Colloid & Polymer Science Colloid Polym Sci 272:885–893 (1994)

Original Contributions

Capacitance switching effect in one-component electrographic developer

P. Mačkus, A. Poškus, and K. Lipskis

Vilnius University, Department of Solid State Electronics, Vilnius, Lithuania

Abstract: Step-wise capacitance increase with voltage (C-switching) effect has been experimentally and theoretically investigated in the case of one-component electrographic developer powder pressed in tablet-shape samples. Peculiarities of capacitance (current)-voltage characteristics as well as frequency dependences of components of complex dielectric constant indicate that C-switching effect is related to the extent of ferromagnetic carrier capsulation by polymeric compound. The application possibilities of the C-switching effect have been proposed.

Key words: Capacitance switching – dielectric properties – polystyrene composites

1. Introduction

The utilization of one-component developer (OCD) has become the next step in the advancement of a latent image visualization process in electrography. The grain of ferromagnetic material which is incorporated in the bulk of such developer's particle serves as a carrier. As it is clear from principles of electrographic development process, advantages of OCD as compared to a two-component developer must be associated with the extent of ferromagnetic carrier (FC) capsulation by a polymeric compound [1].

There are two main technological methods of the one-component developer production [2]:

i) FC is directly fully capsulated during the developer production process,

ii) mixing of developer components, melting, cooling, and subsequent crushing of the compound to the proper powder.

It is obvious that in the ii)-case full FC-capsulation is quite problematic. Besides affecting the quality of OCD, different extent of ferromagnetic carrier capsulation causes some physical effects in a system composed from particles of developer mentioned. We had investigated one of them, i.e., capacitance switching effect which is related to the FC-capsulation extent. Obtained data which indicate the application use are presented in this paper.

2. Experimental

The main components of investigated OCD were the following: polystyrene, carbon black, and ferromagnetic mineral which was mainly composed of Fe and its compounds (29% of Fe was in FeO). Let us name the latter component magnetite. Particles of crushed magnetite crystals were mainly of cubic shape; their size ranged from 0.5 to 2.0 μm while diameter of one-component developer powder particles was about 10 μm. The one-component developer powder was prepared by ii)-method (see Section 1).

Cylindric samples for investigation were prepared by pressing powders of one-component electrographic developer and of its main components in the specially constructed cell. The pressing pressure value was chosen on the basis of the following consideration. A defined volume of OCD powder comprises a two-phase heterogeneous system composed of powder particles and of surrounding air. Therefore, by sealing of this volume it is possible to exclude the air-phase and, as a consequence, to obtain the one-phase powder

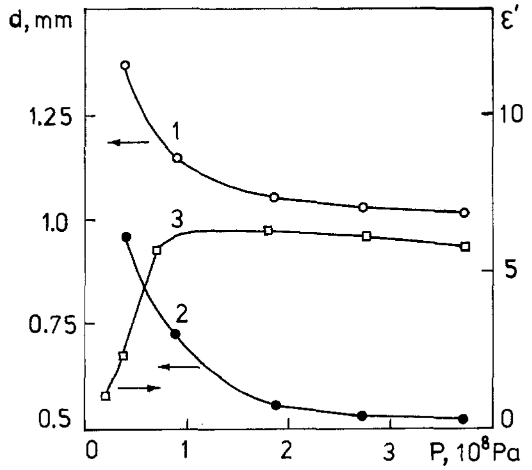

Fig. 1. Sample thickness and dielectric constant dependences on pressing pressure $d(P)$: curves 1 and 2 – polystyrene ($m = 0.6$ g) and magnetite ($m = 1$ g), respectively. Curve 3 – $\varepsilon'(P)$ for polystyrene-carbon black. $\nu = 10^3$ Hz.

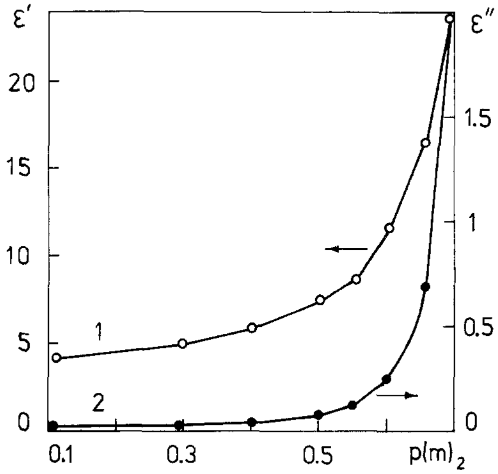

Fig. 2. ε^* dependence on magnetite weight part for OCD-samples. Curves 1 and 2 – ε' and ε'', respectively. $P = 2 \cdot 10^8$ Pa, $\nu = 10^3$ Hz, $U_{ac} = 5$ V.

system. In order for this to happen, the same mass m of developer powder which filled the pressure-cell has been pressed at different pressure values P and the thickness of samples d has been measured. The saturation of $d = d(P)$ dependence with P will be the indication of OCD-powder homogenization mentioned, i.e., the presence of air in samples will be minimized. In the case of polystyrene and magnetite this investigation has been performed and data obtained are presented in Fig. 1. Hence, for investigated samples the pressing pressure value $\geq 2 \cdot 10^8$ Pa has been chosen. For polystyrene-carbon black system the dependence of dielectric constant ε' (calculated from capacitance C) on P can serve as confirmation of the proposed method. This dependence is presented also in Fig. 1 (see curve 3).

