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Influence of temperature on output load characteristics of polycrystalline silicon solar cells

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Influence of temperature on output load characteristics of polycrystalline silicon solar cells

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Abstract. Studies have been carried out of the effect of temperature on the load current-voltage characteristics of a polycrystalline silicon solar cell, which has been illuminated by solar radiation with a power of 80 mW/cm^2. It has been accepted that with an increase in the temperature of the solar cell, in the range of 25 - 90 ^{0}C, the efficiency decreases, from 16.6% to 13%, and the load factor of the current-voltage characteristic decreases. This is due to an increase in series resistance. The shunt resistance of the solar cell decreases. These variations in R_{ser} and R_{sh} are related with the modulation of photoactive layers of solar cells under the influence of solar radiation.

INTRODUCTION

Studying the photoelectric characteristics of solar cells at different ambient temperatures will make it possible to establish the energy depletions that comes in solar cells and determine the temperature range where photovoltaic modules consisting of solar cells with given parameters will operate effectively [1-8].

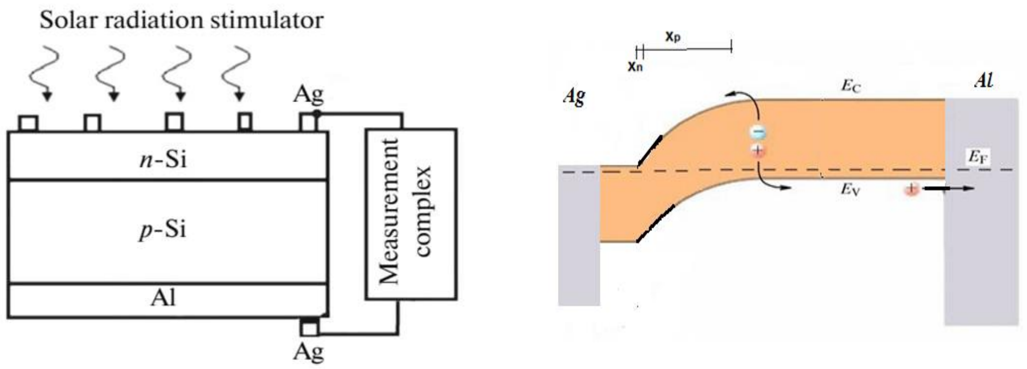
In [9-12], the temperature dependence of the open circuit voltage (V_{oc}) and the filling factor of the current-voltage characteristic (FF) was studied in the temperature range of 295–320 ^{o}K and found that the shunt resistance (R_{sh}) declines almost linearly with T, and its influence on the temperature coefficient dV_{oc}/dT is considerable for cells having less R_{sh} values. The series resistance (R_{ser}) also varies almost linearly with V_{oc}. A study [13-17] of thin-film solar cells made of hydrogenated amorphous silicon (a-Si:H) shows that dV_{oc}/dT also varies linearly with temperature (T). The short-circuit current (J_{sc}) rises linearly with temperature, mostly due to temperature-induced band gap reduction and reduced nonequilibrium charge carrier recombination. The temperature dependence of FF is not linear and has a maximum in the temperature range of 15 °C to 80 °C.

Temperature studies of the load current-voltage characteristics of a solar photovoltaic film based on amorphous hydrogenated silicon [18], under real solar illumination conditions (P_{rad}=870±10 W/m^2), showed that the temperature addiction of J_{sc} increases with two lines, explained by a transform in the generation-recombination mechanism, by increasing the lifetime of minority carriers. The decline in the open circuit voltage with rising temperature is interpreted by the exponential increase in the value of the reverse saturation current and the decline in the band gap of the semiconductor. FF declines with increasing temperature, which is probably due to a descend in R_{sh}. With increasing temperature, the value of R_{ser}, as well as R_{sh}, decreases. The large loss of power generation with enhancing temperature is mainly observed in the series resistance of the solar PV module. With increasing temperature, the loss of generated power across the shunt resistance increases sublinearly. In works [19-23], studies were carried out of the influence of temperature on the output parameters of various types of silicon-based solar cells. However, the output energy parameters were considered without taking into account changes in one of the main parameters that determine the effective conversion of solar energy by a photovoltaic device, such as R_{ser} and R_{sh}, and their changes with temperature.

In connection with the above, the main purpose of this study is to establish the effect of temperature on the main escape energy parameters of a solar cell constructed on polycrystalline silicon and to analyze the mechanisms of photogeneration, considering the influence of temperature on the main parameters of the photosensitive structure of the solar cell, such as R_{ser} and R_{sh}.

