Effects Of Pn Junction Position Depth On Output Current Of Solar Cell

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Abstract: - The effect of position of pn junction on output current for both micro rectangular texturing and planer surface in solar cell has been investigated by ray tracing. This includes in geometric optic modeling and finding the effect of position of pn junction on improving the efficiency. By using ATLAS software show that the position of pn junction is very important when applying texturing to the surface of solar cells. Texturing improves the efficiency but the effectiveness increases with the depth of pn junction. A textured solar cell with 40 µm depth of pn junction has the efficiency 3 times more than same non-textured solar cell. Introducing the current variation in 0.25 volts for two surfaces supports this conclusion.

Key-Words: - texturing, thin solar cell, efficiency, depth of pn junction, current variation

1 Introduction

It was shown texturing can be considered as a good candidate to solve the cost price and efficiency problem of thin solar cell [1]. By texturing the light are traveled more inside the cell and the absorption of it was increased as the length of traveling increased. The shape and the size of the patterns could affects on the efficiency.

The interaction of KOH with silicon was making very fine pyramids as a texturing in the solar cell. In micro-electronics area the photolithography method, made some investigation on texturing and good efficiency such as inverted pyramids that used in PERL cell or PESC cell structure. In both of these two kinds, diffusion and surface passivation, by oxide or nitride, are effected early in the cell fabrication sequence, after surface etching and texturing [2].

In numerical method especially Fast Fourier Transformation (FFT) caused in some opto-electronic software we could directly solve Maxwell equation (or Helmholtz equation).The usage of “Solvacos” software “ATLAS” are already investigated in solar cell application [5]. By this novel model extracts the electrical characteristics of a solar cell based on virtual fabrication of its physical structure, allowing for direct manipulation of materials, dimensions, and doping.

As a per-design of solar cell we have an investigation on dependence of surface texturing and depth of pn junction in 2d geometric optics.

2 Mathematical Approach

In very simple language the generation of electricity by the light energy is the problem. There are several factors to be considered, (1) the theories of light , (2) interaction of light with the mater, (3) producing the electron and hole in semiconductors in a pn junction, and finally (4) creative current electricity. The first approximation is to be begun with geometric optics because it is not only easier to calculate but it gave an idea about the future works. In geometrical optic, light is defined by the rays. Every ray have move straight that was consider with especial amounts of energy. Because of the interaction of light with mater, a specific formula needs to know. This indicates that electrical field of ray at anyplace would be there. The transmitted or reflected ray can be calculated by using simple formulas. These formulas of electrical fields can be found in a command textbook.

The reflection and transmission electrical field of the light for parallel and perpendicular polarization are calculated as shown in Equations 1 to 4. Equations of 5 and 6 show their coefficients.

$$E_r = \frac{n_2 \cos\theta_i - n_1 \cos\theta_t}{n_1 \cos\theta_t + n_2 \cos\theta_i} E_i \quad (1)$$

(Parallel polarization)

$$E_t = \frac{2n_2 \cos\theta_i}{n_1 \cos\theta_t + n_2 \cos\theta_i} E_i \quad (2)$$

(Parallel polarization)

$$E_r = \frac{n_1 \cos\theta_i - n_2 \cos\theta_t}{n_1 \cos\theta_i + n_2 \cos\theta_t} E_i \quad (3)$$

(Perpendicular polarization)

$$E_t = \frac{2n_1 \cos\theta_i}{n_1 \cos\theta_i + n_2 \cos\theta_t} E_i \quad (4)$$

(Perpendicular polarization)

$$R = \left(\frac{E_r}{E_i}\right)^2 \quad (5)$$

$$T = \left(\frac{E_r}{E_i}\right)^2 \frac{n_2}{n_1} \frac{\cos\theta_t}{\cos\theta_i} \quad (6)$$

where E_i is electric field of the incident wave, E_r is the field of the reflected wave; E_t is the field of the transmitted wave. R is the reflection coefficient, T is the transmission coefficient, n_1 is the refractive index on the incident side and n_2 is the refractive index on the transmission side.

The angles of reflection and transmission are given in Equations 7 and 8.

$$\theta_r = \theta_i \quad (7)$$

$$n_1 \sin\theta_i = n_2 \sin\theta_t \quad (8)$$

where θ_i is the angle of incidence, θ_t is the angle of transmission and θ_r is the angle of reflection.

Poisson's Equation relates the electrostatic potential to the space charge density:

$$\nabla.(\varepsilon \nabla \psi) = -\rho \quad (9)$$

where ψ is the electrostatic potential, ε is the local permittivity, and ρ is the local space charge density. The reference potential can be defined in various ways. The local space charge density is the sum of contributions from all mobile and fixed charges, including electrons, holes and ionized impurities.