Measurements of electrical and dielectrical properties of investigated samples have been performed. In order to have assurance that no contact effect governs these measurements different electrode materials, such as Au, Bi and Al, have been used for polystyrene-carbon black system which presents the main OCD component. It has been detected that for these samples $I - U$ characteristics are linear up to 10^3 V/cm independently of electrode material. Thus, Al-electrodes have been applied by thermal vacuum evaporation in the middle of opposite surfaces of a pressed tablet. The Al-electrode and sample square areas were $S_{Al} = 0.8$ cm^2 and $S_s = 5.3$ cm^2, respectively. The thickness of samples ranged from 0.7 to 1 mm. The mass m of developer powder which filled the pressure-cell was of the same value for all investigated samples, i.e., $m = 0.6$ g, while magnetite concentration and some aspects of preparation procedure were different. Values of magnetite weight part $p(m)_2$ varied between 0 and 0.7, while that of carbon black was the same for all investigated samples, i.e., 0.05.

For samples under investigation steady state current-voltage ($I - U$) and capacitance-voltage ($C - U$) characteristics as well as capacitance C and loss angle tgδ dependences on frequency ν had been measured using Keithley electrometers, models 616 and 642, and capacitance bridge Wayne Kerr B609A as well as GenRad 1621 assembly. In the case of $C - U$ investigations the magnitude of ac-voltage U^{ac} has been chosen so that relation $U^{dc}/U^{ac} \geq 10$ has been satisfied in the whole $C - U$ characteristics region. For the recording of capacitance transients a Gould S 50000 plotter served as an output terminal for capacitance bridges.

3. Results

It has been detected that electrical and complex dielectric constant (c.d.c.) ε^* values of OCD

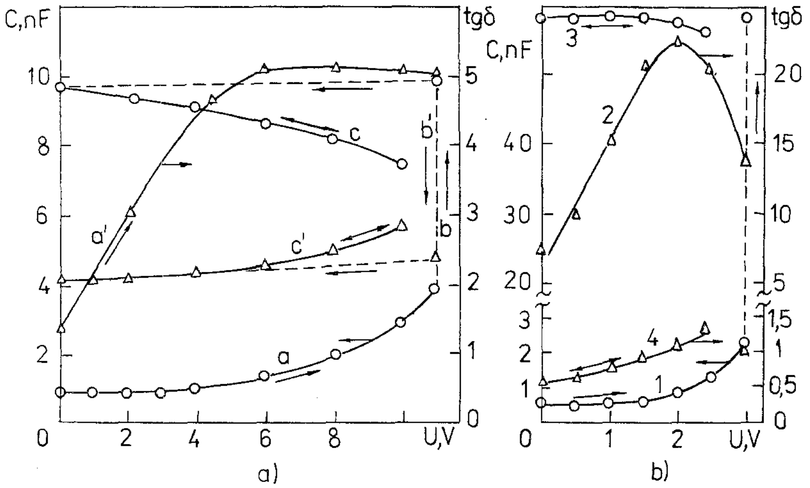

Fig. 3. Capacitance and loss angle dependences on dc-voltage for OCD-samples.
a) Sample No. 85. C vs U^{dc}: curves *abc*; part *a* – C-non-switched state, part *c* – C-switched state. tgδ vs U^{dc}: curves *a'b'c'*; part *a'* – C-non-switched state, part *c'* – C-switched state. $d = 7.7 \cdot 10^{-2}$ cm, $U^{ac} = 10$ mV for C-switched state and 100 mV for non-switched state, $\nu = 10^3$ Hz, arrows near curves indicate the voltage change direction.
b) Sample No. 107. C vs U^{dc}: curves 1, 3; curve 1 – non-switched state, curve 3 – switched state. tgδ vs U^{dc}: curves 2, 4; curve 2 – non-switched state, curve 4 – switched state. $d = 7.4 \cdot 10^{-2}$ cm, $U^{ac} = 11$ mV, $\nu = 10^3$ Hz.

powder are influenced by its composition. The magnetite concentration $p(m)_2$ has the main effect on them: ε^* increases with $p(m)_2$. This is evident from Fig. 2. The carbon black influence is dual: on the one hand, it diminishes OCD resistance, and on the other hand it changes ε^*, too [3]. In our case this is not so significant since the weight part used (0.05) is negligible.

