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Magneto Electret Behaviour of Porous Polytetrafluoroethlyene under Uniform and Nonuniform Magnetic Field

[1]Pragya Ojha, [2]M.S. Qureshi and [2]M.M. Malik

[1]Electret research laboratory, Department of Physics MANIT, Bhopal 462051, India
[2]Department of Physics MANIT, Bhopal 462051, India

Abstract: Charge decay characteristic of magnetoelectrets prepared using 50% porous Polytetrafluoroethlyene is investigated. The influence of temperature, on its surface charge density is also studied. The electrets were heated and prepared under the influence of fixed magnetic field. The decay of surface charge was observed continuously for 40 days and corresponding time constant were calculated accordingly. Negative iso charge is obtained in all the samples which are of the order of 10^{-9}C. The porous material is used for the first time in magnetoelectrets. From the calculated values of time constant it is found that the stability of porous material is very high. The comparative studies of surface charge characteristics were done by preparing Porous magnetoelectrets using uniform and nonuniform magnetic fields. The properties of as prepared magnetoelectrets may have an application in various type of sensors especially in high efficiency Piezo electric sensors.

Key words: Magnetoelectrets (Mes) · Porous Polytetrafluroethlyene (PTFE) · Magnetic field · Surface charge density

INTRODUCTION

Polymers are used for electret [1] applications as most of them are Polar in nature that forms molecular dipoles within the polymer backbones or side chains. However, the nonpolar polymers are widely used because of the high amount of charges, which could be trapped at the surface or in the bulk of a nonpolar polymer electret. Research into such non-polar electrets has increased and expanded after porous and foamed electrets were developed. Therefore an attempt has been made to develop magnetoelectrets of Porous PTFE.

Porous PTFE material is recently developed porous structure fluorocarbon polymer [2]. Its properties include excellent charge storage stability, high mechanical compliance and biocompatibility. Porous PTFE was first employed in clinical medicine to enhance recovery wounds and fracture healing. Recently it has been found that porous PTFE electret also have the curative effects of restraining pain, controlling and reducing brain thromboses, promoting functional recovery of muscle grafts. Therefore, the application of porous electret in biomedicine is one of the foci in the field between electrets and medicine. It may also be used as a new kind of sensitive electret material with space charge for piezoelectric sensors [3-7].

In 1964 Bhatnagar *et al*. [8] replaced the commonly used polarizing electric filed by the magnetic field and observed surface charge formation on the dielectric material. They described it as “magnetoelectret” and also studied its decay parameters. Since then various researchers have worked with different materials with an aim to assess the principle behind the formation of magnetoelectret [9-12]. But there has been no single theory so far that can explain the state of magnetoelectret observed in various dielectric materials also its dependence on forming parameters is yet not reported. Therefore, in the present work the authors have tried to find out the dependence of electret properties on forming parameters such as temperature and nature of magnetic field with an objective to introduce a potentially viable material.

Experimental

Preparation of Magneto Electret: In the present study commercially available 50% Porous PTFE sheets form Bilnex Pvt Ltd, India was used to make pellets of diameter 1.5cm and 2.4mm thick dimensions. Magnetoelectrets were

Corresponding Author: Pragya Ojha, Electret research laboratory, Department of Physics MANIT, Bhopal 462051, India. Tel: +919826299689.

prepared by following the method described by Khare and Bhatnagar [13]. Electromagnets of Polytronic Corporation (Mumbai, India), Type-HEM150, SR No. 9 and 35 were used to provide the magnetic field. In one of the electromagnets the pole pieces were tapered to create nonuniform field. Sample was kept inside the custom made sample holder with heating arrangement. The holder containing the disc shaped sample was kept in the magnetic field in such a way that the circular faces became perpendicular to the magnetic field. The procedure involves heating the sample to a constant desired temperature and the application of the magnetic field at that temperature for a constant duration of time. After that sample was cooled in the presence of magnetic field till they come to room temperature. The main objectives were to check the variation of forming parameters such as temperature and uniform and nonuniform magnetic fields on surface charge density of magnetoelectrets and its decay characteristics. Therefore samples were prepared at six different temperatures 170° C, 180°, C 190° C, 200°C, 210°C, 220°C at fixed field of 1.3T in uniform and non uniform Magnetic field.

