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ANALYSIS OF THE THERMAL STABILITY OF SOLAR CELLS ON A FLEXIBLE SUBSTRATE INTENDED FOR BACKUP POWER SYSTEMS EMERGENCY PREVENTION

The effect of temperature on the output parameters of the ITO/CdS/CdTe/Cu/Au film solar cell on a flexible substrate, intended for use as an autonomous power supply for emergency prevention systems, has been investigated. It has been shown that a solar cell on a flexible substrate based on cadmium telluride with a Cu/Au back contact can be operated without a decrease in efficiency up to a temperature of 45°C. At higher temperatures, deterioration in diode characteristics is observed, due to a decrease in the value of the dark shunting electrical resistance and an increase in the value of the dark density of the diode saturation current.

The analysis of emergency situations shows that one of the problems of localization and elimination of consequences is a power outage due to damage to power lines. Therefore, it is necessary to provide emergency power supplies or the tools used must work autonomously. Modern security and control systems consume only a small part of the total energy consumption of the facility; their uninterrupted operation is ensured by the availability of electricity in the network. As a rule, such security systems have a backup power source in case of an emergency power outage in the network, but, in most cases, its charge lasts no more than 24 hours [1]. In this case, the use of solar cells becomes relevant.

Solar cells have become an ideal alternative to conventional energy sources because of their superior mechanical strength and high energy conversion efficiency, which can meet human needs for environmentally friendly, inexpensive and portable power sources. The rapid development of wearable devices, telecommunications, transportation, modern sensors and, accordingly, the growing demand for affordable power supplies for modern devices of arbitrary shape and stability at elevated temperatures has become a new problem. In this regard, it is necessary to develop solar cells on a flexible substrate capable of efficiently operating at elevated temperatures.

In the field of power supply of large areas and clean energy, solar cells are widely used [2]. As the conversion efficiency increases and the cost decreases, solar cells are finding more and more commercial applications. The concept of flexible solar cells has been around for a long time, since the flexible structure greatly facilitates the collection of solar energy [3, 4]. Silicon solar cells have been intensively studied since the early 1950s, and more and more photovoltaic materials are being researched to improve cell performance. Monocrystalline silicon and polycrystalline silicon are sequentially applied to solar cells. Since the 1970s, amorphous silicon solar cells have been developed [5]. Compared to crystalline silicon, amorphous silicon is much lighter and thinner. In recent years, many solar cells have been developed: dye sensitized solar cells (DSSC), organic solar cells, Cu (In, Ga) Se_2 (CIGS) solar cells, perovskite solar cells, etc. [6]. To overcome the flexibility problem, great efforts have been made to create various flexible component materials [7]. In particular, the transparent electrode is an integral part of solar cells, and conductive ITO films are commonly used [8]. Despite flexible ITO glasses, flexible solar cells with opaque fiber electrodes have been reported [9]. Another important criterion for increasing the demand for the use of solar cells is degradation resistance. In [10, 11], an analysis of the degradation processes that occurs in SC based on cadmium telluride was carried out and a method for restoring their efficiency was proposed. In [12], the radiation resistance of solar cells with an efficiency of ~ 10% with an anti-radiation glass structure was investigated. The authors found that, in this case, the main CdS / CdTe transition is easily destroyed. Thanks to the work of various groups of researchers [13], it was possible to increase the efficiency of solar cells based on CdTe/CdS by more than 16.5% for devices on a glass substrate coated with "transparent conductive oxide" (hereinafter referred to as TCO) [14, 15], while the predicted the theoretical maximum is about 30% [16] and more than 7% efficiency for devices on flexible metal substrates [17]. The polymer substrate has the advantage that the devices can be made in the front and rear configuration, while in the case of metal substrates, only the rear configuration is possible.

Typical experimental dark current-voltage characteristics of an ITO/CdS/CdTe/Cu/Au solar cell on a flexible substrate are shown in Figure 1.

