Estimation of parameters of charge carriers in dielectric materials by CELIV method

IOP Conf. Series: Materials Science and Engineering **240** (2017) 012040 doi:10.1088/1757-899X/240/1/012040

Estimation of parameters of charge carriers in dielectric materials by CELIV method

I I Khafizov[1], T N Saveleva[1], V S Lyubtsov[2]

[1] Kazan Federal University, 18 Kremlyovskaya street, Kazan, 420008, Russian Federation
[2] Ufa State Aviation Technical University, Ufa, Russia

khafizov@kpfu.ru , TNSaveleva@stud.kpfu.ru, vladimir_lyubcov@mail.ru

Abstract. Measuring the mobility of charge carriers by the time-of-flight method has been used for several decades to study organic semiconductors and dielectrics. Modern research in the field of polymer semiconductor devices focuses on the properties of single- and multi-layer thin-film structures with thicknesses less than 100 nm. Such structures are of considerable interest for research, since they are the basis for organic light-emitting diodes, organic solar cells and other electronic devices.

Introduction

Most electronic devices based on organic materials consist of multilayer film structures with thicknesses much less than 100 nm. This significantly limits the time-of-flight method, since it is known from the theory of this method that the thickness of the polymer film must be much larger, and the film should have rather dielectric properties [9]. An important limitation of the time-of-flight method is the small concentrations of charge carriers. Moreover, measurements by the time-of-flight method do not give exact results, since in most cases the dielectric relaxation time $\tau_\sigma = \varepsilon\varepsilon_0 / en\mu$ much less than the time of flight of charges $t_{tr} = d / \mu E$. Thus, measurement of mobility by a time-of-flight method, as a rule, is limited to the concentration of the main carriers $n << 5\times10^{22}$ m^{-3}, for $E=3\times10^7$ V/m, D=100 nm и ε=3.

In this connection, it becomes relevant to use new experimental methods for estimating the mobility of charge carriers in multilayer film structures.

The CELIV method assumes the presence of a uniform density of charge carrier distribution, with the total charge density equal to zero, i.e. electrons and holes compensate each other [5]. It is important to note that the CELIV method is applicable for analyzing the mobility of charge carriers with a significant difference in the mobility of electrons and holes [8].

Methods for measuring the mobility of charge carriers

The mobility of charge carriers is an important parameter that determines the kinetic characteristics of charge carriers in the materials under study. In particular, the efficiency of photocells based on conjugated polymers is significantly reduced due to low mobility of charge carriers. Thus, data on the mobility of charge carriers make it possible to determine the efficiency of polymers for photocells and other practical applications.

The time-of-flight method is one of the most widely used methods of investigating the transport of charge carriers, which was used to study a number of conjugated polymers and organic semiconductors [1, 6]. In this method, the charge carrier packet is generated by a light pulse and drifts through the material under investigation under the influence of an external applied voltage. The arrival time of the charge carrier packet is measured when the opposite electrode is reached and is calculated by the formula

$$\mu_{TOF} = \frac{d^2}{U \cdot t_{tr}}$$

where d is the film thickness, U is the applied voltage and t_{tr} is the time of flight.

A time-of-flight method requires a thick film, which limits this method when measuring mobility in real thin organic films used in electronic devices.

Transport of charge carriers in dielectrics

It is known that dielectrics (insulators) are substances in which there are practically no free charge carriers. The term "dielectric" comes from the Greek word dia - through, through and the English word electric - electric. This term was first introduced by M. Faraday in 1838 to designate substances in which an electric field penetrates. As you know, there is no sharp boundary between conductors and dielectrics, since all substances are able to conduct electric current to some extent. But if in the substance of free charges is 10^{15}-10^{20} times less than in metals, then in such cases the weak conductivity of the substance can be neglected and considered an ideal dielectric. Almost all charged particles inside the dielectric are interconnected and are not able to move around the body. They can only slightly shift relative to their equilibrium positions.

According to the band structure of solids, for a dielectric, a completely filled valence band is distinguished, separated from the empty conduction band by an energy gap of several electron volts (the forbidden band). Neither in the filled or in the empty zone there can be no conductivity unless additional carriers are introduced into the dielectric. Carriers can either be generated inside the dielectric (processes limited by volume), or injected into it from the metal electrode (processes limited by injection). Various processes that determine the passage of current through a dielectric placed between two electrodes.

