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PC-EL TYPE THIN FILM OPTOELECTRONIC MEMORY SYSTEM

Z. PORADA
Institute of Electrical Engineering and Electronics, Technical University, Warszawska 24, 31-155 Kraków (Poland)
E. SCHABOWSKA-OSIOWSKA AND T. KENIG
Department of Physics and Electron Technology, Institute of Electronics, Academy of Mining and Metallurgy, Al. Mickiewicza 30, 30-059 Kraków (Poland)
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1. INTRODUCTION

PC-EL type thin film systems with optical feedback are interesting because of their possible application in optoelectronic logical systems.

In the simplest version the PC-EL system was obtained by series connection of a photoconducting element (PC) with an electroluminescent cell (EL). Such a system was supplied with a sinusoidal voltage with fixed amplitude and frequency. The input signal was in the shape of rectangular light pulses illuminating the PC element, and the output signal—the luminance of the light emitted from the electroluminescent cell (EL). A part of the output signal was directed to the input, thus an optical feedback occurred in the system.

For sufficiently high values of feedback coefficient the investigated PC-EL system was of a bi-stable character[1,2]. Simple, two-element PC-EL systems with optical feedback can be utilized among others in optoelectronic memory elements.

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 voltage U is imposed to the electroluminescent cell EL_1, causing its luminance. Due to the optical feedback the electroluminescent cell illuminates the PC_1 element, i.e., the PC_1-EL_1 system is in the state "switched on". On the other hand, the PC_2-EL_2 system is "switched off" and doesn't emit a light signal as long as the PC_2 element is not illuminated.

2. THEORETICAL CONSIDERATIONS

A mathematical model suitable for analysing the properties of a PC-EL memory system is proposed using the equivalent circuit shown in Fig. 2.

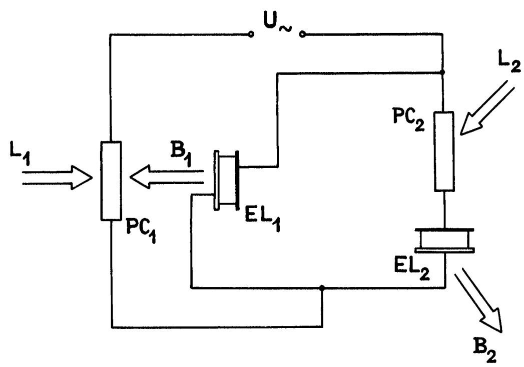

FIGURE 1 Diagram of an optoelectronic memory system

The admittance Y_{EL} of electroluminescent cells EL_1 and EL_2 (assuming, that $Y_{EL} = Y_{EL_1} = Y_{EL_2}$) is described by the formula

$$Y_{EL} = G_{EL} + j2\pi fC_{EL}, \tag{1}$$

where f is the frequency of the alternating sinusoidal voltage supplying the PC-EL memory system, G_{EL} is the leakage conductance of the electroluminescent cell and C_{EL} is the capacitance of the cell.

The admittance Y_{PC} of photoconductive elements PC_1 and PC_2 (assuming, that $Y_{PC} = Y_{PC_1} = Y_{PC_2}$) is given by the formula[3]

$$Y_{PC} = G_0 + \frac{g_1 L_{TOT}}{1 + (2\pi f\tau)^2} + j2\pi fC_{PC} \tag{2}$$

where G_0 is the "dark" conductance of the photoconductive element, g_1 and τ are parameters that are constant for a given photoconductive element, C_{PC} is the ca-

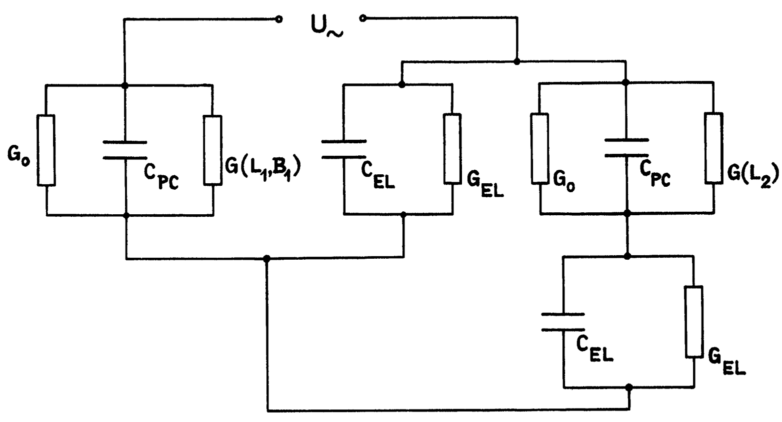

FIGURE 2 Equivalent circuit of a PC-EL system

pacitance of the photoconductive element, and L_{TOT} is the total illumination of the photoconductive element.

