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ANALIZING THE EFFECT OF LIGHT INCIDENCE ANGLE ON PHOTOELECTRIC PARAMETERS OF SILICON SOLAR CELL

Annotation: The study of silicon solar cells by measuring its I-V characteristics and defining of basic photoelectric parameters is executed. By using of new special (tracer) machine the angle of light incidence on a solar cells and panels is determined. First, the location of the sun is determined by the time and coordinates. Second, the AOI is calculated by the location of the sun.

Key words: Geometric models, renewable energy, interactive session, nanotechnology, silicon-based solar cells, energy, alternative, power, socio - humanitarian knowledge.

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АНАЛИЗ ВЛИЯНИЯ УГЛА ПАДЕНИЯ СВЕТА НА ФОТОЭЛЕКТРИЧЕСКИЕ ПАРАМЕТРЫ КРЕМНИЕВОГО СОЛНЕЧНОГО ЭЛЕМЕНТА

Аннотация: Выполнено исследование кремниевых солнечных элементов путем измерения их ВАХ и определения основных фотоэлектрических параметров. С помощью новой специальной (трассирующей) машины определяется угол падения света на солнечные элементы и панели. Во-первых, местоположение Солнца определяется временем и координатами. Во-вторых, угол обзора рассчитывается по местоположению Солнца.

Ключевые слова: Геометрические модели, возобновляемая энергетика, интерактивное занятие, нанотехнологии, солнечные

элементы на основе кремния, энергетика, альтернатива, энергетика, социально-гуманитарные знания.

Today, one of the most pressing issue is widely use of different renewable energy sources to improve the environment. The types of renewable energy sources have been increasing for last few years [1]. The conversion of solar energy into electricity is one of the prosperous way. Increasing the efficiency and the decreasing of semiconductor solar cells cost is being observed lately.[2]. Silicon-based solar cells made up 97% of the solar cells produced in the industry. Silicon is the most common semiconductor material on Earth [3]. There are also solar cells with high efficiency on the base of other semiconductors, but most of them are expensive. Therefore, studying and improving of silicon-based solar cells is of current interest. There are three kind of energy losses in the solar cells: optical, recombination, and thermal. These losses limit the theoretical maximum efficiency of a silicon-based solar cells to 29%and it does not exceed it. [4]. Methods for creating of surfaces textures and coating with optical layers [5] have been developed to improve of the optical properties of solar cells. To reduce the surfaces recombination, the front and back of the solar cell should be covered with optical layers [6]. For improving the thermal conductivity and for defensing the solar cells contour from overheating it is recommended to take the back contact in the grid form. When a nanoparticle is inserted into silicon, it affects properties of solar cells [5]. The position of sun according to the day and hour changes accordingly the angle of incidence of light falling on the solar panel changes. Therefore, in this paper, the dependence of basic photoelectric parameters of a simple solar cell on the angle of incidence light has been studied.

The study of silicon solar cells by measuring its I-V characteristics and defining of basic photoelectric parameters is executed. By using of new special (tracer) machine the angle of light incidence on a solar cells and panels is determined. First, the location of the sun is determined by the time and coordinates. Second, the AOI is calculated by the location of the sun. Many different methods of digital modeling are designed. Currently, the most reliable and widely used programmes by scientists are Silvaco TCAD (Technology Computing Aided Design) and Synopsys Sentaurus TCAD [5]. These programs are designed for high-precision modelling of semiconductor devices in 3d/2d /1d formats [6]. But, Comsol Multyphysics is used for modelling the interaction between the solar cells and environment.

In the latest research the optical parameters of an amorphous silicon solar cells with surfaces silver nanoparticles were studied as a function of the AOI [5]. Improving of the absorption coefficient by 6% in depending on the AOI was founded. Several scientists have studied nanoparticles included into solar cells of the frontal optical layer. The effect of the surface plasmonics on solar cells has been studied [6]. In this work the AOI dependences of the main photoelectric parameters of the silicon solar cells with platinum nanoparticles included in the n region was studied. The reason for the choice of platinum material as a nanoparticle is that, according to previous scientific research its effect on the solar cell is better than other types of nanoparticles [6]. Therefore, the authors of present work has researched the main photoelectric parameters of nanoparticles included solar cell (NISC) and simple solar cell (SSC) in depending on the angle of incidence (AOI).

