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Selected Problems Related to the Durability of Organic Structures (OLED)

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Abstract: ***Organic light emitting diodes (OLED) are surface light sources, wherein the thickness of the active layer - polymer - is generally not greater than 500 nm. The rapid development of OLED technology dates back to 2000 years. In 2002, the first Active Matrix OLED panels, and in 2007. It demonstrated a prototype TV made in OLED technology. The most important disadvantage of the displays produced by the OLED technology is that the stability of such organic materials is not very high. OLED emitting structures covered by an aging processes that depend on a number of factors and cause a systematic decrease in the luminance of the emitted light. The paper proposes a mathematical model describing the process of aging in OLED structures, which satisfactorily describes the aging of such structures and allows the calculation of time, after which the luminance of the emitted light reaches 50% of its initial value (contractual service life).***

Keywords: Organic light-emitting diodes, aging process, electroluminescence.

1. Introduction

The phenomenon of electroluminescence in organic materials was observed for the first time in 1950 by the Frenchman André Bernanos, who along with his colleagues from the University of Nancy noticed weak luminescence in a layer of organic material (a derivative of acridine - acridine orange), when applied to the high alternating voltages (AC) [1-3].

Electroluminescence was observed by Martin Pope in 1963 in the other organic material. Electroluminescence in polymer films was discovered for the first time by Roger Partridge at the National Physical Laboratory in the UK. The structure tested by him was composed of a layer of polymer (*n*-vinylcarbazole), having a thickness of 2.2 microns, which was disposed between two metallic electrodes with voltage applied to them. Described structure was patented in 1975.

First discoveries of electroluminescence in organic materials and research in the 60s and 70s of the 20th century boded little hope for their use in practice. This situation has however changed after publications by Ching W. Tang and Steven Van Slyke.
One of the first organic compound, which revealed a phenomenon of light emission under the influence of an external electric field, was *p*-phenylene vinylene. It was found that the conductive polymer under the influence of an applied voltage can emit green or yellow-green light.

First working monochrome OLED display appeared in 1996, produced by Cambridge Display Technology, but it had a low efficiency of lighting. It was only in 1998 when organic, emitting green light OLED diodes, characterized by sufficient efficiency of conversion of electrical energy into light, were developed.

The rapid development of OLED technology dates back to 2000, when a Taiwanese company Ritek Display Technology began a construction of the first factory producing monochrome, lighting in green SMOLED (Small Molecule OLED) displays for mobile phones.

In 2002, the first AMOLED (Active Matrix OLED) panels with active controlling matrix-developed by the Kodak company, appeared. In October of 2007 the Sony company demonstrated a prototype of a TV made in the OLED technology.

In the last few years, leading global companies have shown production, lightweight and large-size TVs with excellent picture quality. In 2016, LG showed the LG OLED 65EG 960V TV with a 65-inch screen diameter and 4K resolution (3840 x 2160 pixels). The same company in 2018 presented the LG OLED E8 TV, which is available in two sizes - 55 and 65 inches, with 4K resolution, refresh rate at 120 Hz, with a new Alpha 9 processor [3, 9].

2. Aging Processes in Aging Structures

Organic light emitting diodes are usually produced through applying transparent substrate (a film or glass) to the transparent conducting electrode - the anode (ITO layer - Indium Tin Oxide), on which special transport layer for holes is produced; the next layer is an organic *n*-type semiconductor, and a second polymeric layer - the organic *p*-type semiconductor (emissive layer)- is applied on it. The next layer is a special transport layer for electrons and the last layer is the upper electrode (cathode, usually Al + Ca).

Applying a voltage to such a structure causes the flow of electrons from the cathode to the anode, so that electrons will move from the cathode to the emissive layer, while the anode will charge electrons from the conductive layer, so electron holes will move from the anode to the emissive layer.

In the moment of polarization of the connector towards conduction, emissive layer is negatively charged, while the conductive layer becomes positive, since it has an excess of positively charged holes. Electrostatic interaction attracts electrons and holes which recombine with each other. This is done in the area of the so-called emissive layer, because holes in organic semiconductors are more mobile than electrons. Upon recombination an electron moves to a lower energetic level, which is accompanied by the emission of electromagnetic radiation in the visible spectrum.

Degradation of the OLED structures, occurring during operation, is caused by both external factors and internal. External factors can be controlled and largely eliminated (including the effect of humidity) through the use of hermetization or store them in an atmosphere of inert gas.

