Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 18
ISSUE 1-2
September–October
2006

Comparison of electrical characteristics of silicon solar cells

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Received 15.03.2006; accepted in revised form 30.04.2006

Properties

ABSTRACT

Purpose: The aim of this work is comparison of the operational characteristics of photovoltaic silicon cells: monocrystalline silicon, polycrystalline silicon and amorphous silicon.
Design/methodology/approach: The notion of fill factor (FF), which is characteristic for Photovoltaic quality, has been introduced to compare properties of different silicon solar cells. Basing on the indicated characteristic the analysis of cell power efficiency has been carried out and the maximum power points PMM have been determined.
Findings: It has been pointed out that crystal structure and surface texture affect utility properties of the investigated Photovoltaic Silicon Cells. Moreover, it has been stated that along with the radiation intensity growth the maximum cell power increases accompanied by its efficiency deterioration and simultaneous change of the maximum power point position, what causes and short-circuit current increase.
Research limitations/implications: It has been found that the cell surface texture has an important influence on utility properties of the photovoltaic cells, which is connected with the high refractivity of silicon. Therefore, development of the cell surface forming methods is of a significant influence on improvement of the photovoltaic cells properties.
Practical implications: Currently the photovoltaic industry is based mostly on the crystalline and polycrystalline silicon. Limitations of the utility properties resulting from the relationships presented in this paper accompany the advantages of cells fabricated from the amorphous and polycrystalline silicon, like the low manufacturing costs and no geometrical limitations. Analysis of the discussed relationships makes optimization of the cell parameters possible, depending on the service requirements.
Originality/value: Known cells were compared as regards their conversion efficiency in various lighting conditions, depending on their design and material properties.
Keywords: Electrical properties; Solar cells; Crystalline silicon; Amorphous

1. Introduction

Alternative energetics has all technical basis to become the supplement of classic methods of power generation and to be competitive for them. At present the ecological reasons seem to be decisive in the strategy of development of world power generation industry [1-3].

The solar power belongs to the sources of renewable energies which raises the greatest hope. This technology of power generation has features of commercial energetics. The energy can be delivered to the existing power distribution network in a small or large scale. The range of scale refers to some watt or kilowatt domestic power generator as well as the commercial photovoltaic power station.

The conversion of solar radiation energy into electrical energy in photovoltaic cells is direct without any additional equipment and without natural environment pollution. Photovoltaic cells are manufactured of various materials of monocrystalline, polycrystalline or amorphous structure. Which structure and material are to be chosen depends on compromise between costs and efficiency of photoelectric transformation [4- 11].

Generally, it can be stated that the greater the energy efficiency of cell is, the higher production costs are. To decrease production costs and improve efficiency of solar cells new semiconductive materials are searched.

The basic parameter of solar cell quality having direct influence on its lifetime is its efficiency. The main factors determining the conversion efficiency are the following: the kind of semi-conductive material (the width of band gap Eg), the incompatibility of solar radiation with the cell absorption, spectrum sensitivity of photoelement and the construction of a cell [3-8].

Efficiency improvement is possible mainly by means of the increase of fill factor coefficient FF of photoelement by more advanced technology, a decrease of reflection by the application of antireflection layers, choice of more suitable semiconductor, decrease in temperature of absorbing surface, the use of concentrated solar radiation [14].

The aim of this work is the comparison of operating characteristics of monocrystalline, polycrystalline and amorphous silicon solar cells [13].

2. Methodology

Three kinds of photovoltaic cells (monocrystalline, polycrystalline, amorphous) were investigated (Table 1). The cells came from production line.

Table 1
Characteristics of investigated photovoltaic cells

Type of cell	Antireflection layer	Total area of the cell, cm^2
Monocrystalline	transparent	65
Monocrystalline	mirror	52
Polycrystalline	transparent	156
Amorphous	transparent	146

Characteristics were determined with the use of the test stand presented in Figure 1. The test stand consisted of the following elements:

- Lighting – halogen lamp (150W and 500W) of adjustable intensity of light,
- Luxmeter, type LX – 103,
- Decade resistor R in the range from 0.5 to 1000 Ω,
- Ammeter (A), type DT890G,
- Voltmeter (V), type VM 30 D.

