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PHYSICAL PROPERTIES OF QUANTUM TRANSITIONS IN SOLAR PHOTOELEMENTS

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Abstract
In the present paper we have studied the physical properties of quantum transition in solar photo-elements. A method to calculating efficiency of the photo-elements, which depends on solar intensity and photo-element properties was developed.

Keywords: solar station, photo-element, efficiency, energy.

Introduction

Most renewable energies - hydropower, mechanical and thermal energy from the oceans, wind and geothermal energy - are characterized by either limited potential or significant difficulties in widespread use. But there is another source of energy - the sun. When developing highly efficient methods for converting solar energy, the Sun can meet the rapidly growing needs of mankind in energy for many years [1, 2]. The source of solar radiation energy is thermonuclear reactions [1] of proton-proton (at lower temperatures) and carbon-nitrogen (at higher temperatures) cycles, as a result of which a helium nucleus is formed from four protons:

$$_1^4\mathrm{H} \rightarrow {}^4\mathrm{He} + 2e + 2\nu e + \Delta E.$$

where e is a electron, νe is the electron neutrino. When interacting with a semiconductor, optical radiation is partially absorbed, partially reflected from the surface, and partially passes without absorption. The shares of transmitted, reflected and absorbed energy are estimated by appropriate coefficients. Distinguish [2] transmittance coefficient

$$T = \frac{Q_p}{Q_T},$$

reflectivity coefficient

$$R = \frac{Q_O}{Q_T},$$

absorption coefficient

$$F = \frac{Q_Y}{Q_T},$$

where Q_p - power of the transmitted radiation; Q_O is the power of radiation reflected from the surface; Q_Y - power of absorbed radiation; Q_T is the power of the incident radiation. The absorption index [2] α

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is equal to the value of the reciprocal distance from the surface at which the initial power of the incident radiation

$$Q(x) = Q_P \exp[-\alpha x],$$

is weakened by a factor of e. $Q(x)$; where

$$\alpha = -\frac{1}{x} \ln \frac{Q(x)}{Q_P}.$$

where $Q(x)$ is the radiation power at a depth x.

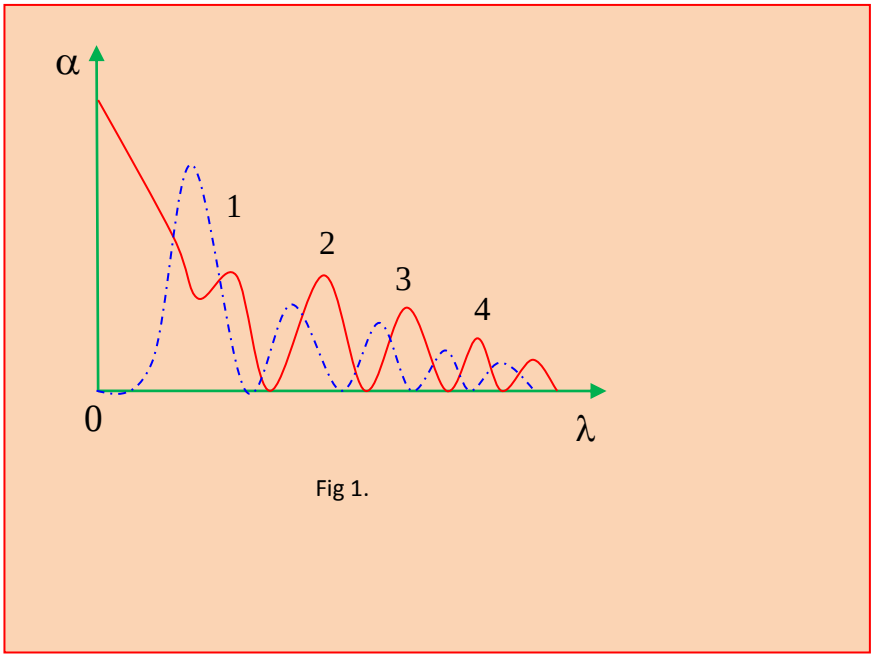

Fig 1.

The dependence of the absorption coefficient $Q(x)$ on the wavelength of the incident radiation $\alpha(\lambda)$ is called the absorption spectrum (Fig. 1) [2]. Section 1 corresponds to its own absorption. The energy absorbed in section 1 is spent on breaking the valence bond and the transition of an electron from the valence band to the conduction band. To transfer an electron to the conduction band, it is necessary that the energy of the absorbed photon exceeds the band gap:

$$E_{ph} = \hbar\nu \geq E_g,$$

where E_{ph} is the energy of the incident photon, E_g is the band gap, $\hbar$ is Planck's constant, ν is the frequency of electromagnetic oscillations of radiation. Therefore, the intrinsic absorption spectrum has a clearly defined border, called the red border of the photoelectric effect:

$$\lambda_g = \frac{\hbar c}{E_g},$$

In the λ_g region, indirect transitions can be observed, at which phonons and excitons participate in the absorption (Fig. 2). The value of λ_g can also be affected by temperature, external fields and the degree

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of doping of the semiconductor with impurities. With an increase in the concentration of impurities, λ_g decreases, which is due to the filling of energy levels near the top of the valence band or the bottom of the conduction band. With an increase in temperature, λ_g increases, which is due to a decrease in the band gap for most semiconductors. In an electric field λ_g is shifted to the long-wave region (the Keldysh-Franz effect); in a magnetic field - to the short-wavelength region (Landau splitting).

