Active and Passive Elec. Comp., 1996, Vol. 19, pp. 111-117
Reprints available directly from the publisher

DYNAMIC CHARACTERISTICS OF A THIN FILM OPTOELECTRONIC MEMORY SYSTEM

Z. PORADA
Institute of Electrical Engineering, Technical University, Warszawska 24, 31-155 Kraków (Poland)

E. SCHABOWSKA-OSIOWSKA
Department of Electronics, Academy of Mining and Metallurgy, Al, Mickiewicza 30, 30-059 Kraków (Poland)

(Received July 7, 1995; in final form September 1, 1995)

1. INTRODUCTION

Among more and more numerous publications devoted to various kinds of optoelectronic systems, a number of articles describing systems with photoconductive (PC) and electroluminescent (EL) elements can be found[1–4].

Thin film electroluminescent cells and photoconducting elements with optical feedback are interesting because of their possible application in optoelectronic memory systems.

In its simplest form, the PC-EL system is obtained by series connection of a photoconducting element with an electroluminescent cell. This system is supplied with a sinusoidal voltage with fixed amplitude and frequency. The input signal is in the shape of rectangular light pulses illuminating the PC element, and the output signal is the luminance of the light emitted from the EL cell. Part of the output signal is directed to the input, and thus an optical feedback is produced in the system.

For sufficiently high values of feedback coefficient, the PC-EL system is bi-stable in character[5, 6]. Simple, two-element PC-EL systems with optical feedback can be used, for example, in optoelectronic memory systems.

A diagram of an optoelectronic memory system is presented in Fig. 1. When the photoconducting element PC_1 is illuminated with a light pulse, the voltage drop on the element is low and almost all the voltage U is applied to the electroluminescent cell EL_1, causing light emission. Owing to the optical feedback, the EL_1 cell illuminates the element PC_1, so that the PC_1–EL_1 system is in the *on* state. The PC_2–EL_2 system is in the *off* state and does not emit light until the element PC_2 is illuminated. Then the electroluminescent cell EL_2 emits light and thereby indicates that the PC_1–EL_1 system is in the *on* state. When the EL_1 cell is not emitting light, despite illumination of the element PC_2, there is no output pulse from the cell EL_2. The PC_1–EL_1 system is then in the *off* state.

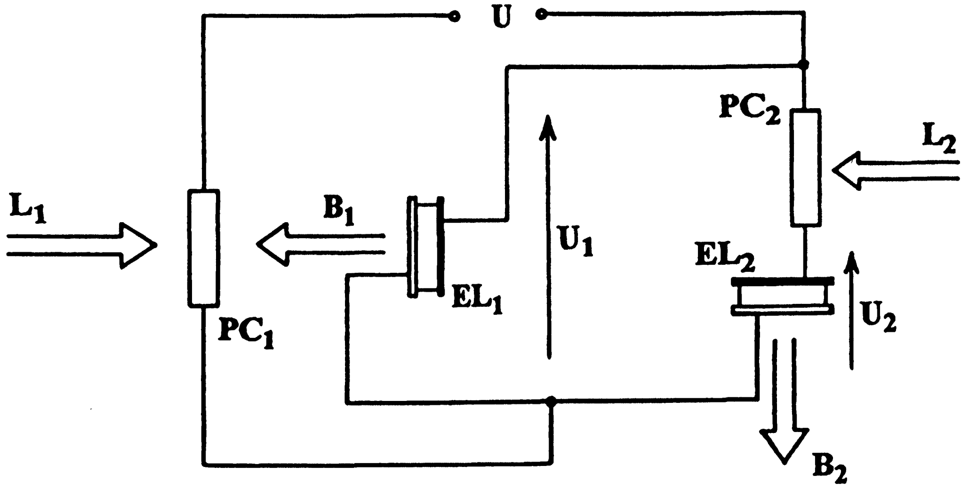

FIGURE 1 Diagram of an optoelectronic memory system.

2. THEORETICAL MODEL

A theoretical model suitable for analyzing the dynamic characteristics of a thin film optoelectronic memory system is proposed using the circuit shown in Fig. 1.

PC-EL memory systems are supplied with an alternating sinusoidal voltage:

$$U = U_0 \sin(\omega t + \varphi), \tag{1}$$

where U_0 is the amplitude, ω is the angular frequency, and φ is the initial phase.

