

## DIELECTRIC PROPERTIES OF POLYMER COMPOSITES BASED ON HIGH-DENSITY POLYETHYLENE AND GALLIUM ARSENIDE

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The dielectric properties of polymer composites based on high-density polyethylene (HDPE) and semiconductors of undoped (GaAs) and tellurium-doped gallium arsenide GaAs <Te> have been studied. The temperature and frequency dependences of the dielectric constant  $\epsilon(T, \nu)$  and the dielectric losses  $tg\delta(T, \nu)$  of the HDPE / GaAs and HDPE / GaAs <Te> compositions with different volume ratios of the components are obtained. It is shown that the changes in the dielectric properties of HDPE / GaAs and HDPE / GaAs <Te> compositions are due to the change in the supramolecular structure (SMS) of the polymer and are described by the two-phase Lichteneker model.

**Keywords:** polymer composite, high-density polyethylene (HDPE), semiconductors GaAs and GaAs <Te>, dielectric properties

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### INTRODUCTION

The production of new polymer compositions with distinctive electrophysical, spectral-luminescent, electrets and other properties [1-3] depends to a large extent on the nature of the filler, on the shape, size, distribution pattern and type of particle connectivity, and on the degree of interaction between the constituent components [4-8]. Usually, new fillers lead to the expansion of the possibilities of practical application of the composite material. From this point of view, polymeric composite materials such as polymer-semiconductor fillers are of particular interest [9-12]. The introduction of semiconductor fillers into the polymer matrix leads to a modification of its structure and properties. In this aspect, composites based on high density polyethylene (HDPE) with semiconductor compound GaAs are of interest. This is due to the fact that this semiconductor has a unique crystalline and band structure, is a promising material in micro and optoelectronics. [7] Since gallium arsenide GaAs, with a density of 5.31 g / cm<sup>3</sup> in the IR region ( $\lambda=1-12 \mu\text{m}$ ) is optically anisotropic, for  $\lambda = 8 \mu\text{m}$ , the refractive index  $n = 3.34$  is characterized by high thermal conductivity, magneto-optical, optical properties. Gallium arsenide is used in semiconductor lasers, diodes and other devices. Lasers have been created on the basis of heterostructures with one n-GaAs-p-GaAs-Al<sub>x</sub>Ga<sub>1-x</sub>As and two Al<sub>x</sub>Ga<sub>1-x</sub>As-GaAs-Al<sub>x</sub>Ga<sub>1-x</sub>As heterojunctions. It should be noted that the production of GaAs layers, at present, is carried out by different methods; in the form of hybrid nanocomposites by sol-gel method or by molecular beam epitaxy method (MBE), etc. [8].

A nonmonotonic character of the dependence of the integrated impurity photoluminescence on the absorbed dose was found and the possibility of using GaAs <Te> as a dosimetric material in the region  $D < 10^6 \text{ rad}$  was shown [9]. The problems of radiation defect formation, impurity photoluminescence and electrophysical properties of polymer/GaAs composites and polymer/GaAs<Te> are also poorly studied in heavily doped GaAs <Te> single crystals. The use of these materials as modifying additives for polymers can lead to the production of new composites with distinctive electrophysical, luminescent

and mechanical properties. The choice of HDPE as a binder is due to the good knowledge of this polymer.

### EXPERIMENTAL METHOD

Homogeneous mixture from the HDPE powders and GaAs and GaAs <Te> semiconductors (with particle sizes ~ 10  $\mu\text{m}$ ), was prepared by mechanical mixing in a ball mill. Then, the homogeneous mixture was hot-pressed at a temperature of  $T = 410 \text{ K}$  with an exposure time of 15 minutes and cooled to room temperature for 30 minutes. This method makes it possible to obtain HDPE samples with a film thickness of 80-100  $\mu\text{m}$  with a uniform distribution of semiconductor microparticles in the polymer volume [1], which seems to be a necessary factor for optical studies. Measurements of dielectric constant ( $\epsilon$ ), tangent of the dielectric loss angle ( $tg\delta$ ) and electrical conductivity ( $\rho_v$ ) were carried out in the temperature range 290-410 K with linear temperature growth. Measurements of  $\epsilon$  and  $tg\delta$  were performed with the help of the E8-7 bridge at alternating current with frequency of 1 kHz.

