

Mobility Dependence on Electric Field in Low Density Polyethylene (LDPE)

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Abstract: The surface potential decay evolutions with time after negative corona discharge of low-density polyethylene (LDPE) have been recorded for different charging levels. It was observed that there was a significant increase in the surface potential decay rate with the increase of charging levels. Electrical conduction characteristics in LDPE have been investigated as a function of electric fields strength. It is found that the mobility of LDPE increases with the increase of electric field and the conduction mechanism is governed by the hopping process of injected carriers between localized trapping centers. A deep trap separation of 3.2 nm, corresponding to 3.10^{19} traps/cm³ has been found.

Keywords: Carrier mobility, Charge transport, Conduction mechanism, Hopping conduction, Poole-Frenkel mechanism.

I. Introduction

Since several years, synthetic polymers have known a large application in electrical industry due to their excellent electrical, thermal, and mechanical properties. Low-density polyethylene (LDPE), which has a good mechanical properties and chemical resistance, may be an attractive electrical insulating material in power cables. The electrical conductions of polymers have been extensively studied in recent years to understand the nature of charge transport in these materials. Knowledge of the conduction mechanism in polymer films is of considerable value because of the application of these films in various areas such as microelectronics, optoelectronics, etc [1]-[3]. Different conduction mechanisms such as Schottky effect, Pool-Frenkel effect, space charge limited conduction and hopping conduction have been suggested for the charge transport.

The surface potential decay (SPD) of the charged insulating materials was shown to be an interest method for studying charge transport mechanism in insulating polymeric materials and more generally to investigate the conduction properties and the electrostatic phenomenon in polymer surface [4]-[8]. Various methods have been used to observe the decay including surface potential decay, thermally stimulated discharge current and the measurement of current/voltage during corona charging. SPD

technique is extensively applied in electrostatic processes such as electrostatic separation, precipitation and electrostatic powder coating [9].

In this work, we have studied the influence of the charging levels on the evolution of SPD kinetic of low-density polyethylene films, negatively charged by corona effect. The conduction mechanisms were analyzed following two different mechanisms of carrier conduction. The surface potential data were treated by numerical derivation with time, dV/dt transformation, which provided possibilities to deduce material parameters such as transit time and consequently charge carrier mobility.

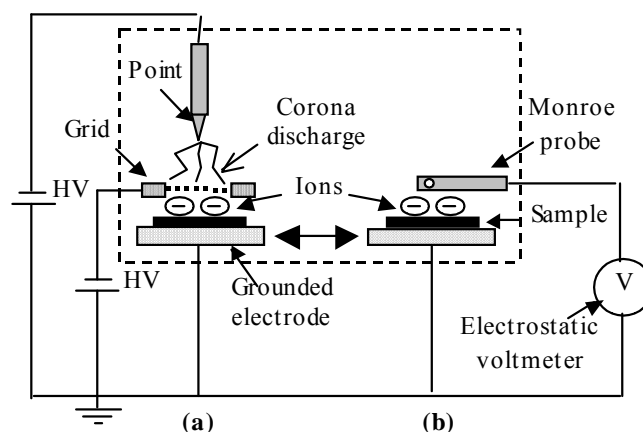


Fig. 1: Surface potential decay principle. Corona discharge (a) and surface potential measurement (b).

II. Experimental Details

The material used in this study is low-density polyethylene from Good fellow. The samples used in the experiment are square sheets of 5 cm side length and thickness L of 50 μm . Before any charging process, the samples were cleaned with distilled water then dried in air ambient. A schematic of the experimental setup used for measuring the SDP is shown in Fig. 1. It consists of corona discharge system and measurements apparatus.

To study SPD, the sample was placed on a grounded plate and charged using corona discharge with a point voltage V_p and a grid of voltage V_g .

For all the experiments reported here, the distance between point and grid (D) was 10 mm and sample to grid distance (d) was 5 mm. A charging time of 5 seconds was found to be sufficient to ensure that the surface potential of low-density polyethylene film V_s reached its maximum. The $(V_p - V_g)$ was held at 4 kV throughout the experiment procedure.

After its charging, the sample was transferred automatically under a non-contacting Monroe vibrating probe (Monroe 1017 AS) connected to an electrostatic voltmeter (Monroe 244A-2 model) to enable the record of V_s as a function of time.

All the charging and SPD measurements were carried out in a climatic chamber in which humidity and temperature are controlled.

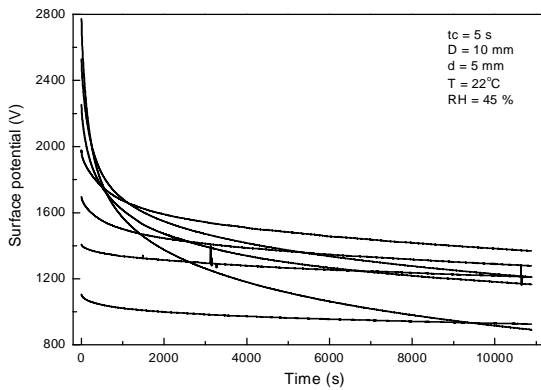


Fig. 2: Surface potential decay for different initial potentials V_0 .

