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SPACE CHARGE INFLUENCE ON THE RESULTS OF VOLUME RESISTIVITY MEASUREMENTS IN SOLID DIELECTRICS

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Abstract - The problems associated with measurements and determination of volume resistivity were presented in the paper. Special attention was paid to the measurements carried out on extremely high resistivity materials. Space charge influence was discussed as the most important factor affecting the uncertainty of results of the resistivity measurements.

Keywords: dielectrics, volume resistivity, space charge.

1. INTRODUCTION

Volume resistivity of solid dielectrics is usually measured for the samples placed between conducting electrodes. Results of measurements are calculated from the resistances and sample dimensions [1÷7]. The resistance is usually measured by indirect method – by the measurement of volume current flowing through the sample under the known voltage U_p applied across the electrodes.

The applied dc voltage U_p causes flowing through the sample of the absorption current I_a , asymptotically decreasing with time to the steady state value I_s – Fig.1.

Decreasing of the current I_a results from the relaxation processes appearing in the particular sample material e.g. relaxation polarisation [8,9]. For materials with volume resistivity ρ_v below $10^{10} \Omega\text{m}$ the current I_a reaches its steady state usually for time shorter than 60 s since the beginning of polarisation. For materials with higher resistivities the current I_a may decrease within the following minutes, hours, days and even years. It was observed, that the current decay characteristics do not depend on the sample material only, but also, especially for materials with extremely high resistivities, on the electrical charge stored in the sample before the measurement.

According to the definition volume resistance is the ratio of the voltage applied across the sample and the steady state volume current value I_s (neglecting surface currents). In case of materials with extremely high resistivities (for which a steady state value I_s may be reached after very long time) the resistivity is determined from the ratio of applied voltage and the transient current value $I_a(t)$ read for the particular time t . For such materials volume resistivity is usually given in the form

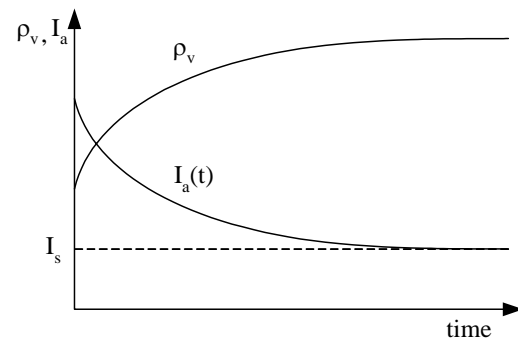


Fig. 1. Time dependencies of the absorption current $I_a(t)$ and volume resistivity $\rho_v(t)$ for the sample of solid dielectric.

of $\rho_v(t)$ characteristics. For comparison and according to the requirements of appropriate standards [1-3], the 1-minute resistivity, determined from the current value $I_a(t)$ measured after 1 min since the beginning of polarisation, is also given.

2. SPACE CHARGE INFLUENCE

Results of the resistivity measurements may be burdened with considerable uncertainty because of many components depending on the investigated object as well as on applied measuring method and devices.

The results may be also strongly influenced by the space charge stored in the sample before the measurement. The charge stored in the sample can be acquired while the sample is processed or e.g. from the earlier stages of the measurement procedure (as a „memorised” charge). The stored charge changes electric field distribution in the sample, as well as density of the absorption current, and finally influences results of the resistivity measurements. The value of the space charge stored in the sample may be characterised by an equivalent voltage U_z . Voltage U_z is produced by the charge stored in the unit volume of the sample on its unit capacitance. The phenomenon is generally present in polymers, especially in materials with extremely high volume resistivity e.g. polytetrafluoroethylene (PTFE), polyethylene terephthalate (PET) etc, as it was shown in the Fig-2 and 3, respectively.

