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OPTIMUM DESIGN OF MICRO-LENS STRUCTURE FOR THIN FILM SOLAR CELL IN BUILDING INTEGRATED PHOTOVOLTAIC

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ABSTRACT

Building Integrated photovoltaic (BIPV) is an important application scenario of thin film solar cells. As an effective means to improve the efficiency of thin film solar cells, the design of micro-lens structure should match its application scenario to maximize power generation efficiency. In this paper, an optimal design method for the structure of micro-lens used in BIPV is proposed. BIPV lighting roof application scenario is taken as an example. The light trapping performance of different micro-lens structures, under solar illumination during the summer solstice, is analyzed through using Tracepro software. The results show that the V-groove micro-lens has the best light trapping performance when the vertex angle is 110° and the groove depth is 300μm. Compared with non-micro-lens scenario, the irradiance flux on the incident surface of the amorphous silicon can be increased by 16.28%.

Keywords: building integrated photovoltaic, micro-lens structure light trapping, thin film solar cell, optimal design

1. INTRODUCTION

Improving the photoelectric conversion efficiency of thin film solar cells is one of the main goals to promote the progress of photovoltaic technology. It is an effective way to improve the photoelectric conversion efficiency by introducing appropriate trapping structure, broadening the spectrum utilization band and increasing the light capture efficiency [1]. Micro-lens structure is one of the trapping structures to increase the propagation length of light in solar cells, and then improve the power generation efficiency of solar cells.

Thin film solar cells are important photovoltaic components for building photovoltaic integration. The design of their micro-lens trapping structure should be consistent with their application scenarios. At present, most of the research of micro-lens structure solar cells is carried out in the normal incidence of light source [2], or the angle deviates from the normal direction range of -23.5° to 23.5°[3]. The research focuses on the improvement of photovoltaic conversion efficiency of solar cells by different kinds of trapping structures, but seldom considers the optimization design of trapping structures in the application scenario of building photovoltaic integration.

For BIPV, the incident angle strongly deviates from the normal direction and largely depends on installation conditions, such as the local latitude and facing direction [4]. Therefore, new micro-lens structure design schemes surely need to optimize the structure of the micro-lens to match the incident light varies with the solar trajectory, maximize the power generation performance in the application scenario.

2. DESIGN IN BIPV SCENE

2.1 Design of theoretical model for micro-lens solar cells

V-groove micro-lens structure has been selected as the research object because of its wide application. Groove depth and vertex angle are two factors determining V-groove structure. The theoretical model of V-groove micro-lens solar cells with varying vertex angle between 70 and 150 degrees and groove depth between 100μm and 1000μm is established as shown in Table 1 and Figure 1.

Table 1 Change range of vertex angle and groove depth

Vertex angle(°)	60	70	80	90	100
Groove depth (μm)	100	200	300	400	500
Vertex angle(°)	110	120	130	140	150
Groove depth (μm)	600	700	800	900	1000

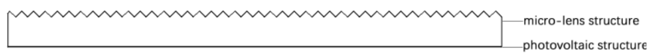

Figure 1 Thin Film Solar Cells with micro-lens structure

There are 100 V-groove micro-lens structure solar cell models built in Tracepro. The glass substrates of solar cells are set to be optical glass with a length of 50 mm, a width of 50 mm and a thickness of 3.2 mm. And the micro-lens structure is arranged on the glass substrate. The transparentconductiveoxide (TCO) layer is made of SnO_2 with a thickness of 900 nm. The active layer of solar cells is made of amorphous silicon with a thickness of 300 nm. The thickness of ZnO conductive film is 80 nm, and its back surface is designed as mirror reflection to simulate back electrode.The structure of the micro-lens solar cell is shown in the Figure 2.

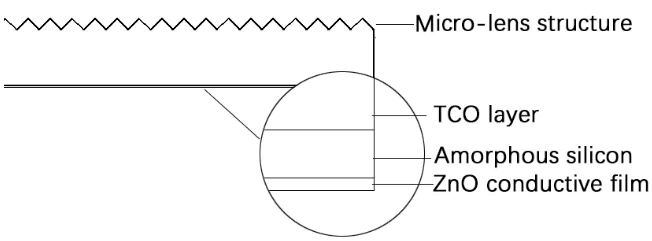

Figure 2 The structure of the micro-lens solar cell

2.2 Design of Solar Simulated Light Source in Summer Solstice

Solar simulated light source in summer solstice is designed by Tracepro Solar Emulator. TracePro Solar Emulator is the tool for analyzing 3D designs and simulating performance-based, standardized definitions for geographical location (latitude, longitude, and elevation), the period of sun travel with multi-axial tracking, and irradiance for both direct and indirect sun contribution [5].

