Shape-induced Effect on c-Si Thin Film Solar Cell Efficiency

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***Abstract-* Nanophotonic light trapping methods play a key role in high thin film solar device. Even many parameters are discussed in cell designs; the shape of the semiconductor grating is rarely included. In this paper, we investigated the shape-induced effects on the absorption of solar cell and demonstrated that even for the structures at the nanometer scale; the shape of the grating is also an indispensable consideration for solar cells.**

Keywords- solar cell; Nanophotonics; shape-induced;

I. INTRODUCTION

Thin film solar cells have developed quickly since they offer a possible way to produce electricity with less material and fabrication cost compared with their bulk counterparts. Besides, thin film solar cells with thinner active layer thickness are superior to bulk solar cells with higher carrier collection efficiency, for the later faces with higher minority carrier recombination in the bulk. Yet thin film solar cell efficiency is still not high enough comparing with traditional thick wafer based solar cells. Poor light absorption is mainly responsible for the low device efficiency. How to improve light absorption efficiently has motivated the search for best light management or light trapping method. Nanostructure, has been proposed and investigated in a great quantity of configurations, including surface patterns, rear gratings[1], embedded particles and nanowires is one of the mostly promising ways. And all of the nanostructures are classified into three kinds: low-index (SiO_2 and ITO), high-index dielectric (Si) structures and metal (Ag, Au and Al) structures. And it is demonstrated that semiconductor structures outperforms their low-index and metallic counterparts[2]. Besides the materials, other main grating parameters are also investigated in various articles. However, the discussions of grating shape come from several familiar structures, and it is even not taken up for the semiconductor structures.

Here we investigate both symmetric and asymmetric structures and discuss the shape-induced effect on nano structure based thin film solar cells. For the investigated cases, we only focus on the semicircle inscribed polygons in the consideration that the effective thickness is nearly the same and the shape changes gently. It is demonstrated that the shape influences light absorption which means the optimized grating shape is also crucial in high efficiency nano light trapping solar cells.

II. METHODS AND RESULTS

The unit device structures are a thin film solar cell incorporating Si grating on the top, an active layer in the middle and a 100nm Ag substrate on the rear respectively, as shown in Fig.1. The grating shape is fixed at semicircle at first. For the asymmetric discussion the semicircle is divided equally into several parts while for the asymmetric case, the divisions for the left and right quadrant are different. The absorption for each considered wavelength can be solved by applying electromagnetic (EM) theory with the help of finite-element method. The model is surrounded by periodic boundaries and perfectly matched layers for the horizontal and vertical directions respectively. It is assumed that the entire solar spectrum is collimated into a normal angle of incident. Both transverse magnetic (TM, Electric field perpendicular to the grating) and transverse electric (TE, Electric field parallel to the grating) polarizations are considered to approximate solar light irradiation. The refractive index data of silver and Si materials can be found from the measurement data in[3].The broadband illumination as an incident plane wave across a range from 300 to 1100 nm was selected to match the solar spectrum and the significant spectral response of Si.

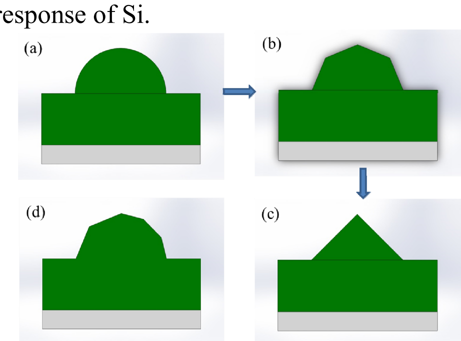

Fig.1. Schematic diagrams of the proposed solar cell structure. From (a) to (c) is the gradual change of the shape. And (a), (b) and (c) are symmetric cases while (d) is asymmetric case. (a), (b) and (c) are semicircle, quartering and equipartition, respectively. (d) shows the semicircle which is divided into five parts. The left quartering is divided into two parts and the right is three parts. The diameter and the active layer thickness are both 400nm.

