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RELATIONSHIP OF THE VOLT-AMPERE CHARACTERISTICS OF SOLAR CELLS TO TEMPERATURE

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Annotation:

In this work, an equation was obtained that allows to explain the experimental results for the temperature dependence of the QE VAX prepared on the basis of semiconductors. By comparing the results obtained by calculating this equation with the experimental results, it was shown that the temperature change in the investigated range does not affect the value of the non-ideality coefficient of QE VAX from a practical point of view.

Key words: solar cells, volt-ampere characteristic, temperature, coefficient of non-ideality, pure operating voltage, saturation current, potential barrier height.

INSTRUCTION:

It is known that the performance of QEs is determined by their photovoltaic parameters. These parameter values are determined from experimental measurements of VAX in lighting QE. When testing the operation of QE in a wide temperature range, for example at T=(-1200C÷1400C), the practical values will be the same as the theoretical ones

[1; pp. 224-232, 2; 55-57 p.] the results determined from the experiment determining the effect of temperature on QE VAX and photoelectric parameters are presented. However, the equations characterizing its parameters are complicated, that is, it is practically impossible to determine some of these parameters directly using VAX. In connection with this, in this work, the experimental results determining the dependence of photovoltaic characteristics on temperature and [3; pp. 174-178, 4; 65-71 p.] studied the effect of temperature on VAX when illuminating QE using theoretically obtained equations.

It is known that the volt-ampere characteristics of solar cells are of two types. VAXes in the light and in the dark. In the dark VAX can be expressed by the following formula:

$$j = j_0\left(\exp\left(\frac{eU}{nkT}\right) - 1\right) \qquad (1)$$

where j_0-saturation current, q-charge of charge carriers, n-coefficient of non-ideality of the diode, k-Boltzmann constant, U-voltage, T-temperature.

$$j_\phi = j_0\left(\exp\left(\frac{eU}{n'kT}\right) - 1\right) - j_{\kappa m} \qquad (2$$

And the VAX when the light falls looks like this:

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where n'-non-ideality coefficient of solar cells when the light is reduced n and n' may differ from each other even for one solar cell. [5; p. 156-157, 6; pp. 45-55, 7; 65-71 p.] it was shown that when the QE works as a diode, its non-ideality coefficient changes in the range 1<n<2, and when it works as a QE, it changes in the range 1<n'<4. jf – photocurrent, jkt-short circuit current. It can be seen that using the formula (2.) it is not possible to explain the experimental results that determine the dependence of VAX of QEs on illumination on temperature. Because, in order to explain these results, it is necessary to know in advance the dependence of the saturation current density and the short circuit current density in expression (2) on temperature.[8; pp. 18-22, 9; 14-18 p.] selected a-Si:H amorphous hydrogenated silicon as a QE model, and semi-empirically obtained simplified equations that determine the temperature dependence of the QE illumination VAX and allow for a sufficiently good interpretation of the experimental results.

To do this, it is necessary to determine the effect of temperature on the short-circuit current density and the saturation current density. The experimental results of VAX in QE illumination show that the output photocurrent density is zero when the output voltage is equal to the operating voltage (Usi) will be Therefore, if $U=U_{si}$ and $J_f=0$ are taken into account in (2), the following equality is fulfilled:

$$j_{кт} = j_0\left[\exp\left(\frac{qU_{си}}{nkT}\right) - 1\right]. \qquad (3)$$

From here we find for the voltage U_{xx}:

$$U_{си} = \frac{nkT}{q}\ln\left(\frac{j_{кт}}{j_0} + 1\right). \qquad (4)$$

For the saturation current density when determining the temperature dependence of the operating voltage [10; 92-97 p.] we use the results obtained:

$$j_0 = q\mu_C N(E_C)E_S \exp\left(-\frac{q\varphi}{kT}\right), \qquad (5)$$

Here, φ- is the potential barrier height of QE, μ- is the mobility of the charge carrier, N (EC) is the effective value of the density of electronic states in the conduction band, ES is the strength of the external electric field created in QE. The numerical value of the given parameters for the studied QE cannot be determined directly from VAX. Thus, it is desirable to find another method that eliminates laborious measurements in determining these parameters. Therefore, we first determine the temperature dependence of the saturation current density in the following form. If we assume that the saturation current density $j_0=j_{00}$ when T_0=300K, then from (5) we get the following expression:

$$j_{00} = q\mu_C N(E_C)E_S \exp\left(-\frac{q\varphi}{kT_0}\right). \qquad (6)$$

