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INFLUENCE OF TEMPERATURE ON FILL FACTOR OF I-V CHARACTERISTICS OF ILLUMINATED SOLAR CELLS

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Annotation:
The article theoretically investigated the effect of temperature on the values of the non-ideality coefficient of the I – V characteristic of an illuminated SC. Semi-empirical expressions are obtained for determining the temperature dependence of the non-ideality coefficient of the current – voltage characteristic of an illuminated semiconductor SC. It is stated that the value of the coefficient of non-ideality of the photo I – V characteristic of the SE has different values for different points of the photo I – V characteristic and also that its value is almost independent of the temperature in the range 160 K <T <500 K.

Keywords: solar cell, saturation current, short circuit current, open circuit voltage, photo CVC not ideal coefficient, effective photo current value, effective voltage value, temperature effect. T <500 K.

Аннотация: В статье теоретически исследовано влияние температуры на значения коэффициента неидеальности ВАХ освещенного КА. Получены полуэмпирические выражения для определения температурной зависимости коэффициента неидеальности вольт-амперной характеристики освещенного полупроводникового СЭ. Установлено, что величина коэффициента неидеальности фото ВАХ ФЭ имеет разные значения для разных точек фото ВАХ, а также практически не зависит от температуры в диапазоне 160 К <Т <500 К.

Ключевые слова: солнечный элемент, ток насыщения, ток короткого замыкания, напряжение холостого хода, фото CVC не идеальный коэффициент, эффективное значение тока фото, значение эффективного напряжения, температурный эффект. T <500 K

1. Introduction

It is known that the efficiency of semiconductor solar cells (SC) is determined by the main photovoltaic parameters, such as short-circuit current (I_{kz}), open circuit voltage (U_{xx}) and CVC filling factor, which is usually denoted (ff fill factor). This parameter, which in combination with I_{kz} and U_{xx} determines the maximum power of the solar cell. The ff value is determined as the ratio of the maximum power of the solar cell to the product of I_{kz} and U_{xx} is a measure of the rectangularity illuminated by the I - V characteristic.

$$ff = \frac{U_f I_f}{I_{kz} U_{xx}} = \frac{P_f}{I_{kz} U_{xx}} \qquad (1)$$

where U eff is the effective value of the voltage, I_f is the effective value of the current.
The dependence of the short-circuit current on the coefficient of non-ideality of the I - V characteristic are expressed:

$$I_{кз} = I_0 \left[\exp\left(\frac{qU_{xx}}{nkT}\right) - 1 \right] \qquad (2)$$

where I0 is the saturation current, q is the electron charge, k is the Boltzmann constant, n is the non-ideality coefficient of the I – V characteristic of the illuminated solar cell, T is the absolute temperature.
No-load voltages also depend on the non-ideality coefficient of the I - V characteristic:

$$U_{xx} = \frac{nkT}{q} \ln\left(\frac{I_{кз}}{I_0} + 1\right) \qquad (3)$$

Differentiating the power by voltage and equating it to zero, $\frac{d(I_\phi U)}{d(U)} = 0$

Allows obtaining an expression for the values of the effective voltage and effective current of the solar cell:

$$U_{эф} = \frac{nkT}{q} \ln \frac{I_{эф}}{I_0} \frac{nkT}{q} \qquad (4)$$

$$I_{эф} = I_0 \frac{qU_{эф}}{nkT} \exp \frac{qU_{эф}}{nkT}$$

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(5)

From equation (2) - (5) it can be seen that all the main photovoltaic parameters, which determine the efficiency of the solar cell, depend on the non-ideality coefficient of the I - V characteristic. This shows the importance of the non-ideality coefficient of the I - V characteristic.

