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Investigation of electret properties of polyolefin films modified in low-temperature atmospheric pressure plasma

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Abstract: The article examines the effect of plasma modification on the electret properties and adhesion characteristics of polyethylene (PE). Plasma modification of the PE surface was carried out using low-temperature plasma from a sliding arc at atmospheric pressure, which made it possible to increase the polarity of the film and create functional groups on its surface. During the experiments, measurements were taken of the electret properties and electric charge density on the surface of the original and modified samples of polyethylene film with a thickness of 100 microns. Modified polyethylene films were studied using scanning electron microscopy and the method of periodic screening of the receiving electrode. A study of the kinetics of changes in electret properties showed that the surface potential values decrease with time due to the release of charge carriers and relaxation of charges on the surface. However, a week after modification, the electret characteristics remain higher than the original values. Electron microscopic analysis revealed an increase in the number of small crystallites on the surface after the first 10 seconds of modification, which helps to improve the electret and adhesive properties of the films.
Keywords: sliding discharge, polyethylene, film, modification, adhesion.

1. Introduction

It is known that plasma modification is one of the ways to activate the surface and improve the adhesive properties of polyethylene (PE) [1]. This process is caused by bombardment by charged particles (ions and electrons), UV radiation from the plasma and its thermal effect on the modified surface [2]. Plasma modification allows both increasing the polarity of the film and creating functional groups on the surface (hydroperoxide (-UN), hydroxyl (-OH), carboxyl (-COOH)) [3, 4]. To determine the effect of plasma modification on the electret properties, a study of the electret properties and an assessment of the electric charge density on the surface of the original and modified polyethylene film samples in the low-temperature plasma of a sliding arc of atmospheric pressure were carried out.

2. Materials and methods

To study the electret properties of the samples, an IPEP-1 device was used. The range of measurement of the density of electrical charges with the IPEP-1 device is 0.02–10 μC/m^2, measurement error 5%. To study the surface of the modified samples, a JSM-6510LV JEOL scanning electron microscope was used with an INCA microanalysis system with a JFC-1600 desktop installation and SEM Control Program software on the equipment of the Progress Center of Common Use of VSGUTU. The measurement range of linear dimensions of the JSM-6510LV JEOL electron microscope varies from 30×10^{-3} to 1000 μm. The error in the range from 30×10^{-3} to 0.1 μm and from 0.1 to 1000 μm is ±5%. Modification of PE GOST 10354-82 with a thickness of 100 microns was carried out on a developed installation for modifying the surface of polymer films in a low-temperature mode for 15-60 seconds (patent No. RU2781708C1).

3. Results and discussion

To determine the kinetics of changes in the electret properties of polymer films (surface potential – V_e, electric field strength – E and effective surface charge density – σ_{eff}) and their influence on the adhesive properties of films modified in sliding arc plasma, the method of periodic shielding of the receiving electrode was carried out. The given values of electret properties are the arithmetic mean of five parallel measurements. The measurement results are presented in Table 1.

Table 1. Electret properties of modified polyethylene.

Modification time, s	V_e, kV/m	E, kV/m	σ_{eff}, μC/m^2
0	0.007	0.004	0.003
10	0.085	5.400	0.044
15	0.083	5.000	0.043
30	0.070	4.800	0.042
60	0.065	4.670	0.040

The highest values of electret properties (V_e – 0.085 kV, σ_{eff} – 0.044 μl/m^2 and E – 5.4 kV/m) were achieved with a 10-second modification, which confirmed the previously studied and determined optimal operating parameters of the plasma installation with the achievement of the greatest adhesion work surface (Wa = 139.8 mJ/m^2) [5]. It has been established that surface activation leads to a change in electret properties due to the injection of charged particles into energy traps, which increases the polarity of the modified surface [6, 7]. According to physicochemical analysis, these traps are impurities, oxygen-containing groups, structural anomalies and the interface between the crystalline and amorphous phases. However, over time, the electret properties of polymers decrease [8–10]. To study the kinetics of electret properties, measurements were taken over 10 days at intervals of 3 times a day and a dependence graph was constructed. Three zones can be distinguished on the chart: a growth zone, a decline zone and a stabilization zone.

