THE RELATIONSHIP BETWEEN THE EFFICIENCY OF SOLAR CELLS AND THE NON-IDEALITY COEFFICIENT OF THEIR CURRENT-VOLTAGE CHARACTERISTIC

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ABSTRACT

Converting solar energy efficiently into electrical energy requires a large built-in potential, since this quantity determines the open-circuit voltage (EMF) of the solar cell. In semiconductors, the built-in potential arises from a p-n junction, a heterojunction, or a Schottky barrier junction. One of the factors that reduces the efficiency of solar cells is that these devices have their own shunt resistance. This resistance is determined by the resistance of the part of the diode that does not function as a solar cell. When manufacturing solar cells, efforts are made to ensure that the value of the shunt resistance is as high as possible.

INTRODUCTION

In addition, solar cells have a relatively small total series resistance. During operation, the voltage drop across this resistance should account for only a small fraction of the EMF. The total series resistance can include the contact resistance, the bulk resistance of the semiconductor film, the surface resistance of the thin, semi-transparent light-conducting layer, and the resistance of the collector grids (meshes).

Light rays are converted into electrical energy not only by solar cells but also by photodetectors and photoresistors. However, these must be connected to a power source. Solar cells, on the other hand, can convert solar radiation energy into electrical energy — and even into other forms of energy — without being connected to an external source.

The sharp rise in the efficiency of solar cells mainly occurred after the theory of electron transitions between bands was confirmed experimentally and after technology was developed for producing pure semiconductors with specified properties.

Second- and third-generation spacecraft operated using solar cells, with an efficiency of 9–10%. First-generation spacecraft, meanwhile, operated on batteries.

Theoretical calculations have now established that the efficiency of solar cells made from crystalline silicon (Si) can reach up to 26%. For solar cells made from gallium arsenide (GaAs), the theoretically calculated efficiency is 30%, while the result obtained under laboratory conditions reached 25.5%.

By substituting the expression obtained for the effective power density into the formula given in [1] for determining the efficiency of solar cells, the following equation for the efficiency of solar cells can be obtained.

$$\eta = \frac{\frac{kTj_{qt}}{q}\left(1+\frac{j_0}{j_{qt}}-\frac{n'_2 kT}{qU_{si}}\right)\ln\frac{j_{qt}}{j_0}\frac{kT}{qU_{si}}}{P_0 S} \quad (1)$$

This expression makes it possible to calculate the efficiency of solar cells. By substituting into (1) the expression obtained in [2, 3] for the dependence of the potential barrier height on temperature, the efficiency of solar cells can likewise be calculated.

This work is devoted to studying expression (1), which determines the efficiency of semiconductor solar cells by a semi-empirical method. The greatest advantage of this formula is that it is not transcendental and has a simple form. All the equations obtained by other authors for the efficiency of solar cells using theoretical methods are, firstly, transcendental, and secondly, considerably more complex in form. Formula (1), by contrast, includes parameters that can be determined directly from experimental measurements of the current-voltage characteristic. For this reason, it expresses the efficiency of solar cells more clearly than the results obtained by other authors using other methods.

Figure 1 presents the calculation results obtained from formula (1) for the dependence of the efficiency of solar cells on the non-ideality coefficient of the current-voltage characteristic at the point where the short-circuit current is determined. This relationship is also very strong: as the non-ideality coefficient increases, the efficiency of solar cells decreases exponentially, changing from 17.5% to 8×10^{-5}% as the non-ideality coefficient varies between 1 and 2. The calculations were performed for the values T_0 = 273 K, T = 300 K, $j_0 = 1.5\times10^{-10}$ A, Usi = 0.65 V, φ_0 = 1.12 V, and $\gamma = 5\times10^{-4}$ V/K.

