Bulgarian Chemical Communications, Volume 48, Special Issue E (pp. 327 - 332) 2016

Polypropylene electrets films stored between two plate electrodes at low pressures

A. P. Viraneva*, T. A. Yovcheva, I. P. Bodurov, M. G. Marudova

Plovdiv University "Paisii Hilendarski", Faculty of Physics 24 Tsar Asen str., 4000 Plovdiv, Bulgaria

The electrets are dielectric materials of specific type which are able to create an external quasi static electric field. In many modern devices, built on electret effects, electrets are placed as active elements between two electrodes with an air gap. In these cases, if the device is under low pressure, one can expect a decrease in the electric charge. In the present paper we investigated the low pressure (*p* from 1013 mbar to 0.1 mbar) influence on the surface potential decay of polypropylene electrets films, placed between two short circuited plate electrodes at various air gaps (*d* values could be from 0.1 mm to 3.00 mm) between the charged surface of electrets and the upper electrode. For all ranges of the *pd* values the main process responsible for the surface potential decay can be associated with the desorption of charged species from the electret surface. In addition it was established that only for some relevant ranges of *pd* values the breakdown voltage following the Paschen's law was reached in the initial moment of the period for which the sample had been situated in the vacuum chamber and a spark breakdown in the air gap could be observed. The results obtained have both phenomenological character and great practical use as the investigated electrets were in similar conditions to those under which the electret elements of various sensors and signal transducers, dosimeters, air filters, generators, focusing systems of the electret optics, etc. operate.

Keywords: electrets, low pressure, Paschen's law, dielectric materials

INTRODUCTION

Polymer dielectric materials, which are able to retain electric charges over a long period of time and create an external quasistatic electric field, are known as electrets. Many kinds of electret devices are widely used in various industrial applications owing to their electric field [1]. The surface potential values and the lifetime of electrets are the most important parameters giving rise to the possibility of practical usage. A number of factors which influence charge storage and charge transport in electrets have been investigated. But there are only a several publications on the influence of low pressure on electret behaviour [2-5].

The investigation of the pressure effect on the surface charge decay was first reported in [2]. The carnauba wax electrets have been studied and the method of dissectible capacitor has been used to measure the equivalent surface charge. It was shown that the surface charge decay became different when the electrets were placed under different pressures, lower than atmospheric. The authors have assumed that surface charge decay is due to discharges in the air gap between the samples and the measuring electrode in accordance with the Paschen's law. The effect of low pressure on surface charge decay of polystyrene and mylar electrets has been studied by Catlin et al. in [3, 4].

The results obtained in [3] have shown that the decrease of effective surface charge observed when electrets are exposed to low pressure is not the result of a spark breakdown between the electret surface and the nearby conductors. It has been supposed that the charge drops are due to ion desorption.

Two years later the electret behaviour at low pressures was studied again in [4]. The results observed have been explained by the spark breakdown theory. Furthermore, the authors have explained the experimental results in [3] in terms of the spark breakdown mechanism by calculating the amount of surface which had been active in the spark breakdown process.

The effect of low pressure on the surface potential decay has also been studied in [5]. It has been supposed when the pressure under which the electrets have been kept decreases ions desorption from the electret surface was most likely to occur.

In [6] polymer foams and void-containing polymer-film systems with internally charged voids combine large piezoelectricity with mechanical flexibility and elastic compliance were investigated. It has been found that the voids can be internally charged by means of dielectric barrier discharges (DBDs) under high electric fields. It was established that the threshold behaviour can be explained with the Paschen's law which describes the breakdown voltage between parallel plate electrodes in a gas as a function of pressure and the gap height.

* To whom all correspondence should be sent.
asia83@abv.bg

In [7] Paschen's curves in air and different gases are obtained by measuring the gas breakdown voltage. It was shown that the Paschen's curve has a different minimum value of *pd* at different gases and it depends on the composition of the gas.

The purpose of the paper is to investigate the low pressure influence on the surface potential decay of the PP electrets stored at different low pressures between two short circuited plate electrodes at various air gaps between the charged surface of the electrets and the upper electrode. The main task is to compare the calculated voltages in the electret surface-electrode gap with breakdown voltages according to the Paschen's law and analyse the results.

EXPERIMENTAL DETAILS

Used material and sample preparation

Isotactic polypropylene (PP) films with thickness of 20 µm produced by "Assenova Krepost" LTD – Bulgaria were investigated. Initially, the PP films were cleaned in an ultrasonic bath with alcohol for 4 minutes then washed in distilled water and dried on filter paper under room conditions. Samples of 30 mm diameter were cut from the films. Each of the samples was put on a metal pad with the same diameter.