### EXPERIMENTAL RESULTS AND DISCUSSION

Tables 1a and 1b show the temperature (a) and frequency dependences (b) of the dielectric constant of the HDPE / GaAs and Te-doped samples. It can be seen that the introduction of GaAs microparticles as a filler in HDPE leads to an increase in  $\epsilon$  at the frequencies and temperatures tested. It is also seen from these tables that the doping of gallium arsenide with tellurium (GaAs <Te>) leads to some additional increase in the values of  $\epsilon$  at a frequency of 10<sup>3</sup> Hz and a temperature range of 300-390 K. These and other changes in the structure of HDPE caused by the introduction of inorganic disperse fillers can be explained within the framework of the concept of a 3-phase structure (the presence of an interphase structure) in the supermolecular organization (NMA) of crystallizable polymers [1-10].

Table 1 a.

The temperature dependences of dielectric constant  $\varepsilon(T)$  of the HDPE/GaAs and HDPE/GaAs<Te>

Composites $\varepsilon$	T,K ( $\nu=10^3$ Hz)												
	293	303	313	323	333	343	353	363	373	383	393	403	413
100%HDPE	2,25	2,25	2,25	2,25	2,24	2,24	2,23	2,22	2,21	2,20	2,19	2,18	2,17
3%GaAs+97%HDPE	2,52	2,52	2,52	2,52	2,51	2,51	2,5	2,48	2,47	2,45	2,44	2,43	2,4
7%GaAs+93%HDPE	2,89	2,89	2,88	2,88	2,88	2,87	2,86	2,85	2,84	2,82	2,81	2,79	2,76
3%GaAs<Te>+97%HDPE	3,02	3,01	3,01	3,01	3,01	3,00	2,99	2,98	2,97	2,95	2,95	2,93	2,93
7%GaAs<Te>+93%HDPE	3,18	3,14	3,14	3,13	3,13	3,12	3,11	3,10	3,06	3,05	3,04	3,03	3,03

Table 1b.

The frequency dependences of dielectric constant  $\varepsilon(\nu)$  of HDPE / GaAs and HDPE / GaAs <Te>

Composites $\varepsilon$	lg $\nu$ , Hz				
	10 <sup>2</sup>	10 <sup>3</sup>	10 <sup>4</sup>	10 <sup>5</sup>	10 <sup>6</sup>
100%HDPE	2,25	2,25	2,22	2,21	2,31
3%GaAs+97%HDPE	2,64	2,60	2,58	2,56	2,65
7%GaAs+93% HDPE	3,07	2,97	2,92	2,90	2,99
3%GaAs<Te>+97% HDPE	2,91	2,89	2,88	2,89	3,07
7%GaAs<Te>+93% HDPE	3,08	3,04	3,02	3,02	3,24

The three-phase model of NMO-crystallizing polymers, in particular for HDPE, allows one to estimate the change in the glass transition temperature  $T_c$  when the polymer is modified by different fillers [1]. In filled HDPE at the boundaries of the polymer filler due to the nucleating activity of the fillers and their specific surface, the size of the spherulitic HMO polymer decreases and these changes of GaAs <Te> are undoubtedly reflected in the dielectric properties of the composites [1,3,12]. Similar changes in NMS of polypropylene binders were also noted in [13], where it was shown that the dielectric properties of  $\varepsilon(T)$  and  $tg\delta(T)$  compositions based on polypropylene (PP) and Na<sup>+</sup> -montmorillonite are described by the Lichteneker model [13,14]. In particular, it was found that the value of  $\varepsilon$  decreases with increasing frequency to  $6 \cdot 10^4$  Hz and then starts to increase. At high filler contents up to 30 wt% due to the increase in dipole-relaxation processes, the dielectric losses and conductivity of the composite as a whole also increase. According to the Lichteneker model [14-17], when the conductivity of the filler exceeds the values of the conductivity of the polymer, then the calculation of the values of  $\varepsilon_k$ . It can be seen from Tables 1a and 1b that the values of  $\varepsilon_k$  and  $tg\delta$

increase with an increase in the content of GaAs and GaAs <Te> fillers.  $\varepsilon_k$  is realized as a static mixture, according to formula

$$lg\varepsilon_k = y_1 \cdot lg \varepsilon_1 + y_2 \cdot lg \varepsilon_2 \quad (1)$$

where  $y_1$  and  $y_2$  are the fraction of the components,  $\varepsilon_1$  and  $\varepsilon_2$  are the values of dielectric constant of the polymer and filler, respectively [17].

The  $\varepsilon_k$  values of the samples of HDPE/GaAs and HDPE/GaAs <Te> compositions calculated from (1) are given in Table 2. In calculating the values of  $\varepsilon_k$  for n-GaAs and n-GaAs <Te>, 11.2 and 12.8 were taken, respectively [7,8].

Tables 1a and 1b show that the values of  $\varepsilon_k$  and  $tg\delta$  increase with increasing content of GaAs and GaAs <Te> fillers. In addition, the doping of GaAs with Te atoms leads to an insignificant increase in  $\varepsilon_k$ , but there is a tendency to decrease dielectric losses.