Measurements were carried out for specific intensity of radiation E = 50000 lx (73.21 W/m^2) for halogen lamp and E = 130000 lx (190.33 W/m^2) for the natural solar lighting.

Efficiency of the tested cells was calculated on the basis of the following relation:

$$\eta = (U_M \cdot I_M / E \cdot S) \cdot 100\% \qquad (1)$$

where:
U_M – maximum voltage [V],
I_M – maximum current [A],
E – intensity of radiation [W/m^2],
S – area of the cell [m^2].

Fill factor of current – voltage characteristic of solar cells can be calculated from:

$$F = U_M \cdot I_M / U_{OC} \cdot I_{SC} \qquad (2)$$

where:
U_{OC} – open circuit voltage [V],
I_{SC} – short circuit current [A].

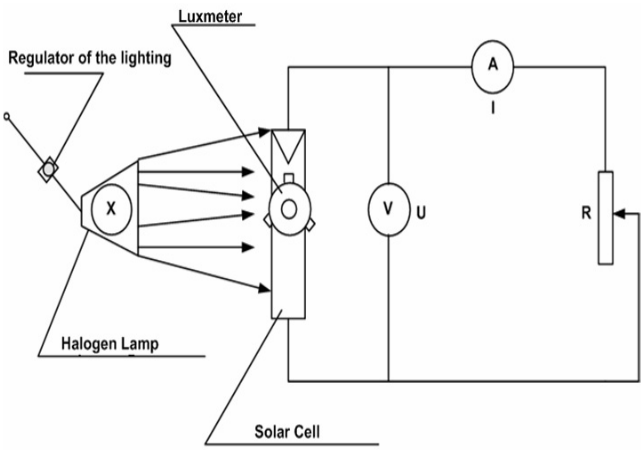

Fig. 1. Test stand

3. Discussion

To compare the obtained results of measurements of the investigated cells for different values of the radiation intensity, the current – voltage characteristic, the power characteristic and the point of maximum power were presented (Fig. 2).

For the monocrystalline cell with transparent layer the increase of radiation intensity causes the increase of voltage. The highest voltage U = 0.55 V for I = 0.07 A/m^2 is obtained for the radiation intensity E = 130000 lx (sunlight). However if the cell is illuminated by the halogen lamp of 500 W power and the radiation intensity E = 50000 lx then the voltage of the cell drops to U = 0.524 V for I = 0.06 A/m^2 (Fig.2a).

For the monocrystalline cell with antireflective mirror layer the highest voltage U = 0.53 V for I = 0.09 A/m^2 is obtained for the radiation intensity E = 130000 lx. However if the cell is illuminated by the halogen lamp of 500 W power and the radiation intensity E = 50000 lx then the voltage of the cell decreases to U = 0.5 V for I = 0.09 A/m^2 (Fig.2b).

For the polycrystalline cell the highest voltage U = 0.541 V for I = 0.032 A/m^2 is obtained for the radiation intensity E = 130000 lx. However if the cell is illuminated by the halogen lamp of 500 W power and the radiation intensity E = 50000 lx then the voltage of the cell decreases to U = 0.497 V for I = 0.03 A/m^2 (Fig. 2c).

