The paper has been shown the results of the study of the parameters of organic light-emitting structures based on the SPICE (Simulation Program with Integrated Circuit Emphasis) model studies. A SPICE model of diode structure has been developed, which is implemented in the form of a substitution scheme based on the basic components of the simulator. This model can be extended by introducing additional components of the substitution scheme, which provides higher accuracy in representing the structure specifics. Graphical results of researches of the model of OLED structure at the change of internal parameters have been presented. The obtained data well represent the parameters of real structures and are characterized by a fairly effective adaptation to the experimental data of specific samples.

Keywords: light emitting structures, model, SPICE modeling.

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I. SPICE model of the OLED structure

The developed model is based on one of the traditional SPICE substitution schemes (equivalent schemes) of diode structures, in particular, Level 1.
Standard SPICE or Level 2 PSpice. If necessary, provide higher accuracy represent the specific structure of the OLED, the model is supplemented by other components, which, in particular, provide higher flexibility in shaping the CVC OLED structure and its thermal characteristics. The SPICE model substitution diagram is shown in Fig. 1 in addition to diode D contains a series RS and parallel RL resistance, as well as two dependent on the bias mode and capacitance current - CJ and CD (hereinafter according to SPICE syntax model parameters are written without indexes). Serial resistance RS describes the resistance of the electrodes and layers of the passive structure of OLED, and parallel RL - parasitic current seepage through the structure of ohmic (linear) nature. The CJ component describes the barrier and the CD diffusion capacitance of the diode structure. The first of them CJ determines the dynamic characteristic at the reverse bias of the diode and depends on the voltage on the diode, and the second CD - the transient process at direct bias and is determined by the diode current due to the accumulation effect in the structure of non-basic charge carriers.

During SPICE model specification diode structures using a set of parameters that describe their CVC, performance, and temperature dependence of these characteristics. The main parameters of the model of diode structures [4] are: IS (Saturation current) - saturation current; N (Emission coefficient) - emission coefficient; ISR (Recombination current) - recombination current; IKF (High-injection "knee" current) - current of transition to a high level of injection; BV (Reverse breakdown "knee" voltage) - reverse breakdown voltage; RS (Series resistance) - series ohmic resistance of the structure; RL (Junction Leakage Resistance) - parallel ohmic impregnation resistance; TT (Transit time) - time of flight of carriers; CJ0 (Zero-bias junction capacitance) - capacity at zero offset; VJ (Junction potential) - barrier potential; M (Junction grading) - barrier potential gradient; EG (Energy gap eV) - bandwidth; XTI (Temperature exponent for IS) - exponential saturation current coefficient; RF (Flicker noise coefficient) - linear flicker noise coefficient; AF (Flicker noise exponent) - exponential flicker noise coefficient; TIKF (IKF linear temperature coefficient) - linear temperature coefficient IKF; TBV1 (BV linear temperature coefficient) - linear temperature coefficient BV; TBV2 (BV quadratic temperature coefficient) - quadratic temperature coefficient BV; TRS1 (RS linear temperature coefficient) linear temperature coefficient RS; TRS2 (RS quadratic temperature coefficient) RS quadratic temperature coefficient; T_MEASURED (Measured temperature Celsius), T_ABS (Absolute temperature), T_REL_GLOBAL (Relative to current temperature), T_REL_LOCAL (Relative to AKO model temperature) - temperatures in degrees Celsius.

CVC diode structure that describes the dependence of the current ID on the voltage VD, a SPICE model is defined as [%1]:

\[
I_D = I_S \left( \frac{V_D}{N \cdot \varphi_T} \right) ^ k \cdot T \cdot q,
\]

where: \( k \) - Boltzmann constant, \( q \) - electron charge, \( T \) - thermodynamic temperature.

The above barrier and diffusion capacitances of the diode are determined by the equations:

\[
C_J = \frac{C_{J0}}{1 + \left( \frac{V_D}{V_J} \right) ^ 2};
\]

\[
C_D = \frac{I_D \cdot TT}{\varphi_T}.
\]

The model is supplemented with resistive components if necessary. This makes it possible to more accurately represent the temperature dependences of the resistance of the layers of the passive structure of OLED. For this purpose, the extended model of the resistor which includes the following parameters is used: R (Resistance multiplier) - the multiplier of resistance; CP (Parallel capacitance) - parallel capacity; LS (Series inductance) - series inductance; TC1 (Linear temperature coefficient) linear temperature coefficient; TC2 (Quadratic temperature coefficient) - quadratic coefficient; TCE (Exponential temperature coefficient) - exponential coefficient; NM (Noise multiplier) - noise multiplier; T_MEASURED (Measured temperature, Celsius) - measuring temperature in °C; T_ABS (Absolute temperature, Celsius) - the absolute temperature in °C.

