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The Efficiency of Qualitatively New Technologies: Investigation of the Tunneling Effect during the Movement of Free Electrons in Solar Cells

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Abstract *- Solar photovoltaic conversion refers to the use of elements that convert solar energy into electrical energy. Today, humanity is actively converting light energy into electrical energy through semiconductors. In this connection, one of the relevant aspects of contemporary physics is studying the need for a more orderly movement of free electrons in solar cells. This can be achieved by using the tunneling effect. Tunneling refers to a quantum mechanical phenomenon when particles pass through a potential barrier that they could not have overcome in the usual classical way. This plays an important role in several physical phenomena, such as alpha decay and nuclear fusion that occurs in the main sequence of stars like the Sun.*

Keywords - *free electrons, solar cells, semiconductors, new technologies, modern physics.*

I. INTRODUCTION

The tunneling effect is one of the basic quantum mechanical effects which play an essential role in various fields of modern physics, including quantum field theory, molecular spectroscopy, as well as in quantum chemistry, and some issues of biology. The problem of analytical description of tunnel effects for various quantum mechanical models has a rich history, which originates from the moment of forming quantum mechanics [1], [2]. A detailed overview of the classical results and applications is presented, for example, in the books [3]-[6]. The current upsurge in interest in the study of quantum tunneling is also associated with progress in nanoelectronics (see, for example, [6]), where the possibility of using quantum effects for qualitatively new technologies arises [7]-[14].

II. METHOD

Using the tunneling effect allows creating a more orderly movement of free electrons in semiconductors and, as a result, increases the efficiency of solar cells.

The work uses generally accepted galvanomagnetic methods for studying semiconductor nanostructures. For the present study, these methods will be useful for creating conditions that will lead to an increase in the ordered movement of charge carriers or from the position of semiconductor nanostructures, which will lead to the appearance of ordered nanostructures thereby creating nanoclusters or the so-called nanodots or nanowires. They are of particular interest since, ultimately, they will allow increasing the efficiency of the created model of solar cells. The concentration of charge carriers in heterostructures is very important, and in this case, using this method is advisable, since it will allow growing a layered structure on the substrate to form a transition or heterojunction between the layers, where the number, and hence the concentration of charge carriers, will increase, and this, in turn, will lead to the emergence of a two-dimensional electron gas. In principle, the created heterostructures will make it possible to control parameters, such as the electronic energy spectrum in semiconductor structures. To create such a heterostructure, it is possible to use molecular beam epitaxy, which will allow creating a high-precision structure.

III. RESULTS

In classical physics, the passage of a particle through a potential barrier is a forbidden situation since the energy of the particle itself is less than the barrier height; therefore, the passage is impossible. If we consider the same situation from the point of view of quantum physics, we can assume that the particle, with a high probability, is in a certain area:

$$\Delta p \Delta x \geq \hbar$$

Based on the Heisenberg uncertainty principle, the internal energy of a particle (kinetic + potential) does not have definite values. Based on the requirements of a continuous wave function – a particle can pass through a potential barrier – an example is the emission of electrons from a metal, alpha decay, transition phenomena in the contact layer of two semiconductors. If the parameters of the barrier change upwards, then the possibility of the particle passing through the barrier decreases. So does the mass of the particle, which affects the probability of passing through the barrier; with mass decreasing, the tunneling effect (probability) increases. Consequently, to increase the tunneling effect, it is necessary to change the parameters of the barrier itself in the direction of decreasing, that is, to reduce the height of the barrier or (and) to reduce the width of the barrier. With a decrease in the named parameters, the number of particles passing through the barrier will increase exponentially, which means the efficiency of the final device (solar battery) will increase.

The passage of a particle (electron) through the barrier will cease to be probable and acquire an ordered structure. When electrons are emitted from a metal, alpha decay, a transition in the contact layer of two semiconductors, is a phenomenon of particles passing through a barrier, which must be ordered and the flux density increased.

Suppose that the electrons of potential energy

$$U(z) = \begin{cases} 0, at\ z < 0; \\ U_0, at\ 0 \le z \le L; \\ 0, at\ z > L \end{cases} \qquad (1)$$

They are trying to pass through a rectangular barrier, and their total energy E is less than U0.

The stationary Schrodinger equations can be written as follows:

$$\begin{cases} \psi + k_1^2 \psi = 0, at\ z < 0; \\ \psi - \ k_2^2 \psi = 0, at\ z \in [0; L]\,; \\ \psi + k_1^2 \psi = 0, at\ z > L \end{cases} \qquad (2)$$

where k1= $\frac{\sqrt{2mE}}{h}$

k2= $\frac{\sqrt{2m(U_0 - E)}}{h}$, are wave vectors; $h = 1.05 \cdot 10^{-34} Js$is the Planck constant

The solution to the wave equation z<0 can be expressed as the sum of $\psi = \exp(ik_1 z) + \exp(ik_1 z) + \alpha \exp(-ik_1 z)$and $z > L$ of reflected waves,$\psi = b \exp(ik_1 z)$. The general solution inside the potential barrier $0 < z < L$ can be written as $\psi = c\exp(k_2 z) + d \exp(-k_2\, z)$.

