EFFECT OF ELECTROTHERMOPOLARIZATION ON DIELECTRIC PROPERTIES IN PE/Ta_2O_5 NANOCOMPOSITE

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Dielectric properties of polymer nanocomposite based on PE and tantalum oxide nanoparticles were studied. It has been shown that the dielectric properties of PE/Ta_2O_5 polymer nanocomposite are significantly changed at 7% and 10% concentration of nanoparticles.

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

Polymers and nanocomposite materials based on them are widely used in practice as dielectric and electrical materials. Qualitative dielectric characteristics of polymers, including specific electrical resistance, electrical strength, etc. due to their properties, they are widely used in the production of insulating materials, electronic devices, capacitors, high-voltage machines, generators, and many other devices. These possibilities increase even more in nanocomposites with new composition obtained by using nanofillers of different origins [1-3, 8]. The diversity of polymer nanocomposites and the ability to obtain materials whose physico-chemical properties can be changed on a large scale, opens wide opportunities for their use as construction materials in microelectronics and radio engineering. As it is known, polymers and nanocomposite materials obtained on their basis undergo volume charge polarization after being exposed to an external electric field at sufficiently high temperatures and have the property of electricity. The main characteristics of the electret material are the value of the electric charge and its stability. Dielectric properties of nanocomposites coated with Al_2O_3 with PE and nanoparticle additives were studied depending on the influence of external factors and the amount of nanofiller. The frequency dependence of the dielectric permittivity and the tangent of the dielectric loss angle in the indicated type of nanocomposites was studied in the intervals of 1kHs-1MHs.

EXPERIMENTAL PART

The inclusion of nanoparticles in a polymer matrix imparts the desired properties required for physical and mechanical applications. The combination of a polymer (continuous phase) with nanoparticles (discontinuous phase) results in a new material known as polymer nanocomposites (Fig.1). Polymer nanocomposites, being a class of materials with amazing properties, have their own problems, which are complex interfacial regions between the polymer matrix and the nanoparticle. These problems are solved with the help of processing methods. Overcoming the disadvantage will lead to the creation of materials with desired properties (optical, thermal, electrical and mechanical).

The method of preparation of nanocomposite materials directly affects the overall characteristics of the materials. A good understanding of the processing parameters (temperature, speed/time and pressure) will contribute to the properties of the nanocomposites. In most cases, materials for the development of polymer matrix composites require preheating in a vacuum furnace at a certain temperature for a given period of time, depending on the nature of the materials.

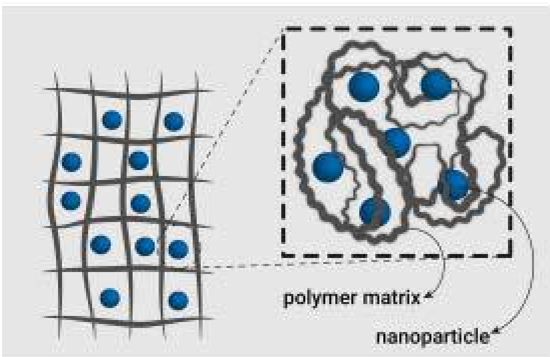

Fig.1. A polymer nanocompozite consists of a polymer matrix and any other substsnce as reinforcement material or filler.

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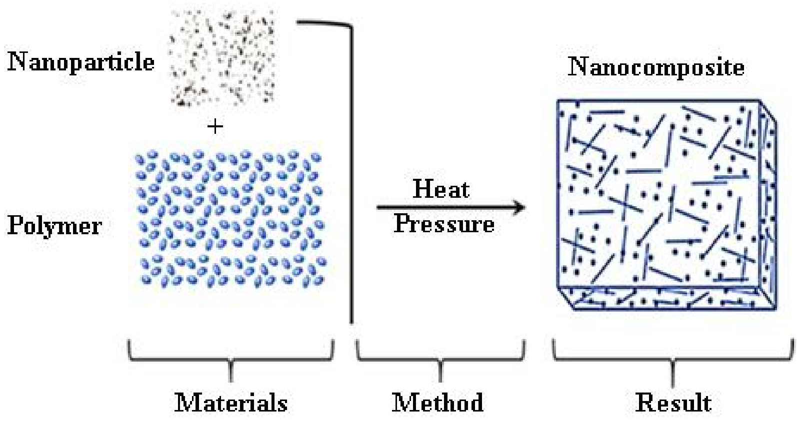

