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PHYSICS

DESIGN OF MICROLENS FOCUSED V-GROOVE TEXTURED SILICON SOLAR CELL WITH DIFFERENT ASPECT RATIO USING ZEMAX®

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Abstract
Improving the utilization ratio of sunlight is a key factor for the development of solar cell. In this work a V- groove model micromachined solar cell is designed and studies can be carried out for improving the efficiency of the microlenses focused solar cells with different aspect ratio. The simulation result shows the maximum of 40% increase in photonic absorption is observed in the V-groove silicon solar cell with 2 µm pitch and 1.5 µm height texture is better for light trapping structure.

Keywords: Light trapping; Microlens; V-groove micromachined Silicon solar cell; Aspect ratio; ZEMAX®.

Introduction

Solar energy is one of the cleanest energy sources in the world, but its utilization ratio is relatively low. Many methods were adopted to improve the utilization ratio of sunlight for solar cell. Dye sensitized [1] and textured [2, 3] silicon are the most common and effective technique to the efficiency of silicon solar cells up to now. A V-shaped grooves texture is obtained by mechanical grooving or wet chemical etching [4, 5].

Light trapping [6] increases the path length of light inside solar cells. This either leads to a highest short-circuit current density J_{sc} or it allows decreasing the thickness of the cell while maintaining the same J_{sc}. In the latter case the open circuit voltage V_{oc} is increased as bulk recombination is reduced with decreasing thickness [7]. In both cases therefore, light trapping improves the solar cell performance. Light trapping is commonly achieved by structuring the surface of the solar cell [8].

To simultaneously obtain high short-circuit current, some form of light trapping is required to boost the light absorbing properties of such thin layers. Two types of schemes have been proposed to achieve light trapping in solar cells. One of the types is based on randomizing the direction of light within the cell substrate. Once so randomized, only a small fraction of the light will lie within the escape cone for small fraction out of substrate surface from within. The rest is totally internally reflected giving rise to very effective light trapping [9]. The second type of scheme is based on regular geometrical structures [10].

In this work a 200 µm thick micromachined solar cell with an improved light trapping capability due to large metal area coverage is presented. The front surface of the cell is etched in KOH solution into V-grooves. One face of a V-groove is coated with Aluminum so that it steers the light onto the opposite face where the light is coupled into the cell. Microlenses concentrate the beam onto the steering reflectors. The microlenses are fabricated on quartz by reflowing patterned photoresist and replicating the profile in the substrate by ion beam milling [11]. Cell series resistance is minimized due to the large metal contact provided and hence enhancing the current collection.

Proceeding from this idea, we therefore investigated in detail about the effect of pitch and height of groove (aspect ratio) and another objective is to determine how light behaves when it strikes the V-groove then varying the angle of incidence and measured the number of times a ray strikes the V-groove silicon solar cells. Finally it should be compared with the flat type silicon substrate shows that the V-groove substrate has better light trapping structures.

V- groove solar cell texturing

One of the ways to improve the efficiency of a cell is to texture the surface of the silicon. Texturing has an effect of reducing reflection losses and improves the light trapping capabilities of the silicon cell. There are many different ways to texture silicon but the overall purpose is to reduce reflection and to increase light trapping [12]. In the design the aim is the fabrication of a thin solar cell that has an improved light trapping capability. In the cell V-grooves are positioned such that the coupled light passes through a V-groove misses the adjacent one as it travels to the bottom of the cell. The pitch of the lenses determines the pith of the V-grooves. In the case of textured solar cells, the incident wave was generated at a boundary, with a condition allowing the generated wave to enter the structure, and the wave reflected from the structure to

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be transmitted through this boundary, into a perfectly matched layer. This perfectly matched layer is simulating the semi-infinite surrounding by absorbing all the outgoing waves with a minimum of reflections. The electromagnetic wave equations were solved on the entire defined geometry taking into account the interference, refraction and reflection effects. In order to fix the geometry of the textured devices used for simulations, irrespective of the pitch, slope of the grating was kept constant for structures having same aspect ratio (pitch:height). Since different pitch structures had different area sizes exposed to the incoming solar flux, the incident power was normalized with respect to 1µm pitch size, giving it the unit of W/m^2. The electromagnetic power dissipation per volume, Q, in the active layer is studied as a criterion to optimize the height and pitch of the structures as well as the active layer. The total power absorbed (W/m^2) in a layer was calculated by integrating Q over the active layer space, summing over all the wavelengths and then normalizing with respect to the 1 µm pitch.