For determining of the photoelectric properties of solar cells, the automatic device “Sinton Instruments Suns-Voc” is utilized. In this device, a xenon lamp as the light source is employed. Main photoelectric properties of the solar cells are the I-V characteristic and the dependence of the open-circuit voltage from the light intensity. The intensity of Suns-Voc changes from 0.1 to 10 suns. Besides, the I-V characteristics of a single solar cell and a solar panel under natural sunlight by using of the mechanical method with a set of resistors R33 class 0.2 GOST 7003–54 were obtained.

For modeling of solar cells Synopsys’s Sentaurus TCAD software has been used. The Sentaurus TCAD consists of 20 instruments, of which 17 are primary and 3 are auxiliary instruments. For modeling solar cells four main tools are used: Sentaurus Structure Editor (SDE), Sentaurus Device (SDevice), Sentaurus Visual (SVisual), and Sentaurus Work Bench (SWB).

Table 1

Information on each area of the geometric model of a silicon-based solar cell embedded in a nanoparticle

		Co	Optic layer	n+ layer	n	p	p+	Na
NI SC	Material type	Si	SiO_2	Si	Si	Si	Si	Pt
	Thickness	3r	3r	5r	7r	46r	4r	
	Width, mkm	0.2	1.8	2	2	2	2	
	Doping atoms type	P	-	P	P	B	B	
	Doping concentration	1e19	-	1e18	1e17	1e15	1e16	

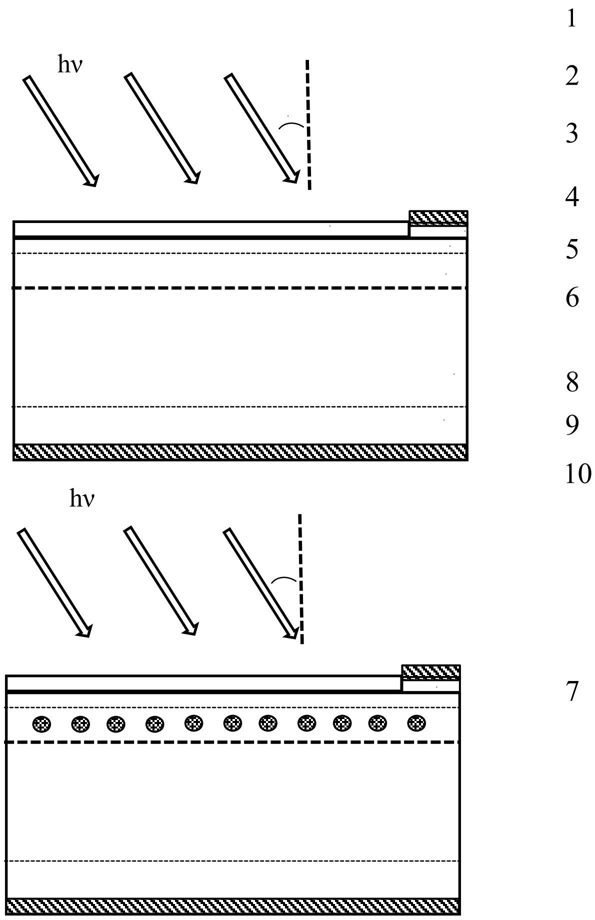
The geometric model of solar cells is created by the following order. 1.The coordinates, names, and material type of the fields are given. 2. Doping concentration and doping type are given. 3. Electrodes are given and activated. 4. All regions are meshed. In region of p-n junction and nanoparticles more smaller meshing are used.

Reflection and transmission factors of surfaces by using the AOI and refractive indices of media are calculated. Here, mainly method of Fresnel coefficients (1) are used.

$$t_{\parallel} = \frac{2n_1 \cos\beta}{n_1 \cos\gamma + n_2 \cos\beta} \quad (1)$$

In (1): n_1 – refractive index of the first media, n_2 – refractive index of the second media, β – AOI γ – refraction angle light.

