Active and Passive Elec. Comp., 1998, Vol. 21, pp. 309–319
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Printed in India.

ELECTROLUMINESCENT DISPLAY WITH PICTURE STORAGE

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(Received 20 April 1998; In final form 4 September 1998)

Memory cells, composed of PC and EL thin film elements, have been utilized to designing of a display with picture storage. Such a picture storing electroluminescent display may prove competitive with used now picture storing methods in the digital form. A mathematical model suitable for analysing the properties of a PC-El system is proposed and the preparation of PC and EL thin film elements is described. For a single pixel the dependences of output signal on the time for various values of amplitude and frequency of supplying voltage are presented.

Keywords: Optoelectronics; thin films; display

1. INTRODUCTION

The increased utilization of various optoelectronic systems has generated interests in optoelectronic circuits with photoconducting (PC) and electroluminescent (EL) thin film devices. They are frequently applied as logical gates, amplifiers of weak light signals [1] and because of the optical feedback in such systems, they can work as memory cells [2, 3].

Memory cells, composed of PC and EL thin film elements, can be utilized, among others, to designing of a display with picture storage.

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Electroluminescent displays of such type are rated as active, *e.g.*, light emitting displays.

An electroluminescent display is generally in the shape of a matrix, in which the elements of a picture are formed in the points of intersection of horizontal (lines) and vertical (columns) strip electrodes. Using such configuration of electrodes it is possible to address $m \times n$ elements of the picture (pixels) by means of "m" lines and "n" columns. The excitation of the pixels may be realized by successive applying of voltages to the electrodes of lines and columns [4]. Such excitation of display's elements shows a number of disadvantages, which can be avoided using the excitation of particular pixels by a light beam. With an adequate structure of systems with single pixels utilizing PC and EL elements a display which will store the pictures can be obtained.

An individual pixel, *i.e.*, separate "point" of projected picture, can be obtained by suitable connection of three photoconducting (PC) and two electroluminescent (EL) elements (Fig. 1). The whole display composed of optional number of pixels, is supplied with sinusoidal voltage so selected as the voltage on every of pixels to be sufficient to produce an emission from the electroluminescent element. Owing to the optical feedback between EL_1 element and PC_1 element, the PC_1-EL_1 system composed of these elements can be a bistable system, *i.e.*,

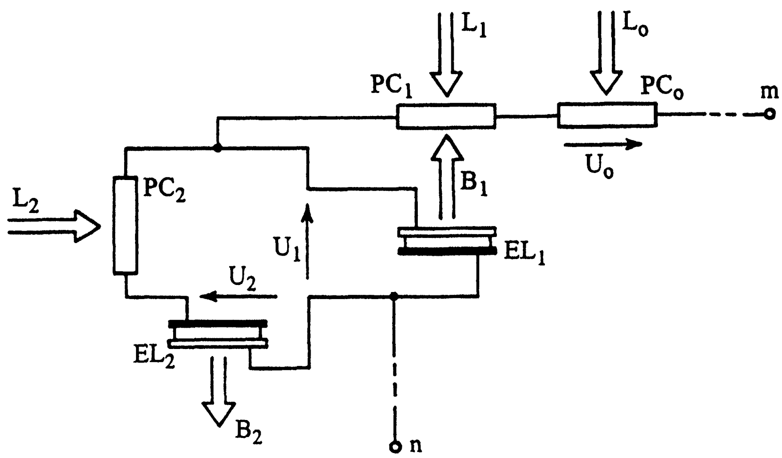

FIGURE 1 PC–EL system with individual pixel.

can be in the "ON"-state or in the "OFF"-state and then the second EL element will emit a light signal corresponding only to an individual pixel when the PC_1-EL_1 system is in the "ON"-state.

The theoretical analysis shows that a PC_1-EL_1 system with optical feedback may be a bistable system on condition that the feedback coefficient β will have a value higher than β_{LIM}. As demonstrated in carried out investigations, the limiting value β_{LIM} depends on the amplitude of the voltage supplying the PC_1-EL_1 system as well as on its frequency [5, 6].

If a PC_1 device is illuminated with an input signal L_1, then at the output of the bistable PC_1-EL_1 system a signal B_1 appears as the light emitted from the electroluminescent device EL_1 which additionally illuminates the PC_1 device. When the output signal B_1 does not fall to zero, in spite of "switching off" the input signal L_1, then the PC_1-EL_1 system is in the on-state, that is to say it remembers that previously it had been illuminated with the input signal L_1.