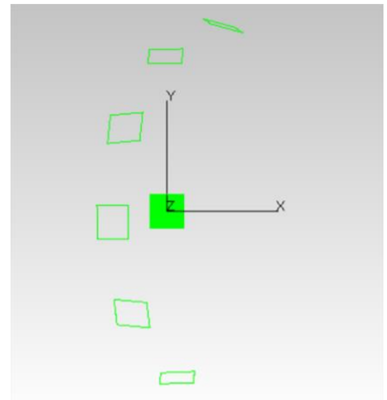

Figure 3 Solar light source during the summer solstice

Tracepro Solar Emulator is used to establish the direct and indirect sun models which are light sources for the simulation. Using the solar emulator to construct a two-hour step solar simulated light source from 8:00 to 18:00 during the summer solstice, which reflects the solar trajectory, and acts as the direct sun model as shown in Figure 3. The indirect sun contribution model under clear sky conditions is established by the Igawa all-sky model in Tracepro.

2.3 Design of Three Application Scenarios of BIPV

Lighting roof, building facade and shading are three common application scenarios of BIPV. These application scenarios is studied in a building sitting north and facing south.The building facade is south-facing, and the shading is located on the south-facing facade and the angle is equal to the latitude of Tianjin, the design site. As shown in Figure 4.

In this paper,taking the lighting roof application

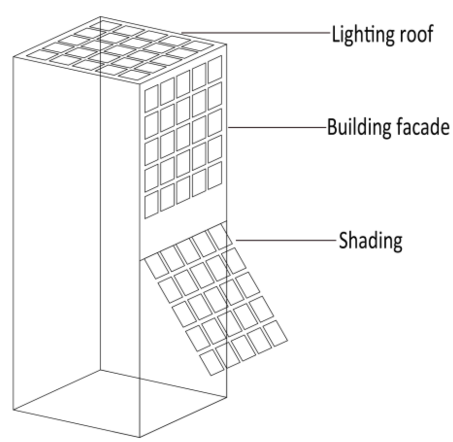

Figure 4 BIPV application scenarios

scenario as an example, the optimization design of micro-lens solar cells is illustrated.

3. RESULT AND ANALYSIS

3.1 Performance Analysis of micro-lens in the Application Scene of Lighting Roof

The performances of v-groove micro-lenses with different structures are analyzed with the irradiance flux on the incident surface of the amorphous silicon as an index. The irradiance flux and optical path of the incident surface of the amorphous silicon are calculated by Mente Carlo ray tracing method through the optical simulation software Tracepro.

100 V-groove micro-lens solar cells are simulated and analyzed under the condition that the light source is the summer solstice sun. The variation of the irradiance flux with groove depth and vertex angle is shown in the Figure 5.

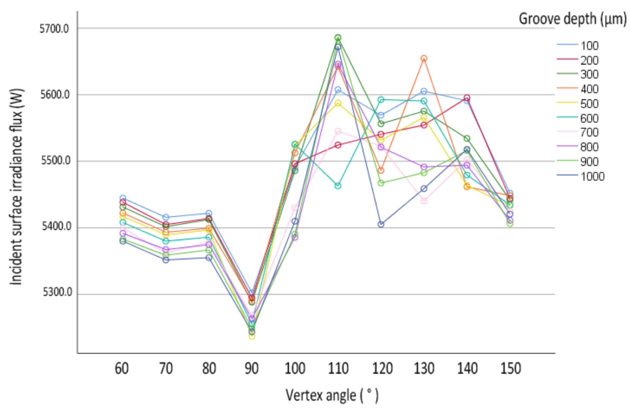

Figure 5 Irradiance Fluxes of Incidental Surfaces with Different micro-lens Structures

The performance varies irregularly with the change of groove depth and vertex angle, and the peak value of micro-lens structure performance occurs when the vertex angle is 110° and the groove depth is 300μm.

The single factor analysis of variance is used to more intuitively reflect the influence of groove depth and vertex angle on the performance through SPSS software. The influence of single factor of vertex angle or groove depth on performance can be obtained by constructing a chart of the average marginal estimation of vertex angle and groove depth as shown in Figure 6.

As can be seen from the figure, when the groove depth or the vertex angle is a single factor affecting the performance of the micro-lens, the change of the performance with the groove depth or the angle is still irregular. When the performance of micro-lens varies with the vertex angle, the peak value appears at 110 °. When the structure performance of micro-lens varies with the groove depth, the peak value appears at 300μm.