In the case of high magnetite concentrations ($p(m)_2 > 0.5$) capacitance switching effect has been detected in some samples under investigation. In those, capacitance slightly increases with voltage and at a certain point (let us denote it as U_{sw}) C almost immediately switches to the higher value C_{sw}. This capacitance switching process is shown in Fig. 3 which presents $C - U$ characteristics for two typical samples. When C-switching occurs the sample remains in the higher capacitance state even if dc- or ac-voltage is turned off and after a certain time C returns back to the initial value. Moreover, for the C-switched sample $C - U$ characteristics qualitatively and quantitatively are quite different in comparison to the non-switched state (compare *a* and *c* parts of Fig. 3a or curves 1 and 3 in Fig. 3b). It has been determined that values of relative capacitance change $\Delta C = C_{sw}/C_o$, where C_o is the capacitance in a non-switched state, range from 6 to $1.5 \cdot 10^2$ for investigated samples and ΔC is related to C_o as well as to U^{dc}_{sw} values. The higher the ΔC, the lower the C_o and U^{dc}_{sw}. For instance, at 10^3 Hz for non-switched capacitances 1.4, 0.9, and 0.5 nF, C_{sw} have values 8.5, 12, and 59 nF, while U^{dc}_{sw} are 11 and 3 V for samples Nos. 76 ($d = 0.72$ mm), 85, and 107, respectively. Moreover, the C-switching process is more sensitive to ac-voltage than to dc-voltage. It has been experimentally detected that for some samples the capacitance switching can take place at U^{ac}_{sw} almost by an order of magnitude lower than U^{dc}_{sw}.

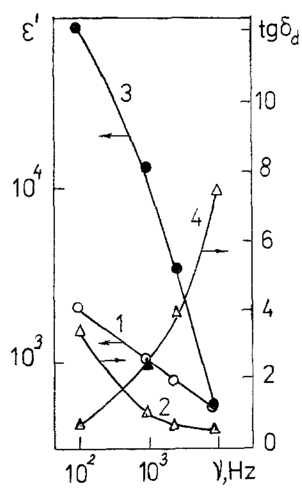

Fig. 4. Frequency dependences of c.d.c. real part and of dielectric losses for sample No. 85 in log–log plot. ε' vs ν: curves 1, 3; 1 – C-non-switched state, 3 – switched state. tgδ_d vs ν: curves 2, 4; 2 – C-switched state, 4 – switched state.

For investigated OCD-samples frequency dependences of complex dielectric constant (c.d.c.), ε^* components (ε', ε'') as well as of dielectric loss angle tgδ_d confirm the occurrence of C-switching effect, too, i.e., these dependences significantly differ in capacitance switched and non-switched states. This is demonstrated in Fig. 4 for sample

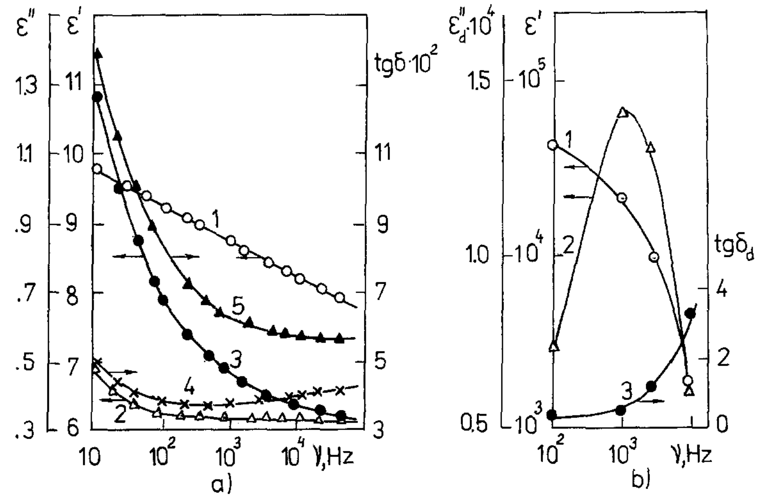

Fig 5. Frequency dependences of c.d.c. components and of loss angle for OCD-components. a) Polystyrene-carbon black system. ε' vs ν – curve 1, ε'' vs ν – curves 2, 3; $\mathrm{tg}\delta$ vs ν – curves 4, 5. Curves 1, 2, 4 – at 293 K, curves 3, 5 – at 317 K temperatures. $d = 10^{-2}$ cm, $U^{ac} = 1$ V. b) Magnetite. ε' vs ν – curve 1, ε''_d vs ν – curve 2, $\mathrm{tg}\delta$ vs ν – curve 3. Temperature 293 K. $d = 7.1 \cdot 10^{-2}$ cm, $U^{ac} = 10$ mV.