Surface Charge Measurement: The charge developed on the magnetoelectrets surfaces was measured with the help of lifted electrode method [14]. Lifted electrode is based on electromagnetic induction. The measuring device consists of a dissectible type of condenser, which has one fixed heavy plate and the other plate is movable. The lower plate fixed plate acts as a platform for the electret and is earthed. The surface of the electret is first brought about in contact with the surface of the movable plate of the condenser, while doing so it is earthed. It is than de earthed and allowed to move away a fixed distance in the field of the electret. The induced charge on the movable electrode is measured by Kithely 610°C electrometer.

RESULTS AND DISCUSSION

Initial Surface Charge Density Measurement: It is observed From Figure 1 (a), (b) that negative surface charge was developed on both the surfaces of magnetoelectrets of Porous PTFE, irrespective of nature of field applied and forming temperature. During the preparation, as far as the formation of surface charge on

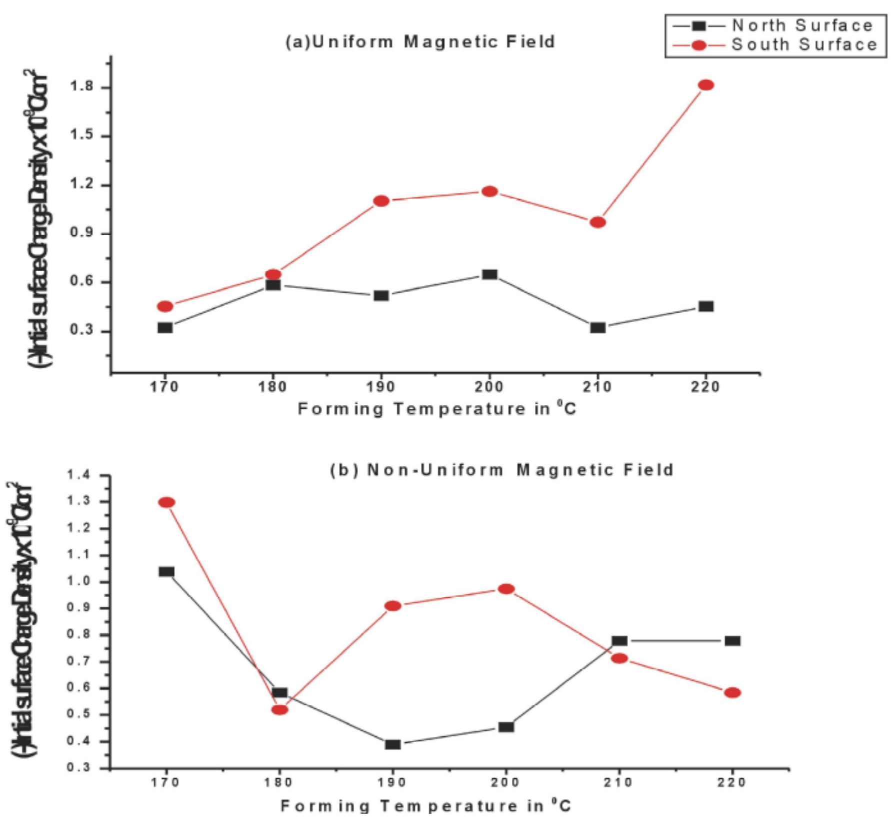

Fig. 1: Variation of initial surface charge density with different forming temperature in (a) uniform and (b) non uniform magnetic field.

Table 1: Variation of iso and idio charge density with different forming temperature in uniform and non uniform magnetic field

	Temperature											
	170°C		180°C		190°C		200°C		210°C		220°C	
Forming	σ_{iso}	σ_{idio}	σ_{iso}	σ_{idio}	σ_{iso}	σ_{idio}	σ_{iso}	σ_{idio}	σ_{iso}	σ_{idio}	σ_{iso}	σ_{idio}
Uniform Magnetic field	-0.889	+0.064	-0.616	+0.032	-0.811	+0.292	-1.136	+0.487	-0.649	+0.324	-1.136	+0.681
Non uniform Magnetic field	-1.168	+0.129	-0.551	-0.032	-0.649	+0.259	-0.714	+0.259	-0.746	-0.032	-0.681	-0.097

the Magnetoelectrets of Porous PTFE is concerned, heat and magnetic field is used as an activation energy source and the polarizing field respectively. Basically charge storage in electrets could occur at three structural level, first is charge trapping at particular sites of the chain due to strong electronegative bonds, secondly charge trapping in free volume and the third level is charge trapping at crystallites and interfaces between different materials therefore as in porous PTFE the charges can be injected to its volume through voids and trapped in particular sites or in free volume, therefore large number of second and third levels are expected as compared to the first level because of the greater area of interface and higher crystalline nature [15].

