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Modelisation of the Incident Solar Rays on the Textured Surface of the Solar Cells

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Abstract: In this study, the development of a new solar cell prototype is presented in order to improve photovoltaic efficiency. In this model we show that the material can have three successive incident ray absorptions instead of two currently, by varying the incidence angle, the aperture between the summit of two neighboring pyramids and their height. This study concerns in particular the photovoltaic parameters such as the spectral response, the absorption coefficient and the generation rate. This model was checked for angles varying between 54 and 60° and for pyramid heights between 5 and 10 μm. For these values of incidence angle, the apertures between the summits of two neighboring pyramids varied respectively from 14.54 to 11.54 μm for a pyramid height of 10 μm.

Key words: Solar cells, textured surface, modelisation, solar rays, spectral response, photovoltaic efficiency

INTRODUCTION

Photovoltaic materials (Grasso *et al*., 2005; Möller *et al*., 2005; Shah *et al*., 2003) are distinguished by an index of refraction greater then 3 and a high reflection coefficient in the visible spectrum. The reflection can be more reduced by covering the cell surface with an anti-reflective layer in order to bring the percentage of the reflected rays to a reasonable value. In effect a normal plane of silicon can reflect up 35% of the received rays (Goetzberger *et al*., 2003). This rate can be reduced to 10% if the plane is covered with an anti-reflective layer and hence making the penetrating rays rate to reach 90%. With the prototype presented in this model three reflection can be minimized to less than 10%, leading to the improvement of the spectral response, the absorption coefficient, the generation rate and the photovoltaic efficiency.

DEVELOPMENT OF THE SUGGESTED MODEL

In this model, the textured surface is obtained by an anisotropic chemical attack on semiconductor material. The pyramids obtained by this mechanism present regular orientations and having a height comprised between 5 and 10 μm.

The model suggested in this study allows the material to have three successive absorptions of the incident rayon, by varying the incident angle i, the aperture between the pyramids f and their height h.

This model is based on reflection and refraction laws of incident rays on the surfaces of two neighbouring pyramids. By considering N the number of rays that are incident on the surface of the pyramid I and r the reflection coefficient, the proportion of the absorbed rays by the material is given

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by N (1-r) whereas that of the reflected rays is Nr. These tatters fall on the surface of the pyramid II where they are absorbed with Nr (1-r) proportion, while Nr^2 proportion is reflected. A change of the aperture between the summits the neighbouring pyramids will allow the Nr^2 rays to fall a second time on pyramid I (Fig. 1). This mechanism will permit to recuperate an third proportion of the incident rays $Nr^2(1-r)$, that will participate to the improvement of the photovoltaic properties such as the spectral response, the absorption coefficient and generation rate. The total amount of the absorbed rays in the sum of the three successive incidences and is given by $N(1- r^3)$.

Let ϕ to be the angle between the incident ray Nr^2 and the face of pyramid I and α the angle between the two neighbouring pyramids:

$$\alpha = i+i' \quad (1)$$

The sum of a triangle angles is π, Thus:

$$\varphi = \left(5i - \frac{3\pi}{2}\right) \quad (2)$$

And as $\phi>0$ then

$$i > \left(\frac{3\pi}{10} = 54°\right) \quad (3)$$

If i represents the angle of the first projection on the surface of pyramids I and i' the angle the second projection on the surface of the second pyramid then:

$$i' = \pi - 3i \quad (4)$$

In the case of crystalline silicon and for wave length $\lambda = 590$ nm; the application of Snell's law between the surfaces of the pyramids I and II, permits to obtain the refraction angles θ, θ', θ''. The angles correspond respectively to the incidences angles i, i' and i'' (Table 1).

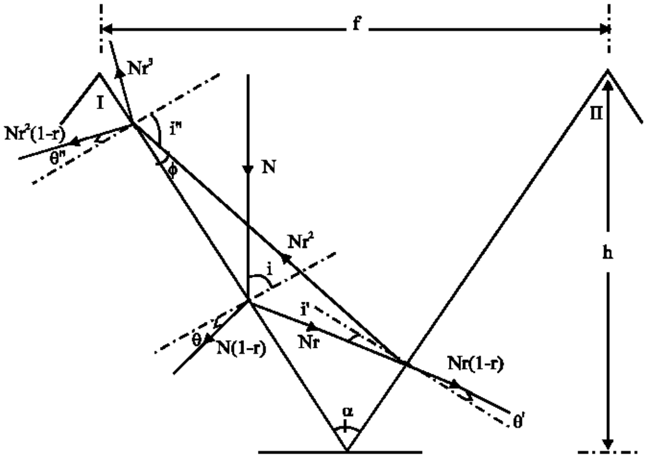

Fig. 1: Textured surface with three successive reflections (suggested model)