For a PC_1-EL_1 system with optical feedback

$$L_{TOT} = L_1 + \beta B_1, \tag{3}$$

where L_1 is the external illumination (input signal), β is a constant determined by geometry and by the degree of spectral overlap of the electroluminescent cell (EL_1) and the photoconductive element (PC_1), and B_1 is the luminance of the electroluminescent cell (EL_1).

For a PC_2-EL_2 system without optical feedback $L_{TOT} = L_2$, where L_2 is the external illumination (second input signal).

Alfrey and Taylor's formula[4] was used to describe the luminances B_1 and B_2:

$$B_1 = B_0 \exp(-\gamma/f) \exp\{-b/\sqrt{U_{EL_1}}\} \tag{4}$$

and

$$B_2 = B_0 \exp(-\gamma/f) \exp\{-b/\sqrt{U_{EL_2}}\}, \tag{5}$$

where B_0, γ and b are constant parameters for given EL_1 and EL_2 electroluminescent cells,

$$U_{EL_1} = \left| \frac{Y_{PC_1}}{Y_{PC_1} + Y_{EL_1} + \dfrac{Y_{PC_2} \cdot Y_{EL_2}}{Y_{PC_2} + Y_{EL_2}}} \right| U_0 \tag{6}$$

and

$$U_{EL_2} = \left| \frac{Y_{PC_2}}{Y_{EL_2} + Y_{PC_2}} \right| U_{EL_1}, \tag{7}$$

where U_0 is the amplitude of the voltage supplying the memory system.

For real PC-EL systems as well as for the frequencies not higher than 5000 Hz, three additional simplifying assumptions are usually fulfilled:

$$C_{PC} \ll C_{EL}, \ (C_{EL} = C), \ 2\pi f C_{EL} \gg G_0, \ 2\pi f C_{EL} \gg G_{EL} \text{ and } (2\pi f \tau)^2 \ll 1.$$

Then the dependence of the average value B_1 of the luminance on the external intensity L_1 and L_2 of illumination can be expressed as follows:

$$B_1 = B_0 \exp(-\gamma/f) \exp\left\{ -\frac{b}{\sqrt{U_0}} \left[x_1^2 + \left(\frac{x_2}{G_0 + g_1(L_1 + \beta B_1)} \right)^2 \right]^{1/4} \right\} \tag{8}$$

and

$$B_2 = B_0 \exp(-\gamma/f) \exp\left\{ -\frac{b}{\sqrt{U_0}} \left[x_3 \left\{ x_1^2 + \left(\frac{x_2}{G_0 + g_1(L_1 + \beta B_1)} \right)^2 \right\} \right]^{1/4} \right\} \tag{9}$$

where

$$x_1 = 1 + \frac{(2\pi fC)^2}{[G_0 + g_1(L_1 + \beta B_1)]^2 + (2\pi fC)^2},$$

$$x_2 = 2\pi fC + \frac{2\pi fC(G_0 + g_1L_2)^2}{(G_0 + g_1L_2)^2 + (2\pi fC)^2},$$

and

$$x_3 = \frac{(G_0 + g_1L_2)^2}{(G_0 + g_1L_2)^2 + (2\pi fC)^2}.$$

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. 3) 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

