Polymer Bulletin 6, 109–111 (1981)

Polymer Bulletin

Measurement of Charge Distribution in Polymer Electrets by a New Pressure-Pulse Method

G.M. Sessler*, J.E. West and R. Gerhard*

Acoustics Research Department, Bell Telephone Laboratories, Murray Hill, NJ 07974, USA

Summary

The charge distribution in the thickness direction of 10 to 100 μm thick polymer electrets can be determined with a new method utilizing a <1 ns laser pulse to launch a pressure pulse in the sample. Propagation of the pressure pulse through the film causes electrode currents which yield the charge distribution. The method has been applied to electron-beam charged PETP and FEP samples.

Introduction

The pressure-pulse method for the investigation of charge-density distributions in thin dielectrics was first described by LAURENCEAU et al. in 1977. The method consists of the excitation of a short acoustic pulse in the sample through one of its surfaces. As the pulse propagates through the dielectric, a current or voltage response is generated across its electrodes. Evaluation of this response yields the charge or field distribution in the sample.

The first pressure-pulse experiments were performed with shock-tube excitation resulting in acoustic pulses with a relatively slow risetime in the order of 0.1 to 1 μs (LAURENCEAU et al. 1977; MIGLIORI and THOMPSON 1980). This corresponds to a spatial resolution of no better than 100 μm. Recently, a pressure-pulse experiment based on the excitation of an acoustic pulse by a quartz crystal was reported (EISENMENGER and HAARDT 1981). In this experiment a resolution of a few microns was achieved. The experimental setup is, however, quite complicated and extreme care must be taken to couple the acoustic pulse synchronously into the sample.

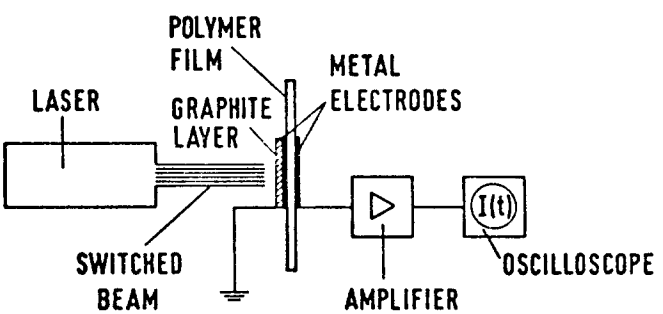

FIGURE 1. Experimental setup for pressure-pulse method

*Permanent address: T. H. Darmstadt, Merckstrasse 25, D-6100 Darmstadt

0170-0839/81/0006/0109/$01.00

Description of new pressure-pulse method

In the present paper, a new approach is described which allows to generate short pressure pulses which are coupled directly into the dielectric. One surface of a two-sided metalized polymer film was coated with a <5 µm graphite layer which was illuminated by a light pulse from a laser as shown in Fig. 1. The laser is an actively modelocked and Q-switched 1.064 µm Nd:YAG system (KUIZENGA 1981; STORZ 1981). Light pulses of 70 ps duration with a pulse energy of 100 mJ were used. The pulse heats the upper layer of the graphite coating to temperatures well above its boiling point and causes ablation of some of the graphite. The recoil due to this ablation launches the desired pressure pulse. After about 1 ns, diffusion of the light energy into the graphite layer causes a drop in the surface temperature such that ablation is terminated.

The pressure pulse of duration τ propagates through the sample with the velocity of sound c. Its length $c\tau$ is assumed to be small compared to all lengths describing changes in the charge distribution of the sample. Then, under short-circuit conditions, the electrode current I(t) generated by the pressure pulse is given by (MIGLIORI and THOMPSON 1980; SESSLER et al. 1982)

$$I(t) = -(2-\frac{1}{\varepsilon})\chi P c^2 \tau(A/s)\rho(x), \qquad (1)$$

where ε and χ are the dielectric constant and the compressibility of the sample, respectively, P is the pressure amplitude of the pulse, A and s are the electrode area and the sample thickness, respectively, and $\rho(x)$ is the charge density in the sample. The coordinate x is related to time t by x=ct.

Equation (1) indicates that the charge density in the dielectric can be determined directly from the current generated in the external circuit by the pressure pulse propagating through the dielectric. The charge distribution in one-sided metalized films can also be measured with this method if the samples are mounted in a sample holder that provides a second electrode.