Constants a, b, c, d are determined by the wave function ψ and the continuity condition of ψ at z=0 b z=L.

The barrier passage coefficient can naturally be considered as the ratio of the transmitted probability flux density of the electrons to one of the random electrons. In this case, this ratio is equal to the square modulus of the wave function. Since z>L, the amplitude of the incident wave is considered to be unity, and the wave vectors of both the incidents and the transmitted waves coincide.

$$D = bb^* \ = (ch^2(k_2 L) + \frac{1}{4} (\frac{k_2}{k_1} - \frac{k_1}{k_2})^2 sh^2(k_2 L))^{-1} \qquad (3)$$

If $k_2 L >> 1\ ch\ (k_2 L)$ then $sh\ (k_2 L)$ and exp $\left(\frac{k_2\, L}{2}\right) canbeapproximatedto(3)$.

Then we can write down

$$D(E) = D_0 exp\left(-\frac{2L}{h}\sqrt{2m(U_0} - E)\right) \qquad (4)$$

where $D_0 = 4\left[1 + \frac{1}{4}\left(\frac{k_2}{k_1} - \frac{k_1}{k_2}\right)^2\right] - {}^1$

Thus, calculating the coefficient of the passage of a rectangular barrier is a simple task. However, it is necessary to find the transmission coefficient of a complex form-barrier. In this case, there is no general analytical solution for coefficient D.

Uncertainty causes atoms and subatomic electrons to be treated as charge "clouds" (uncertainty of position and momentum). The source polarizes the clouds or, more simply, changes the shape of the charge clouds of atoms throughout the quantum wire. According to Gauss' law, no charge can exist inside a conductor. Therefore, the net effects of polarization are visible on the surface of the conductor, which in turn produces an electric field outside the surface of the conductor, despite the absence of a net charge in the conductors (this is the reason that transmission lines, despite being electrically "neutral", have a capacitance relative to the ground and). Clouds, certainly, try to return to their original shapes with the same center for clouds with positive and negative charges, but this is impossible because of the source that maintains this state along the surface of the conductor.

IV. DISCUSSION

The total energy of the Sun is 1.3 million times greater than that of the Earth, while its mass is 330 thousand times greater. This is a huge sphere consisting of ferro thermal gas with a temperature in its center of about 10K and a surface temperature of about 5,800 K. It consists of hydrogen, of which 73% is gas, 25% is helium, and 2% are heavy elements.

The inner space of the Sun is constantly at a high temperature and high pressure, where a thermonuclear reaction is constantly taking place – from the synthesis of hydrogen to the formation of deuterium.

According to calculations, about 6x10^{11} kg of gas is converted per second, while the net mass loss is about 4x10^3 kg.

According to Einstein's theory of relativity, mass can be converted into energy through a thermonuclear reaction.

Formula E=mc^2, where *m* is the mass of matter and *c* is the speed of light in a vacuum (3x10^8 m/s). During a thermonuclear reaction, a large amount of energy is generated. According to the formula, one gram of the substance can be converted into about 9x10^3 of energy. The energy is continuously radiated by the Sun in the amount of up to 3.6 x 18^{20} MW/s. After reflection, scattering, and absorption by the atmosphere, about 70% of the energy is absorbed by the Earth. Although this is a small portion of the solar energy, equal to about 1.8x10^{18} kWh, it is tens of thousands of times higher than the annual energy consumption of the Earth. Taking into account the current rate of loss in solar mass, the thermonuclear reaction of the Sun can last 6x10^{10} years.

For humanity, solar energy is inexhaustible and pure energy. The orbit of the Earth orbiting the Sun has an elliptical shape. The furthest and shortest distance to the Sun is 1.52 x 10^8 and 1.47x10^8 km, and the average distance is 1.49x10^8 km. Due to the change in distance, in

June, the distance from the Sun is maximal. The average energy received by the Earth in December (closest to the Sun) reaches 94%. The intensity of radiation outside the atmosphere is constant. But besides the reason caused by the revolving of the Earth around the Sun, there are also climatic conditions, for example, the thickness of the cloud layer and the composition of the atmosphere, which can affect the solar energy absorbed by the Earth's surface.

