FREQUENCY DEPENDENCE OF ELECTRIC CONDUCTION OF POLYETHYLENE OF HIGH DENSITY/ α-Al_2O_3 NANO-COMPOSITES MODIFIED BY GAMMA BEAMS

M.N. BAYRAMOV, N.Sh. ALIYEV
Institute of Radiational Problems of Azerbaijan NAS, Az 1143,
B.Vakhabzade, 9, Baku,Azerbaijan
nabi.aliyev.1958@ mail.ru

The frequency dependence of electric conduction of initial and γ-irradiated HDPE (polyethylene of high density)/ α-Al_2O_3 nano-composites are investigated in the given work. It is shown that absorption doze of gamma-radiation significantly influences on composite sample electric conduction causing its increase in the direction of high frequencies and this increase connects with accumulation of stabilized charge carriers in irradiated materials. It is established that influence of irradiation dose 100kGy on nano-composite electric conduction is caused by not the change of molecular motion spectrum, but the accumulation of stabilized charge carriers in the samples and at least the radiolysis molecular products presenting the trapping centers. The relatively rapid increase of electric conduction real part at alternating current σ_{ac} (ν) on frequency dependences of HDPE/α-Al_2O_3 nano-composite samples with volume content correspondingly 1,3% and 5% with heterogeneous structure is caused by electron polarization where charge transfer probably takes place with the help of hopping conduction. The values found for *s* index (from 0,081 up to 0,43) in irradiated nano-composite samples are also indicate on this fact.

Keywords: polyethylene of high density, nano-dimensional aluminum oxide, electric conduction, electric conduction real part, irradiation dose, polarization.
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INTRODUCTION

Nowadays, the formation of multifunctional polymer compositional materials (PCM) on the base of nano-dimensional fillers from different metal oxides (Fe_2O_3, Fe_3O_4, TiO2, Al_2O_3, ZnO, CuO, BeO, ZrO_2 and etc.) is the one of the perspective directions of the radiational material science. Note that the structure and properties of nano-and low-dispersed fillers of inorganic origin including polymer composites modified by Al_2O_3 significantly change because of interphase interactions and nano-layer formation near the boundary of polymer with filler particles. By other hand, the properties of polymer composites also depend on the nature of polymer matrix and filler, their initial properties, form and filler sizes, and also on interaction and adhesion between polymer matrix and filler [1,2].

The prediction and taking under consideration of external factor influence (external electric field, magnetic field, temperature, humidity, pressure, ionizing radiation and etc) are ones of the important and key questions at PCM production which are applied in different devices and installations. That's why investigators working in this field pay significant attention to availability of again developed many-functional PCM in radiation field. These materials should be stable to high radiational action and have the minimum dependence on the change of environment properties. By other hand, the study of PCM radiational modification process is also the interest for electron, cable and electro-technical industry. Thus, in cable production the lifetime of cable materials modified by ionizing radiation is bigger in several times [3,4]. It is need to note that PCM stability to radiation, heating and also the fact that it has the less dielectric losses is the main condition of its obtaining.

The investigation of electric conduction of YSPE/α-Al_2O_3 nano-composites modified by gamma-irradiation is the aim of the given work.

EXPERIMENTAL PART

The nano-composite samples HDPE/α-Al_2O_3 on the base of HDPE homogeneous mixture of mark 20808-024 by GOST 16387-85 with powder-like nano-dimensional aluminum oxide α-Al_2O_3 («Skyspring Nanomaterials, Inc.», USA) are prepared in the form of films by thickness 130-200 μm and diameter 20 mm by the way of hot pressing on hydraulic press at temperature 413-423K and pressure 15MPa with the following their hardening of mixture ice-water. In composite the filler mass relation is 1,3% and 5%.

The powder-like HDPE (20808-024 mark, average molecular weight is 95000, crystallinity degree is 52%, melting point is T = 403K, density is d = 0,93 gr/cm^3, resistivity is $\rho_v = 1 \cdot 10^{16}$ Om·cm 20-40) taken as a polymer matrix is mixed in porcelain cup with nano-α-Al_2O_3 filler powder (density is d = 4,4 gr/cm3, average dimension is 50 nm, resistivity is $\rho_v = 1 \cdot 10^{12}$ Om·cm) in the beginning stage of works for the obtaining of

HDPE/α-Al_2O_3 nano-composite. The nano-composite samples by thickness 130-200μm and diameter 20mm, are obtained from this homogeneous mixture on hydraulic press at pressure 15MPa at temperature 423K with ageing during 5 min, which further are cooled at 273K (ice-water mixture). The filler volume content in composite is 1,3% and 5%.

