Effect of Time and Electric Field in Teflon Bioelectrets

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Abstract:

Bioelectret of Teflon sheet was prepared for the polarizing time of 5, 6, and 7 hr with a field strength of 700, 800, and 1000 kV/m at room temperature (300 K). The thermally stimulated discharge current (TSDC) spectra of Teflon were complex and were composed of two peaks of opposite polarity. This suggests that there are two separate mechanisms for the release of TSDC. In addition, TSDC spectra of non-polarized Teflon sheets give triple reversal from positive to negative, negative to positive, and again from positive to negative.

Keywords: Bioelectret, Teflon, TSDC, polarizing time, spectra, homocharge.

Introduction:

Polytetrafluoroethylene (PTFE) also known as Teflon is a class of polymer with the chemical structure of PTFE $[CF_2-CF_2]_n$ is like that of polyethylene (PE), except that the hydrogen atoms are completely replaced by fluorine (hence it is referred as a perfluoro polymer). The fluorine content in PTFE is theoretically 76% and it has 95% crystallinity. It is the size of a fluorine atom which forms a uniform and continuous sheath around carbon-carbon-bonds and hence imparts good chemical resistance and stability to the molecule. This uniform fluorine sheath also provides electrical inertness to the molecule.

PTFE has a wide range of practicable temperatures from -180°C to +260°C and a wax-like surface to which anything is hardly plastics. PTFE has the lowest coefficient of friction of all known solid materials. It has the best electrical properties of all plastics. Today, PTFE applications range from low-tech non-stick frying pan surfaces to high-tech exotic medical and hospital uses including implants, surgical instruments, test equipment, and dramatic uses in firefighting equipment etc[1].

PTFE has excellent properties such as chemical inertness, heat resistance (both high and low), electrical insulation properties, low coefficient of friction (static 0.08 and dynamic 0.01), and exhibits high thermal stability without obvious degradation below 440°C. It has excellent electrical properties such as high insulation resistance, extremely low dielectric constant (2.0) due to the highly symmetric structure of the macromolecules. These properties come from the special electronic structure of the fluorine atom, the stable carbon-fluorine covalent bonding, and the unique intramolecular and intermolecular interactions between the fluorinated polymer segments and the main chains.

Electrets[2,3] are the class of dielectric material containing quasi-permanent electric charge or molecular dipoles, which can generate internal and external electric fields. These materials are essentially made by electrization of dielectric material wherein a high electric field is applied to the insulating substrates.

During the last three decades, development in the field of electrets has continuously extended the fascinating world of micromechanics[4]. Several devices based on electrets, such as various types of transducers, were introduced. In addition to proper electrical characteristics, or more precisely the charge storage and transport properties one has to care about the mechanical properties of the materials used in a micromechanical device. One of the most important aspects of electrets research is bioelectret[5]. For the present study, we used the polymer with good biological compatibility i.e Teflon (PTFE) as bioelectret. The time and electric field effect in bioelectrets are studied with the technique known as thermally stimulated discharge current (TSDC).

Experimental:

The electrets were prepared of Teflon disc of diameter 0.5×10^{-2}m and thickness 3×10^{-3} m. Teflon was obtained from Garware Plastics & Polyester, Mumbai. The samples were polarized at room temperature at field strength 700, 800, and 1000 kV/m for 5, 6, and 7hrs. Therefore, the voltage was disconnected and the samples were kept short-circuited for 24hrs to eliminate the stray charges. The samples were again put into the oven and were heated at a uniform heating rate of 0.7 K/min and the depolarization current was measured as a function of temperature.

Result and discussion:

Figure 1 represents TSDC as a function of temperature for samples polarized at 800 kV/m for different polarizing times, viz 5, 6, and 7 hr at room temperature (300K). I_{max}, the peak current and hence the amount of stored charge (q) increase with polarizing time for the constant field of polarization in the heater charge region, it shows one peak (α_1) on the positive side of the current and one peak (α_2) in the negative side of the current. There is also a ρ-peak in the curve for 7 hr polarizing time.
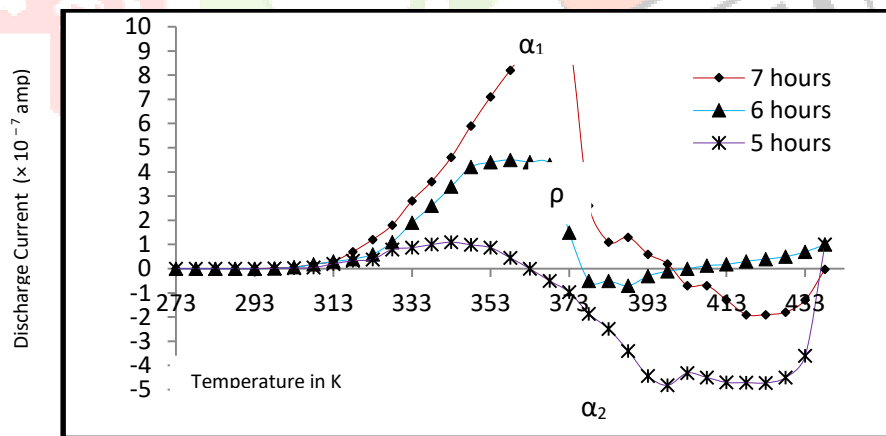