The instantaneous value of voltage U_1 on the electroluminescent cell EL_1 can be described by the equation:

$$\frac{d}{dt} U_1 = \frac{1}{C_{EL1}} [(U - U_1)(G_{01} + G_1) - (U_1 - U_2)(G_{02} + G_2)] \tag{2}$$

where C_{EL1} is the capacitance of the EL_1 cell, G_{01} is the "dark" conductance of the PC_1 photoconductive element, G_1 is the instantaneous value of the conductance of the PC_1 element, G_{02} and G_2 are the "dark" conductance and instantaneous value of the conductance of the PC_2 element, respectively, and U_2 is the instantaneous value of voltage on the EL_2 cell.

The instantaneous value of conductance G_1 can be expressed by the equation[7]:

$$\frac{d}{dt} G_1 = a_1(L_1 + \beta B_1) - \frac{G_1}{L_1} \tag{3}$$

where L_1 is the instantaneous value of external illumination of the PC_1 element (input signal), B_1 is the instantaneous value of the luminance B_1 emitted by the EL_1 cell, β is the optical feedback coefficient of the PC_1 element with the EL_1 cell, a_1 is a constant parameter for the given PC_1 element and τ_1 is the photoconductivity rise time for this element.

The luminance B_1 can be expressed by the formula given by Alfrey and Taylor[8]:

$$B_1 = B_{01} \exp(-\gamma_1 t) \exp(\frac{-b_1}{\sqrt{|U_1|}}) \tag{4}$$

where B_{01}, γ_1, and b_1 are constant parameters for given a EL_1 electroluminescent cell.

The instantaneous value of voltage U_2 on the EL_2 electroluminescent cell can be described by the equation:

$$\frac{d}{dt} U_2 = \frac{1}{C_{EL2}} [(U_1 - U_2)(G_{02} + G_2)] \tag{5}$$

where C_{EL2} is the capacitance of EL_2.

The instantaneous value of conductance G_2 of the PC_2 element can be expressed by the equation:

$$\frac{d}{dt} G_2 = a_2 L_2 - \frac{G_2}{\tau_2} \tag{6}$$

where L_2 is the instantaneous value of external illumination of the PC_2 element (input signal), a_2 is a constant parameter for the given PC_2 element, and τ_2 is the photoconductivity rise time for this element.

The input signal in the shape of luminance B_2 of the light emitted by the EL_2 electroluminescent cell can be expressed also by the formula given by Alfrey and Taylor:

$$B_2 = B_{02} \exp(-\gamma_2 t) \exp(\frac{-b_2}{\sqrt{|U_2|}}) \tag{7}$$

where B_{02}, γ_2, and b_2 are constant parameters for given EL_2 cell.

Solving the set of equation (1)–(7) one can calculate the dynamic characteristics of a memory system containing PC and EL elements.

3. EXPERIMENTAL DETAILS AND RESULTS

A thin film PC-EL optoelectronic memory element was made by vacuum evaporating photoconductive and electroluminescent layers. The photoconductive element (Fig. 2) was prepared as a sandwich-type system on a Corning 7059 glass substrate.

The first layer was a transparent electrode of tin-doped In_2O_3, obtained by the reactive cathode sputtering of 90% In–10% Sn alloy. The second layer was a photoconductive CdS film[9] doped with copper and chlorine and evaporated under vacuum at a pressure 6.7×10^{-3} Pa.

The electroluminescent cell (Fig. 2), was a thin film capacitor with an average thickness of 0.85 μm produced by the vacuum evaporation of copper-, chlorine- and