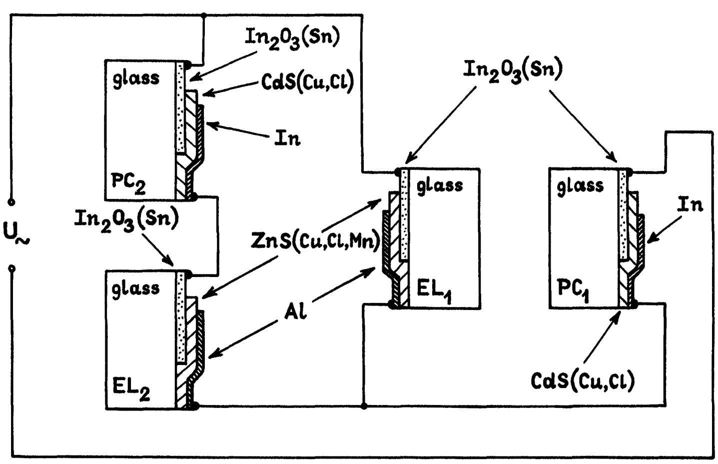

FIGURE 3 Arrangement of the thin film PC-EL systems of an optoelectronic memory element

photoconductive CdS film[5] doped with copper and chlorine and evaporated under vacuum at a pressure of 6.7×10^{-3} Pa.

The electroluminescent cell (Fig. 3), was a thin film capacitor with an average thickness of 0.85 μm produced by the vacuum evaporation of copper-, chlorine- and manganese-doped ZnS[6]. The lower transparent conducting electrode was tin-doped In_2O_3 on a glass substrate, while the upper electrode was a vacuum-evaporated thin aluminium film.

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

G_0	$8 \times 10^{-9}\ \Omega^{-1}$
g_1	$2.38 \times 10^{-7}\ lx^{-1}\Omega^{-1}$
τ	3.1×10^{-5} s
C_{PC}	6.5×10^{-11} F
b	$16.09\ V^{1/2}$
γ	$951\ s^{-1}$
B_0	$104\ cd.m^{-2}$
C_{EL}	2.8×10^{-9} F
G_{EL}	$7.4 \times 10^{-8}\ \Omega^{-1}$

and

β $0.78\ lx.m^2cd^{-1}$.

Figure 4 shows the spectral distribution of the electroluminescence for the ZnS(Cu, Cl, Mn) layer and the spectral response of the CdS(Cu, Cl) photoconductive layer.

The theoretical analysis shows that a PC_1-EL_1 system with optical feedback may be a bi-stable system on the condition that the feedback coefficient β will have a value higher than β_{LIM}[7].

Results from previous investigations[2,7] show that the limiting value β_{LIM} depends on the frequency of voltage supplying the PC_1-EL_1 system (Fig. 5).

If a PC_1 element will be illuminated with an input signal L_1, then at the output of the bi-stable PC_1-EL_1 system a signal B_1 will appear in the shape of the light emitted from the electroluminescent cell EL_1, which additionally will illuminate the PC_1 element. When the output signal B_1 will not fall to zero, in spite of switching off the input signal L_1, then the PC_1-EL_1 system will be in the state "switched on", that is to say it will have a memory it was previously illuminated with the input signal L_1.

In Fig. 6 the dependence of the output signal B_1 on the frequency of voltage supplying the PC_1-EL_1 system for various amplitudes of this voltage is presented

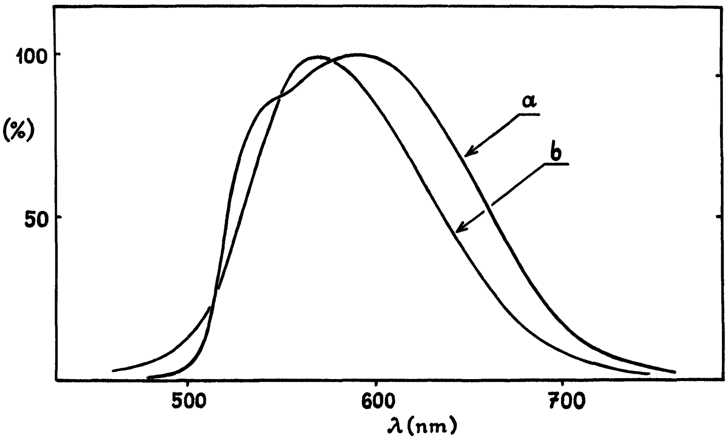

FIGURE 4 Spectral distribution I [%] vs. λ [nm] of the sensitivity of the CdS(Cu, Cl) photoconductive layer (curve a) and of the electroluminescence of the ZnS(Cu, Cl, Mn) layer (curve b)

for a system being in the state of "switched on" (i.e. for $L_1 = 0$). The dependence of the output signal B_1 on the input signal L_1 for the bi-stable PC_1-EL_1 system is presented in Fig. 7.

