ratio of intensities does not correspond to a division according to the statistical distribution of nearest neighbors. This led Bauminger *et al.*[6] to the phenomenological picture of a wide $4f$ level with both natural (homogeneous) and inhomogeneous broadening, which intersects the Fermi level and thus contributes to a pure divalent component even at 0 K. Since a natural broad level implies fast charge fluctuations (so that only an average line should be observed), we conclude that in the case of $EuRh_{2-x}Pt_x$ the width of the $4f$ level is an inhomogeneous width due to second- and further-neighbor effects which determine whether the Eu will be divalent or trivalent.

In conclusion we point out that XPS studies of Eu intermediate valence systems combined with other techniques, in particular the Mössbauer effect, may clarify many details of the mixed-valence phenomenon. In the case of $EuRh_2$, a single number $[p_2(300\text{ K})]$ obtained from the XPS spectrum was sufficient to lead to the deduction of the interconfiguration excitation energy and the charge fluctuation time $(0.6 \pm 0.1) \times 10^{-14}$ sec, which agrees with all theoretical expectations and recent neutron-diffraction results.[12]

We would like to thank I. Felner of the Hebrew University for supplying us with the $EuRh_{2-x}Pt_x$ samples and D. N. E. Buchanan for very valuable technical assistance.

*On leave from the Hebrew University, Jerusalem.

[1]See the review by D. K. Wohlleben and B. R. Coles, in *Magnetism*, edited by H. Suhl (Academic, New York, 1973), Vol. V.

[2]C. T. E. Goncalves da Silva and L. M. Falicov, Phys. Rev. B 13, 3948 (1976).

[3]See the review by M. Campagna, G. K. Wertheim, and E. Bucher, *Structure and Bonding* (Springer, Berlin, 1976), Vol. 30, p. 99.

[4]R. L. Cohen, M. Eibschutz, and K. W. West, Phys. Rev. Lett. 24, 382 (1970).

[5]J. M. D. Coey, S. G. Ghatak, and F. Holtzberg, in *Magnetism and Magnetic Materials—1974*, AIP Conference Proceedings No. 24, edited by G. D. Graham, G. H. Lander, and J. J. Rhyne (American Institute of Physics, New York, 1975), p. 38; J. M. D. Coey, S. G. Ghatak, M. Avignon, and F. Holtzberg, Phys. Rev. B 14, 3744 (1976).

[6]See the review by E. R. Bauminger, I. Felner, D. Froindlich, D. Levron, I. Nowik, S. Ofer, and R. Yanovsky, J. Phys. (Paris), Colloq. 35, C6-61 (1974); E. R. Bauminger, D. Froindlich, I. Nowik, S. Ofer, I. Felner, and I. Mayer, Phys. Rev. Lett. 30, 1053 (1973); E. R. Bauminger, I. Felner, D. Levron, I. Nowik, and S. Ofer, Phys. Rev. Lett. 33, 890 (1974).

[7]E. R. Bauminger, I. Felner, D. Levron, I. Nowik, and S. Ofer, Solid State Commun. 18, 1073 (1976).

[8]S. P. Kowalczyk, N. Edelstein, F. R. McFeeley, L. Ley, and D. A. Shirley, Chem. Phys. Lett. 29, 491 (1974).

[9]J. N. Chazalviel, M. Campagna, G. K. Wertheim, and P. H. Schmidt, Solid State Commun. 19, 725 (1976), and Phys. Rev. B 14, 4586 (1976).

[10]I. R. Harris and G. Longworth, J. Less Common Met. 23, 281 (1974).

[11]J. Rohler, H. Balster, and G. Kaindl, in Proceedings of the International Conference on Applications of the Mössbauer Effect, Corfu, Greece, September 1976 [J. Phys. (Paris), to be published].

[12]R. J. Birgeneau, private communication.

New Principle for the Determination of Potential Distributions in Dielectrics

P. Laurençeau, G. Dreyfus, and J. Lewiner

Laboratoire d'Electricité Générale, Ecole Supérieure de Physique et de Chimie, 75005 Paris, France

(Received 17 June 1976; revised manuscript received 30 November 1976)

In this paper we describe the principles of a new, nondestructive method of determination of the potential distribution in delectrics. It is shown that a pressure discontinuity propagated in a sample acts as a virtual probe sensitive to potentials. The time dependence of such externally measurable parameters as voltages or charges on the electrodes is thus a direct image of the inner potential distribution which existed in the sample before the introduction of the perturbation.