Corona charging and surface potential measurement

Electret charging was carried out in corona discharge by corona triode system consisting of a corona electrode, a plate grounded electrode and a grid placed between them (Fig.1).

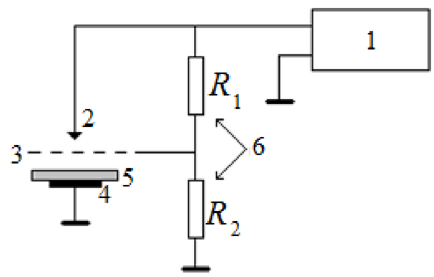

Fig.1. Scheme for obtaining electrets: 1. high voltage source; 2. corona electrode; 3. grid; 4. plate grounded electrode; 5. sample on a metal pad; 6. voltage divider

Charging of the electrets was performed under relative humidity of (45% - 50%), atmospheric pressure and temperature of 23 °C for 1 minute. Positive or negative 5 kV voltage was applied to the corona electrode. A voltage of 500 V, 700 V or 950 V of the same polarity as that of the corona electrode was applied to the grid. After charging, the initial surface potential of the samples V_0 was measured. Electrets' surface potential was measured by the method of the vibrating electrode with compensation [8] and the estimated error was less than 5%.

Low pressure measurement

After charging to the initial surface potential, the samples, together with their metal pads, were placed into a vacuum chamber, consisting of isolated bases and a jar bell, under a low pressure for 1 hour. Dry air (RH = 0%) is provided with silica gel put in the chamber. The humidity is measured continuously with an electronic mini hygrometer placed in the chamber. The pressures created in the vacuum chamber were 0.1 mbar, 1 mbar, 10 mbar, 20 mbar, 66 mbar, 132 mbar, and 1013 mbar. In the vacuum chamber the electrets were placed between two short circuited plate electrodes at various air gaps between the charged surface of electrets and the upper electrode (Fig.2).

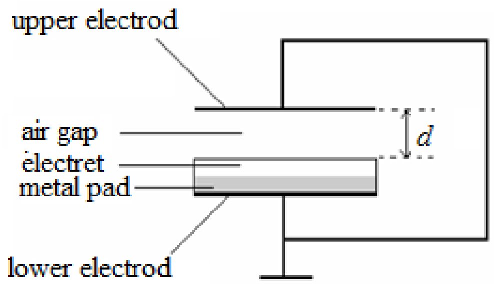

Fig.2. Schematic diagram of the electret stored in the vacuum chamber between two short circuited plate electrodes (*d* is the air gap thickness)

After that the samples on the metal pads were removed from the vacuum chamber, the surface potential V was measured again and the normalized surface potential V/V_0 was calculated.

RESULTS AND DISCUSSION

All electret samples were divided into five groups according to the air gap thickness values (0.10 mm, 0.28 mm, 0.84 mm, 1.69 mm and 3.00 mm). Each group was divided into three sets according to the grid potential values (500 V, 700 V, or 950 V).

The dependences of the normalized surface potential V/V_0 on the air gap thicknesses at the 0.1 mbar pressure for positively charged PP and negatively charged PP samples are illustrated in Fig.3 and Fig.4, respectively. Each column value corresponds to an average value obtained by the measurement of 6 samples. The maximum deviation from the average value determined at confidence level 95% is 5%.

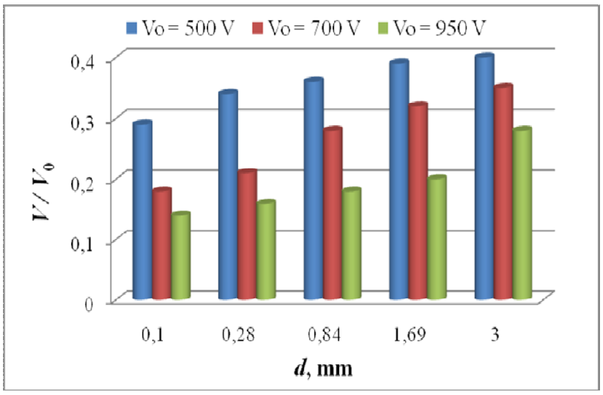

Fig.3. Dependence of the normalized surface potential on air gap thicknesses for PP electrets charged in a positive corona to different values of the initial surface potential and stored at pressure 0.1 mbar

