorber over the entire solar spectrum. The simulations results have qualitatively confirmed that multiple-level grating can be a promising candidate for effective light trapping in high efficiency solar cell devices.

II. Methods and Results

Our numerical computation are simulated in a commercial finite element software package (COMSOL Multiphysics 4.2a), by solving 2D Maxwell's equations. The unite cell we analyzed is surrounded by perfectly matched layers (PMLs) at top and bottom boundaries and periodic boundary conditions at the left, right, front and back boundaries. The sketch of the investigated structures is shown in Fig.1. It contains a multiple-level grating layer, a 400nm active layer based on crystalline Si (c-Si), a 100nm Ag layer from top to the bottom. The refractive index data of silver and c-Si material can be found from the measurement data in [3].

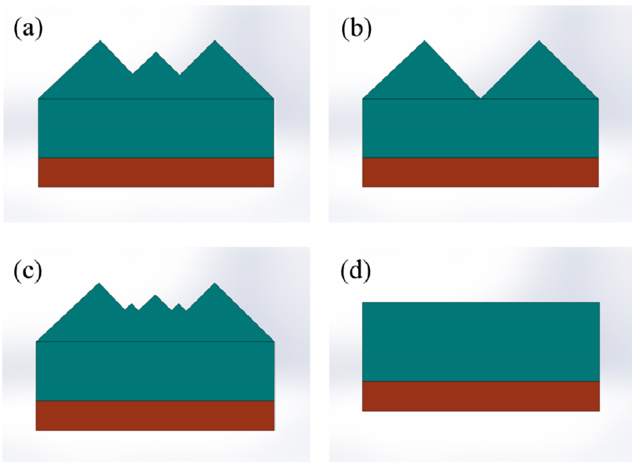

Fig.1. Schematic diagrams of the proposed solar cell structure.(a) and (c) are cross-sectional views outlining the two-level and three-level device's structure to be used in simulations.(b) and (d) are reference solar cells.

We clarified the consideration and principle for the multiple-level grating design firstly and discussed two kinds of multiple-level gratings influence. It is known that the role of surface recombination counts for the degradation of device

978-1-4799-3682-3/14/$31.00 ©2014 IEEE

efficiency. And with the same passivation technology, increased surface area can result in increased surface recombination. Reducing the surface area without degradation of light trapping effect and further increasing light absorption without surface increase are two ways for higher efficiency solar cell devices. In our work, we further increase light absorption with multiple-level grating. For the design of multiple-level gratings, the valley bottom surface of triangular equals to the front surface of the high level grating. In other words the surface of the front grating is fixed as the same with optimized triangular periodic grating.

In order to quantify the absorption properties of the solar cell with the structure under AM1.5G illumination, we calculate the total efficiency with formula [4]:

$$\eta = \frac{\int_{\lambda_{\min}}^{\lambda_{\max}} I(\lambda)A(\lambda)d\lambda}{\int_{\lambda_{\min}}^{\lambda_{\max}} I(\lambda)d\lambda} \qquad (1)$$

Where $\lambda_{\min} \sim \lambda_{\max}$ is the investigated wavelength range (300-1100nm), $A(\lambda)$ is the absorption rate of a fixed wavelength and $I(\lambda)$ corresponds to the spectral intensity. Here only the normal incident light is taken into consideration. Results of the structure are presented in Fig.2. An optimized periodic triangular grating and a planar solar cell are chosen as references.

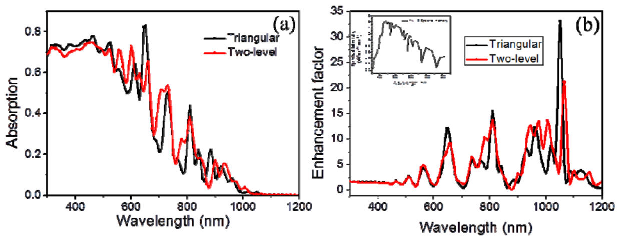

Fig.2. The absorption (a) and enhancement factor (b) spectra for the optimized periodic triangular and two-level grating in 400nm c-Si thin film solar cells.

It is obvious that there are several absorption peaks in the Fig.2 (a). Compared with triangular grating, two-level grating outperforms for several wavelength ranges with more absorption peaks. To evaluate the total efficiency of the two different cells, we calculate η with formula one. It is demonstrated that η reaches 43.01% for the triangular structured, while 1.53% increase is found for two-level structured with $\eta = 44.51\%$. It is notable to mention that periodic triangular grated solar and the maximum enhancement factor is about 34 for the triangular grating in Fig.2 (b). However, the enhancement factor contributes little to the total efficiency. It is due to the two following reasons:

Firstly, the enhancement occurs at the wavelength of 1100nm where the absorption is nearly approaching zero. And even the 30 enhancement factor contributes little. Then wavelength is related to the valley value of AM1.5 spectra which blunts the impact on the total efficiency enhancement.

We also structured the cell with three-level grating and absorption is shown in Fig.3. It is clearly shown that for the short wavelength range, absorption is undermined. Three absorption peaks ($\lambda = 600$, 660 and 780nm) are slightly increased. And the total η of the two cells is nearly the same.

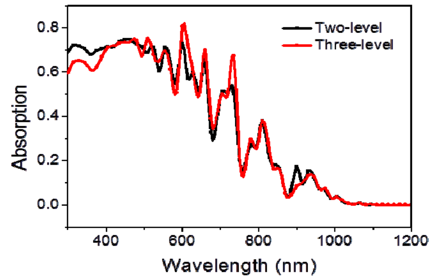

Fig.3. The absorption spectra for two-level and three-Level structured solar cell. The red line is related to the three-level structured cell and the black line is the Two-level structured

III. CONCLUTIONS

In conclusion, we successfully further improve light absorption with multiple-level gratings. Compared with optimized periodic triangular grated solar cell, the multiple-level case shows 1.53% enhancement, under the standard AM1.5 solar spectrum. The further increase of absorption does not at the cost of the increase of surface. In other words, the increase of the absorption does not introduce the extra surface recombination. And the further absorption contributes to the device efficiency. These properties of the multiple-level grating are useful to design high efficiency thin film solar device.

ACKNOWLEDGMENT

This work was supported by Startup Fund by Peking University Shenzhen Graduate School. The authors would like to acknowledge the valuable discussions with other group members in the same group.

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