Under the combined effect of heat and magnetic field during formation, the charge carriers tend to migrate and some of them get trapped during this process. These trapped charges get frozen during cooling process contributing to what is called as the persistent polarization. Therefore appearance of surface charge on the electrets is attributed mostly to the phenomena of persistent polarization. It is also observed that both the surfaces of the electret possess negative charge. According to Khare Bhatnagar hypothesis the charges appearing on the magnetoelectret surfaces are a result of combined effect of iso and idio charges [13]. The isocharge is the charge of the same sign on the surface of electret which may be +ve or –ve depending upon the substance while idiocharge is a charge due to polarization of the dielectric which has opposite charges on the opposite surfaces of electret. From the initial surface charge density data, the contribution of the components of iso and idio charge to surface charge density was calculated by the method given by Khare and Bhatnagar [13]. The calculated data is given in Table 1. It can be seen that the magnitude of idio-charge density is very small as compared to that of iso-charge. Therefore, it is confirmed that the observed surface charge is a negative iso-charge. It may be due to charge trapping at particular sites of the chain due to strong electronegative bonds, charge trapping in free volume or it may be due to charge trapping at crystallites and interfaces.

Effect of Uniform and Nonuniform Magnetic Field on the Initial Surface Charge Density: According to the Qureshi Bhatnagar model [16] for magnetoelectrets, the traits of nonuniformity arises because of the properties of sample holders and other ambient conditions, which may be responsible for the formation of electrets under the uniform field. Therefore in order to establish the effect of nonuniformity, samples using direct nonuniform magnetic field was chosen by using the same sample holder which were used earlier for uniform magnetic field. From Figure:1[(a),(b)] it can be observed that at certain temperatures the magnitude of initial surface charge developed on magnetoelectrets samples prepared under nonuniform field was higher than those prepared under uniform field. However, there is no significant difference in the order of surface charge. The difference in magnitude may arise because of orientation of dipoles by the action of unequal force that acts on the opposite ends of the dipoles. This unequal force arises from the nonuniformity of the field. Also there exists some influence of nonuniformity in magnetic field on the motion of charge carriers.

In the nonuniform field, a force F= q (v x B) will act on moving charges. If the spin dipole moment μ_s, is parallel to applied magnetic field B, there is an expected motion of charge carriers in a direction in which field increases and if μ_s is anti parallel to B, charges move in a direction in which field decreases and while cooling these charges will get frozen and contribute to surface charge. This kind of motion of charged particle is absent in uniform field which may results in the formation of electret with less surface charge density in comparison to the one formed under nonuniform field. Variation in surface charge density with forming temperatures of magnetoelectret samples prepared under uniform magnetic field is comparable with that of nonuniform magnetic field.

Effect of Polarizing Temperature on the Surface Charge Density: The magnetoelectrets samples were prepared at six different temperatures, 170°C, 180°C, 190°C, 200°C and 210°C, 220°C at fixed field of 1.3T in uniform and non uniform Magnetic field.

Figure 1, (a), (b) shows variation in surface charge density with forming temperature. It is observed that the surface charge density is having a greater magnitude at elevated temperature. This can be understood on the basis of rate of capture of charges into the traps. As compared to the effect of magnetic field, the surface charge density is having more dependence on forming temperature because at elevated temperature there is possibility for more electrons to go into the traps due to large voids as well as fibrillated morphology between voids of the material, this may increase the surface charge density. Also the porous materials became soft and show larger mechanical compatibility at elevated temperature during the polarizing process. At the same time, the coulomb forces of the mono charges situated at both sides of the pores with opening structure repel each other. This results in an expansion of the pores. This may be confirmed from XRD [17]. When the sample is cooled to room temperature in presence of magnetic field, the expanded holes are solidified. It may be infer that, higher the polarizing temperature, larger is the diameter of the holes and higher the strength and stability of porous PTFE magnetoelectrets. In the present case all the forming temperatures are below softening point of the material and isocharge formation is also observed in all the cases. This is in confirmation with the work of Bhatnagar et.al. [10-15]. this can be explained by considering the influence of temperature over the drift of charges. Normally dielectrics are bad conductors of heat; therefore temperature at the centre of the sample may not be same as that of, on both of its surfaces. This creates temperature gradient between bulk material and surfaces of sample pellet, which contributes to charge transport and due to this temperature gradient the isocharge may have been occurred.