Sections 3 and 4 in Fig. 2 correspond to impurity absorption (the photon energy is spent on ionization of impurity atoms). Since the ionization energy of impurity atoms is $\delta E_{ph} = E_g$, the impurity absorption spectrum δE_{ph} □ E_g is shifted to the IR region. The electrons of impurity atoms can be in the ground and excited states; therefore, several sections of impurity absorption are possible in the absorption spectrum (for example, 3 and 4). Exciton absorption corresponds to such absorption of photon energy, in which the electron in the valence band does not detach from the atom, but passes into an excited state, forming an electric dipole - exciton with the hole.

The exciton absorption spectrum consists of narrow lines in the λ_g region (it is not shown in Fig. 2). Section 5 in Fig. 2 corresponds to lattice absorption, in which light quanta lead to the generation of phonons and an increase in the thermal energy of the semiconductor. Absorption of radiation by free charge carriers is also possible, associated with their transitions to other energy levels within the allowed band. In this case, the absorption spectrum is practically continuous due to the small gap between the levels. The generation of charge carriers upon irradiation of a semiconductor leads to a change in its electrical conductivity - the photoresistive effect. The total conductivity in this case

$$\sigma = \sigma_0 + \sigma_{ph}$$

where $\sigma_0 = e(n_0\mu_n + p_0\mu_p)$ is the intrinsic dark conductivity, σ_{ph} is the photoconductivity, μ_p and μ_n are the mobilities of holes and electrons, n_0 and p_0 are the equilibrium concentrations of free electrons and holes, and e is the elementary electric charge. The light absorption efficiency is estimated by the quantum yield of the semiconductor

$$\eta = \Delta n + \Delta p,$$

where Δn and Δp are the number of excess carriers arising during the absorption of light, η_{ph} is the number of absorbed photons. Ideally, $\eta_{ph} \approx 1$, that is, one absorbed photon generates one electron-hole pair.

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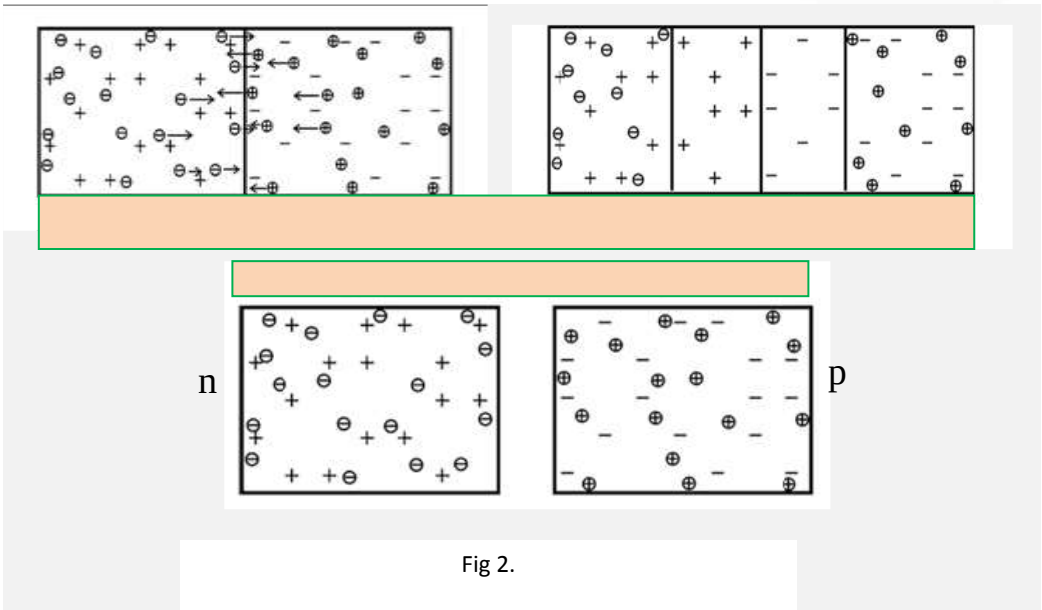

Fig 2.

Photovoltaic effect in the p-n junction. The solar cell makes it possible to convert the energy of optical radiation directly into electricity, bypassing the stages of thermal and mechanical forms of energy. His work is based on the internal photoelectric effect in a semiconductor structure with a p-n-junction (heterojunction, Schottky barrier). The SC of the simplest design consists of two layers of different types of conductivity (electronic - n and hole - p) (Fig. 2) .