Figure 1 represents TSDC as the function of temperature sample polarized at 800 kV/m for different polarizing time viz 5,6,7 hours at room temperature (300K). I_{max}, the peak current and increased with polarizing time for constant field of polarization in the heterocharge region. It shows one peak (α_1) in the positive side of the current and one peak (α_2) in the negative side of the current. There is also ρ peak with the polarizing time.
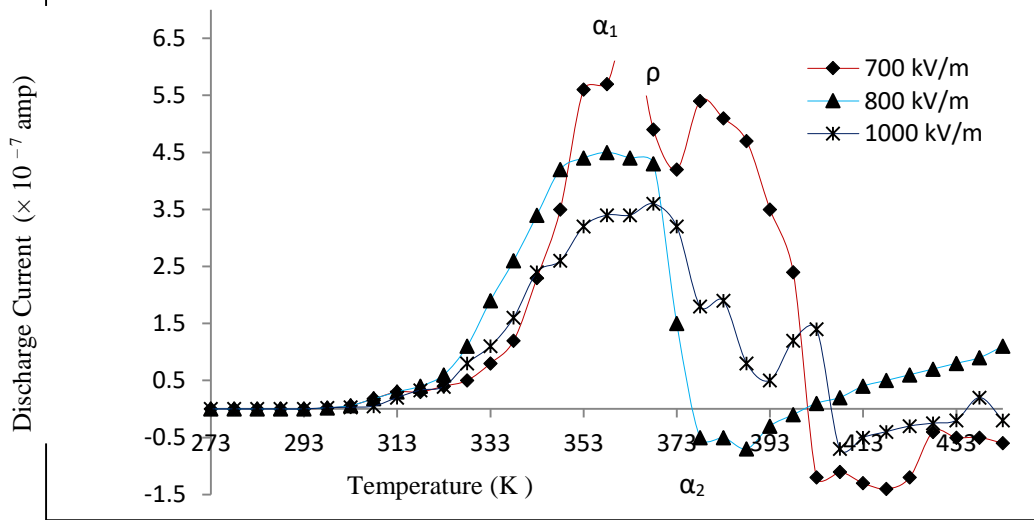
Figure 2 represents the thermogram for 6hr polarizing time with the field 700kV/m, 800kV/m and 1000kV/m at room temperature (300K). All the curves for 6hr polarizing time give polarity reversal are sudden. It also gives one peak (α_1) in the heterocharge region and one peak (α_2) in the homocharge region.
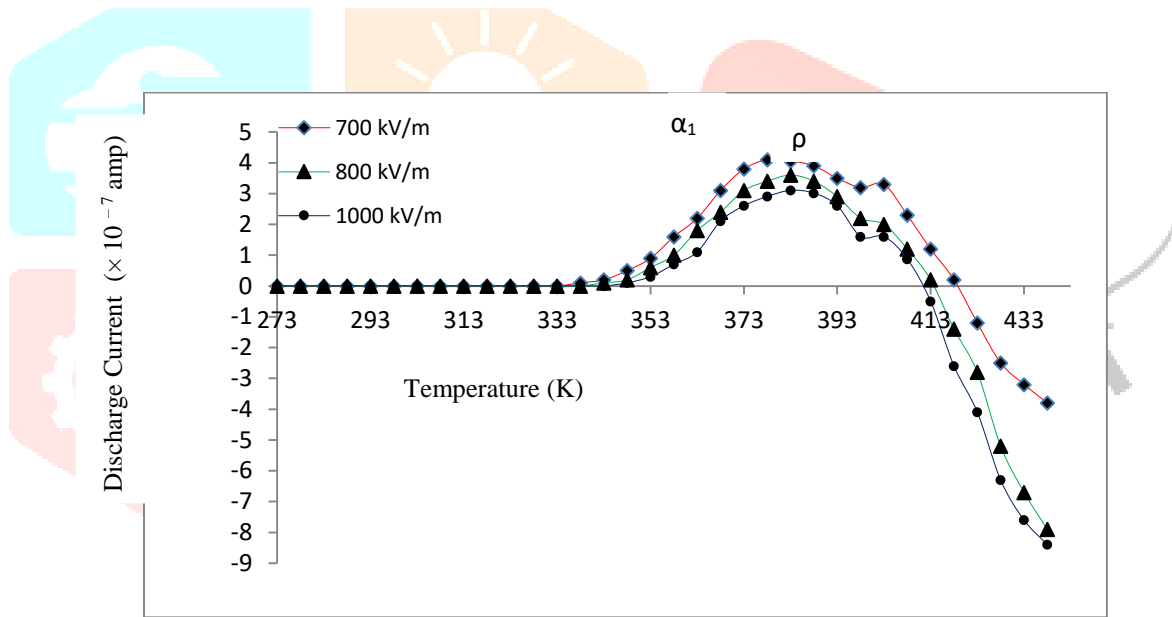