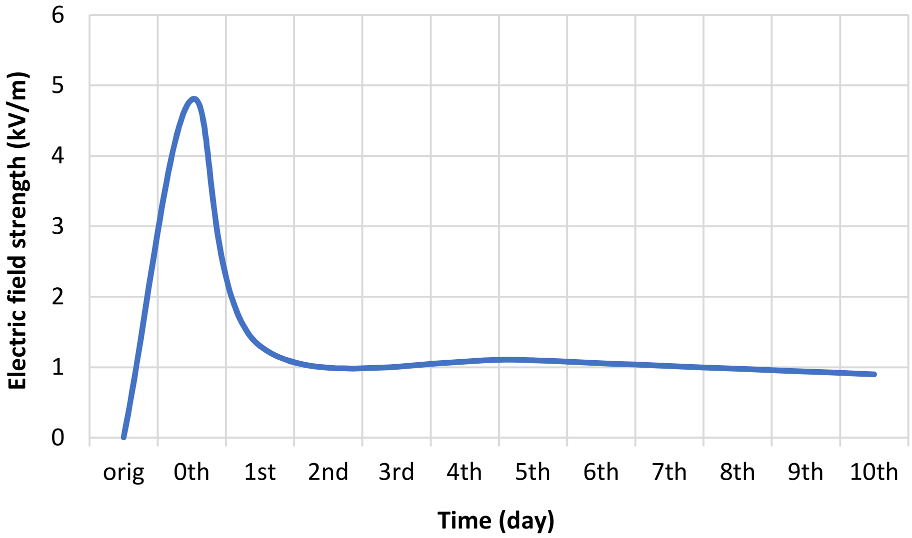

Fig. 1. Electric field strength.

The decrease in surface potential is due to: the release of charge carriers from shallow surface energy traps, relaxation of charges on the surface and adsorption of functional groups from the surface into the bulk of polymer films. After this, the magnitude of the surface potential is determined by the number of injected charge carriers trapped in deeper traps. Despite these processes, after a week the values of the electret characteristics remained higher than the initial ones. To study changes in the supramolecular structure and interface area as a result of plasma-chemical etching, electron microscopic analysis was carried out (Fig.2).