This characteristic shows a good agreement with the theoretical curve represented by the equation (8) for $L_2 = 0$.

Assuming the PC_1-EL_1 system to be in the state "switched on", the application of the second input signal L_2, illuminating the PC_2 element, will cause the appearance of the output signal B_2 in the form of a light emitted from the electroluminescent cell EL_2. As the PC_2-EL_2 system is one without optical feedback, the

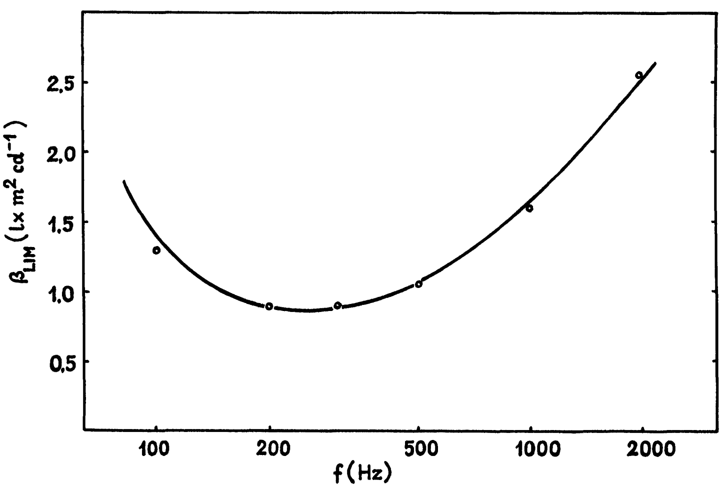

FIGURE 5 Dependence of the coefficient β_{LIM} on the frequency

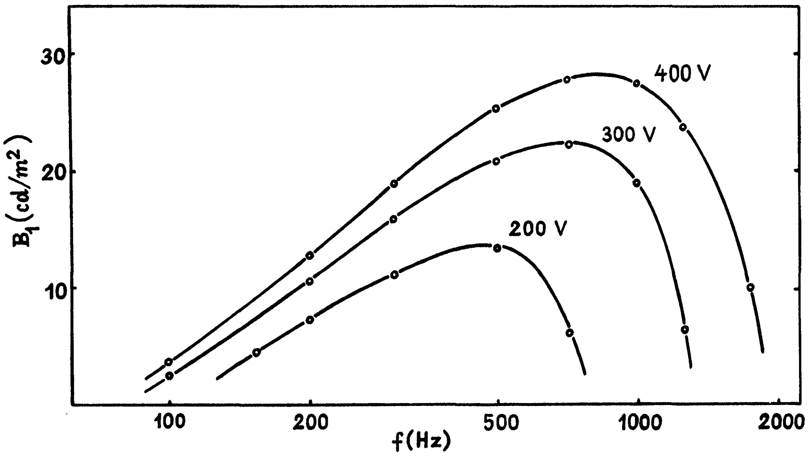

FIGURE 6 Dependence of the output signal B_1 on the frequency of voltage supplying the PC_1-EL_1 system for various amplitudes of this voltage

breaking off of the input signal L_2 will result every time in the decay of the output signal B_2 to a value not far from zero.

According to equation (8), for the PC_1-EL_1 system ($L_1 = 0$, $B_1 > 0$) the output signal B_2 depends on the value of the input signal L_2, the amplitude of the voltage supplying the system, and its frequency.

In Fig. 8 the dependence of the output signal B_2 on the input signal L_2 for various values of amplitude of supplying voltage and fixed value of frequency (f = 300 Hz) is presented.

The dependence of the output signal B_2 on the frequency for a fixed value of amplitude of supplying voltage as well as for several values of input signal L_2, is shown in Fig. 9.

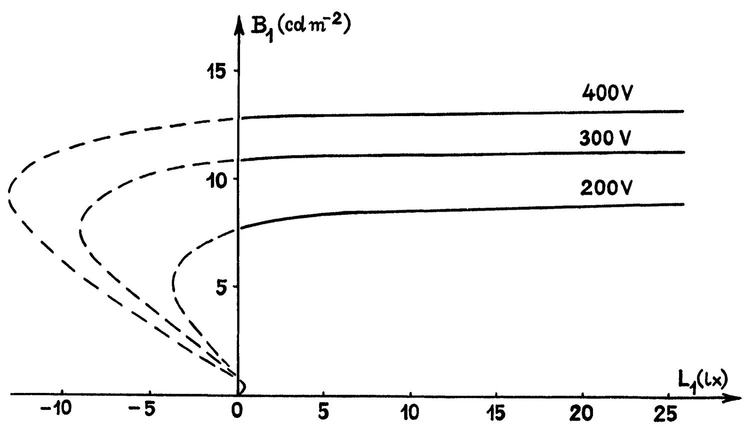

FIGURE 7 Dependence of the output signal B_1 on the input signal L_1 for the bi-stable PC_1-EL_1 system