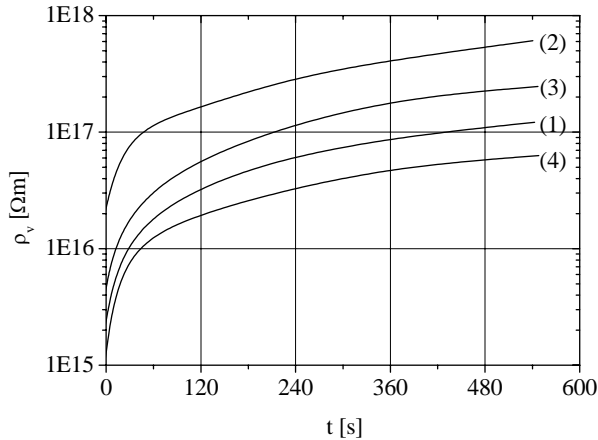


Fig. 2. The volume resistivity ρ_V for PTFE sample, measured for polarising voltage $U_p=+1000$ V:

- (1) – without charge, (2) – charged negatively, $U_e = -300$ V,
- (3) – $U_e = -790$ V, (4) – charged positively, $U_e = +400$ V

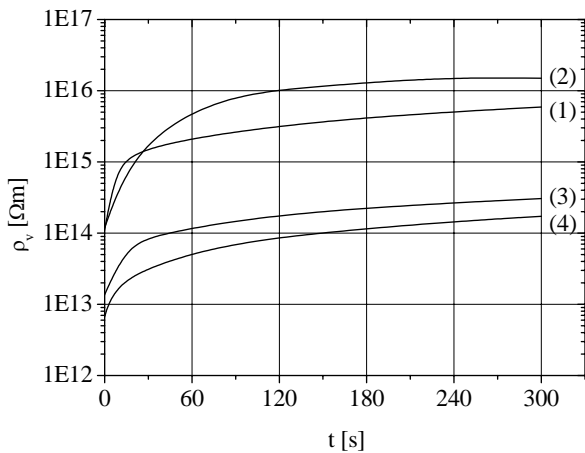


Fig. 3. The volume resistivity ρ_V for PET sample, measured for polarising voltage $U_p=+100$ V: (1) – without charge, (2) – charged negatively, $U_e = -67$ V, (3) – $U_e = +139$ V, (4) – charged positively, $U_e = +411$ V

PTFE and PET samples were prepared from the 500 μm thick Tarflen SM® and 100 μm thick Estrofol ET® foils, respectively.

The charge was injected into the sample before the resistivity measurement by application of corona discharge. The introduced charge was characterised by the sign and value of the equivalent voltage U_e . Resistivities measured for the samples with introduced negative ($U_e < 0$) and positive charge ($U_e > 0$) were respectively higher and lower in comparison to the resistivity of the sample without the charge ($U_e = 0$).

3. SAMPLE DISCHARGING

Discharging the sample before the measurement may diminish space charge influence on the results of resistivity measurements. The standard IEC 93:1980 suggests to short-

circuit the electrodes of the sample through the current meter until the moment when the measured resorption current reaches its steady-state value small (usually $1/10^{\text{th}}$) in comparison to the expected steady state absorption current value. However, for materials with extremely high resistivities (e.g. PTFE) the depolarisation process may last for very long periods of time and for high values of a stored charge the process does not give the satisfactory results. The depolarisation problem may be characterised by resorption current characteristic as it was shown in case of PTFE sample in the Fig.4. The sample was equipped with silver electrodes and was kept in open state before the measurements.

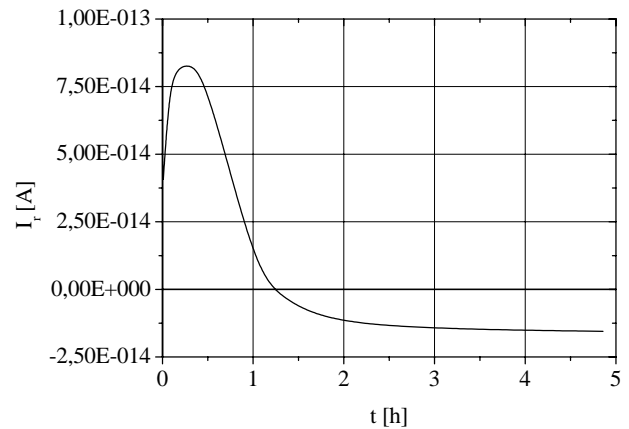


Fig. 4. Time dependence of resorption current for PTFE sample.

