Journal of Engineering Physics and Thermophysics, Vol. 78, No. 6, 2005

SPACE-TIME CHARACTERISTICS OF ORDERED MICROSTRUCTURE (CLUSTER) REGIONS IN WEAKLY CONDUCTING MEDIA

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UDC 538.93; 541.133

Results of investigation of the formation of the peripheral (friable) part of charged clusters in weakly conducting liquids with polar additions under the action of a pulsed electric field are presented.

The space-time characteristics of the formation of charged clusters in liquid dielectrics were experimentally investigated by the method of laser probing in [1]. Two transient processes were detected. One of them is the rapid (~50–400 μsec) process of formation of the ionic part of a near-electrode layer and the other is the slow (~5–10 min) process of formation of the dense part of a charged-cluster layer. However, the transient processes of formation of the peripheral (friable) part of a charged-cluster layer were not investigated because objects differing insignificantly in density cannot be detected by the method of laser probing.

In the present work, we investigated the indicated processes by the method of holographic interferometry, which makes it possible to record small differential changes in the refractive index of a liquid by comparison of its perturbed (in the presence of an electric field) and unperturbed (in the absence of an electric field) states.

Experimental Procedure. The optical scheme of a holographic interferometer [2], modified for operation in a real time, is shown in Fig. 1. An interference pattern is recorded by a videocamera. The data obtained are read, via an interface device, into the hard disk of a computer. The read-in and a pulsed voltage applied to the electrodes of an experimental cuvette are synchronized and the read-in parameters are controlled by a program. To numerically process the measurement data, a program was developed for processing of interferograms. The algorithm of the program is as follows: 1) transformation of a continuous videoimage (avi videoformat), reproducing a changing interference pattern, into a sequence of videoframes (bmp graphic format); 2) digital filtration of the images obtained; 3) calculation of $\Delta n(x, y)$; 4) construction of the graphic dependence $\Delta n(x, y)$; 5) construction of the graphic dependence $\Delta n(t)$; 6) representation of the data obtained in the form of a file. The error in determining the coordinates (x, y) with the use of the above-described setup does not exceed 5%.

Results of Measurements. Figure 2a–c presents interferograms obtained in the gap between the electrodes of an experimental cuvette filled with solutions of butyl alcohol in transformer oil in the absence of an electric field. The strong bend of the interference fringes near the electrodes points to the existence of an adsorbed-ion layer on their surface. The corresponding change in $\Delta\varepsilon$ in the near-electrode layer was investigated in [3] by the method of microwave probing.

When an electric field was applied to the electrodes (Fig. 2d–f), the layers adsorbed on them were discharged, and the discharge region was determined by the polarity of the electrodes and the concentration of an impurity. For example, in the case where a pure transformer oil was used, a discharge and a corresponding straightening of interference fringes were detected only at the positive electrode (Fig. 2d).

When the concentration of an impurity increased to 3% or higher (3–10%), a discharge was detected at the negative electrode (Fig. 2e and f) and then, when the impurity concentration increased to 15% or higher, a discharge was detected at the positive electrode, too. These data correlate with the data on hydrodynamic electron flows arising at a corresponding electrode (they begin where a discharge appears).

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Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 78, No. 6, pp. 118–121, November–December, 2005. Original article submitted February 24, 2004; revision submitted August 25, 2004.

1062-0125/05/7806-1167

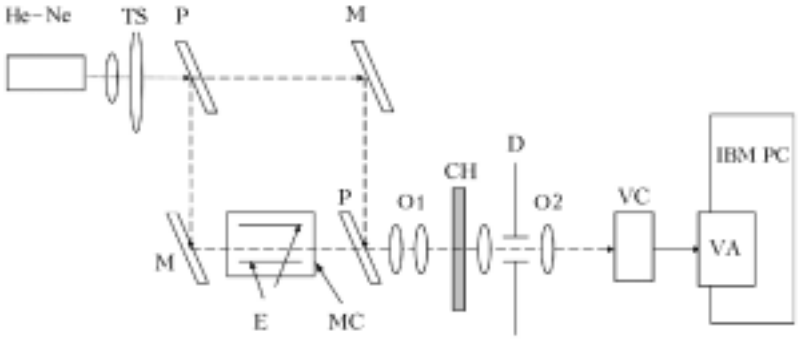

Fig. 1. Optical scheme of a holographic interferometer: He–Ne) helium-neon laser, TS) telescopic system, P) semiconductor plates, M) semiconductor mirrors, MC) measuring cuvette with a weakly conducting liquid, E) removable plane-parallel electrodes, O1 and O2) objectives, CH) compensating hologram, D) filtrating diaphragm, VC) recording videocamera, VA) videoadapter.