Theoretical analysis

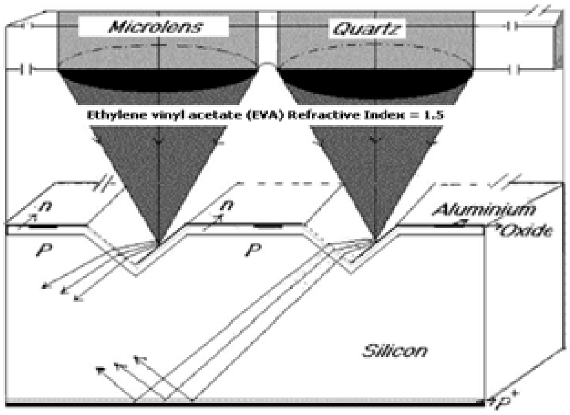
Our objective is to determine which cross-sectional shape will trap the light best. A problem will be trying to determine which cross-sectional shape to choose and how each will perform is that it is very difficult to model how light rays will act in the cell. Light will refract into the silicon and bounce off surfaces, making it extremely difficult to determine exactly what type of light path one could expect. Using ZEMAX®, a powerful ray-tracing program to model the path taken by light striking the surface. The ray tracing software should very precisely predict the path length of the light allowing us to decide which groove shape will provide the longest optical path in the silicon cell according to their aspect ratio. ZEMAX® only outputs the number of internal reflections of a ray inside the cell. From this, the actual light path is estimated by

$$L = 2R$$

Where L is the estimated light path and R is the number of internal reflections.

A solid model of the V-groove solar cell is shown in the figure 1. In this model, it is necessary to separate how the light ray will act in each direction in order to determine the total path length in the solar cell. The advantage of this design is the light trapping capability that is made possible by covering most of the cell surfaces with aluminum except in optical coupling areas. A photon enters the cell obliquely and can be absorbed on first transit or during subsequent passes as it bounces off the internal walls. By comparison in a plain surface solar cell the photons that are reflected from the back surface may be coupled out without contributing to photocurrent generation. Cell series resistance is reduced by the large area of aluminum contact and a minimized power loss in the cell. The effect of oblique incidence was determined using the V–groove profile with unit aspect ratio. This is assuming that oblique incidence will have the same effect on the total light path regardless of the surface texture. First, the source was shifted to the rear of the cell, so that light would strike at the rear and continue to the front of the cell. The source was then tilted by 10 degrees so that rays strike the top surface of the glass at an angle of 10 degrees with respect to the normal. At this angle, a number of rays were sent into the cell and finally the total number of rays hit was recorded. The same procedure was repeated for incident angles up to 90 degrees, at an internal of 10 degrees. Ethylene vinyl acetate (also known as EVA) is used as an encapsulation material for micromachined (V-grooved) silicon solar cell in the device geometry and its refractive index is assumed to be same as that of quartz.

Figure 1. Schematic diagram of EVA encapsulated V-grooved solar cell with microlens array



Result and Discussion

From Figure 2, the ratio of maximum absorption height level and the total height of groove are found to decrease on increasing the pitch. This is because the width, at which light diffraction suitable for trapping takes place, lies closer to the bottom of the groove for bigger pitches. On decreasing the aspect ratio, the groove structure becomes narrower and hence the energy concentration region shifts farther from the bottom of the groove. This explains the reason for lower aspect ratio having larger ratio of maximum absorption height for a fixed pitch, as shown in Figure 2. For 2 µm pitch-1.5 µm height groove structure, the maximum absorption height increases with increasing wavelength of light as seen in Figure 3.