No. 85. If the frequency dependences mentioned are compared to corresponding ones for one-component developer main components, i.e., magnetite and polystyrene-carbon black system, which are presented in Fig. 5, the following regularities are evident. For the OCD-samples in the non-switched state ε' and $\mathrm{tg}\delta_d$ frequency behavior is qualitatively similar to that of the polystyrene-carbon black system (compare data presented in Figs. 4 and 5a), while in the switched state – to that of the magnetite (compare curves 3, 4 of Figs. 4 and 5b).

The polystyrene-carbon black system is a typical dielectric, since its dc-conductivity $\sigma^{dc} = 3.3 \cdot 10^{-16}$ S/cm and losses $\mathrm{tg}\delta = (0.1 \div 10^{-2})$ are totally dielectric ones. For one-component developer and magnetite samples dielectric properties are also peculiar, since only near the lowest investigated frequency (10^2 Hz) and only for magnetite and for OCD-sample with the highest ΔC value (No. 107) is the ratio between dielectric losses and total ones as low as 0.25, and this ratio significantly increases with frequency for all samples (magnetite and OCD in switched and non-switched states). For instance, in all cases the $\mathrm{tg}\delta_d/\mathrm{tg}\delta$ value is higher than 0.8 at 10^3 Hz.

Attention must be paid to the unusual dispersion of ε'' at high-frequency edge in the case of polystyrene-carbon black system, i.e., ε'' is frequency independent in the frequency range wider than two orders of magnitude (see curve 2 in Fig. 5a). This unusual behavior could be caused by grain boundary losses. The influence of temperature on ε', ε'' frequency dependences indicates that, in the system mentioned, ε^* dispersion region takes place at $\nu < 10$ Hz (see Fig. 5a).

As has been mentioned above, the C-switched sample after a certain time returns to the initial state. It has been determined that the duration of C-switched state t_{sw} depends on U^{dc} or U^{ac} value ($U^{dc,ac} \geq U_{sw}$) as well as on the time during which voltage has been applied. The higher the U^{dc} or U^{ac} values and the longer their application time $t_{dc,ac}$, the longer is t_{sw}. Depending on the factors just mentioned, t_{sw} varies from minutes up to several days. The C-reswitching process has been investigated at greater length for the sample No. 107, and data obtained are presented in Fig. 6. The procedure of the capacitance decay curve recording is as follows. The U^{dc} has been applied for time t_{dc} and after the voltage turn-off the capacitance trace has been recorded immediately. The step-wise capacitance return to initial value as well as the t_{sw} dependence on t_{dc} mentioned are evident.

This step-wise capacitance reswitching as well as the C-switching effect on the whole have been detected also by the investigation of $I - U$ characteristics which are presented in Fig. 7 for two typical samples, i.e., Nos. 85 and 107. For non-switched samples at low electric fields (up to 2 V/cm) the current follows Ohm's law (see inserts in Fig. 7), while at higher ones the superlinearity of $I - U$ characteristics starts. A log I versus $U^{1/2}$ plot transforms curves to straight lines in this region. In the case of the sample which possesses high ΔC value (No. 107), the steep current jump with voltage takes place at $U = U_{sw}$, while for the

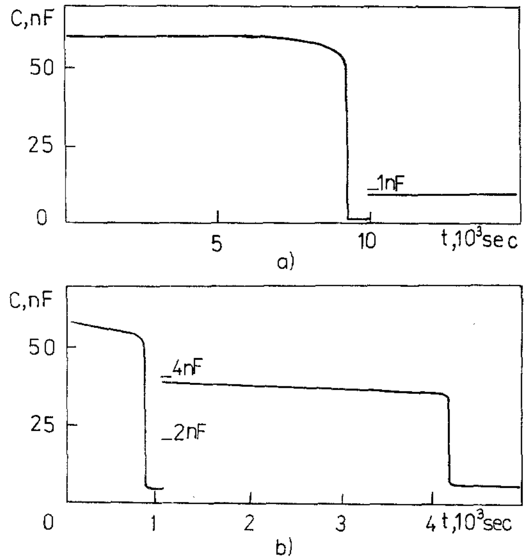

Fig. 6. Capacitance reswitching decay for OCD-sample No. 107.
a) $U^{dc} = 5$ V has been applied during $t_{dc} = 300$ s;
b) $U^{dc} = 3$ V for $t_{dc} = 120$ s.
C vs t measuring conditions: $U^{dc} = 0$, $U^{ac} = 10$ mV.