Fig.2. Schematic diagram of the stages of processing nanocomposites from start to finish

On Fig. 2 shows the stages of processing nanocomposites from start to finish. The dielectric properties were measured using an IET1920 PRECISION LCR METER at a frequency of 1kHz-1MHz at a temperature of 293K. Polymer nanocomposites were electrothermopolarization (ETP) using an external electric field with a strength of $7{\cdot}10^6$-$12{\cdot}10^6$V/m, at a temperature of 373K and then cooling to room temperature for 1 hour. Polymerization provides a strong interaction between the filler and the matrix, which is required in a number of cases. The film thickness is 95–100 µm.

RESULTS AND DISCUSSION

The dielectric permittivity of both nanocomposites and for polyethylene at all frequencies up to the ETP increases. The nanocomposite sample containing 7%Ta_2O_5 shows an increase of about 40% per ε compared to the original PE in the measured frequency range. From Fig.3 it can be seen that the tendency ε gradually increases. With an increase in the content of Ta_2O_5 nanoparticles in the polymer, the number of charge carriers that are captured by the interfacial region increases, which leads to an increase in the degree of interfacial polarization and an increase in the permittivity of nanocomposites. After ETP, the permittivity in the PE sample remains unchanged up to 1 MHz, while in the PE/7%Ta_2O_5 and PE/10%Ta_2O_5 samples, a decrease to 200 kHz is observed. After 200 kHz, for nanocomposite samples, the permittivity increases and a stable state appears up to 1 MHz.

Figure 3(b) further shows that the increasing trend of dielectric constant gradually alleviates when the filler loading exceeds 7wt%. This is mainly attributed to the aggregation of Ta_2O_5 nanoparticles in nanocomposites with high filler loading, and thus the reduction of interfacial polarization contributing to the dielectric property.

Figure 4 (a) shows the dependence of the dielectric loss tangent on frequency for nanocomposites based on PE/Ta_2O_5. Before ETP, the values of tgδ for nanocomposite samples have a peak at a low frequency. PE at low frequencies are stable, and then there is an increase in the value of tgδ in the frequency range from 20 kHz to 1 MHz. After frequencies of 5–10 kHz, both nanocomposite samples show a decrease in the dielectric loss tangent. From a frequency of 200 kHz, the dielectric loss tangent increases in nanocomposites.