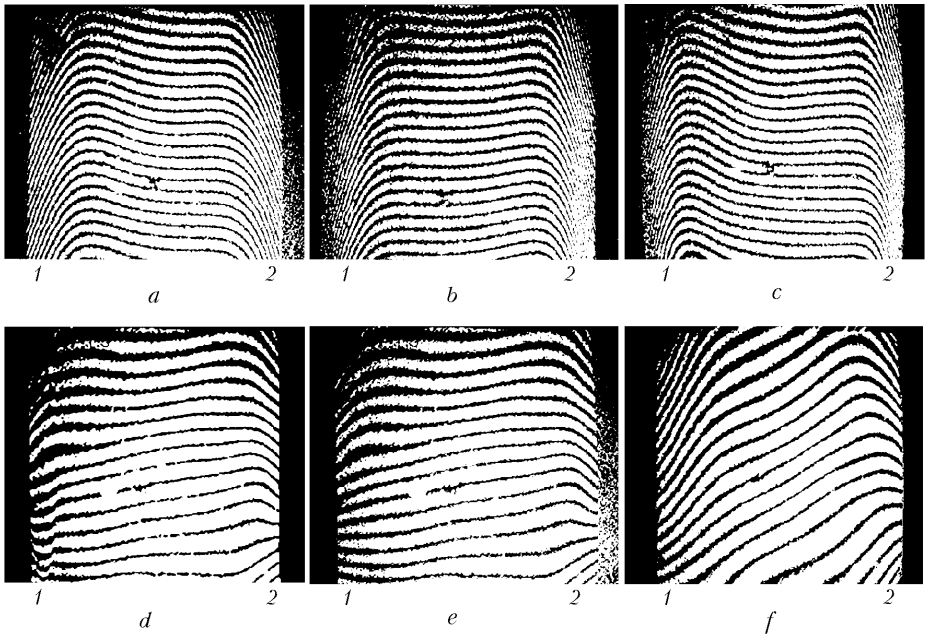

Fig. 2. Interferograms of the interelectrode space of an experimental cuvette with solutions of butyl alcohol in transformer oil in the absence of an electric field (a–c) and in the presence of an electric field E = 2.5 kV/cm (d–f): a, d) pure transformer oil; b, e) 3% solution; c, f) 10% solution; 1) anode; 2) cathode.

Since the large changes in the refractive index of the adsorbed layers make the recording of the changes in the other parts of the interelectrode space difficult, the further recording was performed by the method of holographic interferometry, which allows one to detect, using a correcting hologram, only those changes in the refractive index that arise in the interelectrode space after the discharge of the adsorbed layers. The typical pattern of such a distribution of $\Delta n(x, y)$ is presented in Fig. 3.

Here, the changes in the refractive index are, as before, larger near the electrodes, which corresponds to an increased space charge in the friable parts of the near-electrode liquid layers. The changes in Δn along the y axis are due to the electrode defects and the convection. To eliminate the influence of these heterogeneities, we averaged the values of Δn along the y axis by the method of least squares (Fig. 4).

The refractive index changes most strongly in the near-electrode liquid regions whose thickness is of the order of 0.6 mm. The inhomogeneity of the medium in these regions increases as an electrode approaches, which correlates

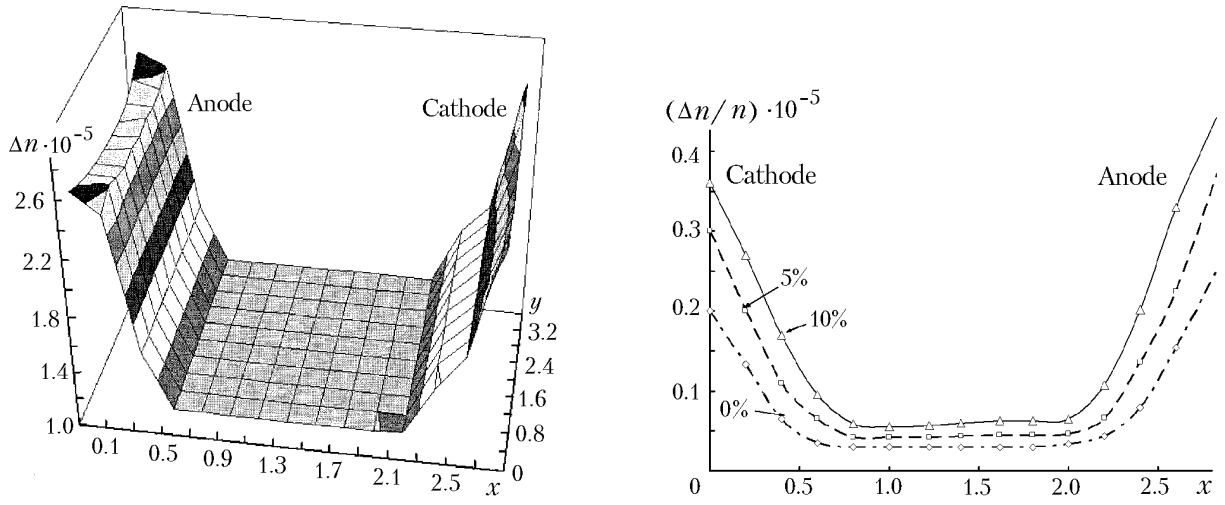

Fig. 3. Measured distributions of the refractive index $\Delta n(x, y)$ in the interelectrode space in the presence of an electric field (10% solution of butyl alcohol in transformer oil, E = 2.5 kV/cm). x, y, mm.