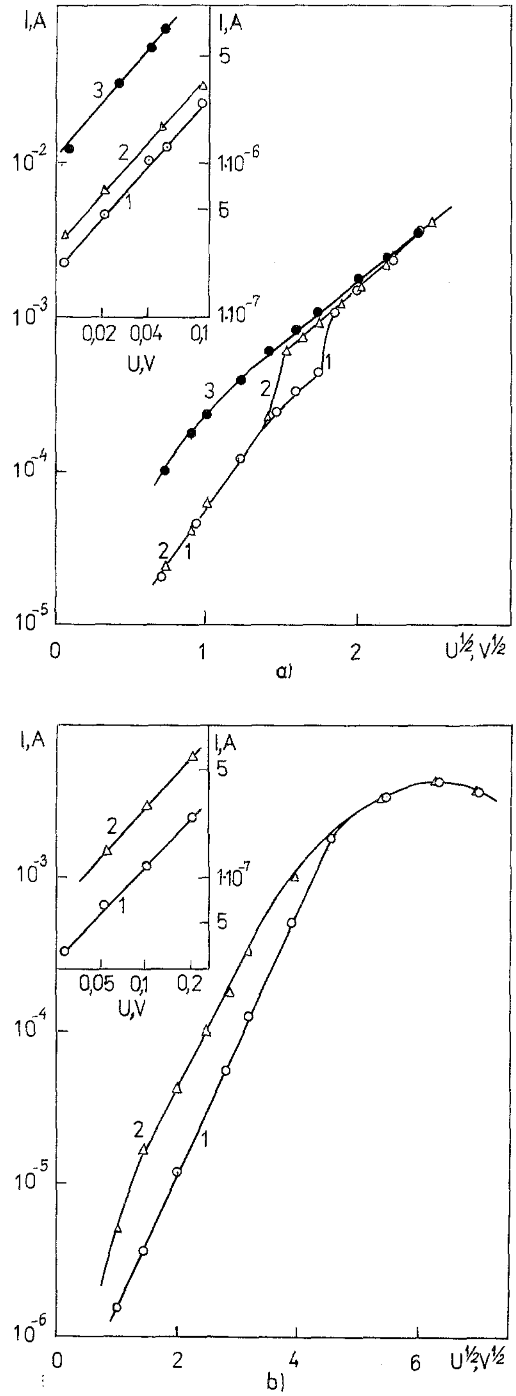

Fig. 7. Steady-state $I - U$ characteristics of OCD-samples.
a) Sample No. 107. Curves 1, 2, 3 – capacitance non-switched, partially reswitched and totally switched states, respectively. Insert: Initial parts of $I - U$ characteristics in log–log plot.
b) Sample No. 85. Curves 1 and 2 – capacitance non-switched and switched states, respectively. Insert: Initial parts of $I - U$ characteristics in log–log plot.

one with ΔC value one order of magnitude lower (No. 85) this effect has not been detected at all (compare curves 1 in Figs. 7a and b). Once the capacitance switching occurs, the slope of $I - U$ characteristics reduces and at voltages well over U_{sw} $I - U$ characteristics saturates and even indicates negative resistance region (see Fig. 7b). For the C-switched state, if compared to the non-switched condition, at a given voltage the current value is higher at $U < U_{sw}$, while at $U > U_{sw}$ they coincide. In the case of partially reswitched state, $I - U$ characteristics are located between those which represent totally switched and non-switched conditions (see curve 2 in Fig. 7a). It has been determined that the higher the capacitance increase during the C-switching process, the higher the current increment at a given voltage in Ohm's law region. This is evident from comparison of $I - U$ characteristics presented in inserts of Figs. 7a, b. For instance, in the case of sample No. 107 dc-conductivities σ^{dc} are $1.9 \cdot 10^{-6}$, $2.5 \cdot 10^{-6}$, and $1.2 \cdot 10^{-5}$ S/cm for sample capacitances 0.5 (non-switched state), 0.9 (partially reswitched), and 58 nF (totally switched), respectively, and for sample No. 85 σ^{dc} are $1.2 \cdot 10^{-7}$ and $2.9 \cdot 10^{-7}$ S/cm for non-switched (0.9 nF) and totally switched states (12 nF), respectively. The σ^{dc}

values determined are needed for the evaluation of dielectric losses performed.

4. Discussion

As has been stated in Section 2, the one-component developer powder has been produced by ii)-method (see Section 1), which cannot ensure the full capsulation of all magnetite particles by a polymeric compound. Keeping in mind the size of crushed magnetite crystals and of developer powder used (see Section 2), it is evident that the number of developer particles containing one or more partially capsulated magnetite crystals will increase with magnetite weight part. At large quantities of such developer particles it is highly probable that during the developer powder pressing process, i.e., the sample preparation, a certain number of partially capsulated magnetite crystals will be located very close to each other but have no direct electrical contact between their free surfaces. Below, it will be shown that introduction of effective cluster parameters makes it possible to regard this region of the OCD-sample as a magnetite cluster whose electric properties, however, are different from those of clusters composed of well-connected magnetite particles.