The electric field is obtained from the gradient of the potential.

$$\vec{E} = \nabla \psi \quad (11)$$

The continuity equations for electrons and holes are defined by equations:

$$\frac{\partial n}{\partial t} = \frac{1}{q} \nabla.\vec{J}_n + G_n - R_n \quad (12)$$

$$\frac{\partial p}{\partial t} = \frac{1}{q} \nabla.\vec{J}_p + G_p - R_p \quad (12)$$

where n and p are the electron and hole concentration, J_n and J_p are the electron and hole current densities, G_n and G_p are the generation rates for electrons and holes, R_n and R_p are the recombination rates for electrons and holes, and q is the magnitude of the charge on an electron.

The cumulative effects of the reflection coefficients, transmission coefficients, and the integrated loss due to absorption over the ray path are saved for each ray. The generation associated with each grid point can be calculated by integration of the Generation Rate Formula (Equation 13) over the area of intersection between the ray and the polygon associated with the grid point.

$$G = \eta_0 \frac{P^* \lambda}{hc} \alpha e^{-\alpha y} \quad (13)$$

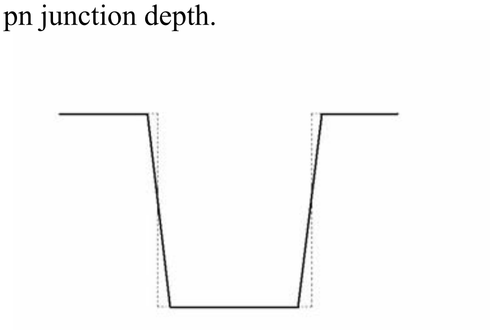
where P^* contains the cumulative effects of reflections, transmissions, and loss due to absorption over the ray path, η_o is the internal quantum efficiency which represents the number of carrier pairs generated per photon observed, y is a relative distance for the ray in question., h is Planck's constant, λ is the wavelength and c is the speed of light α is given by Equation 14.

$$\alpha = \frac{4\pi}{\lambda} k \quad (14)$$

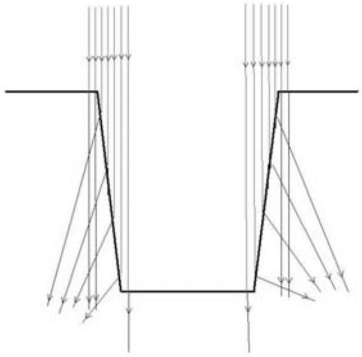
Where α is the absorption coefficient, λ is the wavelength and k is the imaginary part of the optical index of refraction.

3 Atlas Modeling

The solar cell that has been chosen for test is made in usual method in VLSI. A [100] silicon wafer with 50 μm thickness and 1 x 10^{14} boron concentration was chosen. The pn junction was developed by implant of phosphor with 5 x 10^{15} and energy 10. The diffuse time and the temperature are considering variables for investigation. By changing these two variables, eight solar cells with a pn junction at 5 μm to 40 μm below the first surface could be simulated. By plotting the IV graphs, the solar cell with a simple surface and a textured surface will be compare for each. For texturing surface of solar cell, the ATLAS software was used. By using an etching method, a rectangular channel with the dimensions 5 x 5 x 5 μm was made. In this investigation, ray tracing method was used and the channel was changed to conical shape (Fig. 1). This is because the ray can be traced with only 90° incident angle. Fig. 2 shows the computer simulations of simple and textured surfaces of the solar cell with 5 µm pn junction depth.

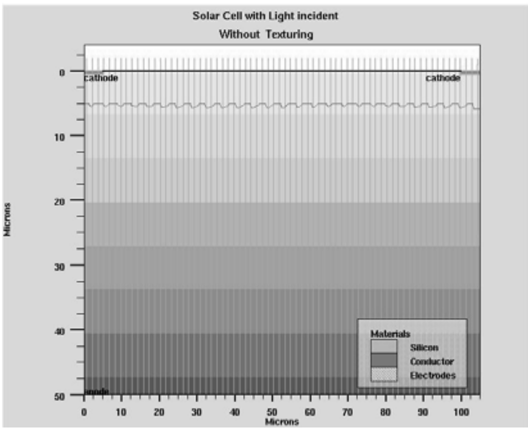


(a)

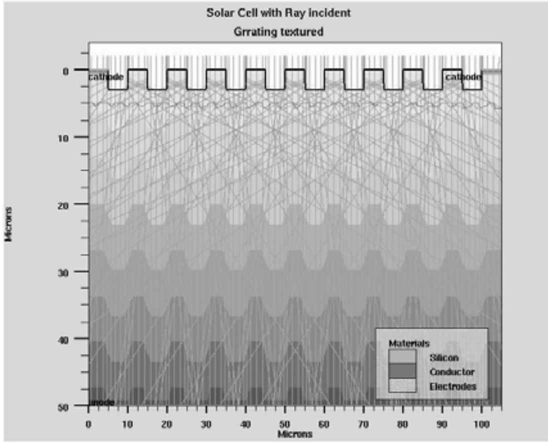


(b)