By using of the Fresnel coefficients, reflection and transmission of surface are determined (2).



$$R = \frac{(r^{\parallel})^2 + (r^{\perp})^2}{2} \qquad T = \frac{n_1 \cos\gamma}{n_0 \cos\beta} \cdot \frac{1}{t} \qquad (2)$$

In (2): R – Reflection, T – Transmission. For determining the light absorption in the Si layers, the Burger-Lambert law is used (3).

$$I = I_0 e^{-\alpha d} \qquad (3)$$

In formula 3: d – thickness of the layer, α – absorption coefficient of layer, I_0 – initial intensity of light, I – the light intensity, which is the end of d layer.

Fresnel formulas only for determining the optical properties of surfaces are used. Burger-Lambert law only for calculating of the absorption in a layer is used. The solar cells are multilayer semiconductor devices. The Fresnel and Burger-Lambert laws can be applied simultaneously by using the Transfer Matrix Method (TMM) (4) [6].

$$\frac{1}{t_{01}}\begin{bmatrix} 1 & r_{01} \\ r_{01} & 1 \end{bmatrix} \equiv D_{01} \qquad \begin{bmatrix} e^{ikd} & 0 \\ 0 & e^{-ikd} \end{bmatrix} \equiv P_1 \qquad \begin{bmatrix} E_i \\ E_2 \end{bmatrix} = D_{01} \cdot P_1 \cdot D_{12} \cdot P_2 \cdot D_{23} \begin{bmatrix} E_t \\ 0 \end{bmatrix}$$

$$D_{01} \cdot P_1 \cdot D_{12} \cdot P_2 \cdot D_{23} \equiv M \qquad \begin{bmatrix} E_i \\ E_2 \end{bmatrix} = M \begin{bmatrix} E_t \\ 0 \end{bmatrix} \qquad (4)$$

In (4): D_{ij} – transmission matrix, P_j – propagation matrix, M – transfer matrix, E_i – the electric field of the incident light, E_r – the electric field of the reflected light, E_t – the electric field of the transmitted light, r_{ij}, and t_{ij} – Fresnel coefficient.

Fig. 1 Picture of SSC and NISC. Here: 1 – the angle of incidence light, 2 – optic layer, 3 – front contact, 4 contact layer, 5 – n++ layer, 6 – n layer, 7 – nanowire, 8 – p layer, 9 – p++ layer, and 10 –back contact.

TMM helps for analyzing the optical properties of solar cells. By using of this method the optical phenomena on the surfaces of nanoparticles and semiconductors can be explained. However, the physical phenomena in nanoparticles cannot be explained by only optics. The electrons inside the nanoparticle vibrate in the electromagnetic field of light. Nanoparticle absorbs light in one spectrum and emits light in another. This phenomenon is called the nanoplasmonic effect.

The nanoplasmonic effect can cause three phenomena. 1. Nanoparticle absorbs light in one spectrum and emits light in another. 2. If the oscillation frequency of the electromagnetic field of light source will be equal to the oscillation frequency of the electrons inside the nanoparticle, resonant phenomenon occurs. Then, the nanoparticle emits extra electron. 3. Both the above events can occur simultaneously.

The occurrence of the nanoplasmonic effect directly depends on the size of the nanoparticle and its material type.

$$I_{sca}(\omega)=\frac{I_0(\omega)}{S}C_{sca}(\omega) \qquad \alpha=3\varepsilon_0 V\frac{\varepsilon_r-1}{\varepsilon_r+2} \qquad \varepsilon_r=\varepsilon_r^{'}+i\varepsilon_r^{''} \qquad C_{sca}=\frac{k^4}{6\pi}\left|\frac{\alpha}{\varepsilon_0}\right|^2 \quad (5)$$

In (5): I_0 – intensity, which is the incidence to the nanoparticle, I_{sca} – light intensity, nanoparticle radiate, α – absorption coefficient, V – the volume of the nanoparticle, ω – light frequency, ε_r – relative permittivity, k – wavenumber.