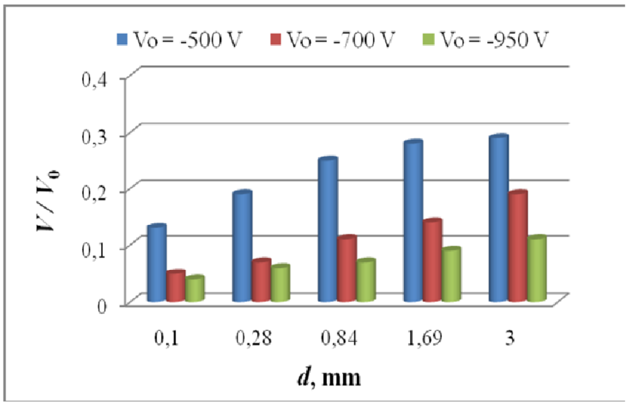

Fig.4. Dependence of the normalized surface potential on air gap thicknesses for PP electrets charged in a negative corona to different values of the initial surface potential and stored at pressure 0.1 mbar

The results obtained show that:

- The normalized surface potential values at 0.1 mbar decrease with the increase of the initial surface potential;
- The normalized surface potential values at 0.1 mbar grow with the increase of the air gap thickness.
- The final values of the normalized surface potential for positively charged PP films are higher than those for negatively charged ones independently of the air gaps thicknesses and the initial surface potential values.

Analogous results have been obtained for the other pressures used in our experiments.

In the papers [8, 9] it is assumed that the electrets charge decay is due to breakdown voltage between parallel plate electrodes in a gas as a function of pressure (*p*) and the thickness (*d*) of the gap itself according to the Paschen's law. For dry air the Paschen's curve has a minimum value of *pd* = 6.65 mbar.mm corresponding to a breakdown voltage of 360 V as shown in Fig.5 [9].

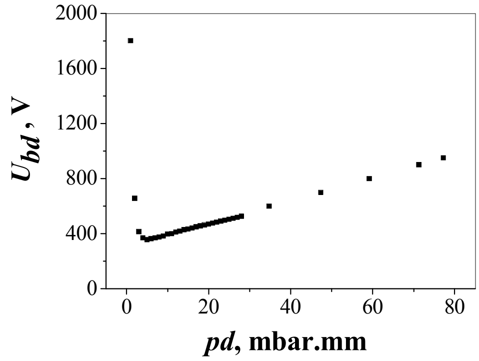

Fig.5. Paschen's curve for dry air and parallel plate electrodes

If the air gap field creates a voltage less than the breakdown voltage for the particular gas, gas discharges will not occur in the gap. When the air gap field creates a voltage equal or higher than the breakdown voltage, a discharge will occur and the electret charge will consequently decrease. The discharge will continue until the voltage across the air gap is reduced to a value below the minimum breakdown voltage for the respective value of the product *pd* and will depend on neither the size nor the polarity of the initial electret surface potential as well as on the air gap thickness. Therefore, the minimal voltage value in the gap at our experiments at which a discharge can be initiated is 360 V [9].

For each value of the pressure at which the samples were stored for 1 hour, the electric field in the electret surface-electrode gap is changed from the initial value E_0 determined by the electret surface potential V_0 measured before placing the sample in the chamber to the final value E determined by the electret surface potential V measured immediately after removing the electret from the vacuum chamber.

The values of the electric fields in the electret surface-electrode gap for PP samples stored between two short-circuited electrodes with air gap thickness of 0.10 mm, 0.84 mm and 3.00 mm are calculated by equation:

$$E' = \frac{\varepsilon V'}{\varepsilon d + \varepsilon_1 L}, \qquad (1)$$

where E' is the air gap field ($E' = E_0$ or $E' = E$), ε = 2,2 is the relative dielectric permeability of PP, ε_1 = 1 is the relative dielectric permeability of the air, d is the air gap thickness, L is the electret thickness, V' is the electret surface potential ($V' = V_0$ or $V' = V$).

The values of the voltages in the electret surface -electrode gap for PP samples stored between two short-circuited electrodes with air gap thickness of 0.10 mm, 0.84 mm and 3.00 mm are calculated by equation:

$$U' = E'd\,, \tag{2}$$

where $U' = U_0$ is the voltage in the initial moment of the period for which the sample has been situated in the vacuum chamber, $U' = U$ is the voltage in the end of the same period.

The calculated values of the electric fields and the voltages for three air gap thicknesses of 0.10 mm, 0.84 mm and 3.00 mm at pressure 1013 mbar are presented in Table 1 to Table 3 respectively.