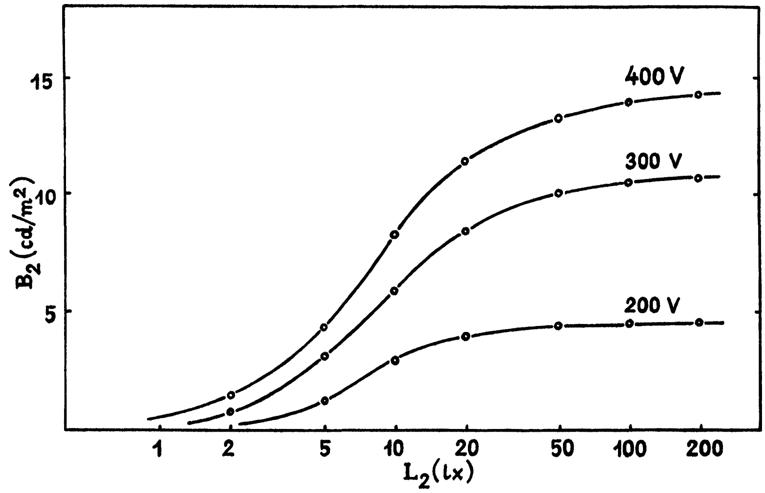

FIGURE 8 Dependence of the output signal B_2 on the input signal L_2 for various values of amplitude of supplying voltage at fixed value of frequency (f = 300 Hz)

In an optoelectronic memory system of PC-EL type switching on of an input signal L_2 influences not only the value of the output signal B_2, but also the value of signal B_1 (equation 8).

In Fig. 10 the dependence of signal B_1 on the input signal L_2 for various values of amplitude of supplying voltage and its fixed frequency, and in Fig. 11 the dependence B_1 on L_2 for various frequencies and fixed value of voltage amplitude are presented.

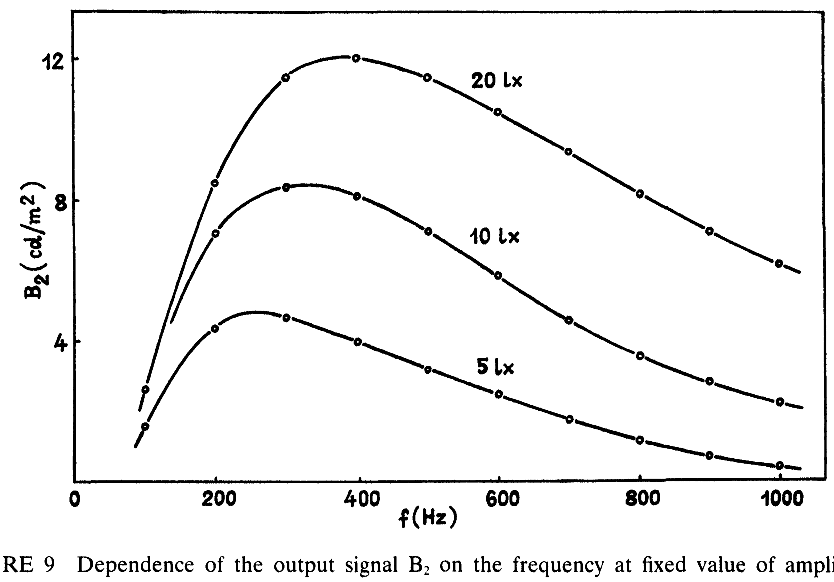

FIGURE 9 Dependence of the output signal B_2 on the frequency at fixed value of amplitude of supplying voltage (U_0 = 400 V) for several values of the input signal L_2 (the PC_1-EL_1 system is in the state "switched on")