An n-type semiconductor contains a number of donor-type impurity atoms, which are practically all ionized at room temperature. Those. there are n_o free equilibrium electrons and the same number of stationary positively charged ions. In a hole semiconductor (p-type semiconductor) there are p_o free holes and the same number of immobile negatively charged ions. When the p- and n-regions come into contact (Fig. 2), due to the gradient of the concentrations of electrons and holes, a diffusion flux of electrons from the n-type semiconductor to the p-type semiconductor appears in them, and, conversely, the flux of holes from p- to n-semiconductor ... The electrons that have passed from the n-region to the p-region recombine with holes near the interface.

Holes recombine in a similar way, passing from the p-region to the n-region. As a result, there are practically no free charge carriers near the p-n junction - on both sides of the p-n junction, a double charged layer formed by immobile ions is formed (depletion layer, or space charge region (SCR)). The SCR electric field counteracts the process of diffusion of the majority charge carriers into the depletion region. Such a state is equilibrium and in the absence of external disturbances it can exist for an arbitrarily long time.

The resulting photocurrent is proportional to the number of electron-hole pairs generated as a result of absorption of radiation, which, in turn, is proportional to the number of radiation quanta absorbed in the substance. Let us consider a homogeneous p-n junction in which the thicknesses of the p and n regions are L_n (the diffusion length of electrons in the p region) and L_p (the diffusion length of holes in the n region), respectively, and there are no reflection from the back contact and surface recombination.

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In this case, most of the minority carriers generated by light are separated by the transition field. Then the photocurrent density

$$J_{ph} = 2e\int_{\nu}^{\infty} \frac{\eta_{ph} Q_Y(\nu)}{\hbar\nu} d\nu.$$

$$Q_Y = AQ_P = Q_P(1-F)[1-\exp(-\alpha(L_n - L_p)].$$

The potential barrier of the transition is reduced by the value of the photo-emf (no-load voltage). A decrease in the potential barrier increases the diffusion current of the majority carriers through the junction, which is directed towards the photocurrent. In the stationary state, the diffusion current density J_D is equal to the drift current density, which consists of the photocurrent density J_{ph} and the transition thermal current density J_0, that is, the condition of dynamic equilibrium is satisfied:

$$J_D = J_{ph} + J_0$$

The current generator simulates the J_D that appears during illumination, the diode parallel to it takes into account the injection current (J_{ph} and J_0). The series resistance RS consists of the resistances of the contact layers, the resistances of each of the p- and n-regions of the element, the metal-semiconductor contact resistances, the parallel resistance RP reflects the possible channels of current leakage parallel to the p-n-junction. According to Fig. 2, we obtain an equation that fairly well describes the I – V characteristic of the SE [2]

$$J = J_{ph} - J_0\left[\exp\left(\frac{e(U - JR_S)}{AkT}\right) - 1\right] - \frac{JR_S + U}{Q_P}$$

The most important characteristic of solar energy - efficiency - determines the efficiency of converting solar radiation energy into electricity

$$f = \frac{Q_M}{Q} = \frac{J_S U_S}{Q}.$$

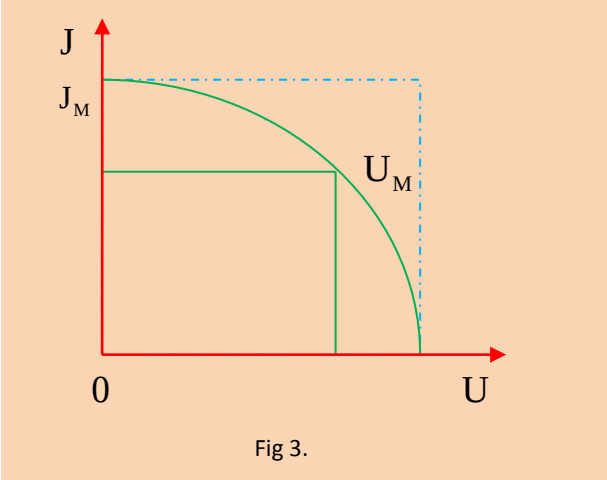

Fig 3.

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where Q is the power of the radiation incident on the solar cell per unit surface, Q_M is the maximum output power of the solar cell relative to its surface area, f is the filling factor (factor) or the shape factor of the I - V characteristic (Fig 3).

$$f = \frac{J_M U_M}{J_{SC} U_{OC}}.$$

where J_M and U_M are the current density and voltage corresponding to the point of greatest power Q_M (Fig. 3). The efficiency of the solar cell shows how much of the energy of the incident light it can convert into electricity. Distinguish efficiency by active surface area

$$\eta = \frac{P_E}{S_A \Phi_O}.$$

where P_E is the electric power generated by the solar cell, Φ_O is the flux density of the light incident on the solar cells, S_A is the area of the active (accessible to light) and common surface of the solar cell. If the type of ESS efficiency is not indicated, then, as a rule, we are talking about η=1.

Conclusion

In this work we study the physical properties of quantum transition in solar photo-elements. We have developed a method to calculating efficiency of the photo-elements, which depends on solar intensity and photo-element properties.

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