THE PHYSICAL ESSENCE OF THE VOLT-AMPERE CHARACTERISTICS OF SOLAR CELLS

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Abctract: To determine the photovoltaic efficiency of solar cells, it is necessary to obtain a volt-ampere characteristic. This work discusses the mechanism of converting light energy into electrical energy in a solar cell, as well as the methods for obtaining and describing the volt-ampere characteristic.

Keywords: photocell, photoelectric effect, semiconductor, silicon, volt, ampere, electromagnetic radiation, wavelength, monocrystal, polycrystal, amorphous silicon, kinetic energy.

Introduction

The photoelectric effect (photoelectric effect) was discovered by the French scientist A.E. Becquerel in 1839 and is based on the ability of conductive materials to emit electrons under the influence of electromagnetic radiation, including light. The three main laws of the photoelectric effect can be formulated as follows:

1) The strength of the photocurrent is directly proportional to the density of electromagnetic radiation.

2) The maximum kinetic energy of electrons emitted by light increases linearly with the frequency of electromagnetic radiation and does not depend on its intensity.

3) For each substance, at a certain state of its surface, there is a limiting frequency of electromagnetic radiation, below which the photoelectric effect is not observed. This frequency and the corresponding wavelength are called the red limit of the photoelectric effect [1-5].

The photoelectric effect is manifested in a photovoltaic system that directly converts solar energy into electricity. Daylight is necessary for the operation of a photovoltaic system. Photovoltaic systems do not necessarily have to be in direct sunlight, so even on cloudy days, photovoltaic panels can generate some electricity.

The simplest design of a photovoltaic or solar cell (PhS) – a device for converting solar radiation energy – based on monocrystalline silicon is shown in Fig. 1. A p–n junction with a thin metal contact is formed at a shallow depth from the surface of a p-type silicon wafer [6-9].

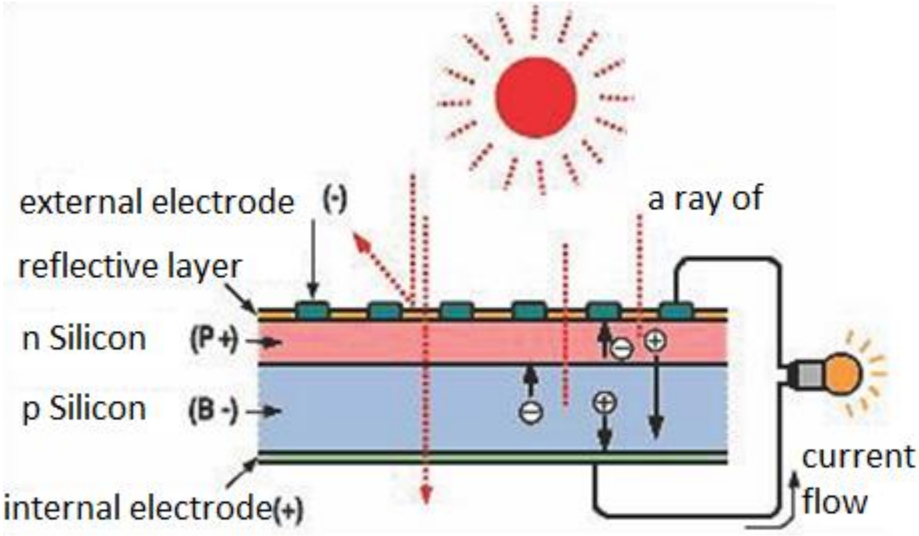

Fig. 1. Construction of a photovoltaic cell

a solid metal contact is applied to the back side of the plate.

Let the p–n junction be located near the illuminated surface of the semiconductor. When using a solar cell as a power source, a load resistance $R_н$ should be connected to its terminals. Let us first consider two extreme cases: $R_н=0$ (short-circuit mode) and $R_н = \infty$ (no-load mode). The band diagrams for these modes are shown in Fig. 2a, b [10-14].

In the first case, the band diagram of the illuminated p–n junction does not differ from the band diagram at thermodynamic equilibrium (without illumination and without applied bias voltage), since the external short-circuiting ensures zero potential difference between the n- and p-regions. However, a current flow through the p–n junction and the external conductor, caused by the photogeneration of electron-hole pairs in the p-region. Photoelectrons formed in the immediate vicinity of the space charge region are carried away by the electric field of the p–n junction and enter the n-region [15-18].