On the dark CVC of the solar cell, two characteristic sections can be distinguished, corresponding to different mechanisms of charge transfer. The first section is exponential. It is observed when a forward bias is applied from 0 V to (0.6-0.7) V. In this section, CVC can be approximated by the theoretical current-voltage characteristic of a solar cell, for which the presence of a potential barrier affects the charge transfer mechanism. In the second section, CVC is linear. This indicates that charge transfer is described by Ohm's law, when the decisive role in the form of the current-voltage characteristic is played by the sequential electrical resistance of the device structure. With an increase in the forward bias, the transition from the exponential section of the SC CVC to the ohmic one is quite natural. This is due to the fact that when an external forward bias is applied, the potential barrier of the p-n junction decreases. When the external electric field becomes equal to the internal built-in field, the potential barrier disappears and the ohmic section sets in.

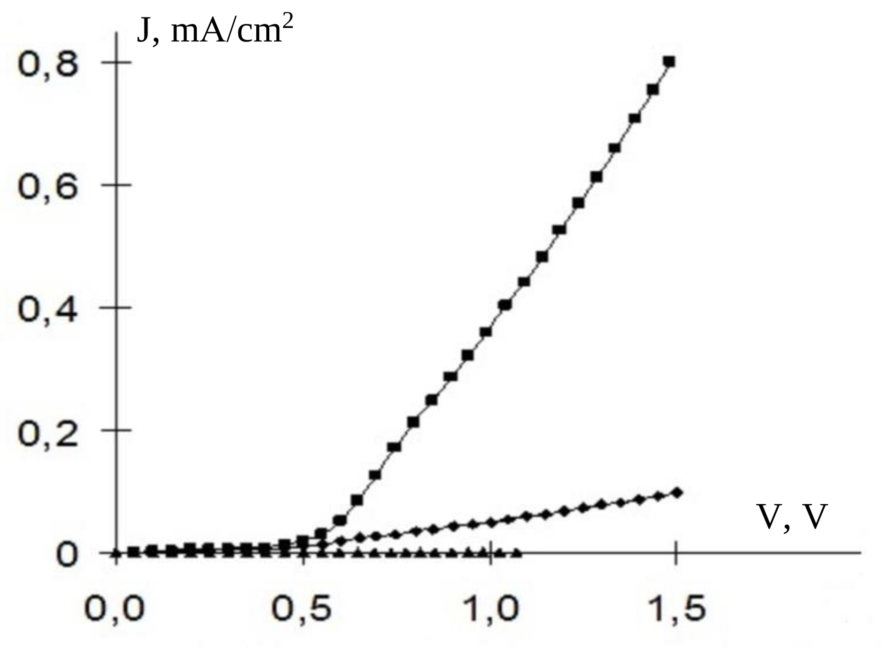

Fig. 1. Experimental dark CVC of solar cells based on CdS/CdTe at different temperatures (▲ – 0 ºC, ♦ – 27 ºC, ■ – 76 ºC)

The conductivity of a semiconductor material is determined by the concentration of equilibrium charge carriers, which increases with increasing temperature due to their thermal generation:

$$n = n_0 \exp(-Eg/kT) \quad (1)$$

where Eg – semiconductor band gap, k – Boltzmann constant, T – temperature, n_0 – initial concentration of charge carriers.

The analysis indicates that with increasing temperature, there is a traditional increase in the density of the dark diode saturation current J_0 by four orders of magnitude in accordance with the traditional relationship:

$$J_0 = J_{00} \exp(-Eg/kT) \quad (2)$$

Correspondingly to the growth of the diode saturation current density J_o, the diode ideality coefficient A also grows (from 1 to 2.2), the value of which is determined by the ratio of the generation and recombination components of the charge transfer mechanism. In the absence of recombination, the ideality coefficient of the diode is A = 1, and in the case of a pure recombination mechanism, A = 2. The contribution of the recombination component naturally increases with increasing temperature as the density of the diode saturation current increases.

A significant problem in the operation of solar cells is the performance of such instrument structures at elevated temperatures, since they are used in conditions of increased solar radiation. An analysis of the obtained dark diode characteristics shows that SC based on cadmium telluride with a Cu/Au back contact on a flexible polyamide substrate can be operated without a decrease in efficiency up to a temperature of 45 °C. At higher temperatures, deterioration in the diode characteristics of a solar cell is observed: a decrease in the value of the dark shunting electrical resistance and an increase in the value of the dark density of the diode saturation current.

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