Fig. 4. Distribution of the relative change in the refractive index in the interelectrode space (10% solution of butyl alcohol in transformer oil, E = 2.5 kV/cm). x, mm.

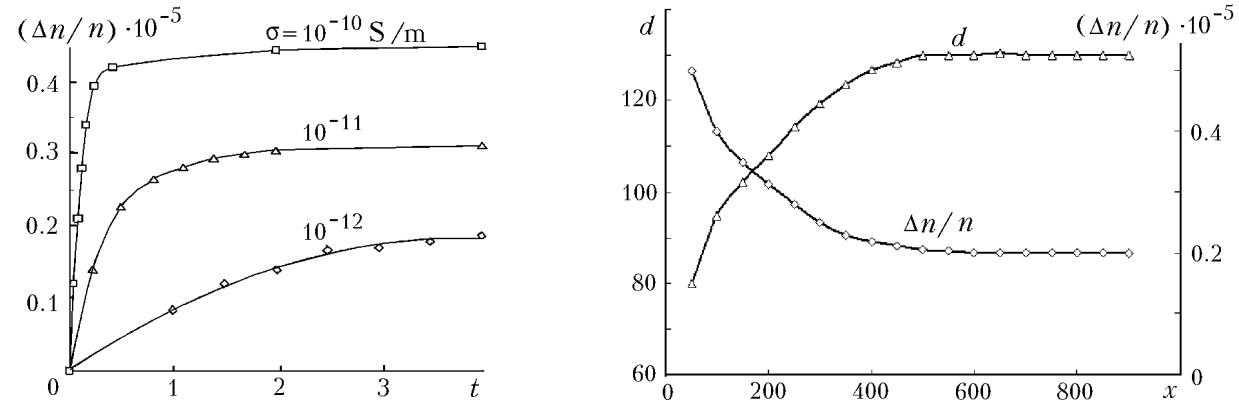

Fig. 5. Dependence of the relative refractive index $\Delta n/n$ on the transient period t in the anode region in weakly conducting liquids of different conduction (solutions of butyl alcohol in transformer oil, E = 2.5 kV/cm). t, sec.

Fig. 6. Dependence of the steady-state sizes of charged clusters d and the change in the relative refractive index $\Delta n/n$ in the anode region on the distance to the electrode x (10% solution of butyl alcohol in transformer oil, E = 2.5 kV/cm). d, Å; x, μm.

with the data that were obtained earlier by the method of laser probing [1], the method of rotation of the plane of light polarization [4], and the method of microwave probing [3].

Figure 5 presents the experimental dependences of the relative refractive index $\Delta n/n$ on the transient period t in the anode region for different concentrations of a weakly conducting liquid. The dependences obtained correspond to the Maxwell relaxation times $\tau = \varepsilon\varepsilon_0/\sigma$.

The measured values of Δn exceed the Kerr effect by more than two orders of magnitude and changes in the medium arise for a much larger time (~0.1–10 sec). These changes are due to the formation of the friable part of charged clusters.

The experimental distributions of the relative changes in the refractive index $\Delta n/n$ in the interelectrode space x obtained by the method of holographic interferometry correlate with the experimental dependences of the steady-state characteristic sizes of charged clusters d determined by the method of laser probing [1] (Fig. 6). It may be suggested that these changes are due to the formation of the peripheral part of the charged clusters, the density of which is much smaller than the density of the center. The results of our investigations also correlate with the data obtained by the methods of microwave probing [3] and rotation of the plane of light polarization [4].

CONCLUSIONS

1. The experimental data obtained by the method of holographic interferometry supplement the space-time characteristics of the formation of charged clusters; they provide evidence on the transient processes of formation of the peripheral (friable) part of these clusters.

2. The transient process of formation of a near-electrode layer can be represented in the following way: after the rapid formation of an ionic near-electrode layer (~50–400 μsec), the friable part of a cluster layer is formed within ~1–10 sec and its dense part is slowly formed (within ~5–10 min) at the final stage.

NOTATION

d, steady-state characteristic size of charged clusters, Å; E, electric-field strength, kV/cm; n, refractive index; t, time, sec; $\Delta\varepsilon$, change in the permittivity; Δn, change in the refractive index; $\Delta n/n$, relative refractive index; ε, permittivity; ε_0, permittivity of free space; σ, conduction, S/m; τ, Maxwell relaxation time of a liquid, sec.

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