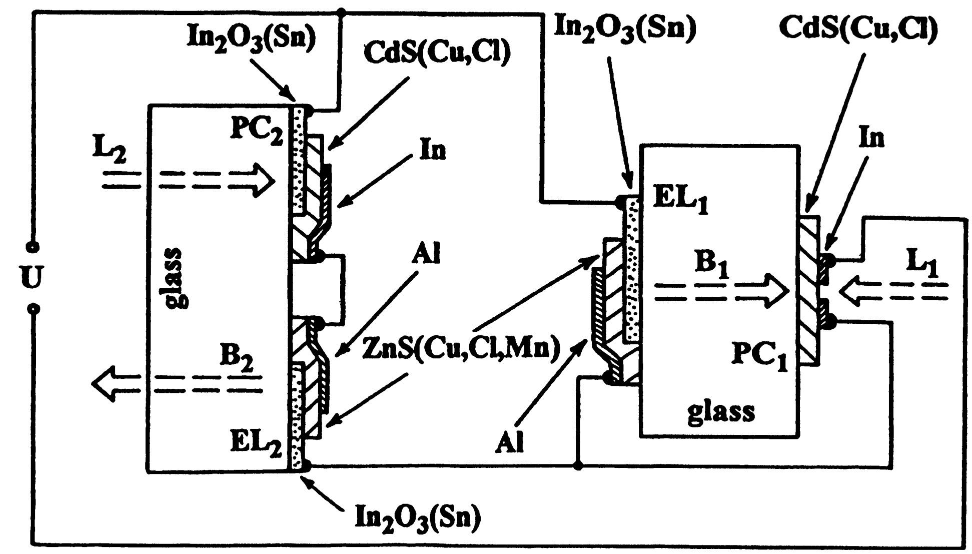

FIGURE 2 Arrangement of the thin film PC-EL systems of an optoelectronic memory element.

manganese-doped ZnS[10]. The lower transparent conducting electrode was tin-doped In_2O_3 on a glass substrate, while the upper electrode was a vacuum-evaporated thin aluminum film.

The elements PC_1 and PC_2 as well as EL_1 and EL_2 were prepared in the same technological processes, to ensure the same values of their parameters.

The experimental values of the parameters of the photoconductive element and electroluminescent cell were found to be as follows:

$C_{EL1} = C_{EL2} = 3 \times 10^{-9}\,F$
$G_{01} = G_{02} = 7 \times 10^{-9}\,\Omega^{-1}$
$\tau_1 = \tau_2 = 0.6 \times 10^{-3}\,s$
$a_1 = a_2 = 8.3 \times 10^{-4}\,\Omega^{-1}.1x^{-1}.s^{-1}$
$b_1 = b_2 = 17\,V^{1/2}$
$B_{01} = B_{02} = 200\,cd.m^{-2}$
$\gamma_1 = \gamma_2 = 600\,s^{-1}$

and

$\beta = 0.5\,lx.m^2.cd^{-1}$.

Dynamic characteristics of an optoelectronic memory system were measured for supplying this system with voltage of amplitudes: 280, 420, and 560 V and for frequencies 100, 200, 500, and 1000 Hz.

In Fig. 3, the dependences of luminance B_1 on the time for supplying voltage of amplitude 420 V and frequencies 100, 200, 500, and 1000 Hz and in Fig. 4 the dependence of luminance B_2 on the time for the same parameters of supplying voltage are presented.

