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THE NEW CONSIDERATION AND MODELING OF ORGANIC TRANSISTORS CARRIERS MOBILITY

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Abstract In this paper, the new considerations related to organic transistors carriers mobility have been implemented. The new model, that incorporates the influence of the lateral and normal factors of the position disorder on the carriers mobility, as well the impact of the lateral and normal electric field components on the carriers mobility, is presented. The advantage of the model is that it is modular and includes some rarely considered parameters.

Keywords: Organic transistors; carriers mobility; electric field; position disorder.

1. INTRODUCTION

The very rapid development of electronics includes research various electronic devices, including transistors made of organic compounds. Due to the complex mechanisms of transport processes of charge carriers in organic transistors, the need for further research is significantly expressed.

Good features of organic devices such as high degree of flexibility, light weight, low price, compatibility with standard devices, possibility of application in different cases, make them interesting to use [1 - 12]. There are different types of these transistors. As an example, organic based thin-film transistors, which have wide application possibilities, can be taken.

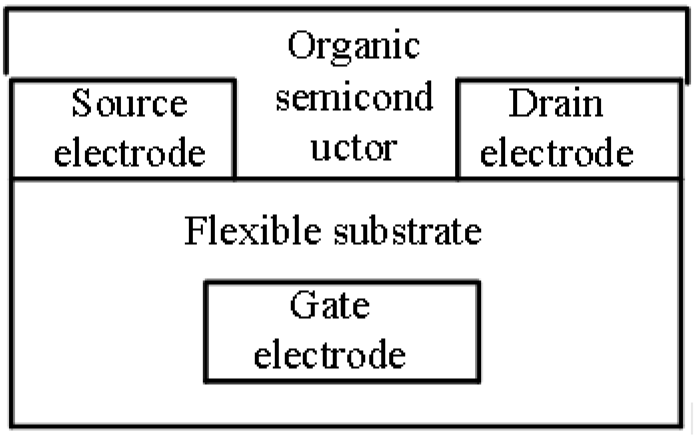

Figure 1. Cross-sectional view of organic thin-film transistor.

In Figure 1, cross sectional view of one possible realization of organic thin-film transistor, is shown. Source and drain electrodes are placed in an organic semiconductor layer. Gate electrode is in flexible substrate.

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The basic and key characteristics of each transistor include the mobility of charge carriers. The carriers mobility in organic structures varies from one sample to another. Taking into account all characteristics (physical, electronic, temperature), the problem becomes very complex.

2. DEVELOPED ORGANIC TRANSISTORS CARRIERS MOBILITY MODEL

Temperature significantly affects the carriers mobility in organic transistors. Higher temperature usually leads to reduced mobility due to stronger thermal vibrations.

Basically, the effect of temperature depends on the transport mechanism. Usually two opposing processes are involved: firstly - enhanced thermal excitation of carriers which would increase mobility and secondly enhanced collisions and dislocations in the material which would decrease mobility. In most cases, the negative effects of thermal chaos are dominant, and thus results in a carriers mobility decrease with increasing temperature. In most organic semiconductors, that is the case - the negative influence of thermal vibrations (collisions and dislocations) is dominant, so with increasing temperature carrier mobility decreases.

The mobility dependence on temperature can be defined as:

$$\mu(T) = \mu_0 \cdot exp\left(-\left(\frac{T_C}{T}\right)^2\right) \quad (1)$$

where T is the temperature and Tc is the characteristic temperature.

Introducing energetic disorder σ, like in [1], the connection between the energetic disorder and the characteristic temperature can be expressed as:

$$kT_C = \frac{2\sigma}{3} \quad (2)$$

Combining expressions (1) and (2), the mobility dependence on temperature can be defined as:

$$\mu(\sigma, T) = \mu_0 \cdot exp\left(-\left(\frac{2\sigma}{3kT}\right)^2\right) \quad (3)$$

Introducing electric field, similar to [1], the analytical model for carriers mobility can be written. The new normal factor δ_N and lateral factor δ_L of the position disorder δ are now introduced. Secondly, the new parameter γ that depends on the geometry and structure of the active area of organic transistor, as well on the position of the transistor electrodes, is suggested:

$$\mu(\sigma, \Sigma, T, E) = \mu_0 \cdot exp\left(-\left(\frac{2\sigma}{3kT}\right)^2\right) \cdot exp\left(\zeta\left(\left(\frac{\sigma}{kT}\right)^2 - \left(\delta\left(1 - \gamma\frac{\delta_N}{\delta_L}\right)\right)^2\right)\sqrt{E}\right) \quad (4)$$

In the equation (4) ζ is the empirical constant typical $2{,}95 \times 10^{-4}$ $(cm/V)^{1/2}$.

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Taking into account the analysis conducted in [2], and the new consideration, the charge carriers transport is affected by the ratio between the normal and lateral components of the applied electric field.

$$\left(E - \frac{\beta \frac{E_N}{E_L}}{\frac{1}{E}}\right)^{\alpha} \quad (5)$$

In the last equation, E_L is the lateral component of electric field and E_N is the normal component of electric field. The value of the coefficient β depends on the structure and transistor electrodes position, and has a value of approx 0.1.

Now, the equation (4) becomes:

$$\mu(\sigma,\delta,T,E) = \mu_0 \cdot exp\left(-\left(\frac{2\sigma}{3kT}\right)^2\right) \cdot exp\left(\zeta\left(\left(\frac{\sigma}{kT}\right)^2 - \left(\delta\left(1-\gamma\frac{\delta_N}{\delta_L}\right)\right)^2\right)\sqrt{\left(E - \frac{\beta \frac{E_N}{E_L}}{\frac{1}{E}}\right)^{\alpha}}\right) \quad (6)$$

the parameter α, which depends on the geometry of the active area of the transistor, is approximately $0.95 < \alpha < 1.25$.