The solar energy received by the Earth in a certain territory varies at different times of the year and in different climatic conditions. Usually, the abundance of solar resources is expressed by the total annual radiation and the total number of solar hours per year. Latitude, altitude, location, geographical, and climatic conditions are closely interrelated. On a global scale, Tibet, the Middle East, and Austria have rich solar resources. The intensity of solar energy radiation can be expressed by the formula

$$\mathrm{P}=\mathrm{I}\ (\varphi)\cos\varphi$$

The total radiation dose per day is $TSI = 2\int^{D/2} I(\varphi)\cos\varphi''\,dt$

where I is the incident energy of sunlight; P is the angle of incidence of sunlight relative to the zenith; φ" is the sunlight, angle to the light receiver $\varphi'' = \varphi - \alpha$; $\varphi$is the angle between sunlight radiation and the light receiver line; α is the inclination angle between the light receiver and the ground; D is the time of sunshine; T is the time.

When sunlight hits the Earth, some of the light is reflected or scattered, and a certain portion of the light is absorbed. Only about 70% of the light can pass through the atmosphere as direct or diffused light.

The intensity of sunlight radiation in free space at its average distance from the Earth is defined as a solar constant equal to 1,353 W/m^2. The effect of the atmosphere on sunlight falling on the Earth's surface is defined as air mass.

The state of zero atmospheric mass (AM0) refers to the state of receiving sunlight in extraterrestrial space, which is suitable for spacecraft and satellites. The state of atmospheric mass equal to unity (AM1) means that sunlight falls directly vertical when irradiated on the Earth's surface, and its power is 925 W/m^2, which is equivalent to the sunlight, received at sea level in summer. The difference between them consists of the attenuation of sunlight by the atmosphere, which mainly involves the absorption of ultraviolet rays by water vapor and solids suspended in oxygen. When the sun's rays and the earth form a certain angle, the atmosphere is calculated by the formula

$$\mathrm{AM} = \frac{1}{\cos\theta}$$

whereθ= 48.2%. If air quality is AM1.5, this means that sunlight falls on the ground on a normal sunny day, and the total radiation is 1 kW/m^2, which is often used in solar cells. The wavelength of sunlight varies within the range from 10 microns to ~10 km, but the wavelength of more than 97% of solar energy is within the range of 0.29~3.0 microns, which is a relatively short wavelength and refers to short-wave radiation.

V. CONCLUSION

Solar energy conversion methods are mainly divided into three types: photochemical conversion, solar photothermal conversion, and solar photovoltaic conversion. Photochemical conversion refers to the chemical and biological reactions of substances under the impact of sunlight, whereby solar energy is converted into electric energy. Most commonly, photosynthesis occurs in plants. Under the action of plant chlorophyll, carbon dioxide and water react to light to form carbohydrates and gas, completing the conversion of solar energy. Solar thermal conversion refers to the accumulation of solar radiation energy by reflection, absorption, etc., and converting it into thermal energy, used for example, in solar house heaters, solar water heaters, and solar greenhouses.

Solar photovoltaic conversion refers to using solar energy elements when converting solar energy into electrical energy. Currently, people actively convert light energy into electrical energy through semiconductors. Semiconductors are used in almost every device people are familiar with. These are phones, pads, notebooks, computers, cars, cameras, etc. The role and importance of semiconductors in the modern economy cannot be overestimated. Over the past 50 years, they have played perhaps one of the key roles in all technical revolutions and are used in absolutely all spheres of the economy.

Semiconductors are materials that have the properties of both conventional conductors and insulators. Semiconductors fall into two broad categories: monocrystalline semiconductors, consisting of only one type of material, such as silicon and germanium, as an example. On the other hand, polycrystalline semiconductors are internal semiconductors with other substances added to change their properties; that is, they contain different elements.

Semiconductors and insulators differ from metals by the population of electrons in each band. Under normal conditions, the valence band in any metal is almost filled with electrons. In semiconductors, there are only a few electrons in the conduction band just above the valence band, while the insulator has practically no free electrons.

Tunneling has many applications in semiconductor devices, such as electronic circuits and integrated circuits designed at the nanoscale. In such a tunnel diode, electrons tunnel through a single potential barrier at the contact between two different semiconductors. In the junction, the tunneling electron current changes nonlinearly with the applied potential difference across the junction and can rapidly decrease with increasing bias voltage.

Another type of electronic nanodevice uses resonant tunneling of electrons through potential barriers that arise in quantum dots. A quantum dot is a small area of a semiconductor nanocrystal grown, for example, in a silicon or aluminum crystal.

In conclusion, it should be noted that the widest interest in the tunnel effect is because it is fundamentally a quantum mechanical effect that has no analog in classical mechanics. By its existence, the tunnel effect confirms the fundamental statement of quantum mechanics – the particle-wave dualism of the properties of elementary particles. This aspect sparks the main interest in the tunnel effect in physics and physicists.

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