The high values of c.d.c. ε^* of investigated OCD-samples (composite) and magnetite tablets indicate that in both these cases ε^* is an effective quantity caused by concentration of electric field to thin insulating layers between conducting particles. Thus, the value $|\varepsilon^*|$ must be directly related to the degree of the just mentioned interface properties' influence on the effective properties of the material. Therefore, the observed change of the composite c.d.c. in the course of the C-switching means the increase of electric field between neighboring magnetite crystals in clusters, so that the insulating part of the composite is additionally screened out. This conclusion is corroborated by the fact that, as has been mentioned in Section 3, dependence $\varepsilon^*(\omega)$ for composite in C-switched condition bears some resemblance to that for pressed magnetite samples, while that for the non-switched state definitely does not. The mentioned step-wise delayed reversibility of the C-switching effect makes it unlikely that it is caused by a change of the surrounding medium's properties – for example, breakdown phenomena. Therefore, this increase must be caused by the fact that those clustered particles which are separated by thin gaps of air are packed closer together by some external force so that their mutual capacitance increases and/or additional conducting links are formed. The possibility of such particles' displacement may be justified by the following considerations.

Bearing in mind the poor adhesion between magnetite and polystyrene [4], the above-mentioned particles can get closer to each other if an external force stronger than the surrounding medium static resistance force is applied. This force may be caused in external electric field by interaction between polarization charges induced on the surfaces of the particles or by their deformation if they possess piezoelectric properties [5]. The detected experimental fact that, in some cases, the sample preparation procedure alone, i.e., the pressing of OCD-powder, produces permanent dc-voltage between Al-electrodes, can serve as a confirmation of the latter possibility. The value of this voltage varies in $(0.01 \div 0.2)$V limits from sample to sample. It must be noted that in the case of polystyrene-carbon black system this effect has not been detected.

Unfortunately, experimental data obtained cannot give any preference for either of the effects mentioned above since following facts, i.e.,

i) the step-wise composite capacitance reswitching decay (see Figs. 6 and 7b),
ii) the pronounced composite sample polarization effect which takes place at voltages exceeding U_{sw} (see Fig. 7b) and
iii) the higher sensitivity of the C-switching process to ac-voltage than to dc-one,

are in accord with both C-switching mechanisms proposed. It seems worthwhile to detalize the i)-position just stated above. Since the distance between neighboring magnetite particles in a cluster varies throughout a composite sample, it is evident that different voltage values and different time durations are needed for the C-switching and the reswitching occurrence, respectively. Moreover, some clusters could be mechanically switched during the one-component developer powder pressing. Due to higher electrical homogeneity of these clusters in comparison to the earlier mentioned ones, their influence to the composite c.d.c. is similar to that of pure magnetite units. The existence of such mechanically switched clusters explains the C_0 relation to ΔC and U_{sw} mentioned in Section 3.

The above said indicates that only clustered magnetite particles can be responsible for the C-switching effect. This means that the magnetite amount must be large enough for the clustering effects to be significant. In the case of investigated samples which display C-switching effect, this requirement is fulfilled: from the weight part of magnetite ($0.55 \div 0.70$), bearing in mind densities of magnetite and polystyrene (7.3 and 1.0 g/cm^3, respectively [6]), one concludes that its volume part $p_2 = 0.14 \div 0.20$. In fact, these values coincide with generally observed percolation thresholds [7–9].

Values of sizes of magnetite particles and investigated samples presented in Section 2 indicate that the composite ε^* value results from statistical averaging of each inclusion's effect on the surrounding electric field. Therefore, one may expect that effective properties of the composite should be adequately represented by the effective medium theory (EMT) [10] modified so as to give the sufficiently low percolation threshold value presented above, i.e., so as to account for dipole–dipole interaction between conducting inclusions [7]. Below, an attempt is made to find EMT parameters whose change in the course of the C-switching may cause the increase of the composite ε^* and to relate the latter to the magnetite capsulation amount.