Surface Charge Decay Characteristics: The quality of electret is mainly decided by its stability. The dynamics of the activation process, time and field dependence of the carrier concentration in the conduction band are responsible for the electret stability. The stability of electret charge is predicted by considering the rate of current carrier generation in activation processes and the rate of annihilation is due to carrier capturing and recombination [18, 19].

Some other factors that affect the stability of electrets are resistivity, degree of crystallinity and the temperature at which the crystalline domains of the polymeric system used for electret fabrication which undergoes transitional motions [20]. The charge decay occurs mainly because of the two reasons that is deposition of compensation charge from the atmosphere and the internal decay through conduction or drift, perhaps accelerated by invasive humidity.

Surface charge decay is studied in order to maintain the optimum conditions for getting an electret with maximum persistence in terms of surface charge developed on it. To find out the stability of electrets, surface charge decay of as prepared electrets was observed continuously for 40 days, but since no observable change were observed after first 30 days of decay, therefore this duration (30 days) was chosen to study decay of all the as prepared magnetoelectrets. Surface charge density decay graph is given in Figure: 2[(a), (b)]. An exponential decay of surface charge is observed in all the samples. During formation of electret, surface and volume trapping of charge carriers is taking place. Impurities, broken polymer chains, or surface defect can act as surface traps and atomic sites in the molecular chain or crystalline domain boundary can act as the volume trap. The energy associated with these traps will be different and some act as deep traps and some as shallow traps. Therefore detrapping or decay of charges from these traps may not be uniform and it may give rise to the exponential decay of surface charge as observed. The presence of humps on the decay curve indicates that the decay of charge do not take place in a continuous manner. The sudden Increase in decay curves may be because of the recapturing of the electrons in the shallow traps after they have been liberated due to thermal agitation at room temperature. The decay on sample is attributed to compensation of the electret charges by atmospheric ions attracted by the electret. Internal charge decay processes in dielectrics are governed by conduction phenomena which depend on carrier mobility, carrier concentration etc [21]. By the method of successive reduction of the semi log plot, the decay parameters can be calculated as follows.

An exponential decay of surface charge is observed in all magnetoelectrets. By the method of successive reduction [22] of semi log plot. The decay parameters can be calculated as follows.