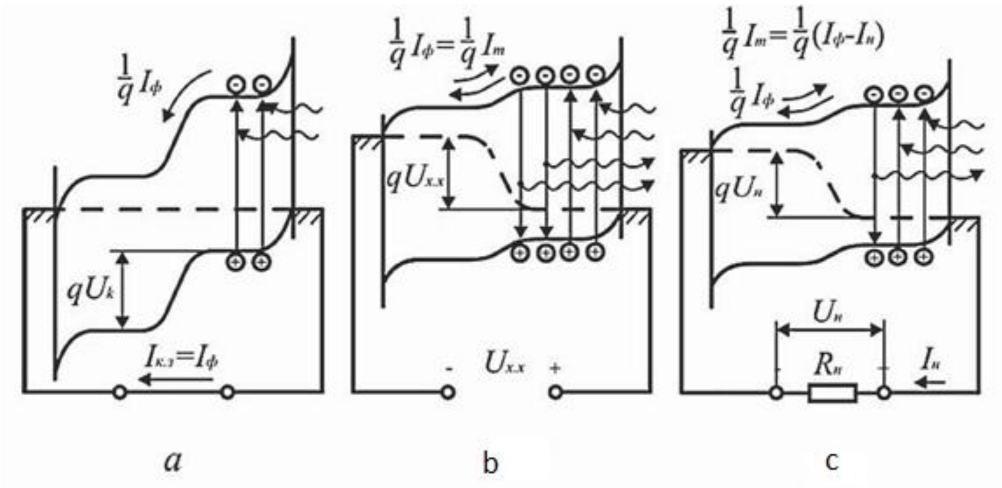

Fig. 2. Energy band diagrams of the p–n junction when illuminated in different modes: a – short circuit; b – no-load; c – switching on to load resistance

The remaining electrons diffuse to the p–n junction, trying to compensate for their loss, and eventually also end up in the n-region. In the n-region, there is a directed movement of electrons to the rear metal contact, flowing into the external circuit and into contact with the p-region. At the boundary of the contact with the p-region, recombination of the electrons that have arrived here with photogenerated holes occurs. When the external circuit of the p–n junction is open (Fig. 2b), photoelectrons, entering the n-region, accumulate in it and charge it negatively. The excess holes remaining in the p-region charge the p-region positively. The potential difference that arises in this way is the open-circuit voltage (U_{xx}), the polarity of which corresponds to the forward bias of the p–n junction [19-24].

The flow of carriers generated by light forms a photocurrent (I_{ph}). Its value is equal to the number of photogenerated carriers that have passed through the p–n junction per unit time. At zero internal ohmic losses in the solar cell, the short-circuit mode (Fig. 2a) is equivalent to zero bias voltage of the p–n junction, therefore the short-circuit current (I_{sc}) is equal to the photocurrent (I_{ph}). In the no-load mode (Fig. 2b), the photocurrent is balanced by the “dark” current ($I_т$) – the direct current through the p–n junction that occurs at the bias voltage (U_{xx}). The “dark” current is accompanied by the recombination of minority current carriers (in this case, electrons in the p-region). During recombinations, the potential energy of electron-hole pairs is released either by emitting photons with $hv \approx E_g$, or is spent on heating the crystal lattice (Fig. 2b). Thus, the idle mode of a solar cell is equivalent to the operating mode of LEDs, as well as rectifier diodes in the throughput direction [24-26].

If a variable load resistance is connected to the p–n junction (Fig. 2c), the direction of the current in it always coincides with the direction of the photocurrent (I_{ph}), and the load current ($I_н$) itself is equal to the resulting current through the p–n junction. The load current-voltage characteristic (VAC) of the illuminated p–n junction

Conclusion

Where U_n is the voltage on the load equal to the voltage on the p–n junction, V; In is the load current, A; I0 is the saturation current, A; I_{ph} is the photocurrent, A; k is the Boltzmann constant, 1.38·10-23 J/K; T is the absolute temperature, K; q is the electron charge.

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