During the last few years many efforts have been devoted to the determination of charge, potential, or field distributions in condensed matter. In a plasma or in a liquid, such a determination can be easily done using moving probes. In solids, this information, which can be highly valuable in the analysis of the polarization processes, space-charge build up, and transport phenomena, is so far obtainable in some limited cases only: either by the combination of standard surface-charge measurements and thermally stimulated currents,[1-3] or by successive surface-charge measurements or progressively thinned samples[4,5] or by spectroscopic methods.[6] These first two techniques have the disadvantage of being destructive. The latter ones are applicable to transparent materials only. Recently Collins has proposed[7] a new method based on the nonhomogeneous deformation of a sample produced by local heating. However this method, which requires a deconvolution technique in order to derive the charge distribution from the measured parameter, does not yield a unique solution.

In the present paper we describe the principle of a new, nondestructive method of determination of the potential distribution in a solid. We consider, as shown in Fig. 1, a dielectric plate of thickness d, area S, and infinite-frequency dielectric constant ϵ, with electrodes a and b in contact with the sample. We assume that there is in the sample a potential distribution $V(z)$ produced by a charge density $\rho(z)$ and that all variables are constant at constant z; with electrode a grounded, and electrode b at a potential V, the charge densities σ_a and σ_b have been calculated[8]:

$$\sigma_a = -\frac{d-\langle z\rangle}{d}\frac{Q}{S} - \epsilon\frac{V}{d}, \quad \sigma_b = \frac{\langle z\rangle}{d}\frac{Q}{S} + \epsilon\frac{V}{D},$$

where

$$\langle z\rangle = \frac{\int_0^d z\rho(z)\,dz}{\int_0^d \rho(z)\,dz}, \quad \frac{Q}{S} = \int_0^d \rho(z)\,dz.$$

It can be seen from these expressions that if $V = 0$ and if the sample is not piezoelectric, a uniform deformation along the z axis does not alter the charges on the electrodes since $(d - \langle z\rangle)/d$ is constant. This implies that in order to obtain the potential or charge profiles, a nonhomogeneous deformation must be used. For this reason we consider a step-function compressional wave propagated in the sample at velocity v, from electrode b toward electrode a which is supposed fixed. As long as the wave front has not reached electrode a, the right part of the sample is compressed while the left part is unaffected, as is shown in Fig. 1. The charge induced on electrode b is a function of the charge profile, of the position of the wave front in the sample, but also of the boundary conditions at the electrodes: open-circuit or short-circuit conditions. In the first case the observable parameter is the voltage, in the second case the external current.

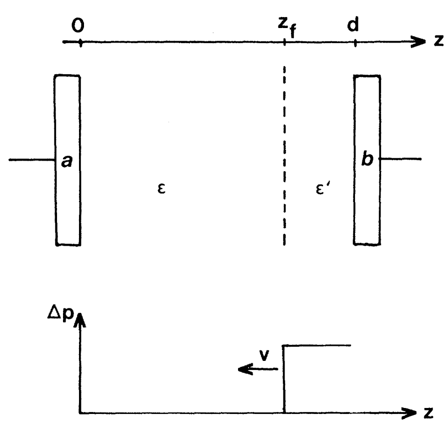

FIG. 1. Charge dielectrics between two electrodes, divided into a compressed region of permittivity ϵ' and an uncompressed region of permittivity ϵ; the step-function compression travels from right to left at the velocity of sound.

