

An optical technique to measure the induced mechanical strain by a dc electric field in thin organic insulating films

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Abstract-An optical noncontact measurement technique based on the tracking of successive positions of computerized markers has been developed which enables one to characterize the electric field induced strain response of the plane gold-metalized surfaces in thin organic insulating films. The test results demonstrate that the newly developed method is capable of detecting displacement of selected markers when the sample is subjected to the application of a dc high voltage. The field-induced mechanical strain measurements have been performed as a function of time and then analyzed with respect to the applied electric field. The observed strain levels varied from $\sim 10^{-3}$ to 10^{-2} . The differences consisted mainly in the duration of dc electric field, the loading protocols, the thickness and the morphology of tested samples. The analysis of the strain characteristics indicates that this novel measurement technique can indeed be used reliably for giving a clear concept of breakdown mechanisms and aging phenomena in a polymeric material.

I. Introduction

Due to many advantages of polymeric materials there is a constant effort to develop high performance based electro active polymer for electromechanical transducer applications, and to provide electrical insulation as a dielectric in manufacturing of capacitors. In these applications, the polymeric material behaviour under a dc electric field is of prime concern in the material selection. In previous works [1], the authors have shown that both the electrostriction and Maxwell stress effect "Coulomb force" contribute to the electromechanical response of the material. Currently, it still remains a great challenge to reliably determine the strain induced by a dc electric field in thin polymer films without any constraint imposition. The recent development of the image processing system demonstrated the high sensitivity of the captured numerical image of gold-metalized flat surface of the tested sample. The image reveals small, contrasting spots. These spots are identified with computerized marking. The displacement of spots when the sample is subjected to electric field allows us to measure in real time the electric field induced strain in thin polymeric samples based on the computer tracking of successive positions of the four markers. The results from software DEFTAC analysis indicates that the present device can indeed be used reliably for improving this measurement technique in order to characterize the electric field induced strain response in a polymeric material. Several measurements are reported and discussed in this paper.

II. Experimental method

A. Experimental apparatus and procedure

Figure 1 shows the schematic diagram of the experimental apparatus developed to conduct the electric field induced strain measurement by using an optical technique based on the tracking of successive position displacement of four computerized markers by DEFTAC software [2], associated with an optical system formed by an optical microscope connected to a charge coupled device (CCD) camera (resolution =768 pixels. 576 pixels with 256 gray levels) provided by MATROX -METEOR II, image processing card permitted the observation of the sample surface in reflected light. To guarantee a better electrode/polymer contact, the test samples were metalized by gold coating using a S150B plasma sputter coater. Electrodes of 20 mm diameter and 30 nm thickness were thus obtained on both sides. The prepared sample was placed between two external brass electrodes. The upper one, the negative, was constructed as a hollow cylinder of 12 mm diameter. This permitted the use of a flexible light source to illuminate the upper face of the sample. The lower electrode, the positive, was

connected to a high dc voltage source (HCN 35-20000; 20kV and 1.5mA limited current) with controllable output. The samples were placed between electrodes in the measuring cell, the electrodes were short-circuited a few hours before the testing in order to eliminate the initial charges existing on the sample faces before applying the electric field.