Experimental results for PETP and FEP films

The polymer samples used in the present experiments were 75 µm thick two-sided metalized films of polyethylene terephthalate (Mylar PETP) and poly-fluoroethylenepropylene (Teflon FEP), both charged by means of a 55 keV monoenergetic electron beam. The experimental setup is shown schematically in Fig. 1. Phase inversion in the amplifier together with the negative sign in equation (1) results in positive signals for positive charge layers and vice versa.

The results, taken directly from the oscilloscope, are depicted in Fig. 2. The initial negative spike is always found (even in uncharged samples which show no other signals) and is probably caused by photoionization. The subsequent positive signals in Figs. 2a and b represent the positive induction charge on the front electrode. Uncharged regions and the negative electron-beam-deposited-charge zones follow. Finally, positive charge layers on or close to the rear electrode can be seen.

FIGURE 2. Observed current signals from two-sided metalized polymer films charged by injection of 55 keV electrons: a) 75 µm thick PETP, b) 75 µm thick FEP

After one transit the pressure pulse is reflected from the rear surface of the sample with phase and direction of propagation reversed. Therefore, the signals recorded after reflection of the pulse are of the same sign. The transit time of the pulse can be determined from the position of the center of the second positive peak and its distance from the first positive peak. Transit times of about 33 ns for PETP and about 60 ns for FEP correspond to sound velocities of 2.3 km/s in PETP (MOORE 1970) and 1.25 km/s in FEP. The present measurements show that the electron-beam generated charge penetrated about 27 μm into both samples which agrees approximately with earlier findings by GROSS et al. (1977) and SESSLER and WEST (1981).

There are, however, interesting differences between the PETP and the FEP sample. In PETP (Fig. 2a) the positive compensation charge is obviously confined to the vicinity of the rear electrode whereas the negative electron-beam-deposited charge is distributed between the positive charge and the maximum electron range. In FEP (Fig. 2b), however, the negative charge forms a rather thin layer at the expected centroid location and the positive charge extends from the rear electrode far into the sample. Further experiments are necessary in order to clarify these differences which might be explained in terms of different carrier mobilities and injection rates.

Conclusion

The method described in this paper permits a non-destructive determination of space-charge distributions in thin polymer films. From the original pressure-pulse duration of about 1 ns resolutions of about 2.5 μm in PETP and 1.5 μm in FEP should be possible. Furthermore, the sound velocity in the thickness direction of polymer films and the sound attenuation in these materials can be measured. A more detailed study of the present method as well as results for thinner samples and for corona-charged samples will be reported in a forthcoming publication.

Acknowledgements

The experiments were carried out using the high-energy laser facility of the Electronics Research Laboratory at Bell Laboratories, Holmdel, New Jersey. The authors are grateful to Drs. C. G. Bethea, J. E. Bjorkholm, H. Kogelnik, E. D. Shaw, R. H. Storz and H. von Seggern for stimulating discussions and to R. Kubli for sample preparation. One of the authors (R. G.) is indebted to the Deutsche Forschungsgemeinschaft for a travel grant.

References

EISENMENGER, W. and HAARDT, M.: Solid State Commun., in print (1981)
GROSS, B., SESSLER, G. M. and WEST, J. E.: J. Appl. Phys. 48, 4303 (1977)
KUIZENGA, D. J.: IEEE J. Quant. Electr. QE-17, 1964 (1981)
LAURENCEAU, P., DREYFUS, G. and LEWINER, J.: Phys. Rev. Lett. 38, 46(1977)
MIGLIORI, A. and THOMPSON, J. D.: J. Appl. Phys. 51, 479 (1980)
MOORE, R. S.: Sound Absorption, in Encyclopedia of Polymer Science and Technology 12, 700, New York, London, Sydney, Toronto: John Wiley & Son 1970
SESSLER, G. M. and WEST, J. E.: 1981 Annual Report Conf. on Electrical Insulation and Dielectric Phenomena, 145, Piscataway: IEEE 1981
SESSLER, G. M., WEST, J. E. and GERHARD, R.: to be published (1982)
STORZ, R. H.: Laser Focus 17, 65 (1981)

Received November 11, accepted November 12, 1981