The non-ideality coefficient characterizes the quality of the p-n-junction and speaks of the type of recombination of charge carriers in the SC. In the presence of conventional recombination mechanisms, n = 1. In other cases, n can be 2 or more.
Practice shows that a high value of n decreases not only ff, but since it shows the presence of rapid recombination, it causes a decrease in I_{kz} and I_f. Therefore, the problem of identifying the nature of the change in the non-ideality coefficient of the I - V characteristic of the pn junction with a variation in the ambient temperature is considered urgent in order to more accurately describe the temperature dependence of photoelectric parameters, including the efficiency of the solar cell.
It is known that the photocurrent in the circuit of the illuminated solar cell is determined by the expression:

$$I_{\phi} = I_0\left[\exp\left(\frac{qU}{nkT}\right)-1\right]-I_{кз} \quad (6)$$

where U is the output voltage and I_f is the solar cell photocurrent. From this formula for the non-ideality coefficient of the I - V characteristic of the illuminated solar cell, one can obtain the expression:

$$n = \frac{qU}{kT}\frac{1}{\ln\left(\frac{I_{\phi}+I_{кз}+I_0}{I_0}\right)} \quad (7)$$

However, using this expression, the temperature dependence of the non-ideality coefficient of the I - V characteristic of an illuminated solar cell can only be determined experimentally, since there is no expression that determines the temperature dependence of voltage and photocurrent.
In [1, 2], the correlation between the open-circuit voltage, short-circuit current, effective voltage and effective current versus temperature was investigated in the range 200 K <T <500 K and it was concluded that the non-ideality coefficient of the I – V characteristic does not depend on temperature ... At the point where the short-circuit current is determined, the value of this coefficient is greater than 1 (n>

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1) And at the point at which the effective values of the photovoltaic characteristics are determined are greater than 2 and lie in the interval (2> n□3). It follows from this that the value of the non-ideality coefficient of the I - V characteristic of the illuminated SC differ at different points of the I - V characteristic. Indeed, the coefficient of non-ideality of the I – V characteristic of an illuminated SC is determined by the selected point of the photocurrent curve [3], so it cannot have the same value at different points of the I – V characteristic. Since at the point of determination of the open-circuit voltage, the photocurrent is zero and the value of the non-ideality coefficient of the I-V characteristic is equal to 1 or the open-circuit voltage does not depend at all on the non-ideality coefficient of the I – V characteristic [4].

Taking into account the above, this work is devoted to the study of the temperature dependence of the non-ideality coefficient of the I - V characteristic of the SC.

In work [2] for the saturation current, open-circuit voltage and short-circuit current at T0 = 300 K, the following expressions were obtained,

$$I_0 = I_{00}\exp\left[\frac{q\varphi}{k}\left(\frac{1}{T_0}-\frac{1}{T}\right)\right] \quad (8)$$

$$U_{xx} = (U_{0xx}-\varphi)\frac{T}{T_0}+\varphi \quad (9)$$

$$I_{\kappa з} = I_{00}\exp\left[\frac{q\varphi}{k}\left(\frac{1}{T_0}-\frac{1}{T}\right)\right]\times\left[\exp\left[\frac{q\varphi}{n_1 k T_0}\left(\frac{U_{0xx}}{\varphi}-1+\frac{T_0}{T}\right)\right]-1\right] \quad (10)$$

where - - and I00 are no-load voltage and saturation current, at temperature T0 = 300 K, n1 is the non-ideality coefficient of the I – V characteristic at the point where the short-circuit current is determined (point 1), φ is the height of the potential barrier of the solar cell. As you know, the potential barrier of FE also depends on temperature in an explicit form:

$$\varphi = \varphi_0 - \gamma T \quad (11)$$

where φ0 is the height of the potential barrier of the solar cell at absolute zero temperature, γ is the temperature coefficient of the potential barrier, and its value for the main semiconductors lies in the range γ = 5 × 10-3 ÷ 5 × 10-5 V / K

When the photocurrent is zero, the output voltage of the solar cell is the open circuit voltage, therefore, from (2), the following formula can be obtained:

$$n_1 = \frac{qU_{xx}}{kT}\frac{1}{\ln\left(\frac{I_{кз}+I_0}{I_0}\right)}$$

(12)

Substituting (8) - (11) into formula (12), we obtain the expression for the temperature dependence of the non-ideality coefficient of the I - V characteristic of an illuminated solar cell.