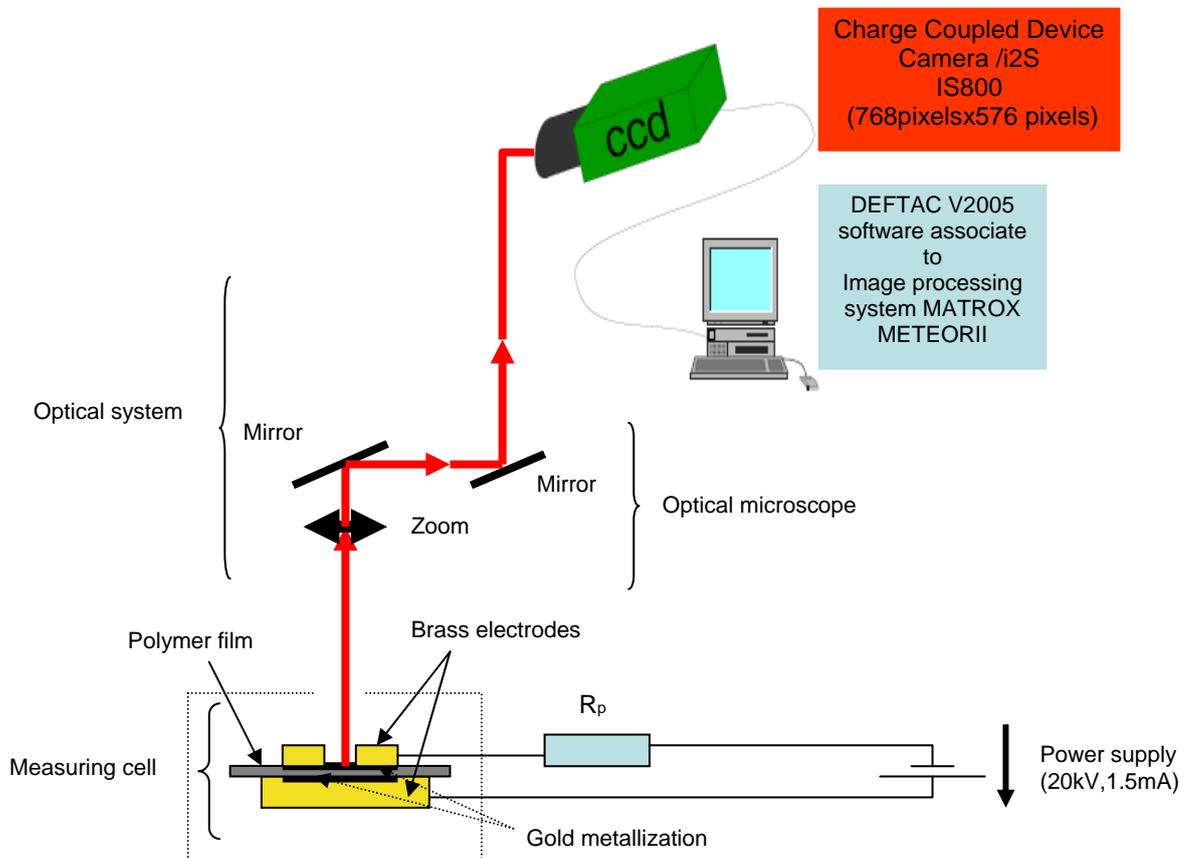


Figure 1. The schematic diagram of the experimental setup.

B. Experimental samples

Commercial PEN (Teonex TM) provided by Teijin DuPont Films (Luxembourg), in A4 sheet format, were employed for experiments. These polymer films were as-received Poly (Ethylene 2.6 Naphthalene dicarboxylate) PEN, amorphous, 70 μ m thick..

C. Strain measurement technique

We used for this study an original optical technique that allows to follow and quantify in real time the mechanical deformation induced by dc electric field on PEN thin films. Measurements were carried out under the room conditions and for very short durations, in order to minimize the influence of the environment. This technique is based on the tracking of four spots present on the surface of a gold metallized sample (Figure 2).

When a gradual step voltage is applied to the sample, the markers move, and a computerized tracking of the successive positions of the four markers permit us to quantify the induced deformation using Lagrangean formalism. A good description of this process is given in reference [3], in which the authors analyzed the contribution of principal components ϵ_1 and ϵ_2 on local sample surface presenting the main contributors of the strain that leading to the calculation of the equivalent induced deformation.

