# STUDY OF THE STABILITY OF THE ELECTRET STATE IN A NANOCOMPOSITE POLYMER FILM BASED ON POLYETHYLENE WITH A NANOPARTICLE $Ta_2O_5$

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Have studied the electret properties of polymer nanocomposites based on PE and tantalum oxide nanoparticles. At a nanoparticle concentration of between 7% - 10%, it is possible for the electret properties of PE/$Ta_2O_5$ polymer nanocomposites to change significantly. The results of structural changes of polymer nanocomposite PE/$Ta_2O_5$ in its volume and interphase zone are also presented.

**Keywords:** nanocomposites, polyethylene, tantalum oxide, polymer nanoparticles, electrothermopolarization.
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## INTRODUCTION

The creation of nanocomposite polymer materials with an improved complex of properties is a major direction in the physics, chemistry and technology of polymers. This task can be solved, for example, by modifying the surface of the polymer by various methods, which is essential for controlling its dielectric properties, or by adding various dispersed nanofillers to the volume of the polymer.Using numerous methods of modification of polymers, it is possible to improve, in particular, their electrophysical and adhesive characteristics [1-3].

The study of electrophysical properties of nanocomposite polymer films is an actual problem of condensed state physics. Currently, the mechanical properties of nanocomposites have been studied in detail, which is explained by their active use as construction materials. At the same time, there are no systematic studies of the electrophysical properties of nanocomposite films, although materials based on them are used both in the manufacture of electroacoustic and electromechanical signal converters, dosimeters,pressure sensors, air filters, and when solving a number of applied problems.

In this work, high-density polyethylene (HDPE) and tantalum nanooxide ($Ta_2O_5$) were chosen as the polymer matrix. At present, there are practically no models that help to reveal the mechanisms of the influence of nanofillers on the electret properties of composite polymer films and the regularities of the relaxation processes occurring in them. In this regard, the study of charge relaxation processes in composite films based on HDPE with the addition of a nanofiller (tantalum dioxide) is an urgent task of scientific and practical interest. The mechanisms and parameters of electrical relaxation processes in nanocomposite polymer films based on HDPE with nanofiller (tantalum dioxide) were determined to clarify the nature of the electret state in these films, as well as the factors limiting the stability of the electret state [6,7,9,10].

Literature data on the study of the electret state in nanocomposite HDPE films with tantalum dioxide inclusions are practically absent. In this regard, the study of the electret properties of nanocomposite materials based on HDPE remains an urgent problem in condensed matter physics.

## EXPERIMENTAL PART

Materials: HDPE polyethylene granules (SOCAR, "Azerikimya" ProductionUnion "Etilen-Polyethylene" plant, 15803-020), CCl4 organic solvent (Code 141245, 99.5%, Cas No-[56-23-5], Common Chemistry- P.L.C); tantalum oxide nanoparticles ($Ta_2O_5$), (Hongwu International Group, Ltd, China, size 100-200nm, 99.9%, T502).

PE/$Ta_2O_5$ polymer nanocomposites were obtained as follows: polyethylene granules were dissolved at room temperature in 60 ml of an organic solvent, carbon tetrachloride ($CCl_4$), at a temperature of 70°C. $Ta_2O_5$ nanoparticles were added to the polymer solution at various volume concentrations and mixed for 5 hours until a homogeneous mixture was obtained. The mixture was transferred to a Petri dish and dried in a vacuum oven for 24 hours. Then, thin films of nanocomposites were obtained from these samples by hot pressing at the melting temperature of polyethylene and a pressure of 15 MPa. After hot pressing, the films were cooled in water; the cooling rate of the nanocomposite films was 200 deg/min.

X-ray phase studies of nanocomposites were performed on a D2 Phaser X-ray diffractometer in reflection mode (Bragg-Brentano geometry) using CuKa radiation (average wavelength $\lambda$=1.5406 Å, nickel $\beta$-filter). Registration was carried out in a continuous mode in the range of angles $2\theta$ = 5–80°.

Polymer nanocomposites were electrothermopolarized (ETP) using an external electric field with a strength of $7\cdot10^6$-$12\cdot10^6$V/m, at a temperature of 373K and then cooling to room temperature for 1 hour. The film thickness is 95–100

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µm. The electret characteristics were measured with an EFPM-1 device.

## RESULTS AND DISCUSSION

To establish the effect of the content of nanoparticles on the structure of nanocomposites, XRD analyzes were used [8].