By using of (5) the relationship between the light intensity, which is incident on a nanoparticle and the light intensity which is emitted by the nanoparticle is determined.

I-V characteristics of solar cells with p-type silicon and 100 nm SiN_x layer and 1 cm^2 area under 0.7 suns was tested. Coordinates of experimentation place is: 40 ° 440 ° 47′17,72°22′217′17″ and time: 17.03.2020 13:00.

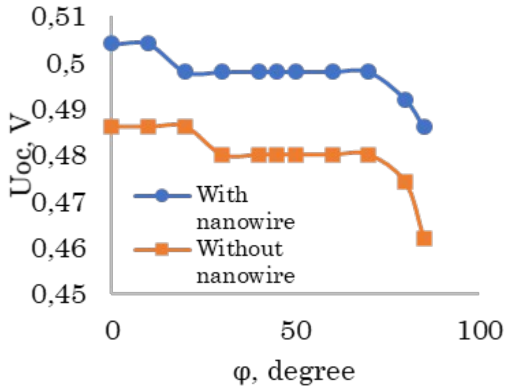


Fig. 2. . Graph of the dependence of the open-circuit voltage of a SSC with NISC on the AOI

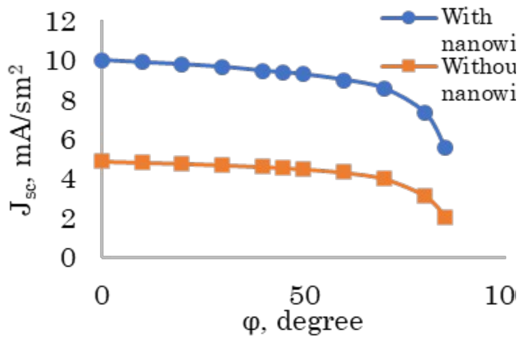


Fig. 3. Graph of the dependence of the short-circuit current density of a SSC and NISC on AOI

By using of standardized equipment of Renewable Energy Sources Laboratory at Andijan State University also main parameters of industry type of solar panels are measured.

Graph of the dependence of the open-circuit voltage of a SSC and NISC on the AOI in Fig. 2 has been brought. Both curves quality of the open-circuit voltage for NISC and SSC are approximately the same. However, open-circuit voltage of NISC is over to 0.02 V than SSC. Analogical quality dependences of other main photoelectric parameters on the AOI for both type of solar cells are observed: short-circuit current density, maximum power density and fill factor.

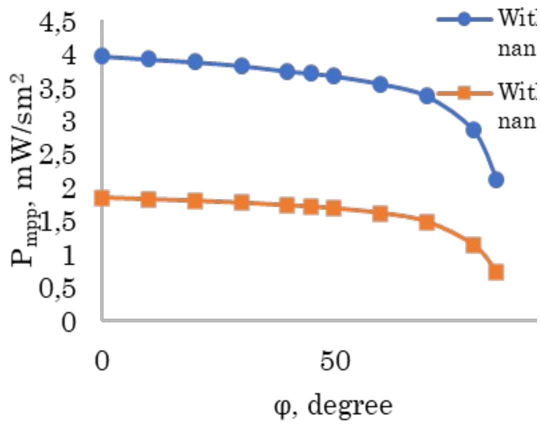


Fig. 4. Graph of the dependence of maximum power of a SSC and NISC on the AOI

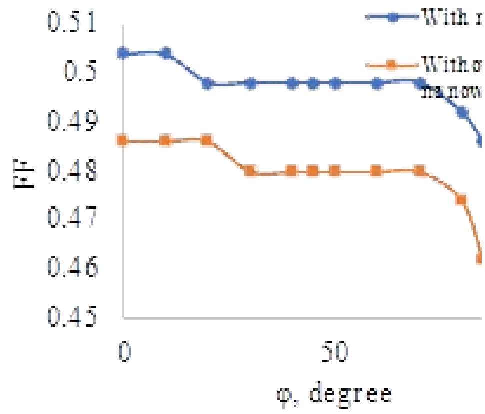


Fig. 5. Graph of the dependence of the fill factor of SSC and a NISC on AOI

In fig. 3 short circuit current density for NISC is two times greater than that for SSC. But curves quality of them is identical. Linearity of curve for NISC is better than for SSC. In figure 6 power density curve is similar to short circuit density curve for both type of solar cells. In Fig. 5. The dependences of fill factor on AOI for both type of solar cells are not linear. Fill factor of I-V characteristics of solar cells changes variously at different AOI. However, curves quality of dependence of fill factor on AOI for NISC and SSC are same.

