Journal of Electrostatics 68 (2010) 384–389

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Preparation and surface charge studies of bio-magnetoelectrets of L-serine

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ARTICLE INFO

Article history:
Received 22 February 2010
Received in revised form
8 April 2010
Accepted 21 May 2010
Available online 4 June 2010

Keywords:
Magnetoelectrets
Biopolymers
Amino acid
L-serine
Dielectric materials
Homogeneous and inhomogeneous magnetic field

ABSTRACT

This paper reports the study of surface charge characteristics of bio-magnetoelectrets of amino acid L-serine. Electrets were prepared under the combined effect of heat and magnetic field. Three different forming temperatures and five different magnetic fields were used for the study. The bio-magnetoelectrets prepared this way were observed to have a surface charge of the order of 10^{-9} C. The decay of surface charge was studied continuously for 20 days and corresponding time constant was calculated. The comparative studies of surface charge characteristics were done by preparing bio-magnetoelectrets using homogeneous and inhomogeneous magnetic fields.

1. Introduction

An electret can be considered as a piece of dielectric material with the presence of quasi-permanent electrical charges. The electret charge may consist of surface charge or space charge or a combination of these two [1]. It behaves like a voltage source or acts as an electrical counterpart of a permanent magnet [2]. The electret effect elucidates the mechanism of polarization and absorption well in dielectrics [3]. Electrets have a wide range of applications in engineering and industry that includes their use in transducers, sensors, microphones [4,5] and as reliable filters in vacuum cleaners and air-conditioners [6,7]. Depending upon the type of activation energy source and polarising field Sessler et al. [1] had described different types of electrets. In 1964 Bhatnagar [8] replaced the commonly used polarizing electric filed by the magnetic field and observed surface charge formation on the dielectric material he used. He described it as "magnetoelectret" and also studied its decay parameters. Since then various researchers worked with different materials and their aim was to assess the principle behind the formation of magnetoelectret [9–12]. But there has been no single theory so far that can explain the magnetoelectret state observed in various dielectric materials and its dependence on forming parameters. Therefore present work aims to find out the dependence of electret properties on forming parameters such as temperature, magnetic field, etc. Another objective is to introduce a potentially viable material. Normally polymers are used for electret applications, however, most of them are non-degradable. Because of environmental problems due to non-degradability, in recent years there is a growing concern to develop a biocompatible material as an alternative electret material. The presence of charge storage has already been reported in electrets of bone, blood vessel wall material, keratin, cellulose, DNA and many other biopolymers [6,13–17]. Therefore an attempt has been made to develop magnetoelectrets of amino acid. Among all the other amino acids L-serine is found more suitable because it has OH group in its side chain. Its presence lends the side chain a capacity to interact with NH_2 and COOH groups and ionise them [18]. These ions and polar entities can take part in polarization process during electret formation and it can contribute to electret properties. The prime motivation for the present work was provided by the excellent charge generation capability and polar nature of molecules of L-serine and it is expected to help in explaining the surface charge formation and orientational dynamics in magnetoelectret state.

2. Materials and methods

L-serine is one of the 20 naturally occurring amino acids with formula $C_3H_7NO_3$. It is one of the simplest amino acid with molecular weight 105.09 gmol^{-1} and is having a melting point of

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doi:10.1016/j.elstat.2010.05.009

228 °C which is relatively a high melting point on considering other polymeric systems used for electret preparation. Its crystalline nature and the presence of hydroxyl group on the side chain make this material suitable for electret studies. The thermoelectrets of L-serine and their TSDC analysis have already been reported [19,20]. The essentially polar nature of L-serine was suspected to give rise to a strong relaxation current above room temperature. The presence of hydroxyl group on the side chain lends it a polar nature, which can be explored to analyse the apparent surface charge behaviour of the magnetoelectret of L-serine. It is already observed that the amount of polarization is having a dependence on composition, temperature, applied field and the molecular weight of the polar component [21]. So we carried out studies at different forming temperatures and magnetic fields.