In [4], the following expressions were obtained for the effective values of the voltage and current of the solar cell:

$$U_{эф} = \frac{n_2 kT}{q}\ln\left(\frac{I_{кз}}{I_0}\frac{n_2 kT}{qU_{xx}}\right)$$

(13)

$$I_{эф} = I_{кз}\left(\frac{n_2 kT}{qU_{xx}} - 1 - \frac{I_0}{I_{кз}}\right)$$

(14)

where n2 is the value of the non-ideality coefficient of the I - V characteristic at the point of determining the effective values of the solar cell photovoltaic characteristics (point 2).

When the voltage is equal to the effective value, the photocurrent will also be equal to its effective value.

$$I_{эф} = I_0\left(\exp(\frac{qU_{эф}}{n_2 kT}) - 1\right) - I_{кз}$$

(15)

Therefore, for the non-ideality coefficient of the I - V characteristic from formula (15), one can obtain:

$$n_2 = \frac{qU_{эф}}{kT}\frac{1}{\ln(\frac{I_{эф}+I_{кз}+I_0}{I_0})}$$

(16)

The results of calculating the temperature dependence of the non-ideality coefficient of the I - V characteristic at the point of determining the short circuit current according to expression (12) for solar cells made on the basis of semiconductors indicate its insignificance. In other words, the non-ideality coefficient of the I - V characteristic of an illuminated SC does not depend on the temperature in the range 160 K <T <500 K. In this case, calculations were performed for the parameter values: I00 = 3.468 × 10-10 A / cm2, φ0 = 1.12 V and γ = 2 × 10-4 V / K and the value for the coefficient is n1 = 1.0018.

The table shows the results of calculations for solar cells based on semiconductors for the temperature dependence of the non-ideality coefficient of the I - V characteristic at the point of determining the effective value of the photovoltaic characteristics. As follows from the table, the non-ideality coefficient of the I - V characteristic weakly depends on temperature in the range 160 K <T <500 K; the range of variation of the coefficient is 2.1 <n2 <2.3. We believe that these changes occur due to a more significant change in the photocurrent at the point of determining the effective values of the photovoltaic characteristics. These calculations were performed for the values I00 = 3.468 × 10-10 A / cm2, φ0 = 1.12 V and γ = 2 × 10-4 V / K. The maximum value of the coefficient was n2 = 2.5.

Table Temperature dependence of the non-ideality coefficient of the I - V characteristic of the illuminated SC, calculated for the effective point

T, K	**163**	**183**	**203**	**223**	**243**	**263**	**283**	**303**	**323**
n_2	2.2177	2.2189	2.2200	2.2212	2.2223	2.2234	2.2245	2.2256	2.2267
T, K	**343**	**363**	**383**	**403**	**423**	**443**	**463**	**483**	**503**
n_2	2.2278	2.2288	2.2299	2.2309	2.2320	2.2330	2.2340	2.2351	2.2361

The value of the photocurrent in semiconductor structures is 105–106 times higher than the value of the dark current. Therefore, the effect of temperature on the rate of recombination of charge carriers in the space charge region of the pn junction and, therefore, on the non-ideality coefficient of the I – V characteristic for an illuminated SC is insignificant. A small change in the values of n at the effective point of the I – V characteristic of an illuminated SC with temperature is mainly associated with a change in the series and shunt resistance of semiconductor structures with surface ohmic contacts. Consequently, from a physical point of view, it can be considered more expedient to use equation (16) in experimental problems of the physics of semiconductor devices.

Thus, in the present work, we investigated the effect of temperature on the values of the non-ideality coefficient of the I – V characteristic of an illuminated SC. Semi-empirical equations are obtained to determine the temperature dependence of the non-ideality coefficient of the I - V characteristic of an illuminated semiconductor solar cell. It is shown that its value is almost independent of temperature in the range 160 K <T <500 K.

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