Assuming the PC_1-EL_1 system to be in the on-state, the application of the second input signal L_2, illuminating the PC_2 device, causes the appearance of the output signal B_2 in the form of light emitted from the electroluminescent device EL_2.

As the PC_2-EL_2 system is one without optical feedback, the removal of the input signal L_2 results every time in the decay of the output signal B_2 to a value not far from zero.

2. THEORETICAL CONSIDERATION

A mathematical model suitable for analysing the properties of a PC–EL system is proposed using the circuit shown in Figure 1.

The instantaneous value of the current i_1^{PC} through a PC_1 element is given [7] by the formula:

$$i_1^{PC} = u_1^{PC}(G_{01} + G_1^{PC})/(1 + \omega^2\tau_1^2), \tag{1}$$

where u_1^{PC} is the instantaneous value of the voltage on the PC_1 element, G_{01} is the dark conductance of the PC_1 element, G_1^{PC} is the instantaneous value of conductance of PC_1 element illuminated with a light of illumination L, ω is angular frequency of the alternating sinusoidal voltage supplying the PC–EL system and τ_1 is average relaxation time of PC_1 element. The illumination L is given by the expression:

$$L = L_1 + \beta B_1, \tag{2}$$

where L_1 is the instantaneous value of illumination of PC_1 element by an external light source, B_1 is the instantaneous value of luminance of electroluminescent cell EL_1 and β is the optical feedback coefficient of PC_1 element with EL_1 element.

The instantaneous value of conductance G_1^{PC} may be calculated [8] by solving the equation:

$$\frac{d}{dt} G_1^{PC} = a_1 (L_1 + \beta B_1) - \frac{G_1^{PC}}{\tau_{g1}}, \tag{3}$$

where a_1 is a constant for the PC_1 element, and τ_{g1} is the photoconductivity growth time for this element.

The instantaneous value of luminance B_1 can be given [9] by the formula:

$$B_1 = B_{01} \exp(-\gamma_1 t) \exp(-b_1 / \sqrt{|u_1|}), \tag{4}$$

where B_{01}, γ_1 and b_1 are constant values for EL_1 element, and u_1 is the instantaneous value of the voltage across this element.

The instantaneous value of the current i_1^{EL} through an EL_1 element is given by:

$$i_1^{EL} = C_1^{EL} \frac{d}{dt} u_1 + G_1^{EL} u_1, \tag{5}$$

where G_1^{EL} and C_1^{EL} are the leakage conductance and the capacitance for EL_1 element respectively.

The instantaneous value of the current i_0^{PC} through a PC_0 element is given by the formula:

$$i_0^{PC} = u_0 (G_0 + G_0^{PC}) / (1 + \omega^2 \tau_0^2), \tag{6}$$

where u_0 is the instantaneous value of the voltage on the PC_0 element, G_0^{PC} is the instantaneous value of conductance of PC_0 element illuminated with a light of illumination L_0, G_0 is dark conductance of PC_0 element, and τ_0 is average relaxation time of this element.

Since $i_1^{PC} = i_0^{PC}$ and $u_1^{PC} = u - u_1 - u_0$, where u is the instantaneous value of the voltage supplying the PC–EL system, the equation:

$$(u - u_1 - u_0)\frac{G_0 + G_1^{PC}}{1 + \omega^2\tau_1^2} = u_0\frac{G_0 + G_0^{PC}}{1 + \omega^2\tau_0^2} \tag{7}$$

is obtained.

The instantaneous value of conductance G_0^{PC} may be calculated by solving the equation:

$$\frac{d}{dt}G_0^{PC} = a_0\, L_0 - \frac{G_0^{PC}}{\tau_{g0}}, \tag{8}$$

where a_0 and τ_{g0} are the constant and the photoconductivity growth time for PC_0 element respectively.

The instantaneous value of the current i_2^{PC} through a PC_2 element is given by the formula:

$$i_2^{PC} = u_2^{PC}(G_{02} + G_2^{PC})/(1 + \omega^2\tau_2^2), \tag{9}$$

where u_2^{PC} is the instantaneous value of the voltage on the PC_2 element, G_2^{PC} is the instantaneous value of conductance of PC_2 element illuminated with a light of illumination L_2, G_{02} is dark conductance of the PC_2 element and τ_2 is average relaxation time of this element.

The instantaneous value of conductance G_2^{PC} may be calculated by solving the equation:

$$\frac{d}{dt}G_2^{PC} = a_2\, L_2 - \frac{G_2^{PC}}{\tau_{g2}}, \tag{10}$$

where a_2 and τ_{g2} are the constant and the photoconductivity growth time for PC_2 element respectively.