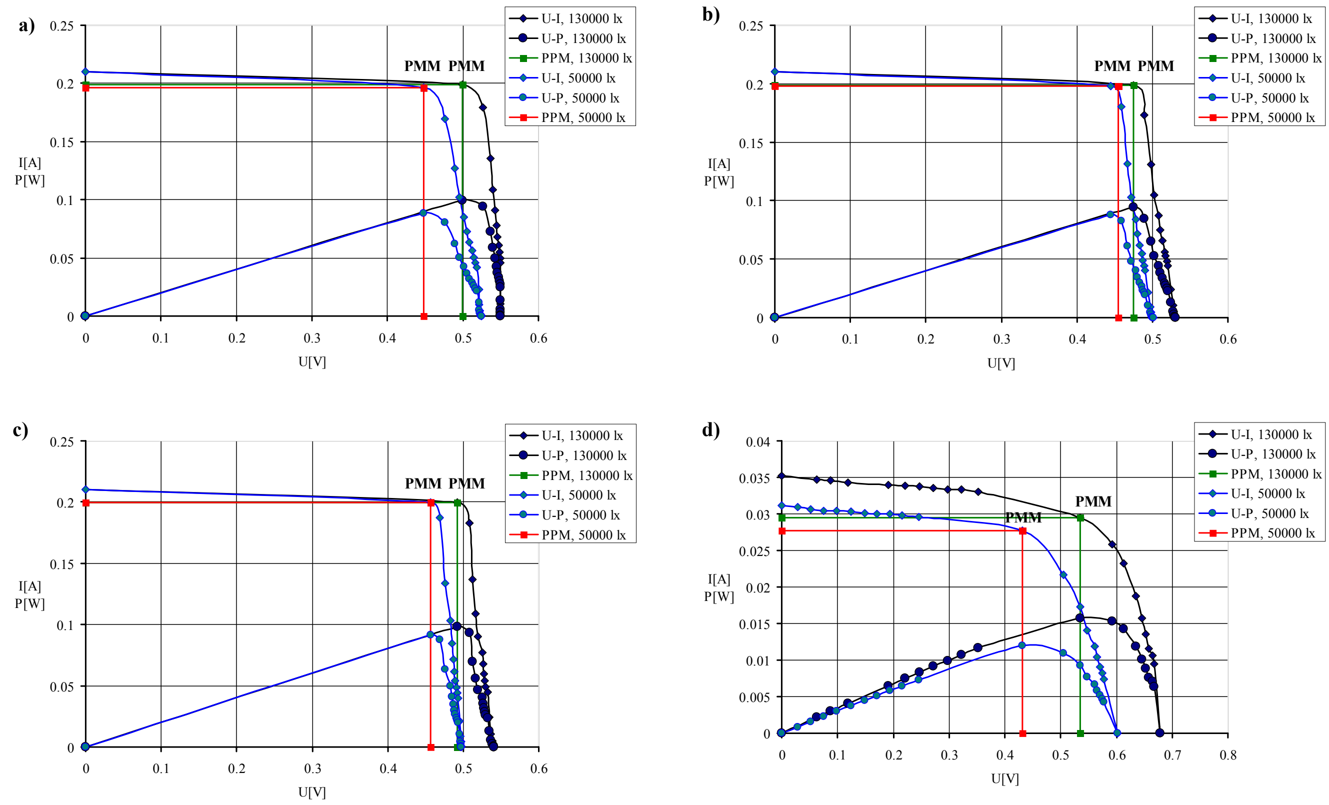

Fig. 2. The comparison of I(U) characteristics, P(U) characteristics and delimitation the points of the maximum power of studied photovoltaic cells: a) monocrystalline silicon solar cell with transparent layer, b) monocrystalline silicon solar cell with mirror layer, c) polycrystalline, d) amorphous

In order to present I(U) characteristics for the studied amorphous module it was necessary to calculate voltage and current for the individual cell. Also for this cell, the decrease of voltage is caused by the decrease of radiation intensity. The highest voltage $U = 0.666$ V for $I = 8.51$ A/m^2 is obtained for the radiation intensity $E = 130000$ lx. However if the cell is illuminated by the halogen lamp of 500 W power and the radiation intensity $E = 50000$ lx then the voltage of the cell decreases to $U = 0.576$ V for $I = 6.629$ A/m^2 (Fig. 2d).

For all the investigated cells it can be observed that the increase of the radiation intensity causes the increase of the short-circuit current that conditions the increase of the power and changes of the point of maximum power in the current – voltage characteristic.

The conducted investigations of operational characteristics of the photovoltaic cells allowed to compare their conversion efficiency in different conditions of lighting according to the construction and the cells material. The results of investigations showed that in natural conditions the maximum values of current and voltage were higher than for artificial lighting.

The results of monocrystalline and polycrystalline cells are comparable. The maximum voltage in both cases is equal to 0.53 V, however for the amorphous module the voltage is higher and is equal to 0.6 V. Differences in these results are caused by the construction of the cells, type of antireflection layer and applied technology [8, 9].