In order to apply EMT, first of all it is necessary to separate homogeneous components which form macroscopic areas randomly distributed throughout a sample and evaluate their complex dielectric constants. Bearing in mind the comparatively large size of magnetite particles (see Section 2), it is evident that from the point of view of the composite's effective properties, the binary system polystyrene-carbon black may be considered to be homogeneous insulating material whose c.d.c. frequency dependence $\varepsilon_1^*(\omega)$ is presented in Fig. 5a. As for the second component (magnetite), it is not necessary to concern oneself with its electrical properties in pure state, but, instead, assign to it an effective c.d.c. ε_2^* which accounts for particle interface effects. Such an approach should not fail even if some particles are well isolated and are far from the other ones, since in this case only the fact that absolute value of the magnetite c.d.c. is much higher than that of host medium is important [11]. A corresponding frequency dependence which is presented in Fig. 5b may be approximated by a conducting polycrystal model expression [12]

$$\varepsilon_2^*(\omega) = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + i\omega\tau} - i \cdot \frac{\sigma_2^{dc}}{\varepsilon_0 \omega} \simeq \frac{\varepsilon_s}{1 + i\omega\tau} - i \cdot \frac{\sigma_2^{dc}}{\varepsilon_0 \omega} \,. \quad (1)$$

Parameters figuring in this expression are determined by charge transport conditions across interfaces between particles: ε_∞ – by mutual capacitance of neighboring crystals, σ_2^{dc} – by the quality of their electrical contact, while τ is an effective RC-constant of a polycrystal which is roughly proportional to the ratio $\varepsilon_s/\sigma_2^{dc}$. Therefore, it is reasonable to assume that partly capsulated magnetite particles have lower values of $\varepsilon_s = \varepsilon_s^{(0)}$ and $\sigma_2^{dc} = \sigma_2^{dc(0)}$ as compared to those corresponding to fully capsulated ones ($\varepsilon_s^{(1)}$ and $\sigma_2^{dc(1)}$, respectively), i.e., behave as a third component.

Assuming the validity of the proposed physical mechanism of the C-switching, one concludes that the C-switching effect, in terms of cluster effective parameters, must be caused by the change of values of $\varepsilon_s^{(0)}$, $\sigma_2^{dc(0)}$ and $\tau^{(0)}$ so that they become closer to $\varepsilon_s^{(1)}$, $\sigma_2^{dc(1)}$ and $\tau^{(1)} \simeq \tau^{(0)} \frac{\varepsilon_s^{(1)} \sigma_2^{(0)}}{\varepsilon_s^{(0)} \sigma_2^{(1)}}$. That is, the step-wise change of partly capsulated clusters' effective properties causes the C-switching effect on the whole. Therefore, these clusters may be called "switching clusters," whose volume part is p_{sw}. Expression $p_2' = p_2 - p_{sw}$ must be used for volume part of fully capsulated magnetite.

Because of the large number of unknown parameters (p_2, p_{sw} and cluster parameters $\varepsilon_s^{(0)}$, $\sigma_2^{dc(0)}$, $\tau^{(0)}$, $\varepsilon_s^{(1)}$, $\sigma_2^{dc(1)}$) quantitative testing of the proposed EMT is problematic at this stage. However, it seems worthwhile to use the model described above for calculation of dependence of sample capacitance relative increase due to the C-switching effect ΔC on p_{sw} when cluster parameters are known. On the basis of Figs. 4 and 5a, and of measured dc-conductivity of magnetite samples ($10^{-6} \div 10^{-4}$ S/cm), the following values have been chosen:

$$\varepsilon_s^{(0)} = 10^3,\ \sigma_2^{dc(0)} = 10^{-7}\ \text{S/cm},\ \tau^{(0)} = 10^{-4}\ \text{s}\,,$$
$$\varepsilon_s^{(1)} = 10^6,\ \sigma_2^{dc(1)} = 10^{-4}\ \text{S/cm},\ \tau^{(1)} = 10^{-4}\ \text{s}\,.$$

Let us require that in the course of C-switching all "switching clusters" change their properties so that they become identical to those of fully capsulated particles. Then EMT with dipole-dipole interaction equations governing composite effective c.d.c. ε^* are [7, 10]:

for the C-non-switched state

$$9(1-p_2)\frac{\varepsilon_1^*-\varepsilon^*}{\varepsilon_1^*+2\varepsilon^*}+(p_2-p_{sw})\times\left[2\frac{\varepsilon_2^{*(1)}-\varepsilon^*}{L\varepsilon_2^{*(1)}+(1-L)\varepsilon^*}+\frac{\varepsilon_2^{*(1)}-\varepsilon^*}{(1-2L)\varepsilon_2^{*(1)}+2L\varepsilon^*}\right]+p_{sw}\cdot\left[2\frac{\varepsilon_2^{*(0)}-\varepsilon^*}{L\varepsilon_2^{*(0)}+(1-L)\varepsilon^*}+\frac{\varepsilon_2^{*(0)}-\varepsilon^*}{(1-2L)\varepsilon_2^{*(0)}+2L\varepsilon^*}\right]=0, \tag{2a}$$