We call d_0 the unperturbed thickness of the sample, Δp the magnitude of the pressure excess in the compressed region, χ the compressibility (defined as $\chi = -V^{-1}\Delta V/\Delta p$), ϵ' the dielectric constant of the compressed part of the sample, and z_f the position of the wave front, which can be expressed as $z_f = d_0 - vt$. In the compressed region, the charges, supposed to be bound to the lattice, are shifted towards the left by a quantity $u(z,t) = -\chi\Delta p(z - z_f)$, while in the uncompressed part the charges remain at their original position. Let z be the abscissa of a plane which is motionless relative to the particles of the solid: When this plane lies in the compressed region $z > z_f$) it moves to the left with a velocity $-\chi\Delta p v$; if it is in the uncompressed region it does not move. The conservation of charge and Gauss's law imply the following relation:

$$\frac{d}{dt}D(z,t) = \frac{d}{dt}D(0,t) = \frac{J(t)}{S}, \tag{1}$$

where $D(z,t)$ is the electrical displacement, which is a continuous function of z throughout the sample, and $J(t)$ is the current flowing in the external circuit. We can now express the boundary conditions:

$$V(d,t) - V(0,t) = -\int_0^d E(z,t)\,dz, \tag{2}$$

where d is the thickness of the sample at time t: $d = d_0 - \chi\Delta p v t$. The integral on the right-hand side of relation (2) may be split into two terms, one related to the uncompressed part $(0 < z < z_f)$ and the other one related to the compressed part $(z_f < z < d)$:

$$\int_0^d E(z,t)\,dz = \int_0^{z_f} E(z,t)dz + \int_{z_f}^d E'(z,t)\,dz.$$

It can be noted that we have kept the notations $E(z,t)$ for the electric field in the uncompressed region and used $E'(z,t)$ in the compressed region. These fields can be related at the interface between these two regions, that is to say at $z=z_f$, by $\epsilon E(z_f,t)=\epsilon' E'(z_f,t)$.

In the first term, the only time-dependent variable is z_f, while in the second term z_f, d, and z are time dependent. However, the quantity $w=d-z$ is independant of time since electrode b and the z plane both move to the left with velocity $-\chi\Delta p v$. One has

$$\int_{z_f}^{d} E'(z,t)\,dz=\int_0^{d-z_f} E'(d-w,t)\,dw.$$

With this choice of variables, we can now differentiate relation (2) relative to time. Using relation (1), Leibniz's differentiation theorem, and the continuity of the electric displacement at the front, one obtains

$$\frac{d}{dt}\Big[V(d,t)-V(0,t)\Big]=vE(z_f,t)\Big[1+\frac{\epsilon}{\epsilon'}\Big(\chi\Delta p-1\Big)\Big]-\Big(\frac{z_f}{\epsilon}+\frac{d-z_f}{\epsilon'}\Big)\frac{J(t)}{S}. \quad (3)$$

This relation describes the evolution of the system during the propagation of the pressure wave. It holds for any type of boundary conditions. We shall examine the solutions of this equation for two particular cases, namely the open-circuit and short-circuit conditions.

(a) *Open-circuit conditions.*—We are interested in the voltage developed across electrodes a and b when the external current is zero. Equation (3) then reduces to

$$\frac{d}{dt}\Big[V(d,t)-V(0,t)\Big]=vE(z_f,t)\Big[1+\frac{\epsilon}{\epsilon'}\Big(\chi\Delta p-1\Big)\Big]. \quad (4)$$

Since the charges in the uncompressed region are not altered until they are reached by the wave front, one has

$$E(z_f,t)=E(z_f,0).$$

Consequently relation (4) may be integrated to

$$V(d,t)-V(0,t)=V(d,0)-V(0,0)+v\Big[1+\frac{\epsilon}{\epsilon'}(\chi\Delta p-1)\Big]\int_0^t E(z_f(\tau),0)\,d\tau.$$

Since $z_f(\tau)=d_0-v\tau$, the last integral can be written as

$$\int_0^t E(z_f(\tau),0)\,d\tau=v^{-1}[z_f,0)-V(d_0,0)]. \quad (5)$$

Consequently, assuming that initially both electrodes are at the same potential and that electrode a remains grounded, $V(0,t)=0$. One has

$$V(d,t)=[1+(\epsilon/\epsilon')(\chi\Delta p-1)]\,V(z_f,0). \quad (6)$$

This expression shows that the time dependence of the potential difference across the sample during the propagation of the compressional wave is an image of the spatial distribution of the potentials inside the sample prior to the perturbation. The front of the compressional wave acts as a virtual moving probe swept across the sample at the velocity of sound.