To produce the samples, glass with a transparent layer of ITO (indium and tin oxides) was used as the substrate. The size of the substrates was 1.5x2 cm^2.

The cleaning of the substrates was carried out according to standard technology in 3 stages in an ultrasound bath. The first stage - purification in acetone is pure for analysis, the second stage - in ethyl alcohol 95%, the third stage - in distilled water. After that, the substrates were dried in a drying cabinet (SNOL-350/65) at a temperature of 150^0C for 45 minutes.

The purified substrate was centrifuged (centrifuge with a variable speed of rotation SM-50) with a 2-5% (weight fraction) polymer solution of polydiphenylenephthalide. The rotational speed of the centrifuge was 1000-2000 rpm, the spinning time of the centrifuge was 20 seconds. After application of the polymer, the samples were dried in air for 45 minutes at room temperature of 24^0C (± 1^0C) and humidity - 26% (± 1%). Then the samples were placed in a drying cabinet for 45 minutes at a temperature of 150^0C (± 5^0C).

Metal tracks were produced by the method of thermal evaporation of metals in a high vacuum at the VUP-5M plant. Aluminum (Al) was used as the metal. The time of spraying was 1-2 minutes. The shapes and sizes of the tracks were set using contact masks.

To estimate the mobility in the polydiphenylenephthalide films, experimental samples of different thicknesses were made. The results obtained on samples with a thickness of ~ 0.8 μm and ~ 0.17 μm are presented.

Conclusion

The main task of this work was to assemble a measuring device for carrying out the CELIV study. The method is new to researchers, but at the same time the first mention of it was made in the early 80's of the last century. In the literature, in general, the method is used to estimate the mobility of charge carriers in organic semiconductors. In this connection, the actual task was to measure the mobility in dielectric materials. Studies were carried out on a polymer from the class of polyarylenephthalides, polydiphenylenephthalide [7, 10, 11].

References

[1] Antoniadis H, Abkowitz M A and Hsieh B R 1994 Carrier deep-trapping mobilitylifetime products in poly(p-phenylene vinylene), *Appl. Phys. Lett*. 65 pp 2030-32
[2] Khafizov I I 2015 Processing methods with imposing of electric field at low- waste division of materials *IOP Conf. Series: Materials Science and Engineering* 86 **012013**
[3] Khafizov I I 2016 Economic efficiency and effectiveness of ways of separating materials electro diamond processing *IOP Conf. Series: Materials Science and Engineering* 134 **012014**
[4] Gil'manshin I R, Kashapov N F 2014 Energy service contracts in regional engineering center for small and medium businesses *IOP Conference Series: Materials Science and Engineering* 69 **012010**
[5] Juska G, Arlauskas K and Viliunas M 2000 Extraction Current Transients: New Method of Study of Charge Transport in Microcrystalline Silicon, *Phys. Rev. Letts.*, 84 **4946**
[6] Kreouzis T, Poplavskyy D, Tuladhar S M, Quiles M C, Nelson J, Campbell A J and Bradley D D C 2006 Temperature and field dependence of hole mobility in poly(9,9-dioctylfluorene), *Phys. Rev.* B 73, 235201(1)-(15)
[7] Rafikov S R, Tolstikov G A, Salazkin S N, Zolotukhin M G 1981 Polyheteroarylenes for the manufacture of heat-resistant materials and the method for their production. 734989 USSR. / *Bul. Invention.* - No 20 p 259
[8] Sebastian Bange 2009 Transient Optical and Electrical Effects in Polymeric Semiconductors *Dis…Potsdam*, pp 107-120
[9] Tsung K K and So S K 2008 Carrier trapping and scattering in amorphous organic hole transporter, *Appl. Phys. Lett. 92* **103315**
[10] Zolotukhin M G, Skirda V D, Sedova E A, Sundukov V I, Salazkin S N 1993 Gelation in the homopolycondensation of 3-arel-3-clorphtalides *Macromol. Chem* V 194. No 2 pp 543-49
[11] Zolotukhin M G, Kovardakov V A, Salazkin S N, Rafikov S R 1984 Some regularities in the synthesis of polyarylene phthalides by homopolycondensation of n- (3-chloro-3-phthalidyl) - biphenyl [Text] *High-molecular. Soed.* T 26a No 6. pp 1212-17