EXPERIMENTAL RESEARCH

In this work, experimental studies of solar cells based on polycrystalline silicon (pc-Si) with an area of 2.00±0.02 cm^2 were carried out. PC-Si SC under "standard test conditions" (Standard Test Conditions (STC), P=100 mW/cm^2, T=25 °C), had an efficiency factor (efficiency) = 17%. Figure 1 shows the design of a pc-Si SC with the Ag-n-Si/p-Si-Al-Ag structure (a) and its energy band diagram (b). The energy value of the internal built-in potential of the homojunction was eV_D≈0.890±0.01 eV where eV_D=eV_p+eV_n: in the p-layer eV_p≈0.885±0.002 eV and in the n-layer eV_n≈0.005± 0.002 eV, space charge region with x_p≈260±5 nm and x_n≈1.5±0.1 nm, x_p/x_n≈170±5.



(a) (b)

FIGURE 1. Design (a) energy band diagram and (b) of Ag-n-Si/p-Si-Al-Ag structural pc-Si solar cells

Experimental studies of the dark and light current-voltage characteristics of pc-Si SC were carried out on a complex for measuring the current-voltage characteristics of Oriel Sol 3A class AAA, using a solar radiation simulator Model - 94043A, in the temperature between 25 °C - 90 °C under normal lighting conditions (NLC), radiation power P=80 mW/cm^2. The illumination spectrum of the simulator corresponded to the spectrum of solar radiation at AM1.5 [24-27]. The power of the falling radiation was determined using a reference certified single-crystalline silicon solar cell from the manufacturer Newport Oriel (USA). The temperature was recorded using a TS/K temperature sensor. The current-voltage characteristics were recorded using a Source Meter Keithley 2400 instrument.

To study the spectral dependence of sensitivity, a research complex was used using a mirror monochromator ZMR - 3 and a combined digital device Sh - 300, which made it possible to study the spectral dependence of the studied photosensitive structure in the spectral wavelength range of monochromatic radiation from 300 nm - 2500 nm, with length accuracy wave ± 10 nm, current 0.01% and voltage 0.1%.

RESEARCH RESULTS

Figure 2 demonstrates the spectral dependence of the sensitivity (S is the external quantum yield) of the pc-Si SC. The SC had a spectral sensitivity range from 400 nm to 1100 nm. Figure 3 shows (on a logarithmic scale) the results of the dark current-voltage characteristic of pc-Si solar cells, curve A is the direct branch and curve B is the reverse branch of the current-voltage characteristic. The rectification coefficient (K) of the current-voltage characteristic of the pc-Si SC, the correlation of the forward current to the reverse one, at a fixed applied V=0.7 V was equal to K=2*10^3.

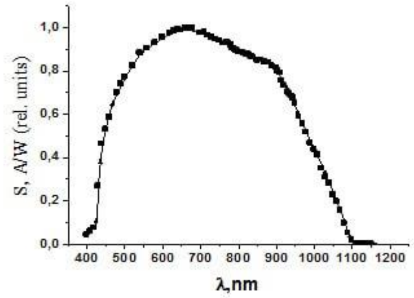


FIGURE 2. Spectral dependence of the sensitivity of pc-Si solar cells

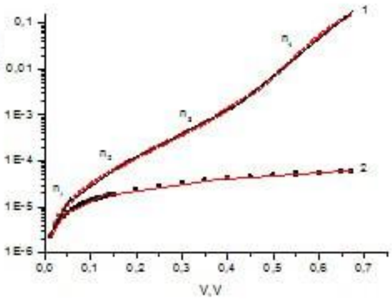


FIGURE 3. Dark current-voltage characteristic of pc-Si solar cells: 1-direct branch, 2-reverse branch

Research of the direct branch of the current-voltage characteristic [28-30] made it possible to estimate the value of the built-in potential of the pc-Si SC, which has a value of V_b=0.9±0.03 eV. The energy value of the internal built-in potential of the homojunction eV_D≈0.890±0.01 eV determined from Figure 1 (b) and the value of the built-in potential of the pc-Si SC V_b=0.9±0.03 eV have almost the same value, within the experimental error. From the direct branch of the current-voltage characteristic [31-33], the options of charge carriers in the high-resistivity region beside the space charge were also estimated: $p_0=2.8*10^{10}$ cm^{-3}; $\mu_n*\tau_n=3*10^{-8} cm^2/V$, where p_0 is the concentration of holes in the photoactive part of the pc-Si SC; μ_n - electron mobility; τ_n - is the lifetime of electrons.