The frequency dependences of σ(ν) electric conduction of HDPE/α-Al_2O_3 nano-composite in alternating field are measured with the help of impedance measurer E7-20 in frequency interval 25-10^6 Hz at temperature 293K.

131, H.Javid ave, AZ-1143, Baku
ANAS, Institute of Physics
E-mail: jophphysics@gmail.com

The composite film samples are treated by γ-radiation at room temperature in installation with irradiation source ^{60}Co. The absorbed dose rate is $3{,}3\cdot10^{3}$ Gy/h.

RESULT DISCUSSION

The frequency dependences of electric conduction logarithmic values of HDPE/α -Al_2O_3 lqσ=f(lqν) nano-composite samples before irradiation, are shown in Fig.1.

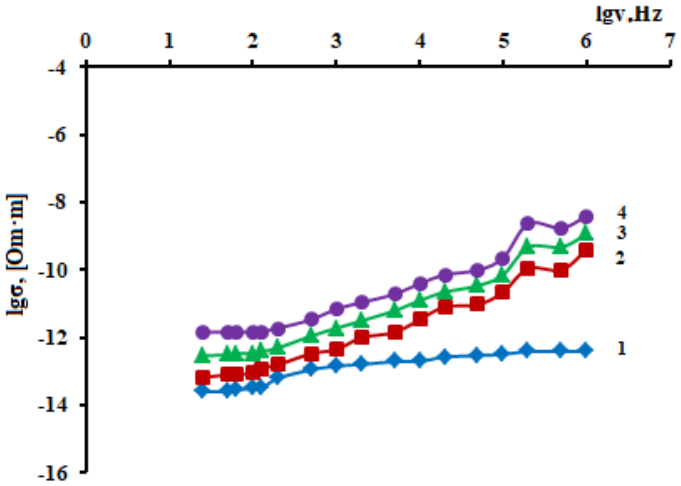

Fig.1. The frequency dependences of logarithmic values of HDPE/α- Al_2O_3 lgσ = f (lgν) nano-composite electric conduction before irradiation: 1 is pure HDPE; 2 is content of 1vol.% nano- α-Al_2O_3; 3 is content of 3vol.% nano-α- Al_2O_3; 4 is content of 5vol.% nano-α- Al_2O_3.

The frequency dependences of electric conduction (Fig.1 and Fig.2) in investigated HDPE/ α -Al_2O_3 nano-composites as heterogeneous structures according to law of universal dielectric response are described by Jonsher power law [9]:

$$\sigma(\omega) \approx \sigma_{dc} + A\,\omega^{s}$$

where σ_{dc} is electric conduction at constant current not depending on frequency, circular frequency $\omega = 2\pi\nu$; A and s are coefficients depending on temperature and frequency. The power frequency dependence σ(ω) shows the hopping conduction in these systems. Value s also defines the charge carrier motion type. The value of frequency index s we calculate from curve inclination of the dependence $\ln\sigma_{ac} = f(\ln\nu)$, where $0 < s = 0{,}081 \div 0{,}43 < 1$.

As it is seen from Fig.1, the three regions of electric conduction change values (curves 2 – 4) are observed for unirradiated HDPE/ α -Al_2O_3 nano-composites; two regions are observed for HDPE polymer (curve 1): I region is observed at frequency (25-120) Hz, II region is observed at $(200\text{-}5\cdot10^{4})$ Hz and III region is observed at frequency $(2\cdot10^{5}\text{-}10^{6})$ Hz.

The linear increase of electric conduction of all samples with frequency increase are character for I and II regions. Herewith, electric conduction value increases with the increase of filler content. At low frequencies (I region) on alternating voltage the insignificant change of (σ_{ac}) electric conduction in the dependence on frequency can be explained by the interphase polarization (Maxwell-Vagner polarization) caused by trapping of volume charges in interphase and polar elements forming as a result of sample partial oxidation at thermal pressing [31]. The voltage applied to the sample in this region transfer the system charge carriers in big distances and σ_{ac} electric conduction dominates in the given region. Here, the frequency increase leads to the decrease of average distance of charge carrier transfer and electric conduction real part changes according to $\sigma_{ac}(\nu) \sim \nu^{0{,}48}$ law after the fact that the frequency achieves the definite value ν_c.