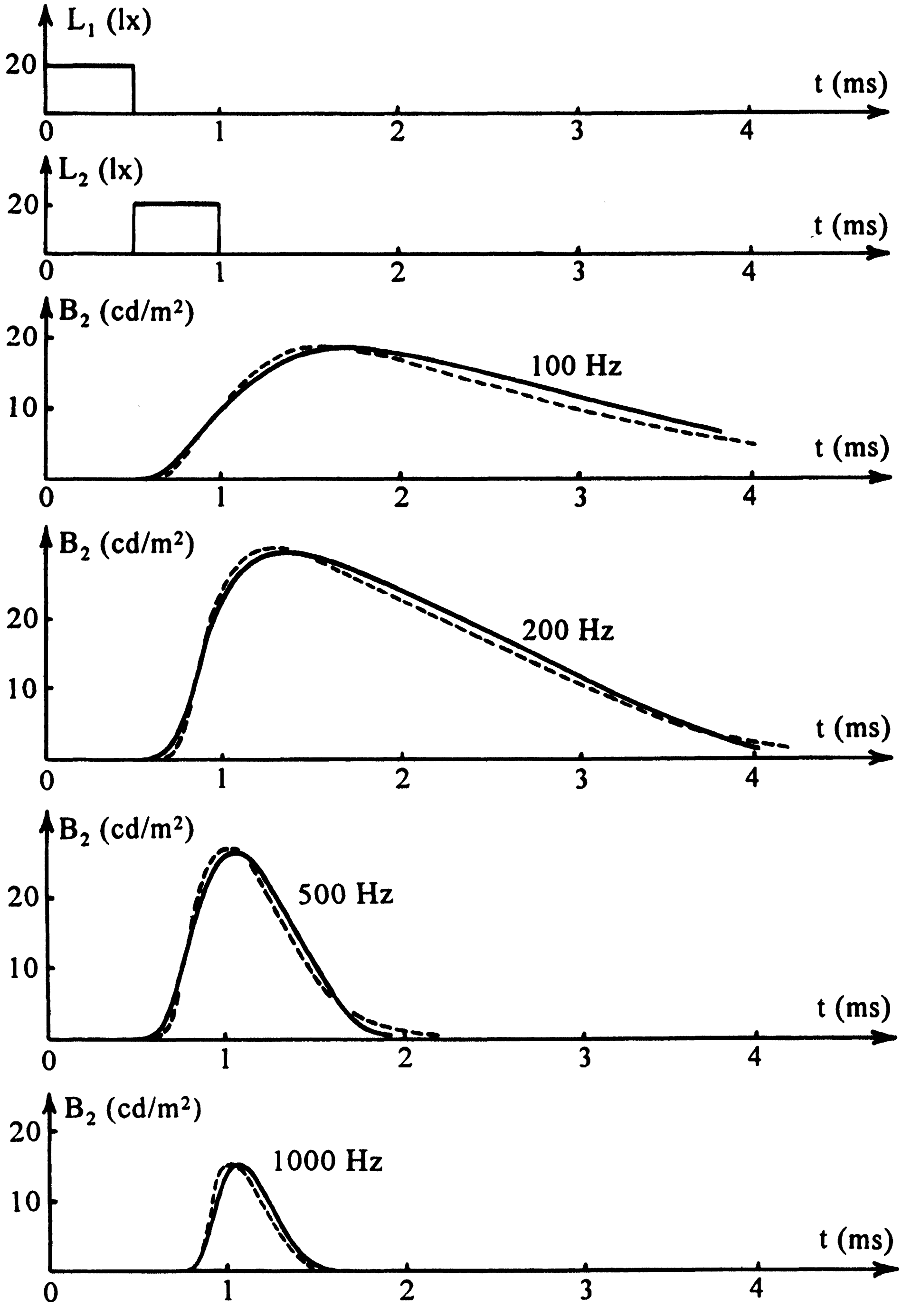

FIGURE 4 Dependences of luminance B_2 on time for U_0 420 V and frequencies 100, 200, 500 and 1000 Hz. - - - measured values, --- calculated values.

In Fig. 5 the time dependences of luminance B_1 and B_2 for frequency 500 Hz and three values of supplying voltage amplitude (280, 420, and 560 V) are presented.

4. CONCLUSIONS

Both the analysis of the proposed theoretical model and the measurements have shown that the maximum values of luminances B_1 and B_2 depend on the amplitude as well as on the frequency of voltage supplying the investigated memory system. As can be seen from Figs 3 and 4, maximum values of luminances B_1 and B_2 for frequencies 200 and 500 Hz are higher than for frequencies 100 and 1000 Hz. From this fact, the limiting value of the optical feedback coefficient β_{LIM} depends on the