Below are the results of experimental researches of the light load current-voltage characteristic of a pc-Si SC (radiation power AM 1.5, P=80 mW/cm^2), in the temperature between 25 °C - 90 °C. The short circuit current (J_{sc}) (Figure 4) decreases slightly with increasing temperature, with a temperature coefficient $(\Delta J_{sc})/\Delta T=1.045*10^{-5}$%. The open circuit voltage (V_{oc}) (Figure 5) decreases with increasing temperature with a temperature coefficient $(\Delta V_{oc})/\Delta T=1.7*10^{-2}$%.

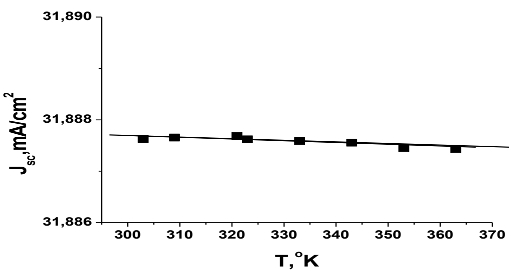


FIGURE 4. Temperature relation of short circuit current J_{sc} pc-Si solar cells

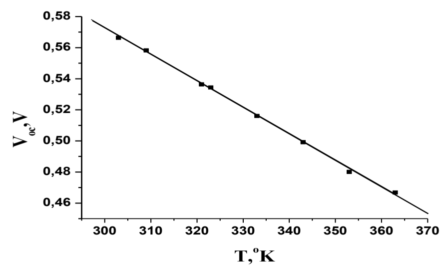


FIGURE 5. Temperature relation of open circuit voltage V_{oc} of pc-Si solar cells

The photocurrent at the point of maximum power ($J_{max}(T)$) (Figure 6) decreases with increasing temperature with a temperature coefficient $(\Delta J_{max})/\Delta T$=0.03%/deg. The voltage at the spot of maximum power ($V_{max}(T)$) (Figure 7) falls with increasing temperature with a temperature coefficient $(\Delta V_{max})/\Delta T$=0.37%/deg. The maximum output power ($P_{max}(T)$) (Figure 8) decreases with rising temperature with a temperature coefficient $(\Delta P_{max})/\Delta T$= 0.38%/deg. The filling factor of the current-voltage characteristic (FF) (Figure 9) decreases with increasing temperature with temperature coefficient (ΔFF)/ΔT=0.09%/deg. The efficiency factor (Efficiency) (Figure 10) decreases linearly with increasing temperature with temperature coefficient (ΔEff)/ΔT=0.31%/deg. From the presented experimental results it follows that the open-circuit voltage falls with increasing T from 570 mV to ≈ 470 mV. The efficiency of solar cells decreases with increasing T from ≈ 16.8% to ≈ 13%, and FF decreases from ≈ 74% to ≈ 70%.

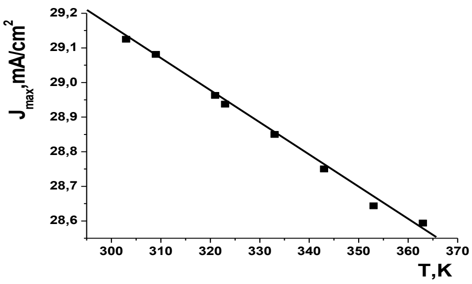


FIGURE 6. Temperature dependence of the photocurrent at the point of maximum power J_{max}(T) pc-Si solar cells

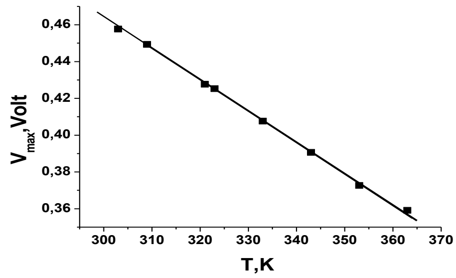


FIGURE 7. Temperature dependence of voltage at the point of maximum power V_{max}(T) pc-Si solar cells

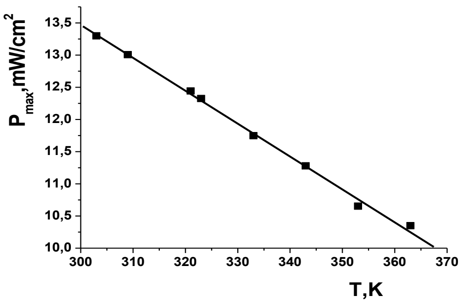


FIGURE 8. Temperature dependence of the maximum output power P_{max}(T) pc-Si solar cells