Table 1: Incidence and refraction angles

i (°)	54.00	55.00	56.00	57.00	58.00	59.00	60.00
i' (°)	18.00	15.00	12.00	9.00	6.00	3.00	0.00
i'' (°)	90.00	85.00	80.00	75.00	70.00	65.00	60.00
θ (°)	11.76	11.91	12.06	12.20	12.34	12.47	12.61
θ' (°)	4.46	3.74	3.00	2.26	1.51	0.76	0.00
θ'' (°)	14.59	14.53	14.36	14.08	13.69	13.20	12.60
ϕ (°)	0.00	5.00	10.00	15.00	20.00	25.00	30.00
α (°)	72.00	70.00	68.00	66.00	64.00	62.00	60.00

i : 1^{er} Incidence angle, i' : $2^{ème}$ incidence angle, i'': $3^{ème}$ incidence angle, θ: 1^{er} refraction angle, θ' : $2^{ème}$ refraction angle, θ'': $3^{ème}$ refraction angle, ϕ: angle between the incident ray Nr^2 and the face of pyramid I, α: angle between the two neighbouring pyramids

Table 2: Distance between the summits of two neighbouring pyramids

	i (°)						
f (µm)	54	55	56	57	58	59	60
h = 5 µm	7.27	7.00	6.75	6.49	6.25	6.00	5.77
h = 6 µm	8.72	8.40	8.10	7.79	7.50	7.20	6.92
h = 7 µm	10.18	9.80	9.45	9.09	8.75	8.40	8.08
h = 8 µm	11.63	11.20	10.80	10.38	10.00	9.60	9.23
h = 9 µm	13.09	12.60	12.15	11.68	11.25	10.80	10.39
h =10 µm	14.54	14.00	13.50	12.98	12.50	12.00	11.54

i: Incident angle, f : Aperture between the summits of the two neighbouring pyramids

The aperture f between the summits of the two neighbouring pyramids is given by the relation:

$$f = 2h\tan\left(\frac{\pi}{2} - i\right) \tag{5}$$

The calculated values of f for different heights h and different incidence angles i are assembled in Table 2.

SPECTRAL RESPONSES

The spectral response is an essential parameter in the characterisation of solar cells for a silicon normal plane this parameter in given by the relation:

$$R_s = \frac{J_{ph}}{qN(1-r)} \tag{6}$$

where, N(1-r) represents the proposition of absorbed rays.

For a textured plane the relation 6 becomes:

$$R_s = \frac{J_{ph}}{qN(1-r^2)} \tag{7}$$

where, $N(1\text{-}r^2)$ represents the absorbed rays. By applying the model that uses three successive incidences, the relations 7 becomes:

$$R_s = \frac{J_{ph}}{qN(1-r^3)} \tag{8}$$

where, $N(1\text{-}r^3)$ represents the absorbed rays.

If we write $x = J_{ph}/qN$ we get

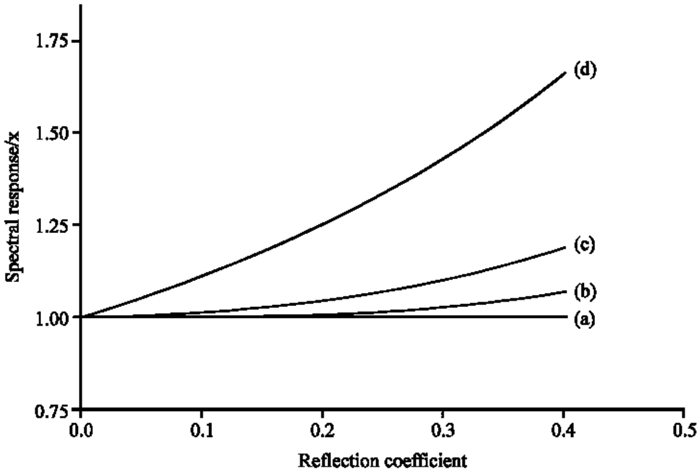

Fig. 2: Spectral response vs. reflection coefficient (a) Ideal case, (b) Suggested model, (c) Textured surface and (d) Normal surface

$$R_s = \frac{x}{(1-r^3)} \tag{9}$$

In the case of this model the variation of the spectral response as a function of the reflection coefficient r is shown in Fig. 2.