The instantaneous value of luminance B_2 of electroluminescent element EL_2, can be given by the formula:

$$B_2 = B_{02}\exp(-\gamma_2 t)\exp(-b_2/\sqrt{|u_2|}), \tag{11}$$

where B_{02}, γ_2, b_2 are constant values for EL_2 element, and u_2 is the instantaneous value of the voltage across this element.

The instantaneous value of the current i_2^{EL} through an EL_2 element is given by:

$$i_2^{EL} = C_2^{EL} \frac{d}{dt} u_2 + G_2^{EL} u_2, \tag{12}$$

where G_2^{EL} and C_2^{EL} are leakage conductance and the capacitance for EL_2 element, respectively.

Since: $i_2^{PC} = i_2^{EL}$, $i_1^{PC} = i_1^{EL} + i_2^{PC}$ and $u_2^{PC} = u_1 - u_2$, the equations

$$C_2^{EL} \frac{d}{dt} u_2 + G_2^{EL} u_2 + u_2 \frac{G_{02} + G_2^{PC}}{1 + \omega^2 \tau_2^2} = u_1 \frac{G_{02} + G_2^{PC}}{1 + \omega^2 \tau_2^2}, \tag{13}$$

and

$$(u - u_1 - u_0) \frac{G_{01} + G_1^{PC}}{1 + \omega^2 \tau_1^2} = C_1^{EL} \frac{d}{dt} u_1 + G_1^{EL} u_1 + C_2^{EL} \frac{d}{dt} u_2 + G_2^{EL} u_2 \tag{14}$$

are obtained.

Solving the set of Eqs. (3), (4), (7), (8), (10), (11), (13) and (14), the time dependence of the luminances B_1 and B_2 of the elements EL_1 and EL_2 were computed. The computations were carried out for the case, when the $PC_1 - EL_1$ system was in the state "switched on", and when this system was in the state "switched off".

3. EXPERIMENTS AND RESULTS

The PC devices can be prepared as gate-type systems on a glass substrate [3]. The photoconductive layer was a CdS film doped with copper and chlorine and evaporated under vacuum at a pressure 0.007 Pa. Special purity undoped cadmium sulphide was used. It was evaporated from an alundum crucible heated by a tungsten wire resistor. The temperature of the source was in the range of 900°C to 950°C. The distance of the substrate from the source was 12 cm. During evaporation the temperature of the substrate was held constant at 150°C. CdS films were simultaneously doped with Cu and Cl, and recrystallized by heating the films whilst embedded in a CdS powder that had previously been doped with Cu and Cl. The recrystallization was carried out at 550°C in air for 30 min. The thickness of CdS(Cu, Cl) films was in the range of 6 to 14 μm. A metallic indium layer, deposited by vacuum evaporation, formed the upper electrode.

The electroluminescent device was a thin film capacitor produced by the vacuum evaporation of copper-, chlorine- and manganese-doped ZnS. The evaporation was carried out under the presssure of 0.01 Pa from an alundum crucible heated to about 1100°C onto the substrate, which was placed 8 cm apart from the source and heated to 200°C. The obtained ZnS(Cu, Cl, Mn) films were recrystallized by heating in a vacuum for 30 min at 300°C. The thickness of ZnS(Cu, Cl, Mn) films was in the range of 0.6 to 1.3 μm.

The lower transparent conducting electrode was tin-doped In_2O_3, obtained by the reactive cathode sputtering of 90%In – 10%Sn alloy on a glass substrate [3], while the upper electrode was a vacuum-evaporated thin aluminium film.

A PC – EL system shown in Figure 1 was supplied with sinusoidal voltage. The input signal was in the shape of rectangular light pulses illuminating the photoconducting elements and the output signal was the luminance of the electroluminescent element EL_2.

The theoretical analysis has shown that a $PC_1 - EL_1$ system with optical feedback may be a bistable system [5] on condition that the feedback coefficient β will have a value higher than β_{LIM}. As demonstrated in carried out investigations [6] the limiting value β_{LIM} depends on the amplitude and frequency of the voltage supplying the PC – EL system (Fig. 2).