The internal factors, and physical mechanisms causing degradation of the OLED structures, are not yet fully understood [3-5]. As one of the main reasons is considered to occur in the functional organic layers irreversible changes, resulting in excessive growth of inter alia the current density in the connector and the temperature rise. This leads to thermal aging of equipment and to gradually reduce the intensity of the light [3-9].

As already mentioned, a very important problem in the use of OLED structures, the current is low stability, who the estimated on 10,000 to 30,000 hours (in the laboratory gave higher values), we therefore should continue to conduct research on their durability. Publications describing the luminance declines due to aging can be found in the scientific literature [3-8]. In one of them, we adopted the assumption that the luminance (L) of OLED structures, over time t, is reduced according to the exponential relationship [5]:

$$L / L_0 = \exp[(-t/\tau)\beta] \qquad (1)$$

where L_0 is the initial value of the luminance (luminance immediately after the formation of the structure OLED) $ß$ - is a parameter constant, and τ - is the time constant of the process of decline in luminance. In such a model, to determine the contractual working time (after which the luminance reaches 50% of its initial value), specify the parameters $ß$ and τ. These parameters have different values, when it changes the value of the current flowing through the OLED structure, as well as the temperature changes. From literature, as well as studies it is known that the time constant τ process of reducing the luminance over time is dependent on the intensity of the current flowing through the OLED structure, and also the temperature.

In this study, it was assumed that the relative value of the luminance (L / L_0) varies in time in accordance with an exponential relationship, expressed by the formula:

$$L(t) / L_0 = a_1 \exp(-t/\tau_1) + a_2 \exp(-t/\tau_2) \qquad (2)$$

where: $L(t)$ is the instantaneous luminance value, L_0 is the luminance at the initial moment and a_1 is a numerical factor associated with the first degradation process of luminescence centers, - τ_1 is the time constant of this process, while a_2 it is an analogous factor associated with the second degradation process, and τ_2 is the time constant of this process, where:

$$a_1 + a_2 = 1. \qquad (3)$$

The values of time constants and decrease with the increase of the current I flowing through the OLED structure and with the increase in temperature ΔT (- temperature rise relative to room temperature), because the aging process of structures is accelerated due to the increase in their operating temperature. It can be written in the form:

$$\tau_1 = \tau_{01} / (1 + b_1 I + c_1 \Delta T) \text{ and } \tau_2 = \tau_{02} / (1 + b_2 I + c_2 \Delta T) \qquad (4)$$

where τ_{01} and τ_{02} are respectively time constants at room temperature, in the absence of voltage applied, for the first and second process, b_1 and c_1 and b_2 and c_2 are constant parameters for the first and second process, respectively.

As it results from formulas 2, 3 and 3, in the discussed model it was assumed that mainly two processes are responsible for the degradation process and the decrease in luminance value. Based on the measurements of the dependence of luminance on the amount of current flowing, shown in Figure 1, and the luminance depending on the temperature (Figure 2), the initial data was obtained to determine the values of parameters present in the discussed model.

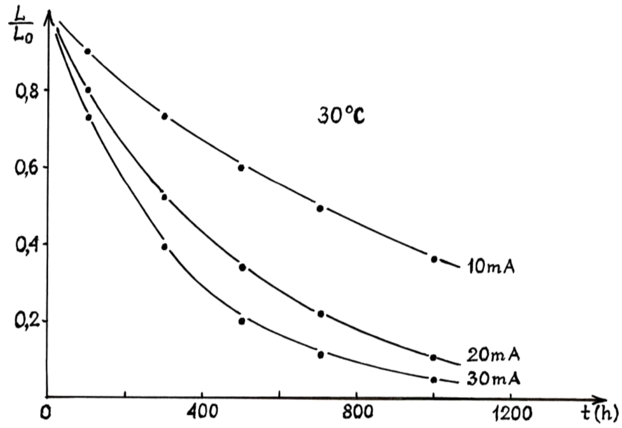

Figure 1: Relative luminance according to the time for the three temperatures of the OLED structure