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In order to quantify the absorption properties of the solar cell with the structure we calculate the absorption with[4]:

$$A = \frac{P_{abs}}{P_{in}} = \frac{-\iint \nabla \cdot \langle S \rangle r dr d\vartheta}{P_{in}} \quad (1)$$

Where $\langle S \rangle$ is the time-averaged poynting vector and P_{in} is the time-averaged incident power. We average the total absorption for the TM-polarized and TE-polarized illumination to simulate the non-polarized illumination.

The semicircle is equally divided into several parts symmetrically. It is demonstrated obviously that the absorption spectra for the four chosen grating differ severely to each other. The spectrum tends to be more incisive with the grating changing from semicircle to halvers. It is also shown that the spectra for sixths, quarters and semicircle nearly coincide to each other which can be explained that the shape changes little from each other.

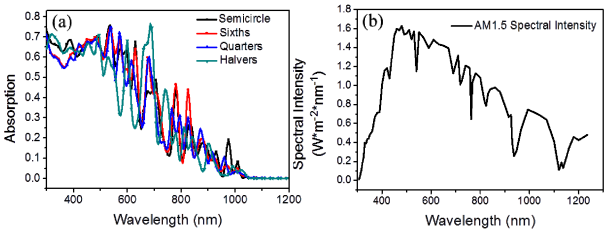

Fig.2 The absorption spectra for the cells structured with four different gratings (a) and the AM1.5G spectral intensity (b).

The peaks for the adequate energy illumination wavelength range benefits the total efficiency much. It is notable to mention that the peak appearing at the wavelength of 700nm is meaningful for it contributes to the total efficiency much in the consideration that the fixed wavelength corresponds to high spectral intensity illustrated in Fig. 2(b). The efficiency is also calculated for the AM1.5G illumination.

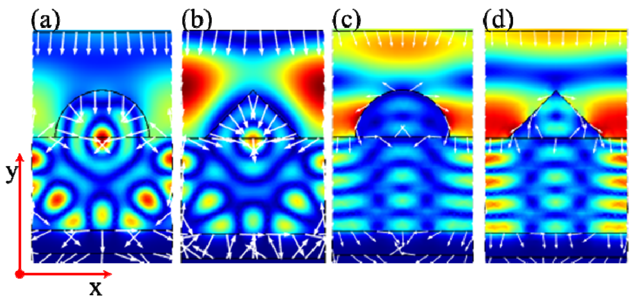

Fig.3.The Normalized field intensity distribution and power flow arrows at the wavelength 705 nm (a) and (c) are for the semicircle grating.(b) and (d) are for halvers-semicircle grating.

It is clear illustrated that both the two gratings leads to ad electric field gather in the center of the structure for TE illumination. The gather in the center corresponds to cavity mode. Compared Fig.3 (d) with (c), it is clearly illustrated that electric field is strengthened which contributes to the highest peak at the wavelength 705nm in Fig.2. (a).

Fig.4 illustrates the comparisons between asymmetric shape (shown in Fig.1 (d)) and symmetric shape.

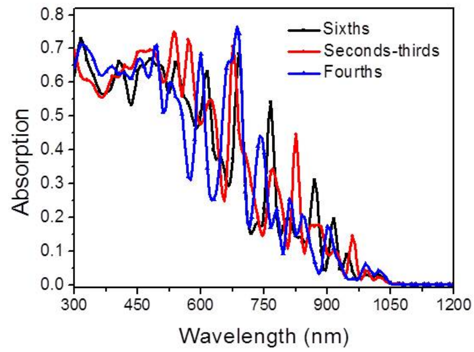

Fig.4 The absorption spectra for the cells structured with symmetric and asymmetric gratings.

For the asymmetric shape grating, there are more absorption peaks waving up. The cell efficiency is calculated under AM1.5G illumination. And the efficiency of asymmetric grating exceeds the other two of 2.31% and 2.22%.

III. CONCLUTIONS

In conclusion, we investigated several kinds of front grating shapes and discussed their influence on the absorption of thin c-Si thin film solar cells. Both symmetric and a symmetric shapes are included. It is demonstrated that the shape has a vital impact on the cell efficiency which has seldom stated. It is also illustrated that the asymmetric grating outperforms its counterparts. Our work makes it clear that for designing high-performance nanostructured thin film solar cells, the shape should be taken into consideration.

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