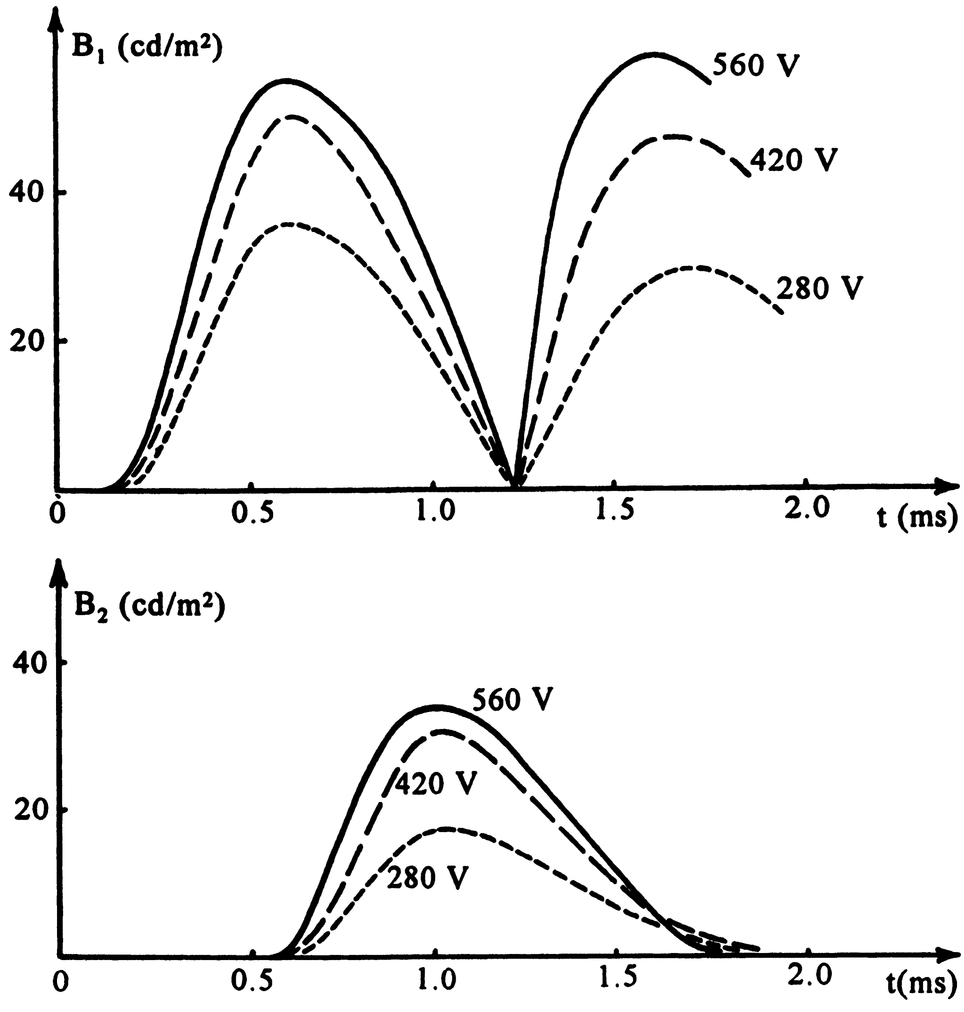

FIGURE 5 Dependences of luminances B_1 and B_2 on time for frequency 500 Hz and U_0 280, 420 and 560 V.

frequency and amplitude of the supplying voltage and reaches a minimum for the frequency of about 300 Hz[11]. Thereby the conditions of optical feedback for frequencies 200 and 500 Hz in the investigated system are more advantageous than for frequencies 100 and 1000 Hz.

The increase of the amplitude of the supplying voltage results also in an increase of the maximum luminances B_1 and B_2 (Fig. 5). Moreover, one observes an earlier appearance of the maximum for higher amplitudes of supplying voltage. It results also from the dependence of β_{LIM} coefficient on the amplitude of supplying voltage.

All measured dynamic characteristics for the thin film optoelectronic memory system showed a good conformity with the characteristics calculated on the base of the proposed theoretical model.

REFERENCES

1. T.I. Coutts (ed.), Active and Passive Thin Film Devices, Academic Press, New York 1978.
2. H.K. Henisch, Electroluminescence, Pergamon Press, Oxford 1962.
3. L.L. Kazmerski (ed.), Polycrystalline and Amorphous Thin Films and Devices, Academic Press, New York 1980.
4. Z. Szepesi, Thin film PC-EL sandwich type image intensifiers, Thin Solid Films *13*, 397 (1972).
5. Z. Porada, Thin Solid Films *109*, 213 (1983).
6. Z. Porada and E. Schabowska-Osiowska, Active Passive Elec.Comp. *13*, 151 (1988).
7. Z. Porada, E. Schabowska-Osiowska, Thin Solid Films *164*, 411 (1988).
8. G.F. Alfrey and J. B. Taylor, Br. J. Appl. Phys., *4*, 44S (1955).
9. Z. Porada and E. Schabowska, Thin Solid Films *66*, L55 (1980).
10. Z. Porada and E. Schabowska, J. Lumin. *21*, 129 (980).
11. Z. Porada, Thin Solid Films *109*, 213 (1983).