Proposed carriers mobility model can be incorporated in organic based transistor current – voltage characteristics model.

For:

$V_{DS} < V_{DSsat}$

$$I_{DS} = \mu(\sigma,\delta,T,E) \cdot \frac{\varepsilon_{sep}}{d_{sep}} \cdot \frac{W}{L} \cdot \left((V_{GS} - V_{th}) \cdot V_{DS} - \frac{1}{2} \cdot {V_{DS}}^2\right) \quad (7)$$

For:

$V_{DS} > V_{DSsat}$

$$I_{DS} = \frac{1}{2} \cdot \mu(\sigma,\delta,T,E) \cdot (V_{GS} - V_{th})^2 \quad (8)$$

In previous equations, V_{GS} is the gate to source voltage, V_{th} is the threshold voltage, V_{DS} is the drain to source voltage, d_{sep} is the separation layer width, W is the channel width and L is the channel length.

3. RESULTS

By using the proposed model, results for organic based transistors carriers mobility, for different temperatures and electric field values, are obtained. In the simulations, following values were used: the temperature T is in the range from 400K to 600K. The obtained results are shown in Figure 2.

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By using the proposed model, organic based transistor current-voltage characteristics can be obtained. The results are presented in Figure 3.

The calculations were performed for the following values: channel length L=25nm, channel width W=200nm, temperature T=300K, electric field $E=10^5$V/cm, vertical electric field $E_N=4.5\cdot10^3$V/cm, α=1.

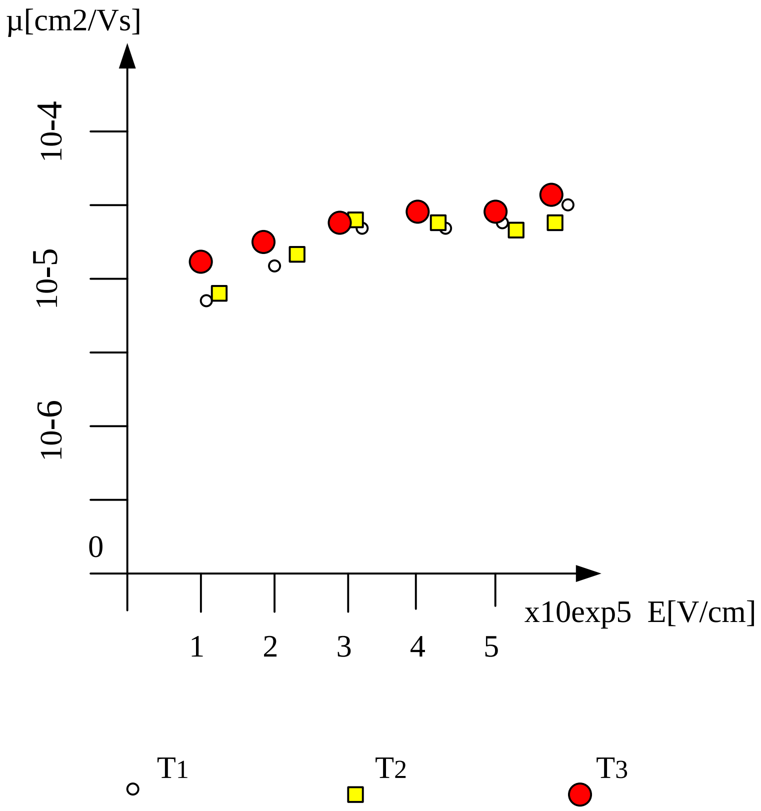

Figure 2. Organic based transistor carriers mobility versus electric field, for different temperatures (400K – 600K).

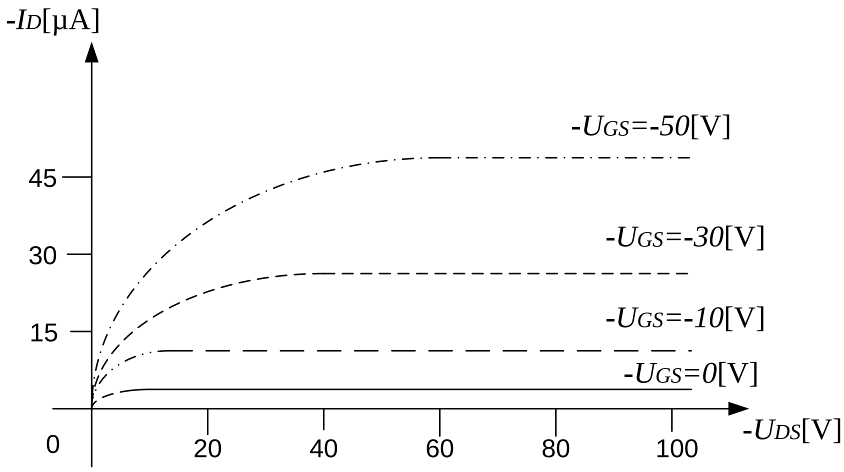

Figure 3. Organic based transistor current - voltage characteristics.

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4. CONCLUSIONS

In this paper, the new carriers mobility model of organic transistor is exposed. In the proposed model, the normal and lateral components of applied electric field, as well as the normal and lateral factors of the position disorder, are introduced. The new parameter γ that depends on the geometry and structure of the active area of organic transistor is proposed. The model also includes the influence of the temperature.

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