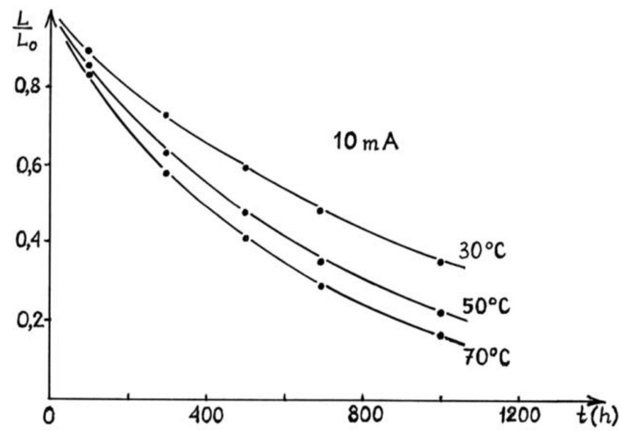

Figure 2: Relative luminance according to the time period (hours) for the tree currents flowing through the OLED structure.

Measurements were carried out for the following OLED structure: ITO (150 nm)/HTL (p-doped hole transport layer) 90 nm/EBL 8 nm/EML (green doped) 30 nm/HBL 8 nm/ETL (n-doped electron transport layer) 25 nm/Al 200 nm. Where EBL is the electron blocking layer, EML is the emissive layer, and HBL is the hole blocking layer. The samples were fabricated using a standard vacuum deposition process.

From the obtained data identified three value of relative luminance (L / L0) for different times, but for the known values of current and at different temperatures.

On the basis of equations (2), (3) and (4) calculated the values of parameters:
$a_1 = 0.14$; $b_1 = 0.9$ mA^{-1}; $c_1 = 0.1$ ^{0}C^{-1}; $\tau_0 = 95$ h;
$a_2 = 0.86$; $b_2 = 1.85$ mA^{-1}; $c_2 = 0.25$ ^{0}C^{-1}; $\tau_0 = 3050$ h;

These values were calculated for the OLED structure described. Are fixed parameters only for this structure. For other structures can take other values.

The proposed model is particularly useful for the displays OLED. It allows easy calculation of the effective time display, using the formula (2), for the condition: $L / L_0 = 0.5$.

These calculations can be performed for different values of the current I flowing through the OLED structure and for different operating temperatures.

In the simulations show that the proposed mathematical model satisfactorily describes the process of aging OLED structures for temperatures of near room temperature (10 to 80 °C) and for a current density not exceeding 50 mA / cm^2. All values calculated on the basis of this model, they do not differ by more than 10% than the measured values.

3. Summary

Organic light emitting diodes (OLED - Organic Light Emitting Diode) light sources are surface, wherein the light emission mechanism different from the mechanism of emission of inorganic LED structures. OLEDs characterized luminance order 1000 - 3000 cd / m^2, and the production technology makes it possible to obtain a light emitting layer with a large area and good homogeneity of the radiation.

They can also emit white light with high color rendering and also a fairly high energy efficiency in the range of 25 lm / W to 80 lm / W, wherein envisaged in the near future, the increase in these values.
The organic light-emitting diodes are also characterized by many advantages, of which the most important may include the following:

- In the production of organic material can be applied to the appropriate flexible and lightweight substrate, which enables the production of roll-up displays, screens sewn into clothing and lighter laptops.
- OLEDs have large-scale color and brightness than the structure of the LCD because OLED pixels directly emit light, which is not retained by the polarizing filters, as in the case of LCD displays.

They require no backlight, so that the contrast may be up 1 000 000: 1. This reduces power consumption when displaying a dark image. No illumination also reduces the cost of production and operation.

The color point of the image on the OLED display remains correct even when the viewing angle is close to 90 ° relative to the normal vector. By using a transparent, flexible substrate, the display can display an image on both sides, and thus the viewing angle is virtually unlimited.

OLED displays are also much shorter reaction time compared to the LCD monitor, which has a response time of 2-12 milliseconds, while the OLED - even about 0.01 milliseconds.

Displays produced based on OLED-s are among the newest types of displays and it is to those whose construction is currently developing most rapidly.

The biggest problem of the OLEDs is not very long period of time of their operation, which is currently estimated at 20,000 hours (in laboratory tests has achieved a higher value), and is significantly shorter than the time inorganic LEDs.

The proposed mathematical model presented in this study, satisfactorily describes the processes of aging OLED structures and enables easy calculation of working time such a structure. It allows you to assess the sustainability of organic light-emitting diodes based on field tests in the initial stage.

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