Table 2.

Calculated values of  $\epsilon_k$  according to the Lichteneker model and the Maxwell-Wagner model and the values of  $tg\delta$  at  $10^3$  Hz quenched samples of HDPE / GaAs and HDPE / GaAs <Te>

№	Composites	$\epsilon_k$		$tg\delta$
		experimental	calculated[14]	
1	HDPE	2,20	-	0,003
2	HDPE +3 vol.% GaAs	2,30	2,26	0,009
3	HDPE +7 vol.% GaAs	2,47	2,39	0,012
4	HDPE+3 vol.% GaAs<Te>	2,31	2,55	0,004
5	HDPE +7 vol.% GaAs<Te>	2,50	2,72	0,012

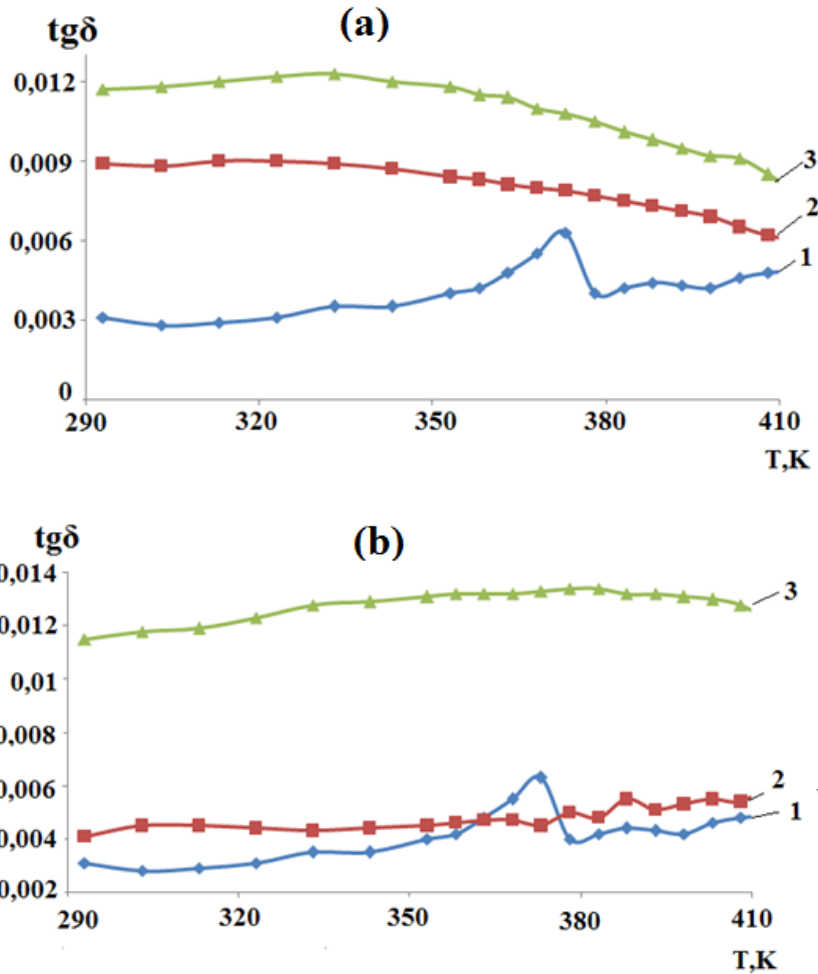


Fig. 1. The temperature dependences of the dielectric losses  $tg\delta$  (T) of the HDPE / GaAs (a) and Te- doped samples of HDPE / GaAs <Te> (b) at 97: 3% (2) and 93: 7% (3) 1-100 vol. % HDPE

Figure 2 shows the frequency dependences of  $tg\delta$  ( $\nu$ ) of HDPE / GaAs (a) and HDPE / GaAs <Te> (b) composites. It can be seen that for samples doped with Te atoms, an insignificant increase in  $tg\delta$  is observed, and the nature of the frequency dependences does not change. At the same time, at doping frequencies of  $10^4$ - $10^5$  Hz, doping leads to a slight decrease in dielectric losses (comparison of curves 3). At high frequencies ( $\nu > 10^5$  Hz), dielectric losses are expected to increase somewhat. It

should be noted that for the HDPE and Te alloyed samples the experimental values of dielectric losses  $tg\delta$  and dielectric constant  $\epsilon$  are in accordance with the calculated values of  $tg\delta$  and  $\epsilon$  for Te-doped atoms of HDPE / GaAs samples < Te>. While for the initial samples of HDPE / GaAs in the indicated frequency regions, it is more acceptable by the Maxwell-Wagner formula [14-15]:

$$\frac{\epsilon - \epsilon_2}{\epsilon + \epsilon_2} = v_1 \frac{\epsilon_1 - \epsilon_2}{\epsilon_1 + \epsilon_2} \quad (2)$$