The equation for the exponential decay of the surface charge can be written as

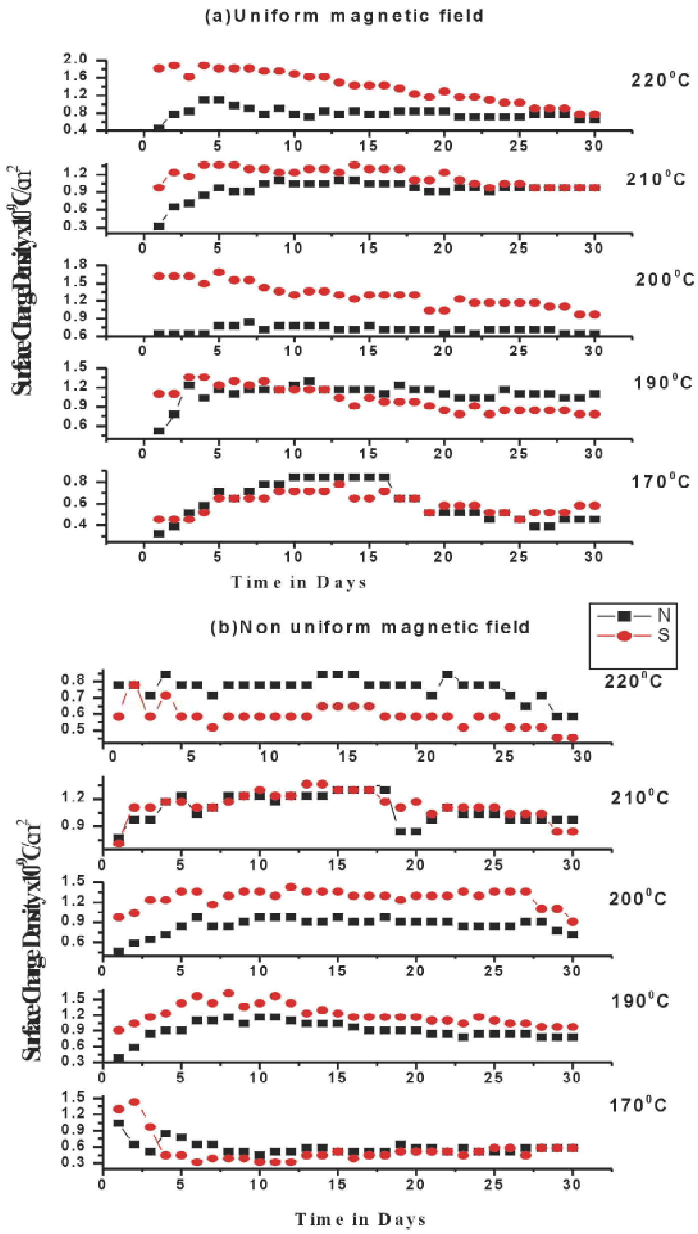

Fig. 2: Surface charge decay characteristics of magnetoelectret prepared at 1.3T (a) Uniform magnetic field (b) nonuniform magnetic field at different forming temperature for North and South surfaces.

$$\sigma_t = \sigma_0 . e - {}^{\tau}\!/_{\tau} \quad (1)$$

Where, σ_0 and σ_t are the initial and instantaneous charge densities and τ is the decay time constant. On simplifying the equation we get,

$$1/\tau = (\ln \sigma_0 - \ln \sigma_\tau)/t \quad (2)$$

The variation in decay time constant of electrets prepared under different conditions was calculated and given in Table 2. It is observed that for those samples prepared at low temperature and in uniform magnetic field the time constant for decay is less compared to that prepared at high temperature and in nonuniform magnetic field.

From the data it may be concluded that in all the cases, north surface decay time constant is higher which

Table 2: Variation of decay time constant with different forming temperature in uniform and non uniform magnetic field

	Temperature											
	170°C		180°C		190°C		200°C		210°C		220°C	
Forming	τ_N	τ_S	τ_N	τ_S	τ_N	τ_S	τ_N	τ_S	τ_N	τ_S	τ_N	τ_S
Uniform Magnetic field	34	57	99	32	236	52	458	63	91	100	162	33
Non uniform Magnetic field	127	221	139	158	1079	107	147	4702	393	280	173	107

implies the better stability of surface charge on north surface as compared to south surface. In the present study it is found that time constant is very high in porous PTFE which is low in non porous material [23]. This implies a better stability of surface charge in porous PTFE. To understand better it is to state that the surface states of non porous PTFE, a much larger interface produce a large number of broken chains, voids, or differences in a short-range order between the interface and inner bulk, etc. As a result, they can significantly reduce conductivity due to a much larger effective surface area and can produce a lot more and complicated defects containg a higher concentration of deep traps. These deep traps are responsible for the ability of the charge capture and stability of the charge storage for the porous PTFE samples.

CONCLUSION

Porous PTFE magnetoelectrets prepared in uniform and nonuniform magnetic field at different forming temperatures shows negative iso charge and having excellent charge storage stability, especially at high temperature and in non uniform magnetic field.

The presence of iso-charge indicates that polarization due to charge separation having more contribution to surface charge density rather than dipole orientation.

It was found that the trend of surface charge decay at room temperature and variation in surface charge density with respect to the forming magnetic field and temperature are same in samples irrespective of the nature of the field applied. The magnetoelectret state of Porous PTFE was studied and it is found that time constant is very high in porous PTFE as compared to non porous material. This implies a better stability of surface charge in porous PTFE and this can be explored further for electret applications especially in Piezo Electric sensors.

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