According to the SPICE syntax, the temperature is denoted by TEMP. In addition, it is important to note that all temperature values, including T_ABS (absolute temperature), are not absolute thermodynamic temperatures, but Celsius temperature for the whole circuit. The resistance function of the resistor to temperature is determined by the quadratic and exponential dependences:

\[
R(TEMP) = R(T_{NOM}) \cdot K_T \cdot K_{TE};
\]

\[
K_T = 1 + TC1 \cdot (T - T_{NOM}) + TC2 \cdot (T - T_{NOM})^2;
\]

\[
K_{TE} = 1.01^{T_{Celsius} - T_{NOM}}.
\]

The TNOM value is the nominal temperature value, which in SPICE models corresponds to 27°C, that is, approximately 300 K of absolute thermodynamic temperature. When specifying the model of a certain component, it is possible to change the temperature of this component relative to the temperature of its base model. Use the concept of AKO model clone (an acronym for A Kind Of) with the corresponding

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Fig. 1. Scheme of substitution of SPICE model of OLED structure.
temperature values: $T_{\text{REL\_GLOBAL}}$ (Relative to current temperature, Celsius) - relative temperature in °C and $T_{\text{REL\_LOCAL}}$ (Relative to AKO model temperature, Celsius) - relative temperature of the cloned model in °C. In this specification version, the actual temperature of the component (Device operating temperature) is determined by one of three values: $T_{\text{ABS}}$, $T_{\text{REL\_LOCAL}} + T_{\text{ABS}}$ (of AKO parent), $T_{\text{REL\_GLOBAL}} + \text{TEMP}$ (global temperature, °C). The SPICE specification window of the resistor model and an example of temperature dependences of resistance $R$ (RDT) for a certain set of temperature coefficients are presented in Fig. 2, and examples of temperature dependences of absolute values of current $\text{ABS}$ (I (DOLE)) of the diode on temperature - in Fig. 2, b.

II. Study of the OLED structure model

Research CVC OLED semiconductor structure by changing certain parameters is shown in Fig. 3 (RL =
The notation $V(D)$ corresponds to the value of the voltage on the diode, and $\text{ABS}(I(DOLE))$ — the absolute values of the current, where DOLE — the model name of the OLED structure (according to SPICE syntax, the name of the diode model must begin with the letter D — DOWN). The designation $VS$ corresponds to the transition voltages from the barrier to the predominantly ohmic current-carrying mechanism.

You can see that the CVC received generally well represent actual specifics OLED structures and are characterized by the ability to adapt sufficiently effective under these experimental data specific models.

The temperature dependence of the studied structure is reflected by the dependence of the absolute values of the current $\text{ABS}(I(DOLE))$ and its steepness (Fig. 5, a).

For greater clarity, the temperature dependence can be represented as a derivative (slope) of the temperature, denoted by $DD(A)$, where $A$ is the studied value. This is shown in Fig. 5, b, where $DD(\text{ABS}(I(DOLE)))$ — the slope of the current function $\text{ABS}(I(DOLE))$.

The study of the dynamic characteristics of the SPICE model of OLED structure is to establish the time of flight of TT carriers (Transit time) taking into account the values of barrier CJ and diffusion CD capacity. $2E-6$ (sec) are presented in Fig. 6 and Fig. 7.

The simulation results reflect the transients in the OLED structure and can be used to determine the mobility of charge carriers by extraction in the case of linear voltage rise (CELIV) [4-6]. The use of this method allows the calculation of technological parameters, in particular, to determine the film thickness of
The problem of building a SPICE model for studying the parameters of OLED structures is substantiated and solved. The model is based on the basic elements of the simulator in accordance with the generalized equivalent scheme that reflects the internal structure. For modeling results that match the actual parameters of the structures set up data structures diode SPICE model describing the CVC, performance, and temperature dependence of these characteristics.

The mathematical study of the measurement process CVCs and shows the value and impact of the barrier $C_j$ Cd capacity diffuse transition. Calculations of the magnitude of thermal influence on the parameters of the elements are presented, which in the software specification of the model are included.

The CVC characteristics of OLED structures are obtained and the magnitude of the drift caused by the change in the value of $R_L$ under the influence of temperature is established. The possibility and example of research of temperature dependence of absolute values of current and its steepness are shown.

The possibilities of using the developed model for research of dynamic characteristics of the organic structure are shown. The results of such modeling can be used to determine the mobility of the charge carriers of the semiconductor junction and the film thickness of the test sample.

**Conclusions**

The problem of building a SPICE model for studying the parameters of OLED structures is substantiated and solved. The model is based on the basic elements of the simulator in accordance with the generalized equivalent scheme that reflects the internal structure. For modeling results that match the actual parameters of the structures set up data structures diode SPICE model describing the CVC, performance, and temperature dependence of these characteristics.

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The proposed approach to the implementation of the model provides for the possibility of expanding its functionality by expanding the detail of the structure with a corresponding expansion of the equivalent scheme, which will provide higher accuracy of the results.

The model can be successfully used for the construction of power management OLED which uses dynamic control of the CVC and potential adjustments.


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Моделювання органічних світловипромінювальних структур

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В роботі приведені результати дослідження параметрів органічних світловипромінюючих структур на основі SPICE (Simulation Program with Integrated Circuit Emphasis) моделей досліджень. Розроблено SPICE модель діодної структури, яка реалізована у вигляді схеми заміщення на основі базових компонентів симулятора. Дану модель може бути розширена шляхом введення додаткових компонентів схему заміщення, що забезпечує вищу точність представлення специфіки структури. Представлено графічні результати досліджень моделю OLED структур при зміні внутрішніх параметрів. Отримані дані добре представляють параметри реальних структур та характеризуються достатньо ефективною адаптацією до експериментальних даних конкретних відгуків.

Ключові слова: світловипромінювальні структури, модель, SPICE моделювання.