The corresponding values calculated for the inclination of $\lg\sigma_{ac} = f(\lg\nu)$ dependence linear sections show that s parameter depends on filler volume concentration and increases with the increase of Al_2O_3 filler concentration in polymer matrix. In I region s_1 decreases from 0,43 up to 0,081, s_2 decreases from 0,37 up to 0,18 that well coincides with results obtained in [14]. The found values of s parameter (from 0,081 up to 0,43) shows on the fact that the rebound conduction is the near-wall mechanism [10, 13]. According to this model, the electric conduction frequency dependence can be explained as charge carrier jumps $\sigma_{ac}(\nu)$ on localized levels round Fermi levels [5,6,7,8].

At low frequencies the insignificant increase of electric conduction values is observed in I region in the polymer pure sample (curve 1), linear increase of electric conduction values is observed in II and III regions. The electric conduction significantly increases with the increase of filler volume concentration to the direction of high frequencies in samples of HDPE/α -Al_2O_3 nano-composites. Note that electric conduction maximums in frequency range $2\cdot10^{5} \div 10^{6}$ are observed on resonance frequency.

The frequency dependences of logarithmic values of electric conduction of HDPE/α -Al_2O_3 nano-composite samples lqσ=f(lqν) after γ-irradiation by dose D=100kGy are shown in Fig.2.

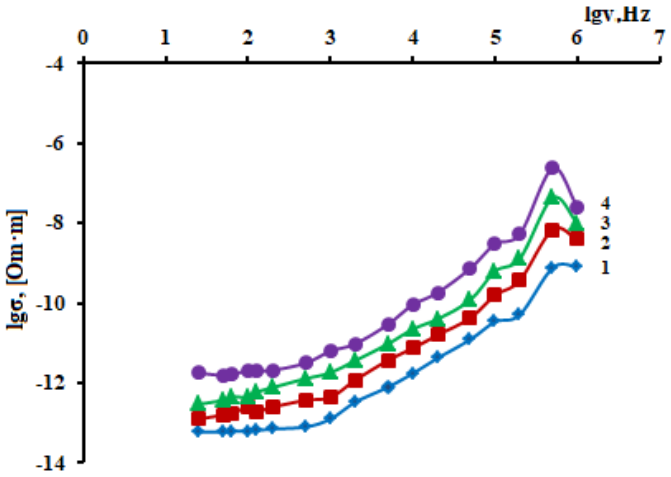

Fig.2. The frequency dependences of logarithmic values of HDPE/α- Al_2O_3 lgσ = *f* (lgv) nano-composite electric conduction after γ-irradiation by dose 100kGy: 1 is pure HDPE; 2 is content of 1vol.% nano- α-Al_2O_3; 3 is content of 3vol.% nano-α- Al_2O_3; 4 is content of 5vol.% nano- α- Al_2O_3.

As it is seen from the Fig.2 the value change character of electric conduction in all regions is identical one on $\ln\sigma_{ac} = f(\ln\nu)$ dependences after γ-radiation by dose D=100kGy of polymer sample and nano-composites containing 1,3 and 5 vol.% of nano-α -Al_2O_3.

The three regions of electric conduction value changes lgσ: I region at frequency 25 – 200 Hz, II region at frequency $(5\cdot10^2\text{-}5\cdot10^4)$Hz and III region at frequency $(1\cdot10^5\text{–}10^6)$ Hz, are observed in the comparison with unirradiated samples. At influence of γ -radiation the electric conduction values of polymer and nano-composite samples increase with the increase of nano- α -Al_2O_3 content in the comparison with analogous unirradiated samples [15,15].

The relatively rapid $\sigma_{ac}(\nu)$ increase is caused by electron polarization with the frequency increase [6,11]. As a rule, the presence of the linear sections on $\ln\sigma_{ac} = f(\ln\nu)$ dependence for heterogeneous system in which HDPE/α -Al_2O_3 nano-composites investigated by us are included, shows the hopping of charge transfer.

CONCLUSION

The study of frequency dependences $\lg\sigma = f(\lg\nu)$ in frequency interval 25 - 10^6 Hz shows the presence of the two linear regions with higher values of γ-irradiated samples by dose 100kGy than unirradiated samples have which change according to law $\sigma_{ac}(\nu) \sim \nu^{0,43}$. The change character of the electric conduction values in all regions is identical one. The electric conduction values of HDPE/α -Al_2O_3 nano-composites increase with the increase of volume content of nano- α -Al_2O_3 on frequency dependences.

The relatively rapid increase of conduction real part at alternating current σ_{ac} (ν) in frequency dependencies of HDPE/α -Al_2O_3 nano-composite samples after γ-irradiation by dose 100kGy is caused by electron polarization where charge transfer takes place probably with the help of conduction hopping.

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