Table 1. Electric fields and voltages in a 0.10 mm air gap at pressure 1013 mbar and different grid voltages values

V_0, V	492	693	941
E_0, kV/cm	45.10	63.50	86.30
U_0, V	451	635	863
V, V	490	685	937
E, kV/cm	44.90	62,80	85,90
U, V	449	628	859

Table 2. Electric fields and voltages in a 0.84 mm air gap at pressure 1013 mbar and different grid voltages values

V_0, V	500	687	950
E_0, kV/cm	5.89	8,10	11.19
U_0, V	495	680	940
V, V	500	679	950
E, kV/cm	5.91	8.00	11.20
U, V	496	672	941

Table 3. Electric fields and voltages in a 3.00 mm air gap at pressure 1013 mbar and different grid voltages values

V_0, V	500	680	944
E_0, kV/cm	1.66	2.26	3.14
U_0, V	498	678	941
V, V	500	664	933
E, kV/cm	1.60	2.20	3.10
U, V	480	660	930

The calculated values of the electric fields and the voltages for three air gap thickness of 0.10 mm, 0.84 mm and 3.00 mm at pressure 0.1 mbar are presented in Table 4 to Table 6 respectively.

Table 4. Electric fields and voltages in a 0.10 mm air gap at pressure 0.1 mbar and different grid voltages values.

V_0, V	492	677	925
E_0, kV/cm	45.10	62.10	84.80
U_0, V	451	621	848
V, V	72	30	34
E, kV/cm	6.60	2.80	3.10
U, V	66	28	31

Table 5. Electric fields and voltages in a 0.84 mm air gap at pressure 0.1 mbar and different grid voltages values

V_0, V	485	685	933
E_0, kV/cm	5.71	8.07	1.10
U_0, V	480	678	923
V, V	136	77	62
E, kV/cm	1.60	0.91	0.70
U, V	134	76	59

Table 6. Electric fields and voltages in a 3.00 mm air gap at pressure 0.1 mbar and different grid voltages values

V_0, V	493	691	946
E_0, kV/cm	1.64	2.30	3.14
U_0, V	492	689	943
V, V	154	124	96
E, kV/cm	0.50	0.40	0.30
U, V	150	120	90

Analogous calculations have been made for the other gaps and pressures used in our experiments. At atmospheric pressure and various thicknesses of the air gap used in our experiments the pd values change from $pd_{\min}$ (d = 0.1 mm) = 101.3 mbar.mm to $pd_{\max}$ (d = 3 mm) = 3039 mbar.mm, which corresponds to breakdown voltages according to the Paschen's curve higher than 950 V (Fig.5). At pressure of 0.1 mbar and air gap thicknesses from 0.10 mm to 3.00 mm, the pd product values lay in the range (0.01 - 0.30) mbar.mm, which corresponds to breakdown voltages according to the Paschen's curve higher than 1800 V. The calculated pd values for different pressures and air gap thicknesses obtained of our experiments are presented in Table 7.

It can be found that the Paschen breakdown voltage is reached at certain pd product values in the initial moment of the period for which the sample has been situated in the vacuum chamber (Table 7):

- (3 - 16.80) mbar.mm for samples charged at grid voltage 500 V;
- (2 – 30.00) mbar.mm for samples charged at grid voltage 700 V;
- (2 – 60.00) mbar.mm for samples charged at grid voltage 950 V.

Table 7. Experimental and breakdown voltages at different values of *pd*.

pd, nbar.mm	**p, mbar**	**d, mm**	**V_g = 500 V**				**V_g = 700 V**				**V_g = 950 V**				**U_{bd}, V**
			V_0, V	**U_0, V**	**V, V**	**U, V**	**V_0, V**	**U_0, V**	**V, V**	**U, V**	**V_0, V**	**U_0, V**	**V, V**	**U, V**	
0.01	0.1	0.10	492	451	72	66	677	621	30	28	925	848	34	31	>1800
0.08	0.1	0.84	485	480	136	134	685	678	77	76	933	923	62	59	>1800
0.10	1	0.10	487	446	86	79	687	630	50	46	928	851	72	66	>1800
0.30	0.1	3.00	493	492	154	150	691	689	124	120	946	943	96	90	>1800
0.84	1	0.84	494	489	130	129	695	688	65	64	950	940	75	74	>1800
1.00	10	0.10	496	455	60	55	693	635	42	39	938	860	47	43	1800
2.00	20	0.10	495	454	140	128	696	638	32	29	949	870	45	41	656
3.00	1	3.00	486	485	170	170	686	684	137	137	945	942	120	120	414
6.60	66	0.10	489	448	194	178	683	626	50	46	938	860	38	35	365
8.40	10	0.84	480	475	139	138	684	677	73	72	922	912	70	69	380
13.20	132	0.10	499	457	169	155	673	617	38	35	929	852	40	37	418
16.80	20	0.84	484	479	182	180	682	675	73	72	937	927	65	64	448
30.00	10	3.00	483	482	164	164	679	677	150	150	936	933	90	90	550
55.44	66	0.84	497	492	496	491	690	683	91	90	942	932	70	69	767
60.00	20	3.00	491	490	491	490	671	669	132	132	921	918	110	110	800
101.30	1013	0.10	492	451	490	449	693	635	685	628	941	863	937	859	>950
110.88	132	0.84	494	489	479	474	699	692	270	267	938	928	70	69	>950
198.00	66	3.00	488	487	485	484	695	693	685	683	948	945	935	932	>950
396.00	132	3.00	487	486	481	479	679	677	675	673	945	942	932	929	>950
850.92	1013	0.84	500	495	500	496	687	680	679	672	950	940	950	941	>950
3039.00	1013	3.00	500	498	500	480	680	678	664	660	944	941	933	930	>950