III. Experimental Results and Discussion

A characteristic family of surface potential decay $V_s(t)$ curves obtained after negative corona charging with different initial potentials surfaces V_0 is shown in Fig. 2. The initial potential for charge deposition was

varied from 1100 to 2770 V and their potential decay was observed until 3 hours. The results show that under the same charging and measuring conditions ($T = 22^\circ\text{C}$, $\text{RH} = 45\%$ and $t_c = 5\text{s}$), the curves recorded for high initial potential present a rapid decay of surface potential than those recorded for low initial potential.

We notice also that the SPD rate increases with the initial potential. The cross over phenomenon of SPD can be observed, indicating the influence of the high electric field.

Based on previous works [6,7], it may be assumed that the charges formed at low corona voltage are likely to stay on the surface due to deep surface traps. On the other hand, charges formed at high corona voltage are able to drift towards the grounded electrode under the effect of their own electric field by hopping between shallow localized centers, leading by a consequence to fast SPD.

Investigating SPD characteristics of corona charged polymers [10], it has been shown that $dV/dt = f(t)$ in bilogarithmic coordinates is an appropriate mean to explain the most probable mechanism taking place in the charge flow process of insulating surface. If we observe the SPD rate dV_s/dt as a function of time (Fig.3), we note a power law with two different decay parameters α_i and α_f [11], as given by the following

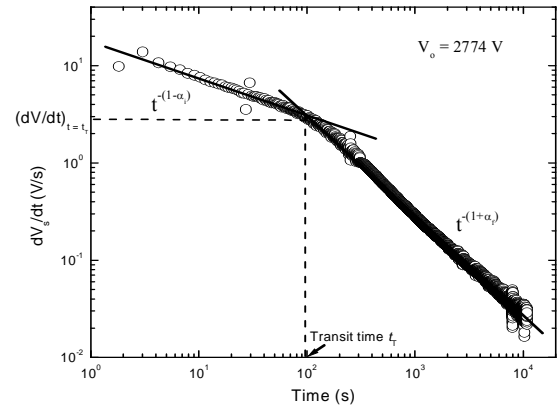


Fig. 3: dV_s/dt versus time, $V_0 = 2774\text{ V}$.

equations:

$$dV/dt = \begin{cases} \left(\frac{dV}{dt}\right)_{t=t_T} \left(\frac{t}{t_T}\right)^{-(1-\alpha_i)} & t < t_T \\ \left(\frac{dV}{dt}\right)_{t=t_T} \left(\frac{t}{t_T}\right)^{-(1+\alpha_f)} & t > t_T \end{cases} \quad (1)$$

where t_T is a characteristic time which corresponds to the carrier transit time through the bulk [10,11].

For clarity, the curve at $V_0 = 2770\text{ V}$ is shown in

Fig.3. Identical behavior is found for other initial potentials. This representation has shown an intersection of two straight lines with different slopes on either sides at mean transit time value. This behavior corresponds to charge injection mechanism

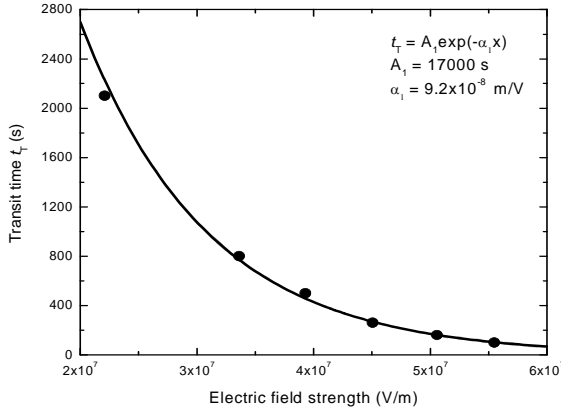


Fig. 4: Plot of the transit time t_T versus electric field strength.

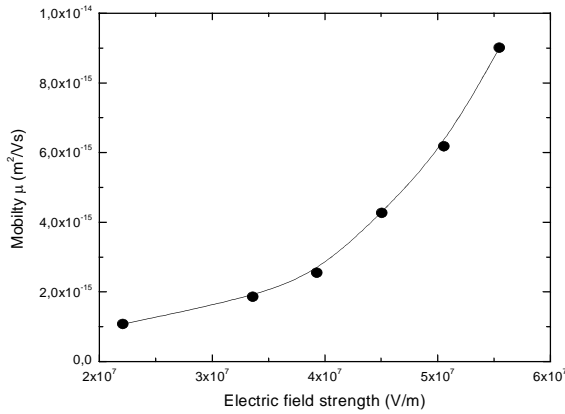


Fig. 5: Electric field dependence of the carrier mobility at 22°C.

explaining the SPD.

The values of transit time t_T , deduced from the SPD rate for different values of initial potential are plotted in Fig.4 as a function of electric field strength ($E_0 = V_0/L$).

The results show that as the electric field strength increases, the transit time decreases, indicating an inverse exponential dependence on the electric field strength, i.e., $t_T \sim \exp(-\alpha E)$, with $\alpha = 9.2 \times 10^{-8} \text{ m/V}$.