Fig. 1: changing the rectangular channel to conical shape. Angle of tilt and ray refraction are exaggerated (a) tilted wall (b) ray tracing in sidelong



(a)

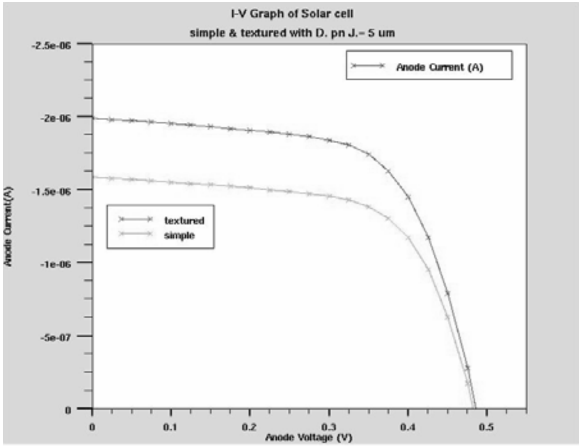


(b)

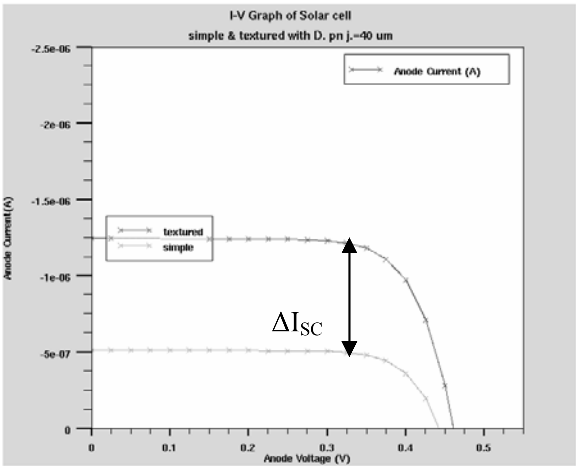
Fig. 2: Solar cell simulation with (a) simple surface and (b) rectangular texturing.

4 Results and Observations

In this project, eight solar cells with different pn junction depths and the same texturing have been investigated. Fig. 3 (a) to 3 (b) show the I-V graphs for two of them in comparison with planar solar cell. By comparing Fig. 3 (a) with Fig. 3 (b), it is found that the pn junction depth is more effective on simple surface and texturing the surface make it more stable with the variation of pn junction depth. Of course this effect show itself in texturing when the depth of pn junction have very serious variations as it could be seen in the other graphs (Fig.4), but still this variation is lesser than simple surface. As it has been showed in Fig. 4 the effect of changing the position of pn junction near the front surface in textured solar cell is negligible. And vice versa in compare to bare solar cell Fig. 4 has been shown depth of pn junction has effectively affect on the current and the efficiency. The effect of position of pn junction is 3 times more than in bare silicon solar cell in the range of 5 to 20 µm and this decrease to 0.75V in the range of 20 to 40 µm (Fig.4)



(a)



(b)

Fig. 3: I-V graph of solar cell with different pn junction depth, (a) 5 µm and (b) 40 µm below the front surface.

The lowest curve is the difference output current between two solar cells. It could be recognized two maxima in it, the first one around depth of 10 µm and the second about the 33 µm.

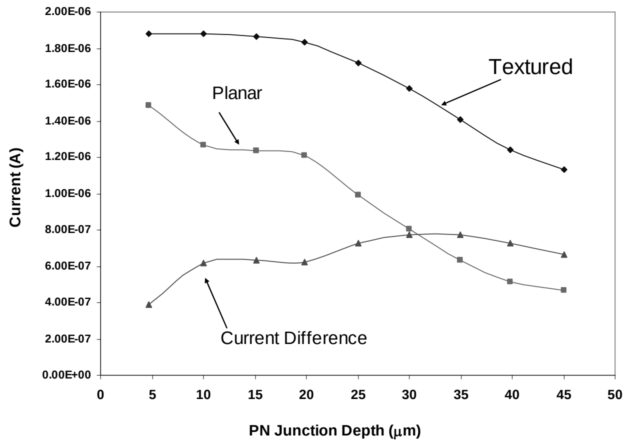


Fig. 4: Variation of photocurrent in voltage 0.25V depends on the position of pn junction for bare and textured surface.

5 CONCLUSIONS

By comparing the graphs in Fig. 4 it is show that effect of texturing changed as the depth of pn junction changed. The effect of the depth of pn junctions is to be considering in this work. In a pervious works, it is better to design solar cell after finding the optimum texturing with maximum absorption. This can be improving the efficiency of the system. It may also consider a special texture for every kinds of solar cell that it means one texturing that may be sufficient for one solar cell and may not useful for another one. This can be suggested that at first step it would be better find the best texturing by Geometric optics or wave optics then will try to improve solar cell efficiency by matching the pn junction depth or materials.

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