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MODELING OF LATERAL AND NORMAL ELECTRIC FIELD COMPONENTS IMPACT ON OFET'S CARRIERS MOBILITY

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Abstract In this paper, the new model that describes the influence of the lateral and normal components of the electric field on the charge carriers mobility in the OFET, is proposed. This model simultaneously includes the dependence of carrier mobility on temperature and trap concentration. The model is modular, so it can be easily upgraded and tested.

Keywords: Organic field effect transistor (OFET); carriers mobility model; lateral component of electric field; normal component of electric field.

1. INTRODUCTION

Electronic components based on organic compounds represent a new and special class compared to the standard and widely used ones made of inorganic semiconductor materials. They have special characteristics that directly affect the current conduction mechanisms, i.e. their behavior in electronic circuits. Research on organic components remains a significant challenge.

The advantages of organic based devices lie in the fact that they are flexible, easily bendable, light weight, cheap, compatible with widely distributed standard inorganic components [1 - 9].

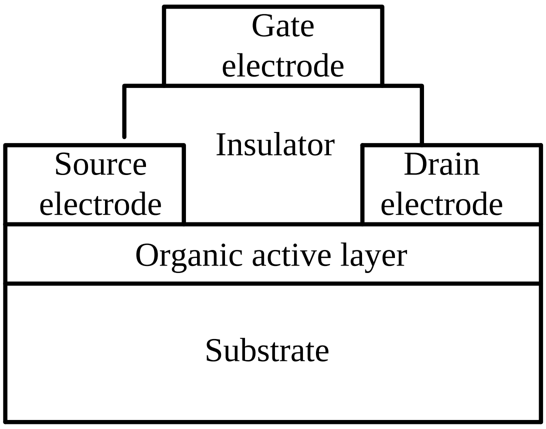

Figure 1. OFET with top gate position.

In Figure 1., cross sectional view of organic field effect transistor (OFET) with top gate position, is shown. OFET has organic based active layer. Source and drain electrodes are placed on organic semiconductor layer (like in standard MOSFET). Gate electrode is on the top, devided by the insulator layer from the active area. There are also other configurations that are used to realize these transistors. It is not easy to reproduce structure of organic based thin semiconductor layers. Thus, the carriers mobility in OFET structures varies from one sample to another. Taking into account geometric structure of OFET, the problem becomes even more complex.

2. SUGGESTED OFET CARRIERS MOBILITY MODEL

As stated in the introduction, compared to inorganic, the electronic characteristics of organic materials are less well researched. What is known is that the mobility of charge carriers in organic components is lower than that of inorganic electronic devices [4 - 6].

In the general case, the mobility of the carriers depends on several parameters, among which the temperature and the electric field stand out., so the following model is proposed in literature [7]:

$$\mu(E,T) = \mu(0,T) \cdot \left(1 - \frac{2 \cdot Q_e \cdot a}{K_p}\right)^{1/2} \cdot exp\left(\frac{4 \cdot Q_e \cdot a \cdot E}{\hbar \cdot \omega} \cdot tanh\left(\frac{\hbar \cdot \omega}{4 \cdot k \cdot T}\right)\right) \tag{1}$$

where E is the electric field, T is the temperature, Q_e is the electron charge, K_p is the polaron binding energy.

Already in this model, an improvement can be made by taking into account the correction factor related to the influence of the electric field, which was proposed in [1]:

$$\left(\frac{E - 0.79 \cdot E_N}{E}\right)^{\alpha} \tag{2}$$

where normal (vertical) electric field is marked as E_N, and the parameter α, which depends on the geometry of the active area of the transistor, is approximately $0.9 < \alpha < 1.1$.

By introducing the last in the previous expression, it is obtained:

$$\mu(E,T) = \mu(0,T) \cdot \left(1 - \frac{2 \cdot Q_e \cdot a}{K_p}\right)^{1/2} \cdot exp\left(\frac{4 \cdot Q_e \cdot a \cdot E \cdot \left(\frac{E - 0.79 \cdot E_N}{E}\right)^{\alpha}}{\hbar \cdot \omega} \cdot tanh\left(\frac{\hbar \cdot \omega}{4 \cdot k \cdot T}\right)\right) \tag{3}$$

However, this model also has its drawbacks. The concentration of dopants should be taken into account, as well as the concentration of traps, like in [3] and in the improved and upgraded version proposed in [1]:

$$\begin{aligned} \mu(E,T,N_{trap}) &= \\ &= \mu_0 \cdot \left(\frac{N_{trap}}{N}\right)^{-1/2} \cdot \left(1 - \frac{2 \cdot Q_e \cdot a}{K_P} \cdot E \cdot \left(\frac{E - 0.79 \cdot E_N}{E}\right)^{\alpha}\right)^{1/2} \cdot \\ &\cdot exp\left(\left(\frac{Qe \cdot a \cdot E \cdot \left(\frac{E - 0.79 \cdot E_N}{E}\right)^{\alpha}}{kT} - \left(\frac{T_0}{T}\right)^2 \right) \right) \end{aligned} \tag{4}$$

In the last equation, N is the concentration of molecules in the structure, N_{trap} is the trap concentration, a is the hopping distance.

A conclusion is reached by consideration: the movement of charge carriers is influenced by the ratio between the normal and lateral components of the applied electric field; secondly this ratio cannot always be taken with the same numerical weighting coefficient. Based on the above, following analytical expression could be suggested:

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

In the last equation, EL is the lateral component of electric field and and the value of the new coefficient β depends on the structure and has a value of approx 0.1.