Decay rate curves dVs/dt allow to estimate the transit time of the charges and consequently the free carriers mobility. According to the theory of surface potential decay, the carrier mobility μ is given by:

$$\mu = \frac{L^2}{t_T V_0} \quad (2)$$

where V_0 is the initial surface potential, L the sample thickness and t_T is the transit time.

As it is shown in Fig.5, a strong field dependence of the carrier mobility is observed. Similar field dependent mobilities have been observed for other

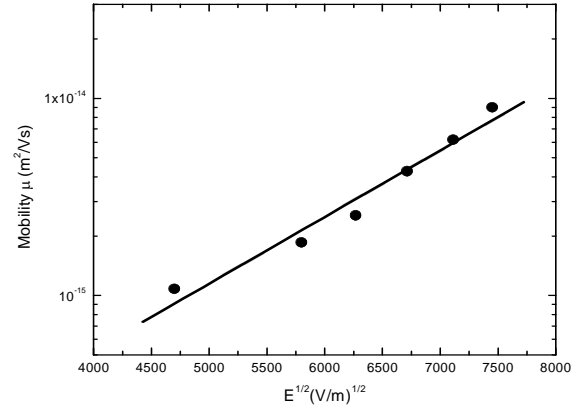


Fig. 6: Field dependent mobility: $\ln \mu - E^{1/2}$.

polymers [10]-[12] and the LDPE mobility values calculated in this work are in good agreement with that obtained in the literature [10] for the polyethylene.

We have analyzed two conduction models, leading to a field dependent mobility given by [12,13]:

(a) Poole Frenkel effect:

$$\mu(E) \sim \exp(\beta_{PF} E^{1/2} / kT) \quad (3)$$

$$\beta_{PF} = (q^3 / \pi \epsilon_r \epsilon_0)^{1/2} \quad (4)$$

(b) Field dependent hopping:

$$\mu(E) \sim \sinh(qE\lambda / 2kT) \sim \exp(qE\lambda / 2kT) \quad (5)$$

where β_{PF} is the Poole-Frenkel coefficient, k the Boltzmann's constant ($k = 1.38 \times 10^{-23} \text{ J.K}^{-1}$), T the absolute temperature, q the electron charge, ϵ_r the relative permittivity of LDPE, ϵ_0 the vacuum permittivity ($\epsilon_0 = 8.85 \times 10^{-12} \text{ F.m}^{-1}$) and λ the hopping distance.

The data of Fig.5 replotted in the form of $\ln \mu$ versus $E^{1/2}$ plot (Fig.6) show a linear behaviour with a slope of about $7.78 \times 10^{-4} (\text{V/m})^{-1/2}$. Using Eq. 4, a relative permittivity ϵ_r of about 14.67 for $T = 294 \text{ K}$ (22°C) has been found. This value is different from the accepted permittivity value in low-density

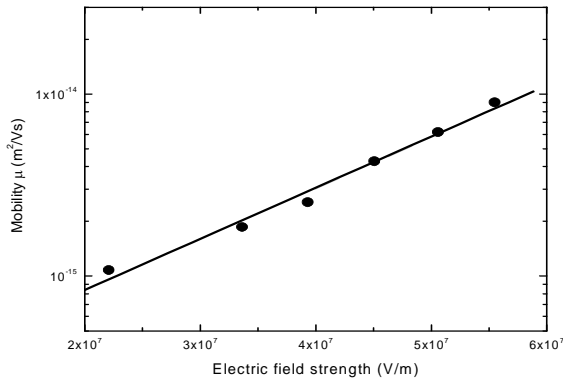


Fig. 7: Field dependent mobility: $\ln \mu$ -E.

polyethylene (LDPE) ($\epsilon_r = 2.2$ [7]). These observations suggest that the Poole-Frenkel effect is not a dominant conduction mechanism in LDPE. Other works achieved by Nath and al. [14] led to the same conclusion. The hopping plot $\ln \mu$ versus E of LDPE film (Fig.7) show a straight line with a slope of about 6.47×10^{-8} m/V. From this value of the experimental slope, we deduced a hopping distance λ of the 3.2 nm for a temperature of 294 K (22°C). This value is in agreement with that reported for PE [2,15] and gives a trap site concentration $N_t = (\lambda)^{-3}$ of about 3.10^{19} traps/cm³ in the same order of the deep trap concentration for crystalline-amorphous interfaces of HDPE [11] and LDPE [15] reported previously.

VI. Conclusion

The electrostatic discharge in low-density polyethylene (LDPE) films after negative corona charge deposition has been studied. Surface potential decay has been shown to depend mainly of the initial charging potential V_0 . The presence of the crossover phenomenon reveals that the bulk transport process dominates surface potential decay. On the basis of the surface potential decay measurements, the values of the carrier mobility were evaluated from the transit time. The electric field dependence mobility has been found to follow the $\exp(q\lambda E/2kT)$ law indicating that charges are transported by hopping of injected carriers between localized trapping centers. We estimated a distance between two traps of order of 3.2 nm and a density of traps of about 3.10^{19} traps/cm³.

V. References

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