Investigation of the influence of technological growth parameters on the characteristics of organic photosensitive structures based on the ZnPc:C$_{60}$ system

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Abstract. The influence of technological growth parameters, namely, the mass of the evaporated substance, on the spectral characteristics of organic photosensitive structures based on the ZnPc:C$_{60}$ system is considered. The absorption, transmission, and photosensitivity spectra of the structures were studied.

1. Introduction
The production of thin films is one of the main tasks of modern electronics technology, which is caused by the tendency to reduce the linear dimensions of devices and chip elements. Over the past decades, vacuum deposition has become the main method of creating thin films for use in science, in the fields of research and development, industry. For application in the field of research, the main manufacturing method is high-vacuum deposition of films.

Thermal deposition is one of the most common methods for making films of simple composition, and also allows you to flexibly and quickly change the conditions in which sputtering occurs, to change the spray materials, etc. This makes it easy to vary the growth parameters, which is especially important in the studies. For example, when creating solar cells based on organic materials. Since organics are easily oxidized in the atmosphere, and, consequently, the operating characteristics of the devices deteriorate, it is necessary to produce structures in a vacuum to create highly efficient solar cells [1].

2. Experiment, measurements and results
In this work, the influence of the thickness of the deposited film of organic materials on the photosensitivity of structures was considered. As a substrate, glass was used, coated with a layer of FTO (Fluorine-doped Tin Oxide). The FTO layer served as an optically transparent contact. On the surface of FTO, ZnPc (Zinc phthalocyanine):C$_{60}$ (Fullerene)/C$_{60}$/Al [2] layers were successively deposited by vacuum thermal evaporation. Layers of organic materials and aluminum contact were deposited at a residual gas pressure of 2 $\cdot$ 10$^{-5}$ torr. During the sputtering process of organic layers, the substrate was heated to 60 °C, and when the metal contact was applied, the substrate temperature was maintained at 70 °C.

Evaporation of the substance occurs when it is heated. In operation, the heating of the evaporated substance is carried out by the flow of the heating current through the boat into which the organic material or metal of the required mass is preloaded. It was found that at a filament current of 80 A,
which roughly corresponds to a temperature of 680 °C, ZnPc and C60 evaporate in the best way. Because when the substance is heated, the kinetic energy of its atoms and molecules increases and becomes sufficient to break away from the surface of the boat and spread into the surrounding space.

Heating of the substrate, during the deposition of organic materials, up to 60 °C, improves adhesion to the substrate and diffusion over the surface, which improves the structural quality of the layers. The thickness of the deposited film is directly proportional to the mass of the evaporated matter and back from the distance between the substrate and the boat. In the experiment, the height from the substrate to the evaporated substance remained unchanged at 15 cm. A series of photosensitive structures with various thicknesses of active layers was manufactured. During the experiment, 3 types of structures were created, in which the mass of the evaporated substance varies. Below are the types of structure and mass of evaporated substances:

- 1 sample: ZnPc (15mg): C60 (15mg) / C60 (25mg) / Al (120mg);
- 2 sample: ZnPc (15mg): C60 (20mg) / C60 (30mg) / Al (120mg);
- 3 sample: ZnPc (15mg): C60 (10mg) / C60 (20mg) / Al (120mg);
- 4 sample: ZnPc (15mg): C60 (10mg) / C60 (20mg) / Bphen (7mg) / Al (120mg).

Sample 4 was also created, in which the additional transport layer Bphen (Bathophenanthroline), used to create an additional energy barrier for holes, suppress recombination and improve the collection of charge carriers, was introduced. Figure 1 shows the energy diagram of the structures under study.

![Energy Diagram](image)

**Figure 1.** Position of the energy levels of the structures studied.

The absorption and transmission spectra of the ZnPc:C60/C60 layers were measured, which were measured on a USB4000 fast scanning spectrometer using an incandescent lamp.

From the analysis of absorption and transmission spectra it is established that in order to optimize the characteristics of photosensitive structures, it is necessary to select the optimal thicknesses of active layers, which ensure high absorption and effective generation of charge carriers. This is due to the peculiarity of organic materials in which, under the influence of light, not free charge carriers are formed, and the associated ones are excitons. The dissociation of an exciton by free charge carriers can be carried out at the ZnPc/C60 heterojunction. The characteristic distance that the exciton travels during its lifetime in zinc phthalocyanine is about 10 nm [3], therefore, only photons absorbed near the heterojunction region can contribute to the photocurrent, which can effectively move to the ZnPc/C60 interface. The addition of a hole-blocking layer Bphen effectively increases the absorption in the green-red region of the spectrum.
Figure 2. Absorption spectrum of structures with different masses of C$_{60}$.

Figure 3. Transmission spectrum of structures at different masses of evaporated C$_{60}$.

Figure 4. The spectrum of photosensitivity for images 1, 2, 3.

The photosensitivity spectrum were studied using a diffraction grating monochromator using a Keithley 6483 picoammeter, an incandescent lamp was used as a radiation source.
The highest value of the width of the sensitivity peak at a half-height of 158.8 nm corresponds to the 3 sample, in the same way for this sample a greater sensitivity is observed in the visible range of wavelengths. This makes it possible to use the sample under study (FTO / ZnPc (15 mg): C₆₀ (10 mg) / C₆₀ (20 mg) / Al (120 mg)) as a solar cell. When the mass of the evaporated fullerene increases, the maximum sensitivity shifts to the long-wavelength region, which corresponds to a greater absorption in the fullerene layer.

3. Conclusion
Thus, the influence of the thickness of ZnPc: C₆₀ / C₆₀ layers grown by vacuum thermal deposition for the photosensitive structure FTO / ZnPc: C₆₀ / C₆₀ / Al on the optical characteristics of photosensitive structures on a glass substrate is considered. The best photosensitivity parameters correspond to sample 3 (ZnPc (15 mg): C₆₀ (10 mg) / C₆₀ (20 mg) / Al (120 mg)), in which the dissociation of excitons into free charge carriers is effective. It is also shown in the paper that the introduction of an additional barrier layer (BPhen) increases the absorption of light in the visible wavelength range.

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