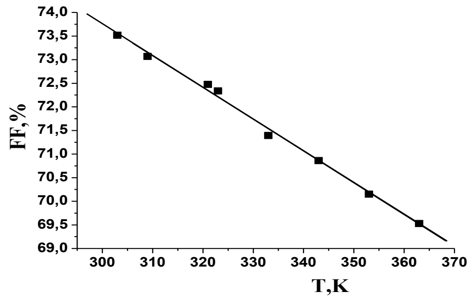


FIGURE 9. Temperature dependence of the filling factor of the current-voltage characteristic FF of pc-Si solar cells

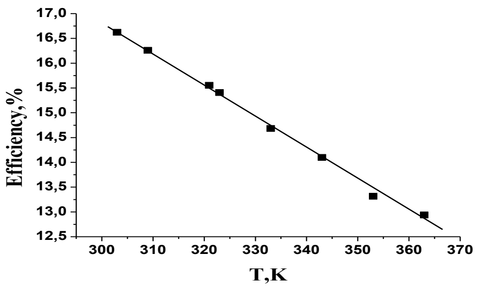


FIGURE 10. Temperature dependence of efficiency of pc-Si solar cells

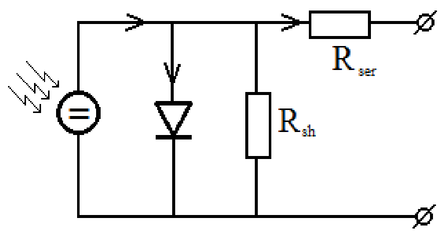


FIGURE 11. Equivalent scheme of a real solar cell.

A real solar cell is characterized by the attendance of series R_{ser} and shunt R_{sh} resistance. R_{ser} consists of the series-connected resistances of the contact layers, the resistances of each of the p- and n-regions of the solar cell, and the metal-semiconductor transition resistances. R_{sh}-represents presumable surface and volumetric current outflow through the resistance parallel to the p-n junction of the SC [3]. In the Figure 11 the equivalent scheme of a real solar cell is presented, taking into account (R_{ser}) and shunt (R_{sh}). Figures 12 and 13 show the experimental temperature dependences of the series (R_{ser}) and shunt (R_{sh}) resistance of the pc-Si SC.

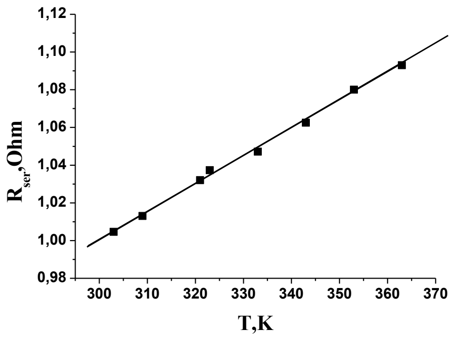


FIGURE 12. Temperature dependence of series R_{ser} resistance of pc-Si solar cells

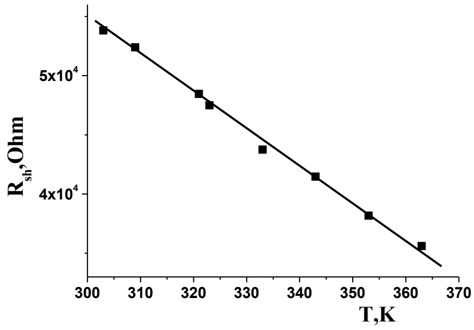


FIGURE 13. Temperature dependence of shunt R_{sh} resistance of pc-Si solar cells

From Figure 12 and Figure 13 it follows that R_{ser} increases and R_{sh} decreases with increasing temperature. The decrease in the filling factor of the current-voltage characteristic (FF) and efficiency (Efficiency) of pc-Si SCs with temperature can be explained from the temperature dependence of R_{ser} and R_{sh}. An increase in R_{ser} and a decrease in R_{sh} with temperature leads to undesirable losses of photogenerated charge carriers on R_{ser} and R_{sh} of a real solar cell based on pc-Si SC.

CONCLUSIONS

A study of the light photovoltaic characteristics of PC-Si SCs at different temperatures showed that the output load parameters deteriorate with temperature. These changes are associated with an increase in the series resistance of the solar cell with increasing temperature, due to an increase in the resistance of metal contacts. Also, the decrease in the shunt resistance of the solar cell is explained by the semiconductor properties of the shunt channels of the p-n junction, which also reduce the conversion efficiency of the solar cell.

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