In Figure 3 the dependences of luminance B_1 amplitude on various values of input signal L_1 by fixed duration of this signal ($\Delta t = 0.5$ ms) and fixed parameters of supplying voltage ($U_0 = 280$, 420 and 560 V, $f = 500$ Hz) are presented. For the input signal ($L_1 < L_{LIM}$) the output signal B_1 vanishes with time. For $L_1 = L_{LIM}$ the second pulse B_1 has the same amplitude as the first pulse, it is then a boundary case for $PC_1 - EL_1$ system. For $L_1 > L_{LIM}$ – the second pulse of signal B_1 is higher than the first pulse, thus even at switched off L_1 signal the system $PC_1 - EL_1$ will be in the ON state.

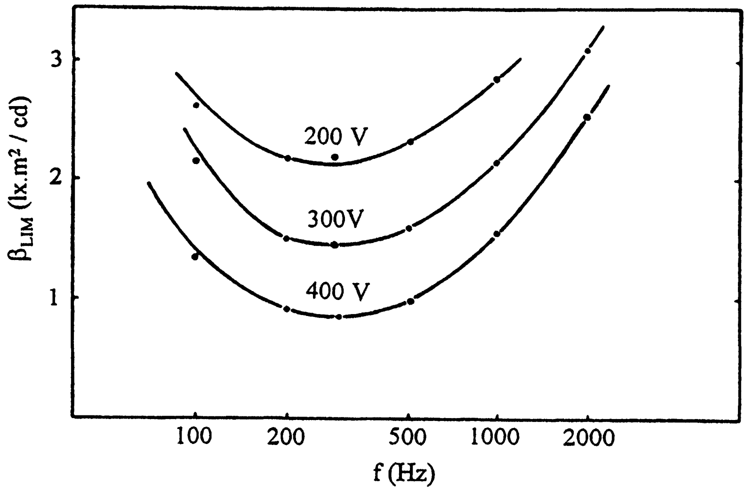

FIGURE 2 Dependences of the coefficient β_{LIM} on the frequency for three values of supplying voltage.

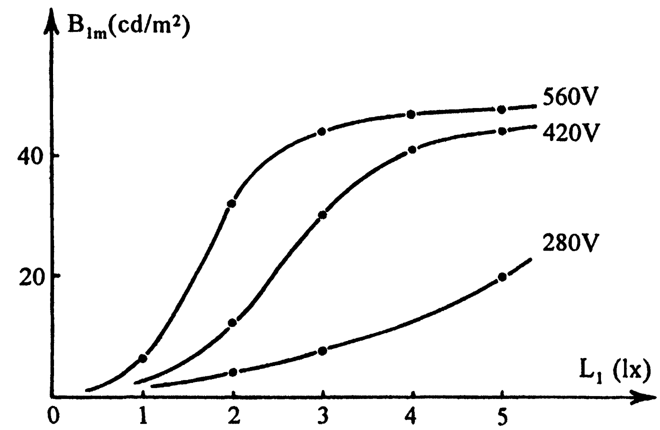

FIGURE 3 Dependences of luminance B_l amplitude on various values of input signal L_l.

Figure 4 shows the dependence of luminance B_2 on the time for applied voltage of amplitude 420 V at frequencies 200, 500 and 1000 Hz, at illumination of the PC elements with light pulses of $L_1 = 20$ lx and duration $t_0 = 0.5$ ms, (both $L_2 = 20$ lx and $L_0 = 20$ lx).