The resorption current changes with time, decreasing to zero after 75 min. For long periods of time the current changes its sign and reaches the negative values. It was found that the discharging procedure, repeated 5 times on the same sample in room temperature did not discharge the sample totally. In case of such materials depolarisation of the sample can be carried out by short-circuiting of the electrodes of the sample maintained in elevated temperatures. Such procedure applied to the PTFE sample, short-circuited in 250°C within 120 min allows to reach the resorption current on the level of 10^{-15} A (incomparable with the expected value of absorption current). However, such a procedure is very time-consuming and additionally can influence the structure and electrical properties of the investigated material.

4. METHOD INCLUDING PERIODICAL POLARITY CHANGES OF POLARISING VOLTAGE

Assuming the time stability of the charge stored in the sample as well as the equivalent potential U_e , the last could be eliminated by two-step measurements of the resistivities, carried out for the same value but for different polarities of the measuring-polarising voltage - U_p [9]. The calculated average value of the resistivity should give its true value.

KEITHLEY INSTRUMENTS has proposed a procedure of the resistivity measurements including periodical polarity changing of the polarising voltage. The procedure includes

multiple measurements of absorption current for periodically changed polarity of polarising voltage. The *Keithley 6517 Hi-R Test* software [6,10] was prepared for realisation of the procedure proposed. Results of such measurements carried out on the totally discharged sample of PET foil were shown in the Fig.5. Within the procedure controlled by *Keithley 6517 Hi-R Test* software, the values of absorption currents for the moments of polarity changing of polarisation voltage U_p are “memorised” and the weighted average value for the last four read-outs is calculated according to the expression [6,10]:

$$I_{aa} = \frac{I_1 + 3(-I_2) + 3(I_3) + (-I_4)}{8} \quad (1)$$

The value I_{aa} is the base for the calculation of the value of measured volume resistance.

However, the space charge may be introduced into the investigated sample within the first step of its polarisation. The phenomenon was illustrated in the Fig.6. showing time dependencies of absorption currents $I_a(t)$, collected for the four following cycles of measurements. The first measurement was carried out on a “virgin” sample (without the charge) and one can expect that in this case $I_a(t)$ values can be used for the calculations of the true values of measured resistance.

After changing polarity of the polarising voltage (according to the mentioned procedure), the charge collected in the sample within the second step will be affected by that introduced in the first one. It is worth to emphasise the visible difference in shape of the first and the following characteristics. Moreover, the mentioned phenomenon appears also for relatively low values of polarising voltage U_p . The obtained results clearly point, that the procedure applied to the resistance calculation according to the *Keithley 6517 Hi-R Test* software may led to serious differences between the true and calculated values of the measured resistance.

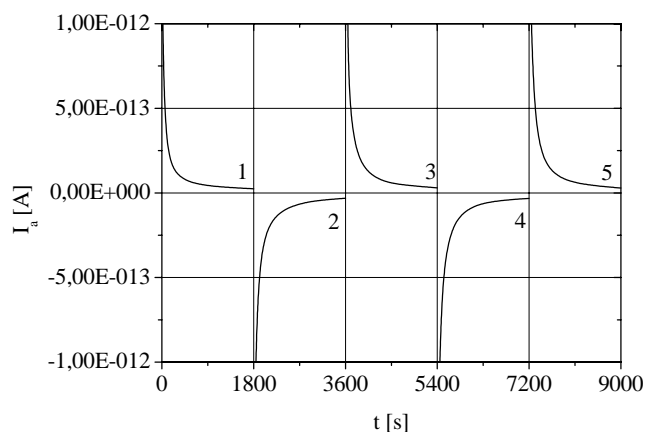


Fig. 5. Time dependencies of absorption currents for PET samples (100 μm thick Estrofol ET® foil) obtained by application of *Keithley 6517 Hi-R Test* software. Polarising voltage $U_p = \pm 100V$

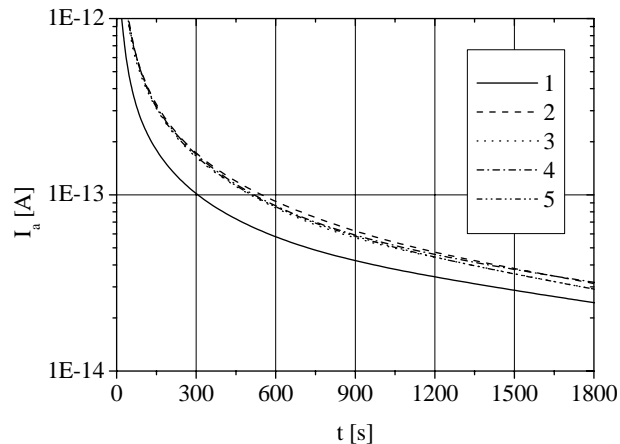


Fig. 6. Absorption current-time characteristics $I_a(t)$, obtained for the PET foil sample (100 μm thick Estrofol ET® foil), - the five following steps. Polarisation voltage $U_p = \pm 100V$