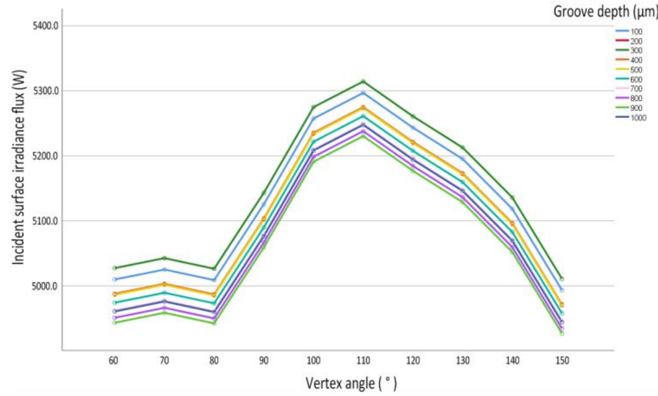

Figure 6 Incidence surface irradiance flux after one-way ANOVA

3.2 Light trapping performance comparison of different micro-lens structure for solar cell

Taking the irradiance flux of the amorphous silicon incident surface at different time as an index. The light trapping performance of three different micro-lens structures are compared in this section.The first is the micro-lens solar cell with a vertex angle of 110°and a groove depth of 300μm. The second is a non-micro-lens solar cell. Under the existing micro-lens processing conditions, a micro-lens light trapping structure with a vertex angle of 60° and a groove depth of 400μm has a nearly optimal performance for different wavelength light [6]. So it is selected as the last contrast object.

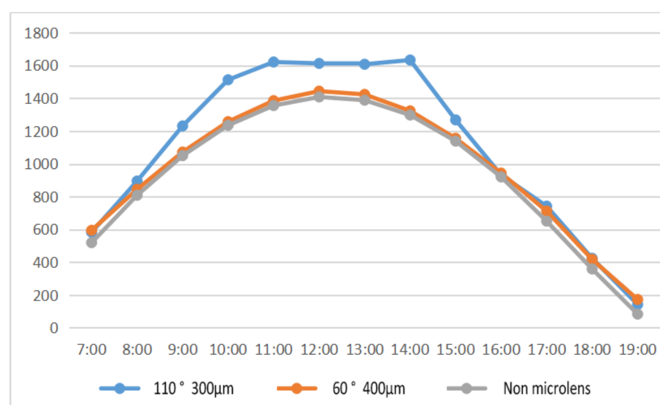

Figure7 Comparison of light trapping performance of different micro-lens structures

The light trapping performance of different micro-lens structures from From 7:00 to 19:00 in summer solstice day is analyzed, as shown in Figure 7.

It can be seen that the light trapping performance of solar cells with different micro-lens structures has little difference under weak light conditions from 7:00 to 8:00 and from 16:00 to 19:00. Under the strong light conditions from 9:00 to 15:00, the light trapping performance varies greatly. The light trapping performance of micro-lens structure with a vertex angle of 110° and a groove depth of 300μm increases fastest, and changes more smoothly in the peak region.

In the summer solstice period from 7:00 to 19:00, the irradiance flux on the incident surface of the amorphous silicon without a micro-lens structure is 12217.25 W/m^2. The incident irradiance flux on the surface of amorphous silicon with a vertex angle of 60° and a groove depth of 400μm micro-lens structure is 12746.98 W/m^2, which increased by 4.33%. The incident irradiance flux on the surface of amorphous silicon with a vertex angle of 110° and a groove depth of 300μm micro-lens structure is 14206.75 W/m^2, which increased by 16.28%.

The photoelectric conversion efficiency of amorphous silicon thin film solar cells is about 7%. When the photoelectric conversion efficiency of amorphous silicon film is 7%, the generation capacity of non-micro-lens solar cells is 0.3971 kWh from 7:00 to 19:00 in summer solstice, the generation capacity of the solar cell with a vertex angle of 110° and a groove depth of 300μm micro-lens structure is 0.4617 kWh, which increased by 16.28%.

3.3 Conclusions and Prospect

An optimization method of thin film solar cells with micro-lens structure for BIPV applications is proposed. In this method, the orientation and the setting angle of micro-lens thin film solar cells in BIPV application scenarios are taken as the research scenarios, and the objective is to obtain the micro-lens structure with the best trapping performance under the condition that the incident light changes with the solar trajectory through Tracepro software.

Taking V-groove micro-lens structure and BIPV lighting roof application scenario as an example, the optimal design of micro-lens structure is carried out. The results show that the micro-lens structure with a vertex angle of 110° and a groove depth of 300μm has the best light trapping performance. The irradiance flux on the incident surface of the amorphous silicon is 14206.75W/m^2, which is 16.28% higher than that of the non-micro-lens solar cells.

The optimization of micro-lens structure in BIPV building facade and sunshade scenario will be completed in the follow-up. The experimental verification scheme has been formulated and will be completed in the near future.

4. ACKNOWLEDGEMENT

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