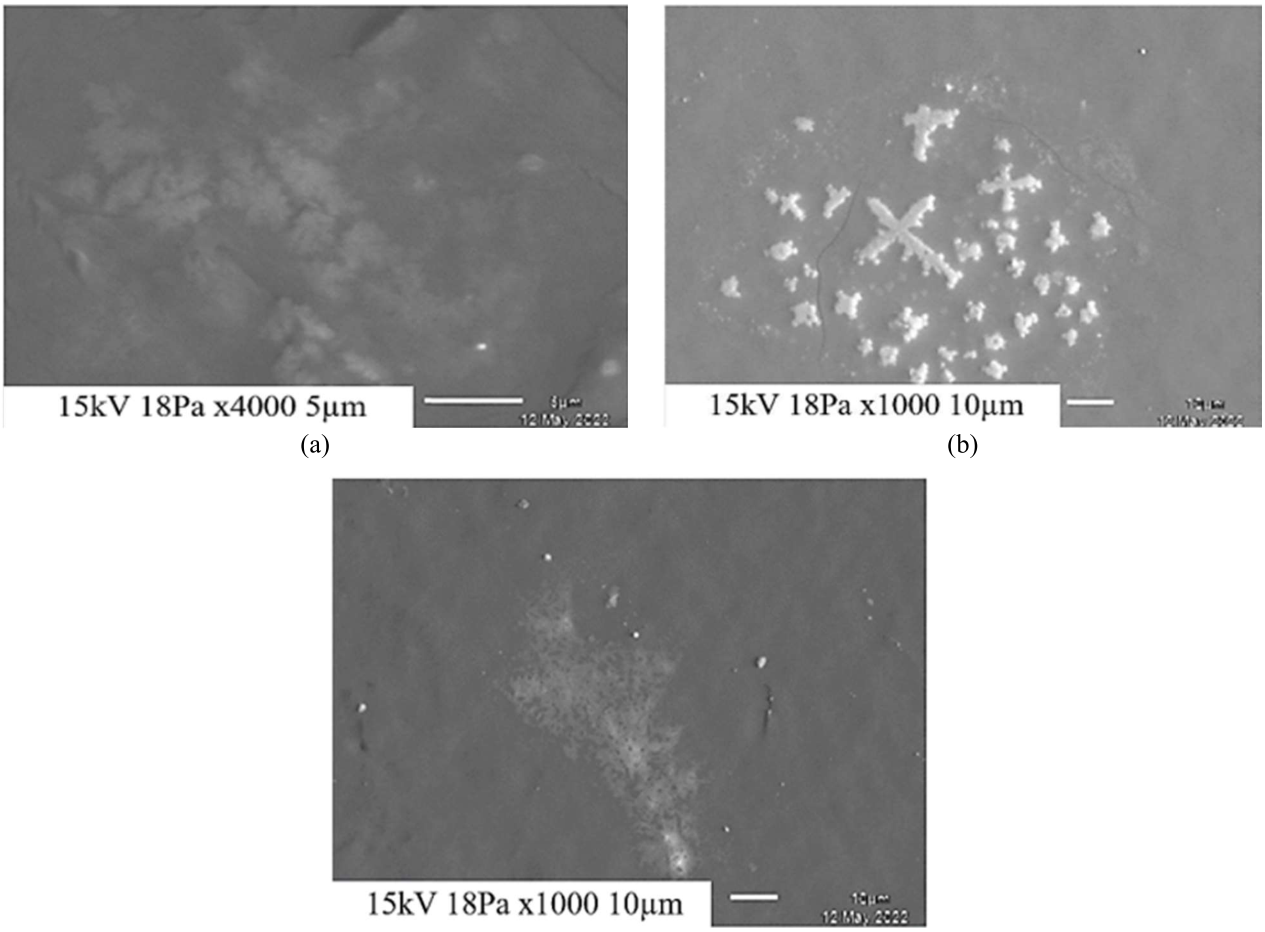

Fig. 2. Electron microphotographs of the surface: (a) – PE without modification; (b) – PE, 10 seconds of modification; (c) – PE, 15 seconds of modification.

The results of electron microscopic analysis showed that in the first 10 seconds of modification there is an increase in the number of small crystallites (2–5 µm in size) on the surface, which increases the length of the interface between the crystalline and amorphous phases. These boundaries serve as energy traps for injected charge carriers, which improves the electret and adhesive properties of polymer films. Further modification leads to an increase in the surface area of the exposed part of the crystal structures, which continues to increase the area of the phase boundaries. Further exposure to plasma discharge has a negative effect. Thermal and photochemical effects lead to heating and melting of the polymer surface, which leads to the removal of functional groups and a change in the supramolecular structure.

4. Conclusion

It was found that the action of sliding arc plasma on the polymer leads to an increase in the size of the interface (ratio) between the crystalline and amorphous phases, which serves as an energy trap for the injected charge carriers. The charge accumulated by the surface and the increase in structural formations improve the adhesive properties of the polymer films. The results of electron microscopy showed an increase in the number of small crystallites (2-5 µm in size), and, consequently, an increase in the interphase boundary, which is a trap for the injected charges. The increase in the interphase boundary is due to plasma-chemical etching in low-temperature plasma of atmospheric pressure. The study of the electret properties showed that the observed processes of decline and subsequent stabilization of the PE values occurred during the first day after modification. Subsequently, the value of the surface potential is determined by the number of injected charge carriers, which fall into deeper traps, but nevertheless remain above the original ones.

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