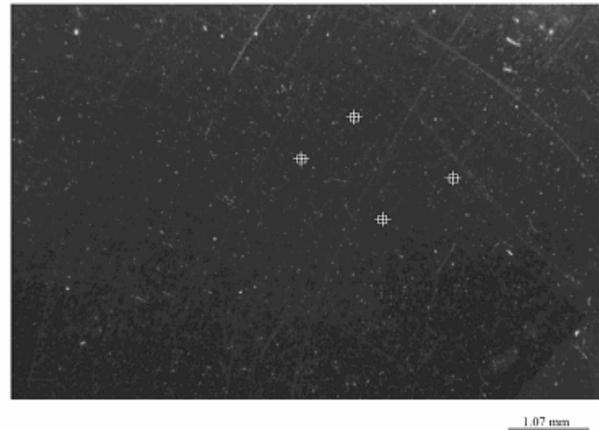


Figure 2. Configuration of four markers on the gold-metalized amorphous sample surface (average distance 1mm between markers).

III. Experimental results

In the present study we highlighted the optical observation of the PEN thin films surface for the analysis of induced strain under a high electric field. These deformations are due the presence of the induced electrical field strengths on the structure of the polymer under study. These forces are more important at higher electric fields. To quantify and analyze the level deformation resulting from applied high dc voltage, PEN films were subjected for periods of 200 seconds at gradually increasing 0.5 kV constant step of high applied voltage. The deformation of the film was recorded with constant CDD camera using a sampling rate (one image per two and half seconds). An attempt was made to compare the level and the evolution of field-induced mechanical deformation in the as-received amorphous and partially crystallized PEN samples in controllable degrees by using isothermal crystallization treatment (annealing temperature 160°C). This thermal analysis of samples was obtained by Differential Scanning Calorimetry [4]. The evolution of the equivalent induced strain ε_{eq} by the electric field shows three zones. Indeed, initially there is a region of very low deformation until an electrical field threshold is attained after which an increasing induced strain level is observed. Finally, there is a diminution of the strain that could be produced by a local densification of the material. This behavior suggests the presence of a thermally dominated mechanism attributed to the propagation of local breakdowns caused by large local fields in micro-voids. It is rather a mechanism of electrical aging having a mechanical origin. In order to explore the influence of crystallinity on the equivalent induced strain in treated films, the results given in Figure 3 reveal higher deformation levels in case of amorphous samples.

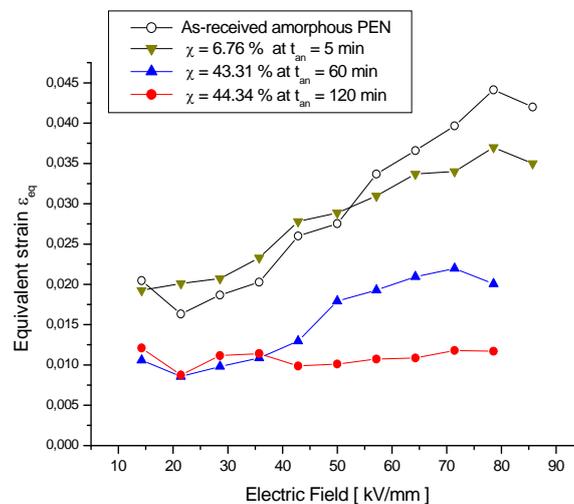


Figure 3. Influence of crystallinity percentage on the equivalent induced strain.

Furthermore; for annealing time up 45 min, the crystallinity degree is constant (about 42%). But the local strain observed for $t_{an} = 120$ min is lower compared to $t_{an} = 60$ min, at the high electric field range. This can be explained by a more ordered microstructure that has higher mechanical strength. This morphology increases the stiffness of the polymer, hence its mechanical properties.

II. Conclusions

In this experimental study, the assessment of the field-induced mechanical strain in PEN thin films with different degrees of crystallinity was investigated by using an original optical technique. The experimental results showed that samples with small crystallinity percentage were more vulnerable to the equivalent field-induced strain compared to semi-crystalline samples. This technique enables us to predict practical application behavior of solid insulating materials used under operating conditions involving electrical stress.

References

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