3. Experimental method

Commercially available L-serine in powder form from CDH India was used to make pellets of 1.44 cm diameter and 2.01 mm thickness. To make pellets a pressure of about 2.4 tons is applied using hydraulic press. Magnetoelectrets were prepared by following the method already described by Khare and Bhatnagar [22]. Electromagnets of Polytronic Corporation (Mumbai, India), Type-HEM 150, SR No.: 9 and 35 were used to provide the magnetic field. Both the electromagnets could create a maximum magnetic field of 1.7 T on application of 220 V. In one of the electromagnets the pole pieces were tapered to create inhomogeneous magnetic 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 [1]. After that samples were cooled in the presence of magnetic field till they come to room temperature. The main objectives were to check the variation of initial surface charge with the forming parameters, the effect of homogeneous and inhomogeneous magnetic fields on surface charge density of magnetoelectrets and to study its decay. Therefore samples were prepared at three different temperatures (150 °C, 170 °C, 190 °C) and at 5 different magnetic fields (0.65 T, 0.83 T, 1.02 T, 1.24 T, 1.40 T at the centre in both homogeneous and inhomogeneous magnetic fields). The surface charge measurements were done using dissectible capacitor arrangement [1]. It is comprised of a sandwich cell assembly made up of spring-loaded upper silver electrode and a lower electrode of aluminium. In order to measure the surface charge of magnetoelectret, it was inserted between the two electrodes. The electrodes were then shorted through a Keithley 6517B solid state electrometer for 30 s. Surface charge was measured after that by releasing the upper silver electrode whereas the lower aluminium electrode was kept grounded during measurement process. After charge measurement, the samples were shorted by wrapping them in aluminium foils and were stored in a vacuum desiccator for further measurements.

4. Results and discussion

4.1. Initial surface charge density measurement

Table 1
Variation in surface charge density with forming temperature.

Forming magnetic fields (T)	Temperature					
	150 °C		170 °C		190 °C	
	$\sigma_N \times 10^{-9}$ C/cm^2	$\sigma_S \times 10^{-9}$ C/cm^2	$\sigma_N \times 10^{-9}$ C/cm^2	$\sigma_S \times 10^{-9}$ C/cm^2	$\sigma_N \times 10^{-9}$ C/cm^2	$\sigma_S \times 10^{-9}$ C/cm^2
1.40	−2.454	−1.840	−8.589	−5.521	−17.791	−15.950
1.24	−1.227	−1.227	−12.147	−4.294	−14.724	−12.883
1.02	−0.896	−0.736	−2.454	−1.227	−6.749	−3.681
0.83	−0.798	−0.920	−1.227	−0.920	−4.908	−5.521
0.65	−0.613	−0.859	−0.491	−0.491	−1.276	−1.521

Table 1 depicts the initial surface charge density of different magnetoelectrets at room temperature. It can be observed that negative surface charge was developed on both the surfaces of magnetoelectrets of L-serine, irrespective of strength of field applied and forming temperature. The formation of surface charge on the magnetoelectrets of L-serine can be described as follows. During preparation heat is used as activation energy source and magnetic field as the polarizing field. L-serine being not an ideal insulator, there is a possibility of electron transfer to the conduction band at elevated temperature, which may leave behind an equivalent positively charged carrier in the valence band. In addition to this there is a possibility for the generation of charge carriers by the application of pressure during pellet formation also. Among the charge carriers thus created, electrons may delocalize through hopping transport across the molecules and ions may migrate through the diffusion process. However the traps present in polycrystalline materials (such as amino acids) that are reported to be exponentially distributed in the forbidden energy region may provide hindrance to their motion [23]. Apart from these there may be several other traps as well which may come, either from impurity atoms and/or from the presence of water molecules. Water molecules have been reported to act as Neutral Electron Trap [13]. Under the combined effect of heat and magnetic field during formation, the charge carriers may tend to migrate and some of them may get trapped during this process. And dipoles on the other hand may possibly undergo an orientation because of the expected magnetic anisotropy [24] of the material. These trapped charges and oriented dipoles will be “frozen in” during cooling process contributing to what is called as the persistent polarization [1]. Therefore appearance of surface charge on the electrets is attributed mostly to the phenomena of persistent polarization. From Table 1 it is also observed that both the surfaces of the electret posses negative charge. According to Khare–Bhatnagar hypothesis which describes the formation of magnetoelectret state, the charges appearing on the magnetoelectret surface are a result of combined effect of what are called as “iso-charge” and “idio-charge” [22]. From the initial surface charge density data, the contribution of iso-charge and idio-charge components to surface charge density was calculated by the method given by Khare and Bhatnagar [22]. The calculated data is given in Table 2. It can be seen that the magnitude of idio-charge density is very small as compared to that of iso-charge. Therefore we can say that the observed surface charge may possibly be a negative iso-charge. There are several factors that can contribute to the development of the negative surface charge on the electret. Some of them are (1) presence of hydroxyl group in the polymer as side chain, (2) diffusion current, (3) bound water molecules and (4) impurities, etc. However, our objective was not to study the effect of these factors on surface charge. Rather we aimed to study the variation in surface charge with respect to the change in forming parameters like applied temperature and magnetic field. Besides this we also studied surface charge decay in order to come up with optimum conditions for getting an electret with maximum persistence in terms of surface charge developed on it.

4.2. Effect of magnetic field strength on the initial surface charge density

In order to evaluate the influence of forming field on the surface charge, magnetoelectrets were prepared under different magnetic fields keeping the forming temperature constant. Fig. 1 shows the