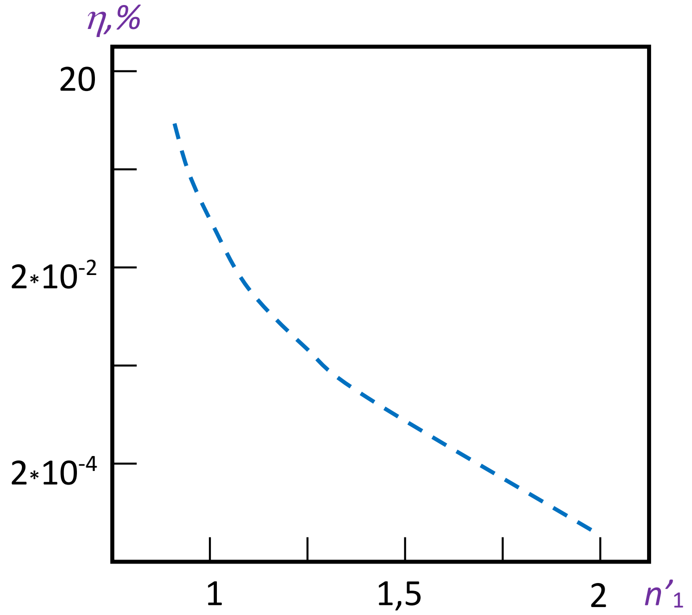

Figure 1. Dependence of the efficiency of solar cells on the non-ideality coefficient of the photo current-voltage characteristic (VAX) at the point where the short-circuit current is determined. The calculations were performed for the values T_0 = 273 K, T = 300 K, $j_0 = 1.5\times10^{-10}$ A, Uoc = 0.65 V, ϕ_0 = 1.12 V, and

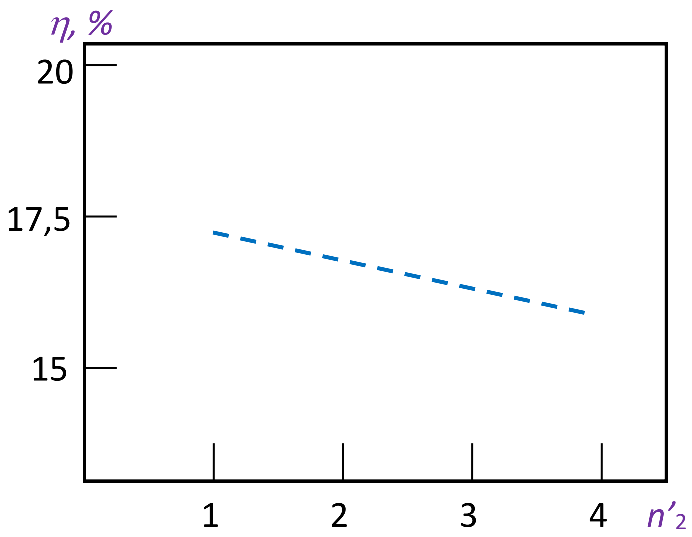

Figure 2. Dependence of the efficiency of solar cells on the non-ideality coefficient of the photo current-voltage characteristic (VAX). The calculations were performed for the values T_0 = 273 K, T = 300 K, $j_0 = 9\times10^{-9}$ A, ϕ_0 = 1.12 V, Uoc = ϕ_0/2 V, $\gamma = 5\times10^{-4}$ V/K, and n_1' = 1.00239.

Figure 2 shows the dependence of the efficiency of solar cells, obtained from formula (1), on the non-ideality coefficient of the current-voltage characteristic at the point where the effective power is determined. This relationship is linear: as the non-ideality coefficient increases from 1 to 4, the effective efficiency of solar cells η decreases within the range of (17.5–15.4)%. The calculations were performed for the values T_0 = 273 K, T = 300 K, $j_0 = 9\times10^{-9}$ A, φ_0 = 1.12 V, Uoc = φ_0/2 V, $\gamma = 5\times10^{-4}$ V/K, and n_1' = 1.00239.

It was shown that the efficiency of solar cells depends exponentially on the non-ideality coefficient of the current-voltage characteristic at the point where the short-circuit current is determined.

It was shown that the dependence of the efficiency of solar cells on the non-ideality coefficient of the current-voltage characteristic at the point where the effective power is determined is linear.

The calculation results show that an increase in the non-ideality coefficient at the point where the short-circuit current density is determined leads to a sharp decrease in the fill factor of the solar cell. The research further shows that the dependence of the fill factor on the non-ideality coefficient of the current-voltage characteristic at the point where the effective power is determined follows a linear function. The following conclusions can be drawn from the results obtained: any increase in the non-ideality coefficient of the solar cell's current-voltage characteristic leads to a decrease in effective power. This, in turn, causes a decrease in the efficiency of the solar cell.

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