5. THE PROPOSED ALTERNATIVE METHOD (INCLUDING PERIODICAL POLARITY CHANGES OF POLARISING VOLTAGE)

Because of problem illustrated in the Fig.6. the authors suggest some modification of the measurement procedure determined by the *Keithley 6517 Hi-R Test* software. It is proposed to discharge the sample after each period of polarisation with the measuring of resorption current. The described procedure should run accordingly to the example shown in the Fig.7. Time dependencies of absorption current obtained for the proposed procedure were collected in the Fig.8.

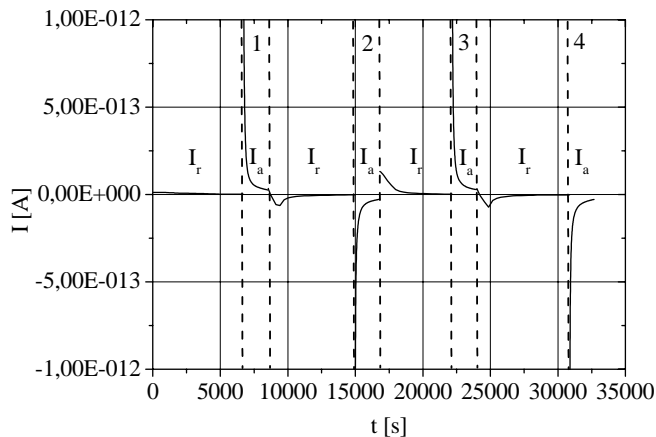


Fig. 7. Time dependencies of absorption and resorption currents obtained for PET samples (100 μm thick Estrofol ET® foil) according to the proposed procedure. Polarisation voltage $U_p = \pm 100V$

It is clearly visible, that all the $I_a(t)$ characteristics run practically in the same way. Therefore, such a procedure allows to find the averaged $I_a(t)$ characteristic and to calculate the true value of absorption current by application of relation (1) for the required time t . Absorption current value obtained in the procedure described above may be used for the determination of the true value of measured volume resistance and finally the resistivity $\rho_v(t)$.

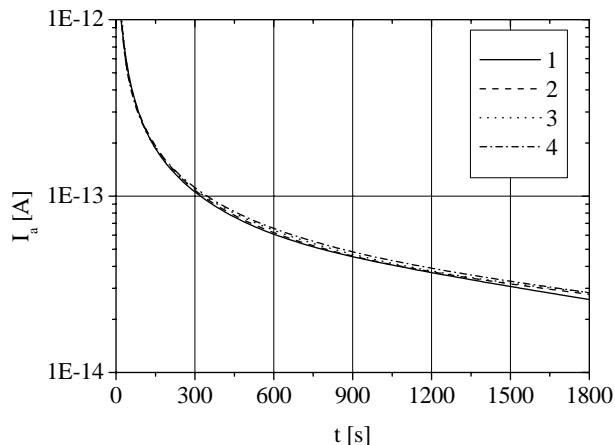


Fig. 8. Absorption current-time characteristics $I_a(t)$, obtained for the PET sample (100 μm thick Estrofol ET[®] foil) according to the proposed procedure - four following steps. Polarisation voltage $U_p = \pm 100\text{V}$.

6. CONCLUSION

The charge stored in the sample may strongly influence the result of resistance measurements. The sample should be completely discharged before the measurement. Application of the known procedure including periodical polarity changing does not allow to eliminate the charge influence on the results of measurements because the charge can be introduced within the first step of the applied procedure. The most representative results for the absorption current can be obtained for the completely discharged sample within the first step of the procedure.

Application of the procedure containing sample discharging process, following each step of the polarisation procedure, should allow to eliminate influence of the charge stored in the sample on the value of measured absorption current and finally on the calculated resistivity $\rho_v(t)$.

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