Taking into account (6) and changing (5), we get the following expression for the saturation current density:

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$$j_0 = j_{00}\exp\left(\frac{q\varphi}{k}\left(\frac{1}{T_0}-\frac{1}{T}\right)\right). \qquad (7)$$

Substituting (7) into (4), we get the following expression:

$$U_{cu} = \frac{nkT}{q}\ln\left(\frac{j_{\kappa m}}{j_{00}}\exp\left(-\frac{q\varphi}{k}\left(\frac{1}{T_0}-\frac{1}{T}\right)\right)+1\right). \qquad (8)$$

It is known that the condition for QE is satisfied, so (4) can be written in the following form:

$$U_{cu} = \frac{nkT}{q}\ln\left(\frac{j_{\kappa m}}{j_0}\right). \qquad (9)$$

Then we get the following expression from (7) and (9):

$$U_{cu} = \left[\ln\left(\frac{j_{\kappa m}}{j_{00}}\right)-\frac{q\varphi}{kT_0}\right]\frac{nkT}{q}+n\varphi. \qquad (10)$$

[11; pp. 38-41.] using the formula for the temperature dependence of the saturation current density, an expression for the temperature dependence of the operating voltage was obtained:

$$U_{cu} = [\ln j_{\kappa m} - \ln(q\mu_C \mathrm{N}(\mathrm{E}_C)\mathrm{E}_S)]\frac{nkT}{q}+n\varphi. \qquad (11)$$

The results of the calculation of the operating voltage as a function of temperature with the help of (10) and (11) characterize a single curve. So, according to the formula (10), it is possible to determine the temperature dependence of the operating voltage.

Experimental results show that the QE short-circuit current in the temperature range -100oS<t<+100oS is practically independent of temperature [12; pp. 36-40, 13; 14-16 p.] From (10) and (11) it follows that the operational voltage has a linear relationship with the temperature, and by extrapolating this relationship at the temperature (T=0), we get Usi=n.

Figure 1 shows the experimental results of temperature dependence of pure operating voltage for α-Si:H QE. As can be seen from the graph in Figure 1, the relationship Usi(T) is indeed linear.

Using these data, we can determine the equation of the straight line passing through the points (0, nph) and (T0, Usi0) and as a result we get the following:

$$U_{cu} = (U_{cu0}-n\varphi)\frac{T}{T_0}+n\varphi, \qquad (12)$$

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Here Usi0 –T_0=only working voltage at 300 K.

The calculation results obtained from the formula (12) for the dependence of the operating voltage of QEs on temperature are presented in Figure 2. It can be seen from the figure that the dependence of the operating voltage on the temperature changes very strongly with the change of the non-ideality coefficient of VAX. In these changes, if the coefficient of non-ideality of VAX is greater than 1, the value of the pure working voltage of QEs becomes greater than the value of the height of the potential barrier of ideal QEs.

$$\varphi_0 = \frac{E_{g0}}{q} ,$$

where Eg0 is the energy width of the band gap of ideal QEs. Therefore, the non-ideality coefficient of VAX is equal to 1 at the point where the operating voltage of VAX of QEs is determined

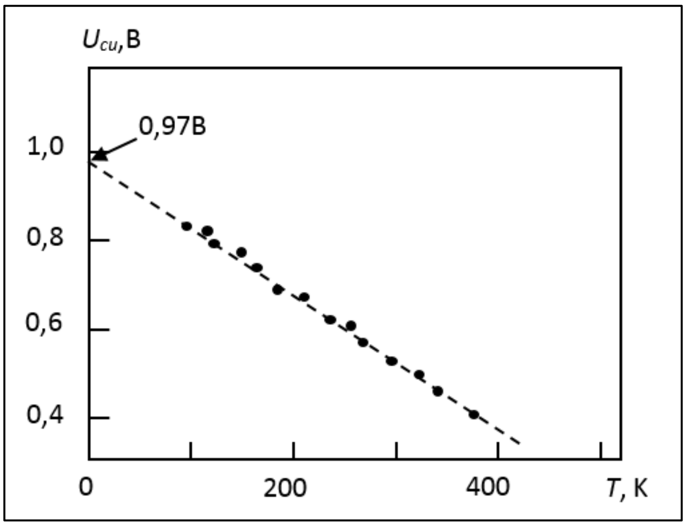

Figure 1: Experimental results determining the temperature dependence of the operating voltage of hydrogenated amorphous silicon-based QEs (0=0.97 V) [2; pp. 405-410]