For solar cells in a practical environment where sunlight can be quite diffused, it is important to evaluate the absorptance over a wide range of incident angles. Figure 4 suggests that 2 µm pitch-1.5 µm height groove structure has a distinguished advantage over flat device for all incident angles and thus in the real environment. The absorption efficiency of flat surface drops more abruptly as the incident angle increases when compared to grating structure, as shown in Figure 5. Hence Higher relative energy dissipation in groove structure is attributable to the suppression of reflection loss.

Figure 2. Dependence of the ratio of maximum absorption height of groove and height of pitch size for 1:1, 4:3 and 2:1 (aspect ratios)

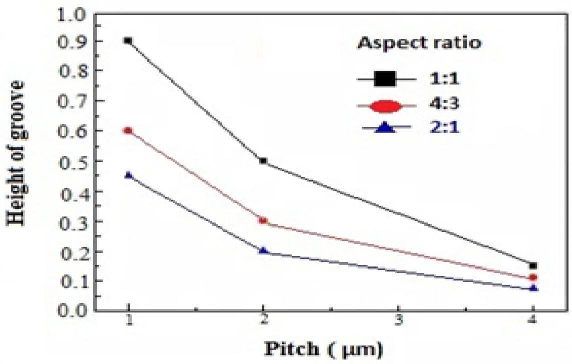


Figure 3. Variation of maximum absorption height with wavelength in 2 µm pitch-1.5 µm height structure

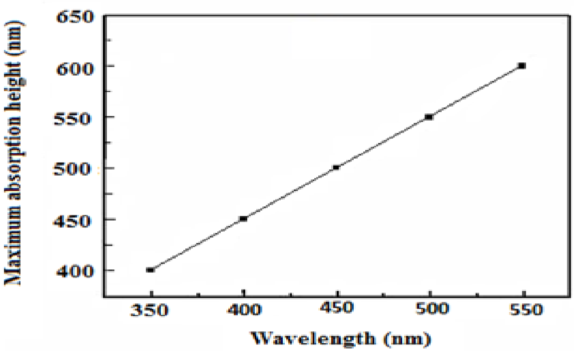


Figure 4. Energy dissipation as a fraction of incident power

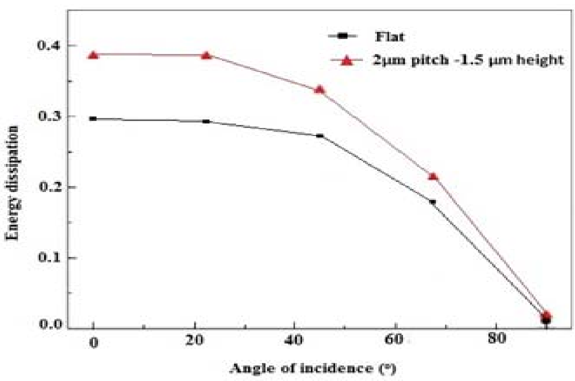
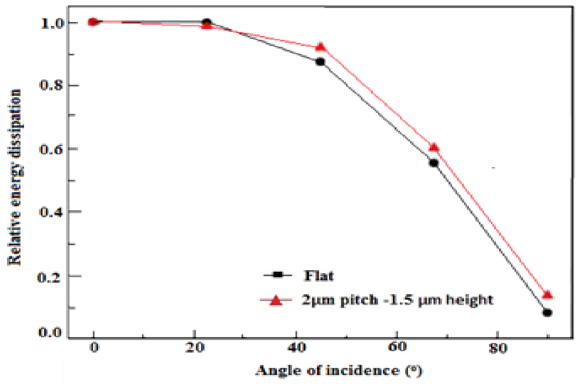


Figure 5. Relative Energy dissipation as fraction of energy dissipated at 0° (normal incidence)



Conclusion

Using a Zemax®, we have modeled the microscale V-groove textured silicon solar cell and to determine the effect of rays entering the cell through microlens with different aspect ratio. A maximum of 40% increase in photonic absorption is observed in the V-groove silicon solar cell with 2 µm pitch and 1.5 µm height textures. Finally a comparison was performed between the flat and V-groove solar cell of different incidence angles. Overall, the V-groove texturing with unit aspect ratio should be used to better light trapping in micromachined solar cells and increase their overall efficiency.

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