Received results show that the angular coefficients of the photoelectric parameters are equal to different values at different AOIs. Angular coefficients of short circuit current and power density for linear part of the curves are calculated. In fig. 3 the angular coefficient of short-circuit current density is $dJ_{sc}/d\varphi$=0.021 mA/sm^{2}degree in the angular range of 0 to 70 degrees for NISC. In figure 6 the angular coefficient of power density is $dP_m/d\varphi$=8.6e-3 mW/sm^{2}degree. For the SSC $dJ_{sc}/d\varphi$=0.013 mA/sm^{2}degree and $dP_m/d\varphi$=5.1e-3 mW/sm^{2}degree. Fill factor isn't linear (Fig.5). If accept the angular coefficient of the photoelectric parameters is θ_n for NISC and θ_s for SSC, relationship between them is approximate as follows:

$$\Theta_n \approx 2\Theta_s \qquad (6)$$

If consider that the short-circuit current is linear at angles of 0 and 60 degrees then it is changed to 11% for SSC and to 10% for NISC. However, short-circuit current was changed to 1.7% when Sharma modelled a silicon-based solar cell by using of PC1D software. Because Sharma considers that the simple solar cell has a textured frontal surface. The textured frontal surface improves the dependence of the photoelectric parameters of the solar cells on the AOI. In his work, at from 0 to 60 degrees interval, crystalline silicon solar module relative short circuit current decreased 1.7 times. Relative error measurements were smaller than one percentage. If light intensity which falls perpendicular on surface of photovoltaic module is 1000 w/m^2, it will be 600 W/m^2 at 60 degrees AOI on surface of photovoltaic modules. In this paper all results can be understood by changing of light intensity. Between the results of present research and others there are little differences. The above results show that the photoelectric parameters for NISC are better than for SSC. However, the variation of photoelectric parameters depending on the AOI is approximately the same. The improvement in the photoelectric parameters for NISC can be explained by using of the nanoplasmonic effect mechanism. Silicon-based SSC absorbs only visible light. If platinum nanoparticles is inserted into the solar cell, the solar cell will begin absorbing both infrared and ultraviolet light. Because platinum nanoparticles behave as light wavelength converter. If the size of the nanoparticle is comparable with wavelength light the nanoplasmonic effect occurs. Due to the nanoplasmonic effect, platinum nanoparticles absorb infra-red light and emit light in a visible spectrum. The electrons inside the nanoparticle vibrate in electromagnetic field of light. If the frequency of the vibrations the electrons inside of the nanoparticle is equal to the frequency of the electromagnetic field, and a resonance emits and releases electrons from the nanoparticle into the silicon.

The efficiency of NISC which is considered as platinum nanoparticles with size 15 nm in n field of Silicon with a distance between neighbor nanoparticles 100 nm relative to the efficiency of SSC increases twice. However, the dependence of the photoelectric parameters of NISC on the angle of incidence light is similar to SSC. Platinum nanoparticles did not affect the function of each photoelectric parameters dependence on the AOI. There can be formed two conclusions. First, if nanoparticles absorb infrared light and emit visible light, the angle of emitted light corresponds to the AOI. Second, if a nanoparticle emits extra electrons when it absorbs light, the output concentration of the electrons changes according to the AOI. And because of the light intensity of reaching to the nanoparticle is changed according to the AOI. In the solar cells with included in the n field metal nanoparticles, above two events can be occurred simultaneously. Therefore, it is clear from the results that the above conclusions do not contradict each other at the same time.

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