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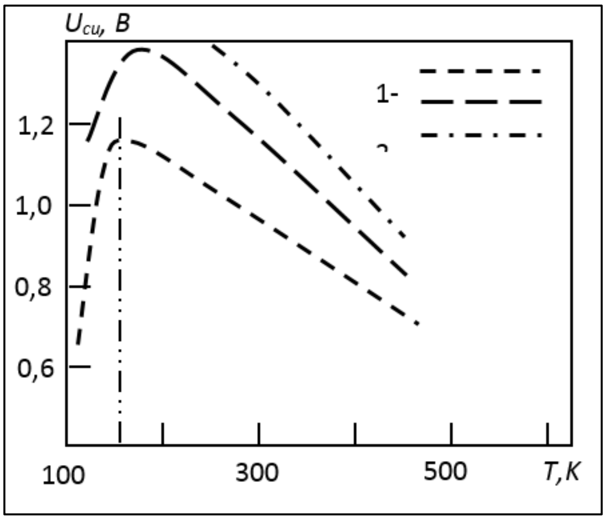

Figure 2: Calculation results obtained from the expression (12) for the temperature dependence of QE's operating voltage: Calculate the coefficient of non-ideality of VAX 1-n=1; 2-n=1.1; and performed for values 3-n=1,2 [2; pp. 405-410]. Or it can be concluded that the operating voltage will not depend on the non-ideality coefficient of VAX at all.

Substituting (12) we get a form similar to (11):

$$U_{cu} = \left(\frac{q}{nkT_0} (U_{cu0} - \varphi) \right) \frac{nkT}{q} + n\varphi . \qquad (13)$$

Numerical calculations using (10), (11) and (13) show that it is possible to ensure mutual compatibility of the curves by choosing the values of jkt, j00, mCN(EC)ES and Ux0. So, equation (13) can be used for the temperature dependence of the operating voltage.

It is known that the height of the QE potential barrier is determined by the width of the bandgap of the semiconductor. Therefore, it can be assumed that the temperature dependence of the QE potential barrier height has the same form as the dependence of the forbidden energy band width on temperature:

$$\varphi = \varphi_0 - \gamma T \qquad (14)$$

Here - QE - the height of the potential barrier at T=0K, - the temperature coefficient of the width of the mobility of holes in an amorphous semiconductor. Its value is in the eV/K range for semiconductors.

Therefore, substituting (7), (12) and (14) into expression (3), the following equation was obtained, expressing the dependence of the short circuit current density of the CE on temperature:

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$$j_{\kappa m} = j_{00}\exp\left[\frac{q(\varphi_0-\gamma T)}{k}(\frac{1}{T_0}-\frac{1}{T})\right]\left[\exp\left[\frac{q(\varphi_0-\gamma T)}{nkT_0}(\frac{U_{cu0}}{(\varphi_0-\gamma T)}-n(1-\frac{T_0}{T}))\right]-1\right].(15)$$

However, the results calculated using (15) [14; pp. 763-771, 15; 1704-1712 p.] shows that it cannot fully explain the experimental results showing the effect of temperature on the short-circuit current density. Based on further research

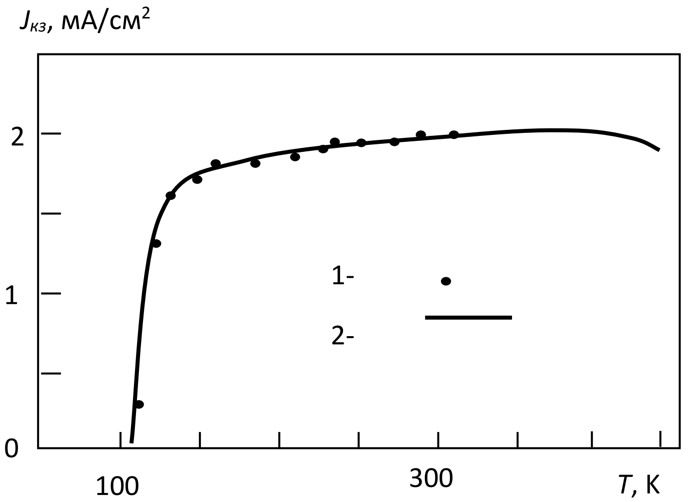

Figure 3: Temperature dependence of short-circuit current density of hydrogenated amorphous silicon-based QEs. Experiment 1 [1; 217 p.] and calculation results obtained from formula (16) when n'=1.006 and φ0=0.97 V.

