Estimation of charge carrier mobility in polymer thin-film structures

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Abstract. In this article, the polymer polydiphenylenophthalide. The estimates of the mobility of charge carriers for FDP films of different thicknesses by the CELIV method are carried out. During the measurements it was concluded that the mobility value does not depend on the thickness of the polymer film within 100-800 nm.

Introduction
Polymers occupy one of the leading places among structural materials for mechanical engineering. Thus, the consumption of plastics in this industry becomes comparable (in units of volume) with the consumption of steel. Currently, there is a great interest in the study of new polymeric materials. One such material is polydiphenylenophthalide (PDF). It is a polymer of polyheteroarylenes class. He has the unique physical properties on the basis of which it can be used in the form of polymer films, binders for reinforced polymers, polymer adhesives in instrumentation, electronics, radio engineering; membranes, diaphragms in galvanic cells, batteries, electrolyzers, etc [1].

Polymer of this class were synthesized in the polycondensation group of the Institute of organic chemistry of Ufa scientific center (UC) by electrophilic polycondensation [2].

Polydiphenylenophthalide and its properties
PDF is a dielectric. The parameters that determine the initial dielectric state are as follows:

- Band gap ~ 4.3 eV
- Electronic work function ~ 4.2 eV
- Electronic affinity of ~ 2 eV
- The first ionization potential of ~ 6.2 eV

Polyacrylonitrile have high heat and temperature resistance. The softening temperature of 3600 C, the Temperature of degradation (Tg – temperature of loss of 1% weight) in argon and in air is 4400 With [3]. The thermal stability of the phthalide cycle in polyarylenephthalides is determined by the nature of the groups that connect the phenyl nuclei in the main chain.
The study of the winter hardiness of polyarylene naphthalides showed that they have good resistance to aggressive media at elevated temperatures. PDF has high film-forming properties. It is highly soluble in methylene chloride, chloroform, tetrachloroethane, dimethylformamide, cyclohexanone and other solvents. Watering from the solution, it is possible to obtain undirected films with tensile strength (800-900 kgf∙mm\(^2\)) with a relative elongation at rupture of 10-20% [4]. It is possible to allocate the following features of film formation of polymers of the PDF type. When using a solvent with a lower boiling point (chloroform) and applying films by centrifugation under the same conditions, a film of a greater thickness is formed than when using a solvent with a higher boiling point (cyclohexanone) [5].

![Figure 1. Structural formula polydiphenylenphthalide and three-dimensional image](image)

Morphology of thin polymer films (especially ultra-thin, obtained from solutions of 0.1% concentration) strongly depends on the nature of the substrate and its properties such as wettability, roughness and pretreatment conditions (cleaning, etc.).

**Prototyping and research methods**

The mobility of charge carriers is an important parameter determining the kinetic characteristics of charge carriers in the materials under study. To estimate the mobility in the films polydiphenylenphthalide was manufactured experimental samples of different thickness. The experimental sample was a thin-film structure of sandwich type indium oxide and tin / PDF / metal(Al). Film PDF received on the centrifuge. The thickness of the film varied depending on the speed of the centrifuge. Measurements were carried out on a specially assembled unit for the method CELIV [6].

The essence of the method is as follows: 2 successive pulses of linearly increasing voltage are supplied. The first impulse is the main one and the second one is the controlling one. The controlling impulse is necessary to evaluate the quality of contact blocking. As a result, we obtain transient current curves. The mobility of charge carriers is calculated by the formula

\[
\mu = \frac{2d^2}{3A \Delta I_{\text{max}}^2 \left[ 1 - 0.36 \frac{\Delta I}{J(0)} \right]} \]

where \( \Delta J \) is the current registered on the sample, \( J(0) \) is the displacement or capacitive current. It can be estimated either by the transient current curve, or by the following formula

\[
j(t) = \frac{A}{d} \Delta \varepsilon_0 = j(0)
\]

where \( A \) is the rate of rise of voltage, and \( d \) is the thickness of the sample.

**Results and discussion**
Figure 2 shows the results obtained on films with thickness of 800 nm and 170 nm at different rates of voltage increase. The insert shows the maximum voltage values.

The table shows the results obtained on the test sample. From the second column it can be seen that with the increase in the rate of voltage increase, the magnitude of mobility decreases. However, at a speed of 2700/mobility does not differ from the values of mobility obtained at a speed of 1500 ln/sec. This is due primarily to the difficulty of estimating the time $t_{\text{max}}$ of the curve of the transient current due to the weak signal and the extended high. At extreme points (near the maximum at 3000 V / s), the mobility value is comparable to the mobility measured at 2700 V/s and 1500 V/s.

![Figure 2. Transient current curves FOR the ITO-PDF-Al sample measured at different voltage rise rates A=U/t.](image)

| $d$, мкм | $dU/dt$, (В/с) | $\mu$, (см$^2$/Вс) | $t_{\text{max}}$, (мс) | $I(0)$, (А/м$^2$) | $\Delta I$, (А/м$^2$) |
|-----------|-----------------|---------------------|-----------------|----------------|----------------|
| 0.8       | 3000            | $3.8 \cdot 10^{-5}$ | 0.57            | 0.2            | 0.06          |
| 0.8       | 2700            | $1.2 \cdot 10^{-3}$ | 0.34            | 0.1            | 0.06          |
| 0.8       | 1500            | $1.2 \cdot 10^{-3}$ | 0.45            | 0.09           | 0.03          |
| 0.17      | 50000           | $2 \cdot 10^{-3}$  | 4.1             | 15.6           | 6.38          |

Table 1. The results obtained from the transient current curves for

Measurements were made on the condition that at least one of the electrodes of the sample is completely (or partially) blocking. In particular, the lower transparent electrode ITO (indium tin oxide) was used as a blocking electrode for measuring mobility in this work. Therefore, due to the specific structure of the sample, the main charge carriers are holes.

Analyzing the obtained results, it can be concluded that the mobility value does not depend on the thickness of the polymer film within 100-800 nm.

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