Now, the proposed carriers mobility model is:

$$\mu\left(E,E_N,E_L,T,N_{trap}\right) = \\ = \mu_0\cdot\left(\frac{N_{trap}}{N}\right)^{-1/2}\cdot\left(1-\frac{2\cdot Q_e\cdot a}{K_P}\cdot E\cdot\left(\frac{E-\beta\cdot\frac{E_N}{E_L}}{E}\right)^{\alpha}\right)^{1/2}\cdot \\ \cdot exp\left(\left(\frac{Qe\cdot a\cdot\left(\frac{E-\beta\cdot\frac{E_N}{E_L}}{E}\right)^{\alpha}}{kT}-\left(\frac{T_0}{T}\right)^2\right)\right) \tag{6}$$

3. RESULTS

Using the proposed model, OFET carriers mobility, for different temperatures and electric field values, is obtained. For some parameters, following values were used: the hopping distance is assumed to be a=5nm, the polaron binding energy K_p=1.6·10^{-20}J, the temperature T in the range from 275K to 400K, the electric field E 250kV/cm, 500kV/cm, 750kV/cm. The obtained results are shown in Figure 2.

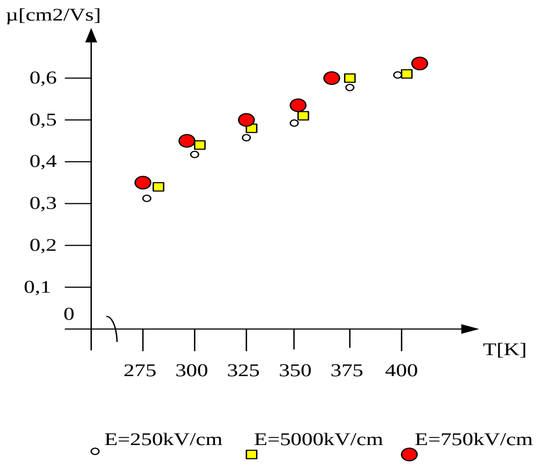

Figure 2. OTFT carrier mobility versus temperature and different electric field values.

Presented carriers mobility model can be incorporated in OFET current – voltage characteristics model, and thus these caracteristics can be obtained. OFET current - voltage characteristics are similar to those developed for inorganic Si MOSFETs. For:
$U_{DS} < U_{DSsat}$

$$I_{DS} = \mu(E, E_N, E_L, T, N_{trap}) \cdot \frac{\varepsilon_{ins}}{d_{ins}} \cdot \frac{W}{L} \cdot \left((U_{GS} - U_{th}) \cdot U_{DS} - \frac{1}{2} \cdot {U_{DS}}^2 \right) \tag{7}$$

For:
$U_{DS} > U_{DSsat}$

$$I_{DS} = \frac{1}{2} \cdot \mu(E, E_N, E_L, T, N_{trap}) \cdot (U_{GS} - U_{th})^2 \tag{8}$$

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

By using the proposed model, OFET current-voltage characteristics can be determined (calculated). It can be valid in the range -75V≤U_{GS}≤0V and -100V≤U_{DS}≤0V. The obtained results are presented in Figure 3.

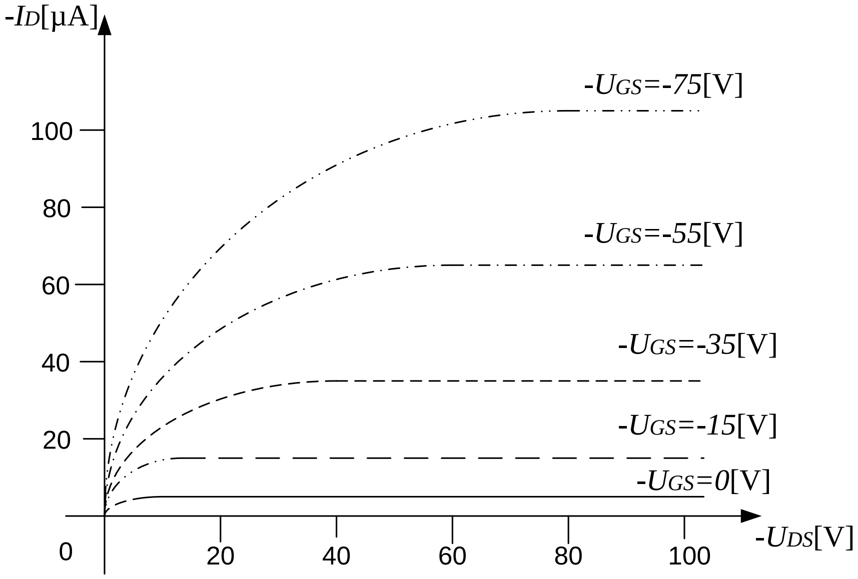

Figure 3. OTFT current - voltage characteristics.

4. CONCLUSION

In this paper, developed carriers mobility model for OFET is proposed. The model introduces the impact of the normal and lateral components of the applied electric field on the carriers mobility. The model also includes the influence of the value of "complete" electric field, temperature, trap concentration. The imact of OFET geometry is also considered by using specific coefficient. In other words, the main characteristics of organic based transistors are taken into account and therefore the presented model can be widely used.

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