Extrapolating the operating voltage at T=0 and Usi=φ gives the following expression that fully explains the experimental results:

$$j_{\kappa з} = j_{00}\exp\left[\frac{q(\varphi_0-\gamma T)}{k}(\frac{1}{T_0}-\frac{1}{T})\right]\left[\exp\left[\frac{q(\varphi_0-\gamma T)}{nkT_0}(\frac{U_{cu0}}{(\varphi_0-\gamma T)}-1+\frac{T_0}{T})\right]-1\right]. \quad (16)$$

Figure 3 shows the calculation data obtained using this equation and the experimental results are shown for comparison (n=1.006 and φ0=0.97 V). From their agreement, it can be confirmed that the VAX non-ideality coefficient in QE illumination is practically independent of temperature. Therefore, when determining the temperature dependence of the short-circuit current density, the temperature effect on the value of this parameter was not taken into account.

Now we turn to the definition of the expression that explains the effect of temperature on VAX in light of QE. Taking (7) and (16) into account, we get the following from (2):

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$$j_{\Phi} = j_{00} \exp\left[\frac{q(\varphi_0 - \gamma T)}{k}(\frac{1}{T_0} - \frac{1}{T})\right]\left\{\exp\left(\frac{qU}{nkT}\right) - \exp\left[\frac{q(\varphi_0 - \gamma T)}{nkT_0}(\frac{U_{cu0}}{\varphi} - 1 + \frac{T_0}{T})\right]\right\}. \quad (17)$$

It can be seen that this expression can be used to describe the effect of temperature on QE VAX.

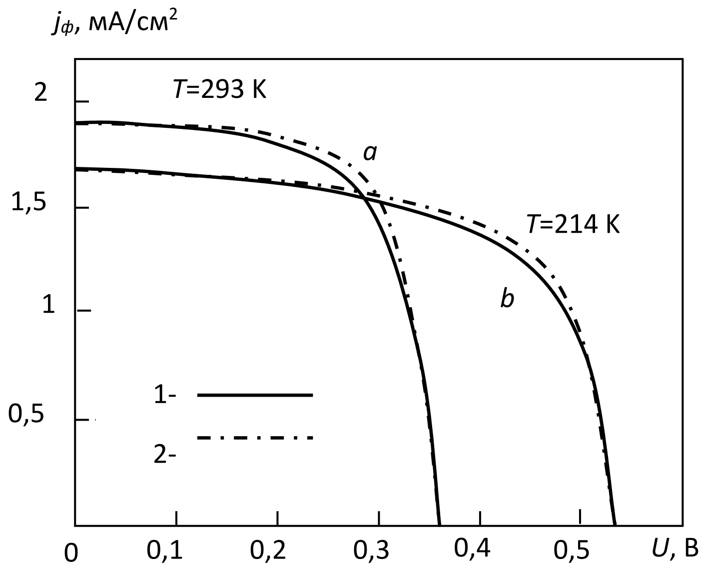

Figure 4: VAX of hydrogenated amorphous silicon-based QEs at 214K and 293K. Experiment 1 [1; 407 p.] and calculation results obtained from formula (17) when φ0=0.97 V, j00=3.96*10-6mA/cm2, g=5*10-5 eV/K

Figure 4 shows the experimental results showing the variation of QE VAX as a function of temperature. There are shown the calculation results obtained using (17) at the values φ0=0.97 V, eV/K, Usi0=0.35 V, j00=1.29*10-8 mA/cm2. As can be seen from Figure 4, the experimental and calculated results are consistent at large and small voltages. But near the effective power points of the VAX there is a serious discrepancy between these results. In our view, the coefficient of non-ideality at a given point of VAX relative to the other part of the curve strongly depends on the real voltage of QE. It is known that the value of the diode non-ideality coefficient determines the character of the electric current passing through it.

It should be noted that in order to match the calculation and experimental results, it was necessary to choose the value of the non-ideality coefficient of QE VAX as follows: n1=1.0034 at T1=214 K, n2=1.0061 at T2=293 K. The difference between n1 and n2 is not so great, so it should be considered within the limits of experimental error.

So, the coefficient of non-ideality of QE VAX does not depend on temperature from a practical point of view. Thus, the mechanism of charge transport remains unchanged in the examined range of temperature and illumination. The following conclusion can be drawn from these

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results. A new equation was obtained that allows more accurate explanation of the experimental results for temperature dependence of QE VAX based on semiconductors. By comparing the calculation and experimental results, it was shown that the temperature change in the investigated range does not affect the value of the non-ideality coefficient of QE VAX from a practical point of view.

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