Figure 3 is shown the case where the sample is first heated up to 433K slowly (0.7 K/min) then it is charged at room temperature (300K) with the field the 700kV/m, 800kV/m and 1000kV/m. The curve shows one and also a reverse of polarity. The peaks for higher polarizing field are higher. Slight shift in the temperatures corresponding to the current peaks is observed, all lying near 393K. The curve also shows a ρ peak at 408 K which is not distinguishable.
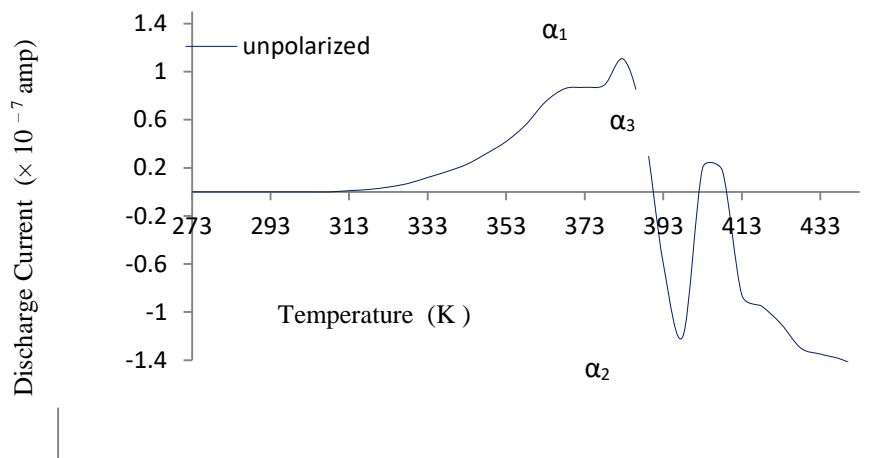
Figure 4 depicts the TSDC for polyethylene terephthalate of thickness 10^{-4} m thickness without any treatment and without external field. Positive current peak (α_1) is found at 385K and then a current reversed takes place and give a negative (α_2) at 393K. Again it goes to the positive side of the current and gives a peak (α_3) and then changes its polarity. The same sample on reheating gives very low current up to 433K.
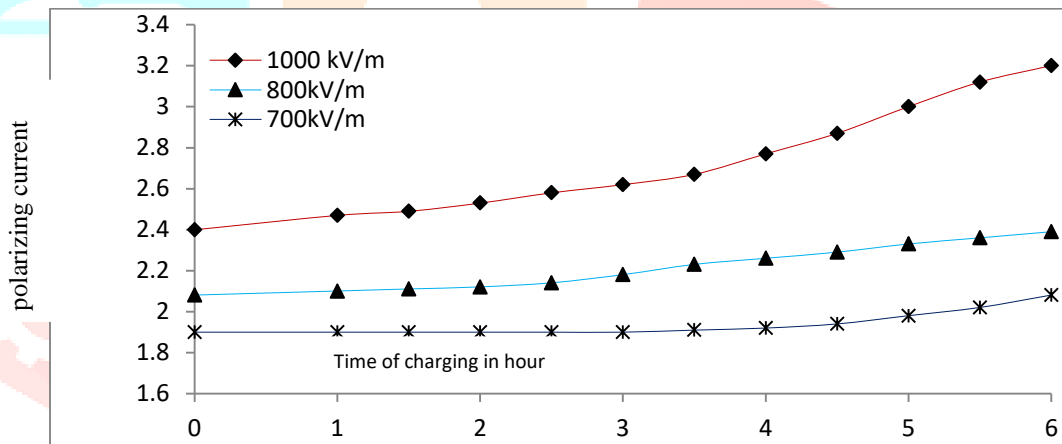

Figure 5 represents the polarizing current as a function of time for the sample polarized at room temperature (300K) with polarizing field of 700kV/m, 800kV/m and 1000kV/m for 6 hour.