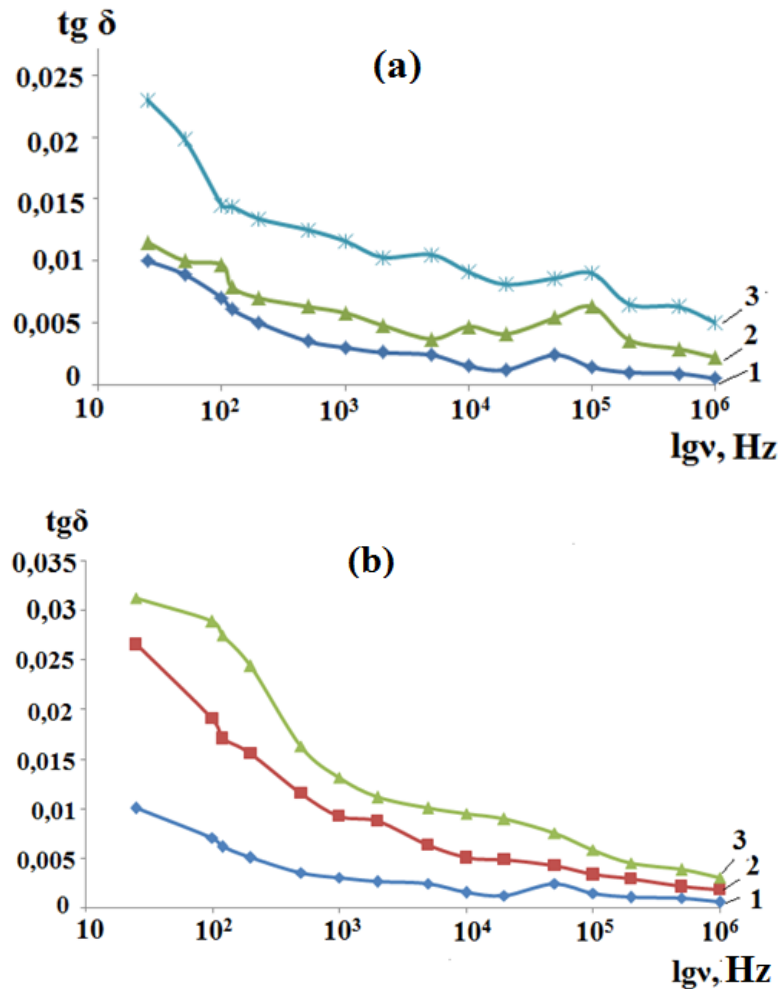


Fig.2. Frequency dependences of dielectric losses  $tg\delta$  ( $v$ ) of HDPE / GaAs (a) and HDPE / GaAs <Te> (b) composites at 97: vol.3% (20 and 93: 7 vol.% (30.1 - 100 vol.% HDPE)

It is seen from Fig. 2 that for Te-doped samples dielectric losses in the resonant frequency range  $5 \cdot 10^4 - 10^5$  Hz decrease. At the same time, at low frequencies, a certain increase in dielectric losses is observed in doped samples.

The observed changes in the dielectric properties of composites according to the three-phase structure of crystallizable polymers in composites PE / GaAs (a) and PE / GaAs <Te> (b) and GaAs, as doped with Te, create new crystallizing regions due to the formation of less ordered new phase.

Indeed, by determining by the method of radiothermoluminescence (RTL) the position of the  $\beta$ -transition, HDPE at 228 K [3,9] is shifted by  $4-5^\circ$  to the high-temperature side, and this fact explains only by the three-phase structure of the crystallized filled polymers.

## CONCLUSION

The dielectric properties of polymer composites based on high-density polyethylene (HDPE) and semiconductors of undoped (GaAs) and tellurium-doped gallium arsenide GaAs <Te> are investigated. The temperature and frequency dependences of the dielectric constant  $\epsilon(T, v)$  and the dielectric losses  $tg\delta(T, v)$  of the HDPE / GaAs and HDPE / GaAs <Te> compositions with different volume ratios of the components are obtained. The values of the dielectric constant are calculated, which are compared with the experimental values  $\epsilon(T, v)$ . It is shown that the changes in the dielectric properties of these compositions are due to a change in the supramolecular structure (NMS) of the polymer and are described by the two-phase Lichteneker model.

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