This variation is compared on the same figure with the ideal case (complete absorption of incident rays), with the case of normal plane and with that of the textured plane. The results show that spectral response of the suggested model approaches more and more the ideal case.

ABSORPTION COEFFICIENT AND GENERATION RATE

The absorption coefficient varies linearly with the incident rays; this coefficient is given by the relation:

$$T = \frac{I}{I_0} = e^{-\alpha d} \tag{10}$$

where, d is the cell thickness.

Thus:

$$T = \frac{I}{I_0} = \frac{N(1-r^3)}{N} = (1-r^3) \tag{11}$$

and

$$\alpha = \frac{1}{d}\ln(\frac{1}{1-r^3}) \tag{12}$$

The generation rate is given by the relation:

$$G = \alpha N(1\text{-r}3)e^{-\alpha d} \tag{13}$$

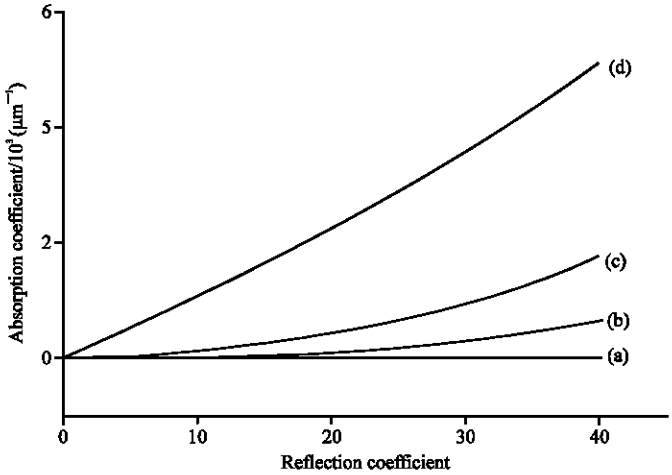

Fig. 3: Absorption coefficient vs. reflection coefficient, (a) Ideal case, (b) Suggested model, (c) Textured surface and (d) Normal surface

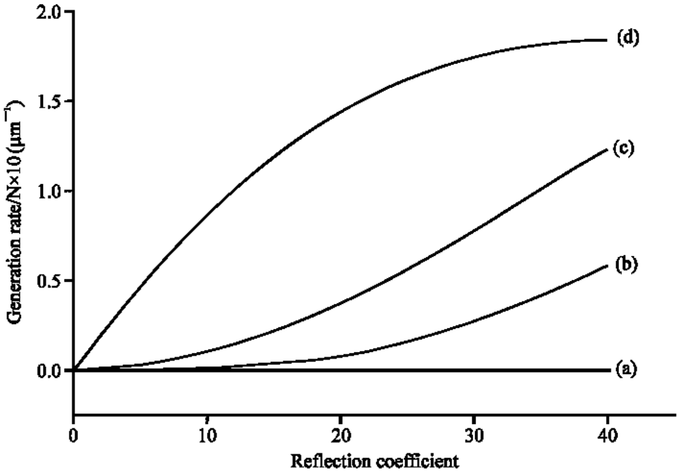

Fig. 4: Generation rate vs. reflection coefficient, (a) Ideal case, (b) Suggested model, (c) Textured surface and (d) Normal surface

Figure 3 and 4, show the variation of the absorption coefficient and the generation rate against the reflection coefficient for d= 100 µm.

These results show that these two parameters approach the theoretical ideal case.

CONCLUSION

This study is based on the use of successive reflections on the surface of textured planes of solar cells, in order to improve the photovoltaic efficiency. For achieving this goal we developed a model that can recuperate a second reflection instead of one currently, by varying the incidence angle and the aperture between the neighbouring pyramids. This model permits the solar incident rays to have three successive absorptions by the material. The calculations of incidence angles on the pyramids surfaces and the aperture f between the neighbouring pyramids were carried out for different pyramid heights. The application of the suggested model shows a significant improvement of the photovoltaic parameters such as the spectral response, the absorption coefficient and the generation rate. The representative curves of these parameters in the case of this model approach those representing the ideal case. In conclusion we can say that this model can contribute to a significant improvement of the photovoltaic efficiency and can be applied to other photovoltaic materials.

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