and for the C-switched state

$$9(1-p_2)\frac{\varepsilon_1^*-\varepsilon^*}{\varepsilon_1^*+2\varepsilon^*}+p_2\cdot\left[2\frac{\varepsilon_2^{*(1)}-\varepsilon^*}{L\varepsilon_2^{*(1)}+(1-L)\varepsilon^*}+\frac{\varepsilon_2^{*(1)}-\varepsilon^*}{(1-2L)\varepsilon_2^{*(1)}+2L\varepsilon^*}\right]=0, \tag{2b}$$

where ε_1^* is effective c.d.c. of the system polystyrene-carbon black, $\varepsilon_2^{*(1)}$ and $\varepsilon_2^{*(0)}$ are effective c.d.c. of magnetite clusters in switched and non-switched states, respectively, and L is an effective depolarization factor of conducting component. Computation with $L = 0.0865$ [7] (this value corresponds to percolation threshold value $p_t = 0.156$) gives the dependences of ratio between OCD-sample dielectric constants in non-switched and switched states $\varepsilon'_o/\varepsilon'_{sw}$ on fully capsulated magnetite particles amount p'_2/p_2 which are presented in Fig. 8. It is evident from Fig. 8 that $\varepsilon'_o/\varepsilon'_{sw}$ diminishes with p'_2/p_2 value lowering, i.e., ΔC increases. Moreover, for a given p'_2/p_2 ΔC is higher the higher the magnetite concentration $p(m)_2$ in OCD. Therefore, these computations qualitatively confirm the statement which has been argued in [13] that the value of capacitance increase during the C-switching process can serve as an indicator of the extent of FC-capsulation for one-component electrographic developer.

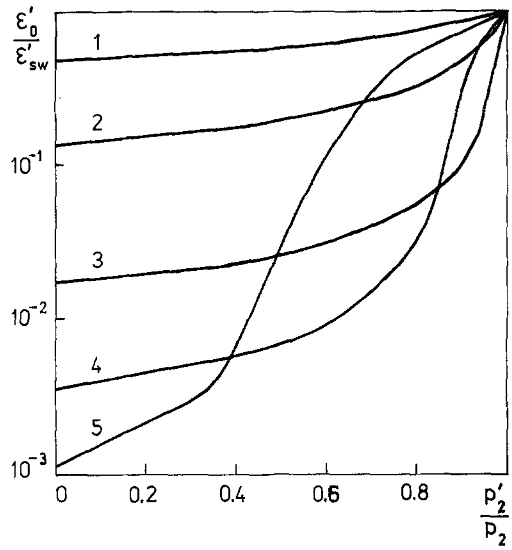

Fig. 8. $\varepsilon'_o/\varepsilon'_{sw}$ dependences on p'_2/p_2 for OCD-samples at different magnetite weight parts. Curves 1, 2, 3, 4, 5 – for $p(m)_2$ 0.52, 0.56, 0.58, 0.62 and 0.76, respectively (corresponding p_2 values are 0.13, 0.15, 0.16, 0.18 and 0.30, respectively). $\nu = 10^3$.

Acknowledgements

We are indebted to Dr. A. Pučinskas for supplying sample materials, to Prof. I. Chudaček for valuable discussions concerning some aspects of the present work and to A. Jankauskas for technical assistance.

References

1. US patent No 4,331,755
2. USSR author's certificate No 1,291,921 MKI G 03 G 9/08
3. US patent No 4,634,465
4. Kume K (1986) Solid St Comm 7:473
5. Ferroelectric ceramics (1985) Publication Cr 3, Quartz and Silice Ltd
6. Weast RC (ed) (1977) Handbook of chemistry and physics: A ready-reference book of chemical and physical data. CRC press, Cleveland, Ohio
7. Granqvist CG, Hunderi O (1978) Phys Rev B 18:1554
8. Kirkpatrick S (1973) Rev Modern Physics 45:574
9. Dulnev GN, Malarev VI (1990) All-Union Monthly Journal of Engineering Physics (USSR) 59:522
10. Landauer R, in *Proceedings of the First Conference on the Electrical Transport and Optical Properties of Inhomogeneous Media, Ohio State University*, 1977, edited by J.C. Garland and D.B. Tanner (AIP, New York, 1978), No. 40, p. 2

11. Mačkus P, Poškus A, Lipskis K, Slavinska D (1992) Colloid Polym Sci 270:1168
12. Krupička S (1973) Physik der Ferrite, B.2, Academia, Prag, p. 463
13. Mačkus P, Chudaček I, Pučinskas A (1990) ČSFR PV 5036/90

Received April 22, 1993;
accepted November 25, 1993

Authors' address:

Dr. C.Sc. P. Mačkus
Vilnius University
Department of Solid State Electronics
Saulėtekio al. 9, corp. 3
2054 Vilnius, Lithuania