(b) *Short-circuit conditions.*—The potential difference across electrodes a and b is now kept constant and equal to zero, which means that charges will flow in the external circuit. The total charge $q(t)$ displaced after a time t following the beginning of the propagation of the compression is

$$q(t)=\int_0^t J(\tau)\,d\tau.$$

Equation (3) can be written as

$$vE(z_f,t)\Big[1+\frac{\epsilon}{\epsilon'}(\chi\Delta p-1)\Big]-\Big(\frac{z_f}{\epsilon}+\frac{d-z_f}{\epsilon'}\Big)\frac{J(t)}{S}=0. \quad (7)$$

Here, because charge is transferred in the external circuit, one has

$$E(z_f,t)=E(z_f,0)+(\epsilon S)^{-1}\int_0^t J(\tau)\,d\tau.$$

Substituting this expression in relation (7), integrating over time using Eq. (5), and supposing that electrode b is grounded, one has

$$\frac{1}{S}\int_0^t J(\tau)\,d\tau = \epsilon\,\frac{1+(\epsilon/\epsilon')(\chi\Delta p - 1)}{z_f + (\epsilon/\epsilon')(d - z_f)}\,V(z_f, 0). \quad (8)$$

This expression shows that the time dependence of the displaced charge in the external circuit is also an image of the spatial distribution of the potentials inside the sample.

A rough preliminary experiment[9] showed qualitatively that the method works. Shock waves[10] were used to produce a compressional step function that was propagated in a previously charged, 1-mm-thick, polyethylene plate, and measurement was taken in the short-circuit current mode. The signal observed had the shape expected for a corona-injected charge, reversed polarity when charges of opposite sign were injected, and was strongly reduced when the sample was thermally discharged.

Further, more quantitative, experiments are underway. Two kinds of difficulties are to be overcome. First, a high-precision shock tube has to be built in order to insure good parallelism between the sample and the wave front. Second, taking into account the fact that for a sound velocity in the sample of the order of 2000 m/s, a spatial resolution of 10 μm implies a time resolution of 5 ns, the bandwidth of the amplifier and of the storage unit must be broader than 200 MHz; such systems are now commercially available.

In this paper we have presented a new principle for the determination of the potential distribution in dielectrics. We have shown that during the propagation of a step-function compressional wave in a sample, the front of the wave acts as a moving probe, traveling at constant velocity through the sample. The time dependences of such externally measurable parameters as voltages (in open-circuit condition) or charges (in short-circuit conditions) are thus direct images of the potential distribution existing in the sample before the application of the perturbation; from this distribution any other internal parameter such as charge densities or fields can be readily derived.

Publication of the paper at this early stage in the experiments was deemed to be valuable to those interested in applying a relatively simple, direct, nondestructive method to determine potential distributions.

The authors are greatly indebted to Professor M. M. Perlman for his very helpful comments on the manuscript of this paper.

[1]G. M. Sessler and J. E. West, Annu. Rep. Conf. Elec. Insul. Dielectr. Phenom. 39, 8 (1970); G. M. Sessler, J. Appl. Phys. 43, 408 (1972).

[2]R. A. Creswell, M. M. Perlman, and M. Kabayama, in *Dielectric Properties of Polymers*, edited by F. E. Karasz (Plenum, New York, 1972), p. 215.

[3]J. Van Turnhout, *Thermally Stimulated Discharge of Polymer Electrets* (Elsevier, Amsterdam, 1975), p. 109.

[4]D. K. Walker and O. Jefimenko, in *Electrets, Charge Storage and Transport in Dielectrics*, edited by M. M. Perlman (Electrochemical Society, Princeton, N. J., 1973), p. 455.

[5]J. Perret, Bull. Dir. Et. Rech. B 2, 27 (1974).

[6]S. J. Sheng and D. M. Hanson, J. Appl. Phys. 45, 4954 (1974).

[7]R. E. Collins, Appl. Phys. Lett. 26, 675 (1975).

[8]G. Dreyfus and J. Lewiner, Phys. Rev. B 8, 3032 (1973).

[9]P. Laurençeau, J. Ball, G. Dreyfus, and J. Lewiner, C. R. Acad. Sci., Ser. B 283, 135 (1976).

[10]See, for instance, R. W. B. Stephens and A. E. Bates, *Acoustics and Vibrational Physics* (Edward Arnold Publishers, London, 1966), p. 495.