The obtained current – voltage characteristics and the point of maximum power allowed to calculate the efficiency η and fill factor FF of the investigated cells (Table 2). On the basis of the obtained operational characteristics it can be stated that the decrease of illumination causes the increase of the efficiency (for monocrystalline and polycrystalline cells). For the amorphous cell the decrease of illumination causes the decrease of the efficiency. Efficiencies of the investigated cells for the following parameters E = 130000 lx and E = 50000 lx are presented in Figure 3.

4. Summary

On the basis of the performed investigations it can be stated that the studied photovoltaic cells allow to convert light radiation into electrical energy in the efficiency range 9 - 22% according to the construction of the cell and light intensity. Increase of the radiation intensity causes the increase of the cell power from the one hand and decrease of the efficiency and change of the point of maximum power accompanied by the increase of the cell voltage and short-circuit current from the other hand.

Table 2.
The account of calculations: efficiency, fill factor, power maximum of photovoltaic cells

Solar Cell	Intensity of radiation [lx]	Efficiency [%]	Maximum Power [W/m^2]	Fill Factor (FF)
monocrystalline silicon solar cell with transparent layer	130000	8	15.32	0.86
	50000	18	13.57	0.80
monocrystalline silicon solar cell with mirror layer	130000	9	17.90	0.84
	50000	22	16.74	0.83
polycrystalline silicon solar cell	130000	3	6.29	0.89
	50000	9	5.84	0.87
amorphous silicon solar cell	130000	14.5	14.12	0.66
	50000	8	10.68	0.63

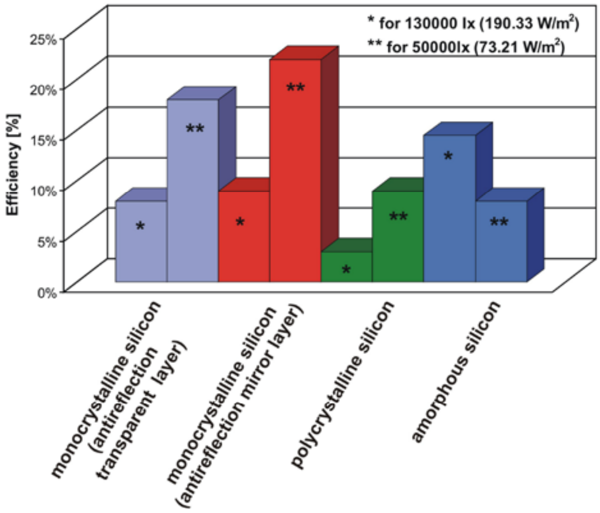

Fig. 3. Comparison of the efficiency of studied photovoltaic cells

The highest efficiency of energy conversion is observed for the monocrystalline cell with antireflection mirror layer. For this cell the maximum power was equal to 17.9 W/m^2 for E=130000 lx. The efficiency of the monocrystalline cell with antireflection transparent layer is equal to 18% and the maximum power is equal to 15.32 W/m^2 for E = 130000 lx. The polycrystalline cells have the lowest efficiency (9 %), the maximum voltage is equal to 0,541 V and the current is equal to 12.79 A/m^2 for E = 130000 lx. The efficiency of the amorphous cell is equal to 14.5 % and it increases with the increase of the radiation intensity. However the amorphous cell has the worst current – voltage characteristic because of low value of the fill factor. The fill factor of the investigated cells decreases together with the increase of the radiation intensity.

For the monocrystalline and polycrystalline cells the fill factor is in the range 0.8 – 0.89. For the amorphous cell the fill factor varies from 0.63 to 0.66.

Main advantages of cells produced from amorphous and polycrystalline silicon are low cost of production and lack of geometrical limitations. But unfortunately there are limitations of utility properties resulting from relations presented in the work. It is possible to improve the utility properties of amorphous and polycrystalline cells by means of texture forming methods.

Acknowledgements

This work has been supported by Polish Ministry of Science and Information Technology in frame of the Project No. 3 T08C 048 29.

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