Therefore in the conditions of our experiments for the relevant range of *pd* in the initial moment of the period for which the sample has been situated in the vacuum chamber a spark breakdown in the air gap can occur. For other ranges of *pd* in the end of the same period a spark breakdown in the air gap cannot be observed.

For all ranges of the *pd* values it can be seen from Table 7 that the calculated voltages in the end of the period for which the sample has been situated in the vacuum chamber decreases to a value lower than the breakdown voltages according to the Paschen's law. Therefore, it is assumed that the different oxygen content in the various cases because of different air pressure is in consequence of various sorption processes on the sample surface. These results make us suppose that the main process responsible for the surface potential decay in all our experiments can be associated with desorption of charged species from the electret surface under the influence of its own electric field. These might be ions deposited on the surface or groups in which the ions have given their charge away. The results obtained are in a good agreement with the results observed and described earlier [10, 11].

CONCLUSION

Our experimental investigations show that the low pressure influence on the surface potential decay of PP electrets films, placed between two short circuited plate electrodes at various air gaps between the charged surface of electrets and the upper electrode. Charging of the electrets was performed in a positive or in a negative corona at 5 kV voltage to the corona electrode. Voltage of 500 V, 700 V or 950 V of the same polarity as that of the corona electrode was applied to the grid. The experimental results obtained show a significant change in the electret behaviour of the PP films after stored at low pressures.

It was established that for all ranges of the *pd* values the main process responsible for the surface potential decay can be associated with desorption of charged species from the electret surface. In addition, it was established that the breakdown voltage following the Paschen's law was reached in the initial moment of the period for which the sample has been situated in the vacuum chamber and a spark breakdown in the air gap can be observed only for some relevant ranges of *pd* values.

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support of the projects MU-15-FFIT-003/23.04.2015, Department of Scientific Research at the Plovdiv University.

REFERENCES

1 G. M. Sessler, and R. Gerhard-Multhaupt, *Electrets* 3rd edition, Laplacian Press, Morgan Hill, California (1999).

2 J. Wild, and J. Stranathan, *Journal of Chemical Physics* 27(5), 1055-1059 (1957).

3 R. Draughn, and A. Catlin, *Journal of Electrochemical Society* 115(4), 391-394 (1968).

4 F. Palaia, and A. Catlin, *Journal of Chemical Physics* 52(7), 3651-3654 (1970).

5 G. Mekishev, T. Yovcheva, E. Gentcheva, and S. Nedev, *Journal of Electrostatics* 63(11), 1009-1015 (2005).

6 X. Qiu, R. Gerhard, A. Mellinger, *IEEE Transactions on Dielectrics and Electrical Insulation* 18(1), 34-42 (2011).

7 M. A. Lieberman, and A. J. Lichtenberg, *Principles of plasma discharges and materials processing* 2nd edition Wiley Interscience Hoboken, N.J.: Wiley (2005).

8 M. Knoll, F. Ollendorff, and R. Rompe, *Gasentladungstabelen*, Springer-Verlag, Berlin, 84 (1935).

9 R. Schaffert, *Electrophotography*, The Focal Press, London, New York (1965).

10 T Yovcheva, A Viraneva, and M Galikhanov, *Journal of Physics: Conference Series* 558, 1-7 (2014).

11 A. Viraneva, T. Yovcheva, and G. Mekishev, *Polypropylene*, ed. by Fatih Doğan, InTech - Open Access Publisher, Rijeka Croatia, 161-184 (2012).