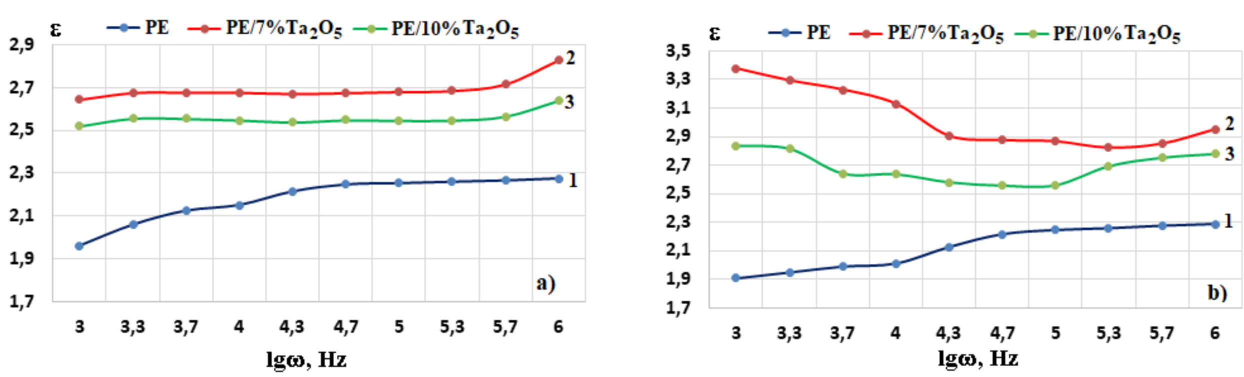

Fig.3. The dependence of the true dielectric permittivity on the frequency: 1.PE; 2. PE/7%Ta_2O_5; 3. PE/10%Ta_2O_5 before (a) and after (b) electrothermopolarization.

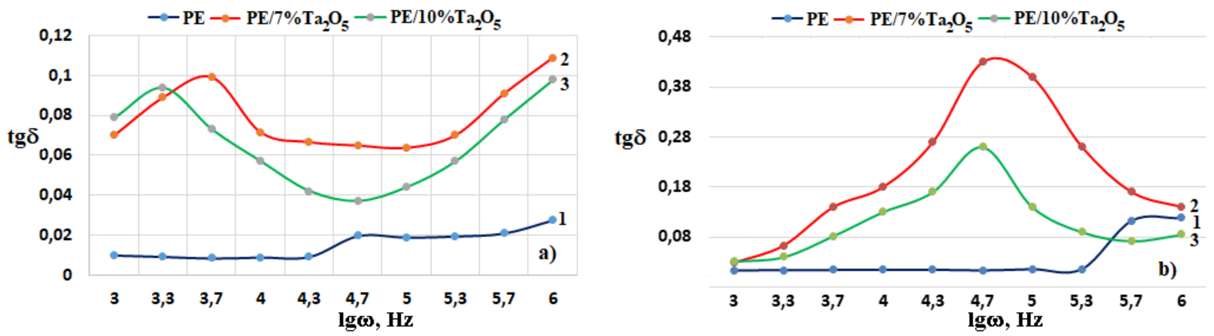

Fig.4. Dependence of dielectric loss tangent on frequency: 1.PE; 2. PE/7%Ta_2O_5;
3. PE/10%Ta_2O_5 before (a) and after (b) electrothermopolarization.

On fig. 4.b there is a peak of dielectric loss tangent relaxation and may be related to electrode polarization or interfacial polarization. It can be seen that, as nanofillers negatively affect the dielectric loss of the polymer in the frequency range above $2{\cdot}10^3$Hz, the main peak is observed for the PE/7%Ta_2O_5nanocomposite (50kHz), and for the PE/10%Ta_2O_5 nanocomposite (65kHz). The dielectric losses of both nanocomposites decrease in the frequency range from 10^3kHz to 600kHz, approaching sufficiently low values. The high-frequency part of dielectric losses arises due to relaxation types of polarization.

The dielectric loss after the ETP of the original PE increases (Fig. 4. b.) and is in a fairly high-frequency range of $200{\cdot}10^3$Hz. From Fig.6 it can be seen that the dielectric loss of each sample is related to the dipole polarization. Due to the large size of these dipoles, their relaxation is much more difficult and there are more obstacles preventing their rotation [4-7]. These forces restrain the rotation of their own dipoles and the molecular chain of polymers under the action of an applied external electric field, and, therefore, reduce the intensity of polarization, which has a negative effect due to the large specific surface of the nanoparticle, they rather affect the own dipoles of the base material.

FINDINGS

From the discussion mentioned above, three conclusions could be drawn. First, nanofillers play an important role in the polarization of nanocomposites and they can change the polarization intensity of their own dipoles in polymers. Second, the depth of the traps can also be changed by incorporating nanofillers, and therefore change the interfacial polarization in the nanocomposites. Thirdly, by controlling the nanofiller content, the dielectric properties can be changed to be higher or lower than that of pure PE. By introducing Ta_2O_5 nanoparticles into the PE polymer matrix, it was possible to improve the physical properties of the polymer. This is achieved by combining a set of material properties.

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