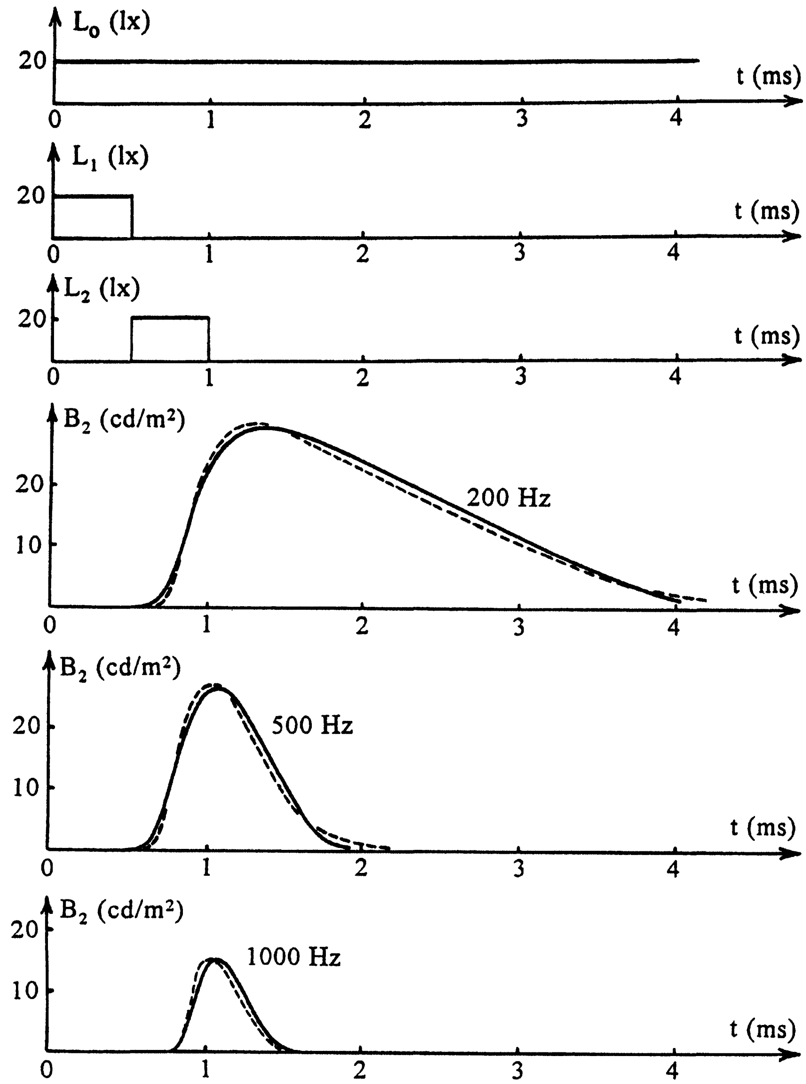

FIGURE 4 Dependence of luminance B_2 on the time for applied voltage of amplitude 420 V at frequencies 200, 500 and 1000 Hz.

In Figure 5 the dependence of B_2 on the time for frequency 500 Hz and three values of supplying voltage amplitude (280, 420 and 560 V) are presented.

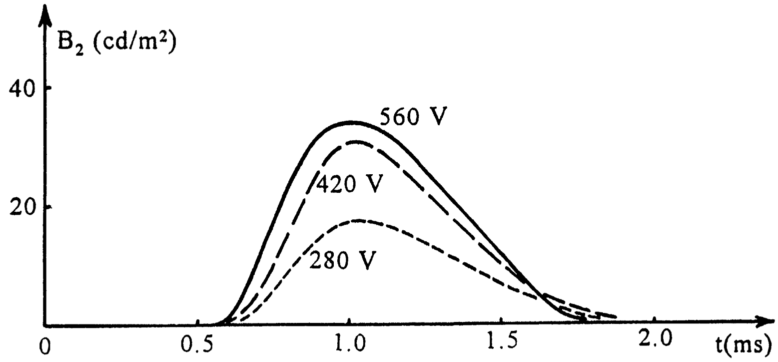

FIGURE 5 Dependence of B_2 on the time for frequency 500 Hz and three values of supplying voltage amplitude (280, 420 and 560 V).

In many cases can arise the necessity of "switching out" of a memory cell, being in the "ON" state. It is possible owing to the utilization of PC_0 photoelement, because the switching off of the light signal L_0 for a sufficient length of time will result in considerable decrease of the voltage on the EL_1 element and the luminance B_1 of this element will fall in practice to zero. Thus, wanting signal L_1, the system PC_1-EL_1 will be in the "OFF"-state.

Erasing the whole pictures stored by the display can be realized for the best by switching off for an adequately long time all supplying voltage.

4. CONCLUSIONS

It results from the investigations carried out by the authors, that thin film photoconducting and electroluminescent elements can be applied in constructing of electroluminescent display excited with a light beam, and in particular of pictures storing displays. In the constructing of such displays an important part is played by single PC_1-EL_1 systems, which can be transposed into the "ON"-state on condition that they are bistable systems.

The illumination with a light beam L_1 of adequate elements PC_1 of whole display will cause that adequate PC_1-EL_1 systems will be in the

"ON"-state. For the display shows us a stored picture, composed of many pixels, one should illuminate to this end all the elements PC_2 of whole display with the light of intensity L_2. Then only these electroluminescent cells, which are connected with adequate PC_1-EL_1 systems, being in the "ON"-state, will emit the light, showing the whole stored picture. The showing time of stored picture will be depending on the duration of signal L_2, playing the role of an information read-out signal.

The picture storing electroluminescent display presented in this work may prove – in many cases – competitive with used now picture storing methods in the digital form and their locating in the computer store, since so stored pictures occupy substantial part of this store.

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