Fig-4 depicts the TSDC for Teflon of 3×10^{-3}m thickness, heated without any pretreatment and any external field. A positive current peak (α_1) is found at 385 K and then a current is reversal takes place and gives a negative peak (α_2) at 393 K. again, it goes to the positive side of the current and gives a peak (α_1) and changes its polarity. The same sample on reheating gives a very low current up to 433K.

Fig-5 represents the polarizing current as a function of time for samples polarized at room temperature (300K) with the polarizing field of 700, 800, and 1000kV/m for 6 hrs.

Discussion:

The observed increase of I_{max} and the total heterocharge stored increase of polarizing time, as well as polarizing field, maybe due to the increased dipolar polarization. This is because the dipoles get a better chance to orient themselves in the direction due to the field direction due to increased field and increased time[6]. Considering only internal polarization, two of the mechanisms which likely to be operative in the polarization process are- (i) the relaxation of the polar group and (ii) space charge polarization. The polymer has a dipole side group which can rotate locally in unison with the main chain[7]. The cooperative motion with the main chain gives rise to α-peak. In the phenolate, the relaxing dipoles are the phenolic (OH) groups; there is also the possibility of the group being ionized to give H^+ and phenolate ion. The ρ-peaks may be attributed to the space charge carrier arising from ionic rather than electronic charge carriers (as the activation energy of ρ-peak is about 2.3 eV). The space charge peak (ρ) appears at a higher temperature than the temperature at which the dipole peak occurs[8] (glass rubber transition temperature). This is because the disorientation of dipole merely requires local orientation, whereas the neutralization of space charge requires them to move over many atomic distances.

At still higher temperatures, the self-motion of space charges is accompanied by a second neutralization mechanism namely recombination with thermally generated carriers. These carriers are generated uniformly in the entire specimen by dissociation of neutral entities. These carriers become more mobile at higher temperatures and constitute a homocurrent in the internal field of the electrets. This current is opposite to the displacement current or current due to dipolar dissociation[9].

Thus, the origin of heterocharge peak ($α_1$) can be explained by Gross[10] two charge theory given as

$$I=I_{het} +I_{hom}$$

Clearly, the resultant current generated is proportional to the net current $I_{het} -I_{hom}$, since I_{het} is assumed to have opposite signs. I_{het} stands for heterocharge current and I_{hom} for homocharge current. When the orientation rate of the dipole is greater than the rate of neutralization by recombination with thermally generated carriers, we first find a heteropolar peak ($α_1$).

The origin of the homopeak can be attributed to the fact that the structure of the crystalline polymer is far from perfect, and consist of lamellae of folded chains, interlink by the molecules and these dielectric domains due to disordered amorphous phase[11]. Now as the temperature is raised above heterocharge peak the I_{hom} starts increasing as the number of thermally generated carriers increases. So a reversal is observed from hetero to homo side of the current. As the temperature is further raised the current goes on increasing on the homo side (Figs 1, 2, and 4). This is because of the dipole of the closed dielectric domains which are broken at this temperature of 403 K nearly and start contributing to the main displacement current I_{het}, whose direction is in the opposite direction to the I_{hom}. This results in a homocurrent peak ($α_2$) at about 403 K for the polarized sample (Figs 1 and 2) and unpolarized sample (Fig 4). When again this dipole of the closed domain is exhausted, the I_{hom} current starts increasing (Figs 1, 2, and 4) as I_{het} decreases. This idea of dielectric domain is further supported by Fig 3. when the sample is preheated to a temperature above 403 K, that is at 433 K before polarization, and then preheated samples are polarized, these show only $α_1$ and ρ-peaks but not a negative peak. This is because the dielectric becomes homogeneous due to preheating above 403 K. the dipolar peak in Fig 3 is lowered because due to preheating some of the phenolic (OH) dipolar groups break into H^+ and phenolate ions. This decreases the number of dipoles available in the sample for polarization and thus the heteropeak is lowered[12]. In Fig. 5, the gradual increase in current confirms the ordering of dipoles and gradual fillings of the traps (development of space charge) in the volume of the dielectrics.

The heterocharge in Teflon electrets was due to dipolar reorientation of charge carriers, space charge, and striping and molding charge. This heterocharge originated from volume polarization. The reversals from hetero to homocharges were due to the second neutralization process of the charge carrier due to ohmic conduction.

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