On fig. Fig.1 shows X-ray diffraction patterns of PE and nanocomposites based on PE/wt.%$Ta_2O_5$. On the diffraction patterns of the modified PE/3-7 wt.% $Ta_2O_5$ nanocomposite at 2θ: PE/3wt.%$Ta_2O_5$- 25,2° (446), 36,9° (248), 47,5° (180), 55,3° (124); PE/5wt.%$Ta_2O_5$-25,2° (464), 36,9° (277), 47,5° (163), 55,3° (151); and PE/7wt.%$Ta_2O_5$- 25,2° (505), 36,9° (288), 47,5° (164), 55,3° (152) peaks corresponding to $Ta_2O_5$ nanoparticles are observed. It can also be seen from the diffraction patterns that the intensity of the peak at 2θ: 24,5°(740), 38,2° (204) and 40,8°(229) in the PE matrix is observed, which indicates an increase in the semi-crystallinity degree of the matrix.

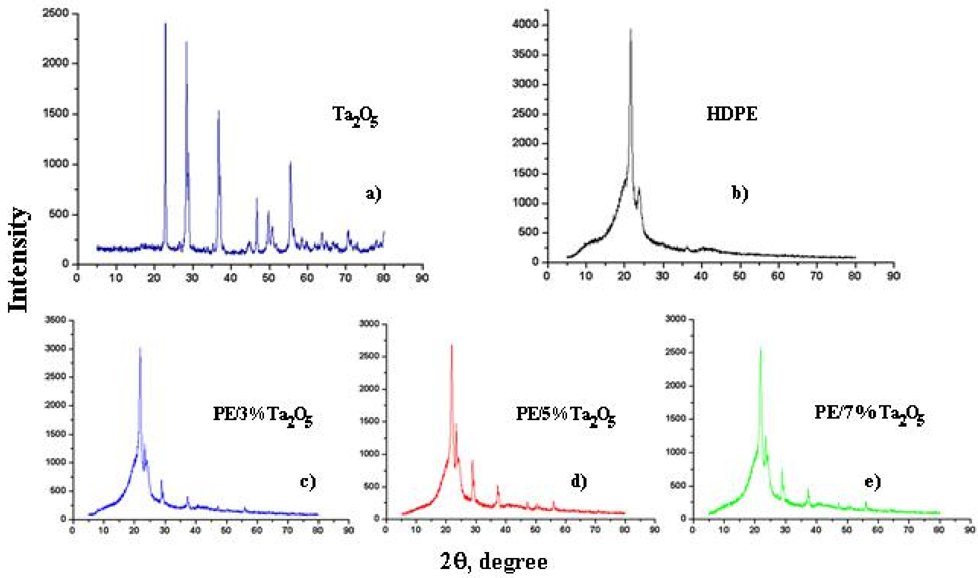


*Fig. 2.* XRD pattern of PE and PE/$Ta_2O_5$ based nanocomposites: a) Nanoparticles $Ta_2O_5$; b) PE; c) PE/3%$Ta_2O_5$; d) PE/5%$Ta_2O_5$; e) PE/7%$Ta_2O_5$

At the first stage, we analyzed the effect of the polymer structure, which can be changed within certain limits during processing, on its electret properties. This can lead to an increase in surface density and charge carrier lifetime. To investigate the effects of structure factors and structural relaxations on electret-effect type processes, we chose HDPE, a classical crystallizing polymer. It should be noted that stable electrets can be obtained from HDPE. The dependence of the surface density of the electret charge (σ) on the lifetime (τ) in PE/$Ta_2O_5$ nanocomposites has been determined. The surface density of the electret charge depending on the lifetime for nanocomposites based on PE/$Ta_2O_5$was calculated using the following expression:

$$\sigma = \frac{\varepsilon\varepsilon_0 U}{d}$$

where, σ is the surface charge density, d is the thickness of the electret, ε is the permittivity of the sample, $\varepsilon_0$-$8.85\cdot10^{-12}$F/m, U is the charging voltage.

The dependence of the electret properties of PE and PE/$Ta_2O_5$ on the lifetime is shown in Fig.1. Polymerization provides a strong interaction between the filler and the matrix, which is required in a number of cases. It can be seen that the inclusion of the $Ta_2O_5$ nanofiller in the polymer matrix contributes to the creation of deep traps for charge carriers and enhancescharge stability in nanocomposite films. The resulting nanocomposites with 5-10wt.%$Ta_2O_5$ content have optimal electret properties. It is shown that the surface density and lifetime of electret charges studied by the inductive method increase in nanocomposites based on PE/wt.%$Ta_2O_5$. The $Ta_2O_5$ nanofiller in the polyethylene matrix can create traps for new electric charges in it.