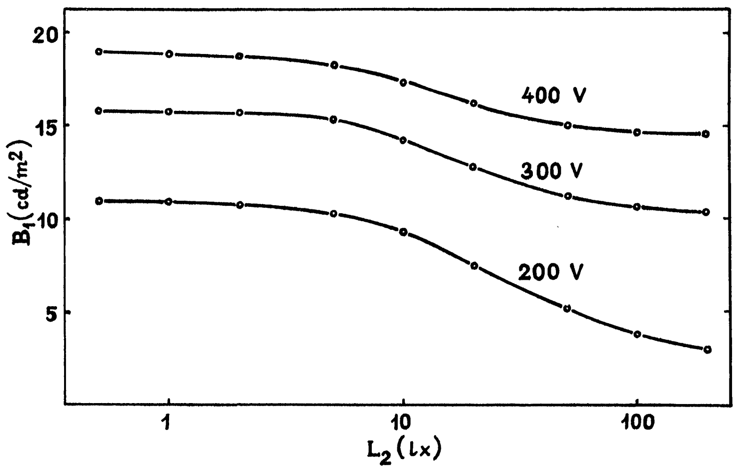

FIGURE 10 Dependence of the signal B_1 on the input signal L_2 for various values of amplitude of supplying voltage at its fixed frequency (f = 300 Hz)

4. CONCLUSIONS

Results of experimental investigations, as well as from the analysis of proposed theoretical model, indicate that the thin film PC-EL type system presented in this work can act as an optoelectronic memory element under following conditions:
—the PC_1-EL_1 system should have an optical feedback with feedback coefficient allowing to transpose it in "switched on" state,

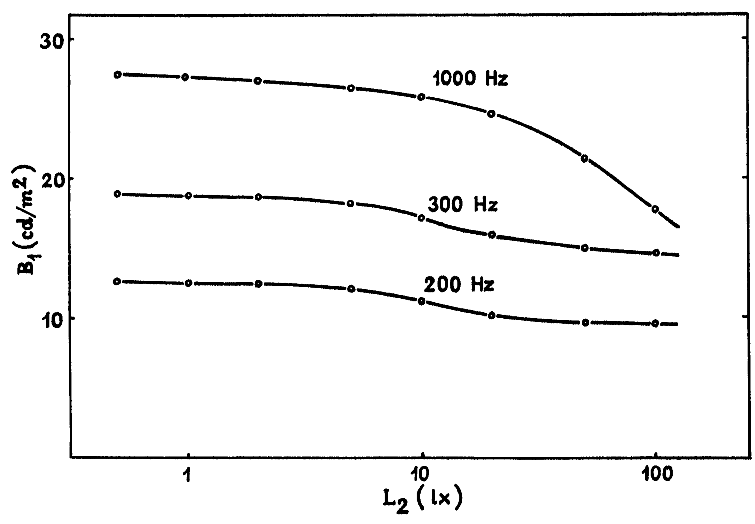

FIGURE 11 Dependence of the signal B_1 on the input signal L_2 for various frequencies at fixed value of voltage amplitude (U_0 = 400 V)

—the PC_2-EL_2 system should be a system without feedback. In an optoelectronic memory element the PC_1-EL_1 system being in the "switched on" state can be switched off only by cutting off the voltage supplying this element.

The magnitude of input signal L_1 should be high enough to transpose the PC_1-EL_1 system in the "switched on" state. For investigated system this state was being obtained at L_1 signal value as low as of the order of several luxes.

Considering the required value of output signal B_2 of the order of several cd/m^2, the second input signal L_2 should have a value in the range of 10 to 20 lx, whereas the frequency of the supplying voltage should be about 300 Hz and its amplitude not lower than 400 V.

REFERENCES

1. Z. Porada and E. Schabowska-Osiowska, Thin Solid Films, 164, 411 (1988).
2. Z. Porada and E. Schabowska-Osiowska, Active and Passive Elec. Comp. 13, 151 (1988).
3. Z. Porada and E. Schabowska, Thin Solid Films, 65, 137 (1980).
4. G.F. Alfrey and J.B. Taylor, Br. J. Appl. Phys., 4, 44S (1955).
5. Z. Porada and E. Schabowska, Thin Solids Films, 66, L55 (1980).
6. Z. Porada and E. Schabowska, J. Lumin., 21, 129 (1980).
7. Z. Porada, Thin Solid Films, 109, 213 (1983).