Samples of 5÷10% PE/$Ta_2O_5$ have higher charge stability σ (curve 3, 4, 5). This is due to the presence of deeper traps in the near-surface layers. As can be seen from Fig.1, for samples at the initial stage with lifetime values up to 6÷10days, the value of σ is characterized by an exponential decrease σ=f(τ), and then a linear decrease in σ (10÷19 days). Comparison of σ in the stable section of dependences σ= f(τ) for different samples shows that samples based on 5÷10 wt.% PE/$Ta_2O_5$ have optimal electret properties, and the value of the surface charge density stabilizes and amounts to $37\div92\times10^{-6}$Kl/m$^2$. The changes in the electret properties of PE and PE/wt%$Ta_2O_5$ according to the supramolecular structure (SMS) of the nanocomposites are related to the charge-stabilizing features in different parts of the structural elements and, accordingly, with the depth of traps in the polymer.

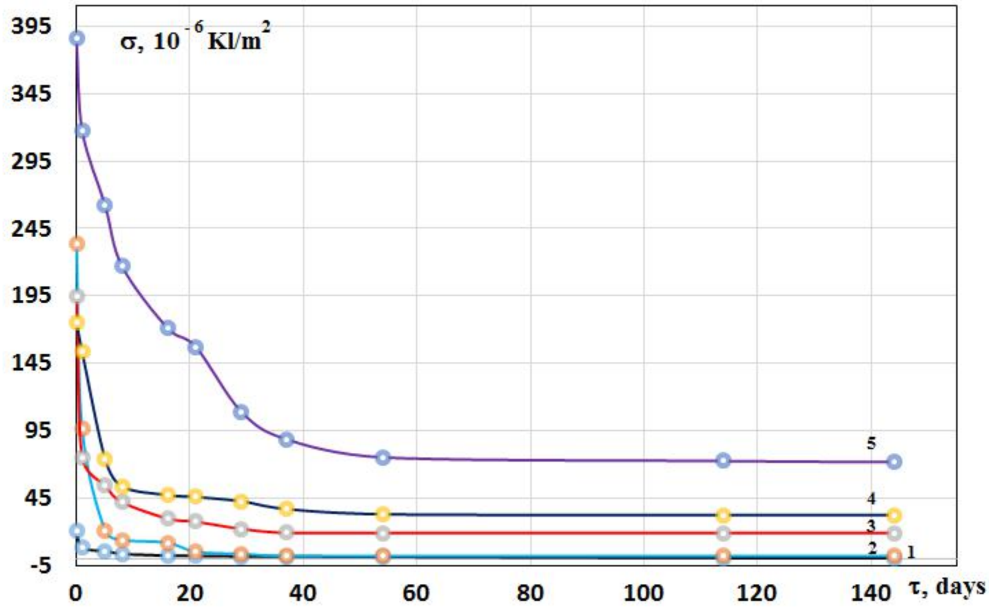


*Fig.2.* The dependence of the surface density of the electret charge σ on the lifetime of the compositions: 1.PE; 2.PE/3%$Ta_2O_5$; 3. PE/5%$Ta_2O_5$; 4. PE/7%$Ta_2O_5$; 5. PE/10%$Ta_2O_5$

It is also seen that σ for nanocomposites based on PE/wt%$Ta_2O_5$ is approximately 17,5 times greater than for pure PE. The nature of the electret properties of the studied systems is similar to each other depending on the mass content of the filler. It can be said that the chemical nature of fillers in improving the electret properties is significant in comparison with the contribution of their structural parameters (specific area and surface area). According to G. Sessler, Borisova M. E., Lushcheikin G. A [4,5], the interface between the amorphous and crystalline phases acts as traps for charge carriers, therefore, it can be the main reason for the significant difference in the electret properties of nanocomposites obtained by the induction method.

## FINDINGS

It has been established that the stability of the electret state in composite polymer films based on HDPE with inclusions of tantalum dioxide is significantly higher compared to the original films without filler. And this makes it possible to consider nanocomposite films based on it as a promising material for the creation of electroacoustic and electromechanical transducers. It is shown that the stability of the electret state in nanocomposite HDPE polymer films depends nonmonotonically on the volume concentration of nanofillersin the sample. The optimal volume concentration of tantalum dioxide, which provides the highest stability of the electret state in HDPE films, has been determined. Two conclusions can be drawn from the discussion mentioned above. First, nanofillers play an important role in the polarization of nanocomposites and are capable of changing the polarization intensity of intrinsic dipoles in polymers. Second, the trap depth can also be changed by introducing nanofillers and, consequently, the interfacial polarization in nanocomposites can be changed. The influence of the nanofilling process on the formation of electret properties and on the process of stabilization of electret charges can be explained from the point of view of modern ideas about the structure of the PE crystallization mechanism.


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