CHARACTERISTICS OF A dc ELECTROLUMINESCENT PANEL UNDER ac OPERATION

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Abstract – A general survey of the optical and electrical characteristics of a dc electroluminescent (DCEL) powder panel driven by ac is given. The luminance of the panel is more than 20 ft-L after 1,000 hours of operation at 110 V, 50 Hz. The behavior of a formed panel with conducting glass negatively biased was studied. It is proposed that in this condition copper ions migrate toward the conducting glass. Such a proposal is supported by the evidence that the resistance decreases and the capacitance increases after the panel has been negatively biased for a few minutes. High maintenance under ac is explained by the renewal of the panel at one of the two half-cycles.

I. INTRODUCTION

A dc electroluminescent (DCEL) ZnS:Mn,Cu powder panel has proven to be a successful display device. Although Vecht[1] and Abdalla[2] have indicated that it can be ac driven and have good maintenance, investigation of the optical and electrical characteristics of the panel under ac operation has not been reported in the literature. We have performed some experiments with regard to brightness and current waveforms, voltage and frequency dependence of light output, as well as maintenance with the hope that it would help in the application of this kind of device in various conditions.

II. PANEL FABRICATION

The panel technology employed is similar to that described in the literature[3]. ZnS:Mn,Cu powder was prepared in our laboratory, with a concentration of Mn = 0.5% and Cu = 0.03%. The phosphor particles were coated with Cu_xS by dispersing them in an aqueous solution of $CuCl_2$. After the powder was dried, it was spread on a conducting glass with a small amount of nitrocellulose binder. Sn was evaporated on the back electrode. The panel was encapsulated in a cell with a molecular sieve as the drying agent.

The panel was then subjected to "forming" which is necessary in order for it to become DCEL. The forming voltage determines the appropriate voltage which should be applied during operation. In order to avoid confusion about the polarity, the conducting glass was chosen to be the reference electrode. When it is positive the panel is said to be positively biased and the applied voltage is said to be positive and vice versa.

III. CHARACTERISTICS OF THE PANEL UNDER ac EXCITATION

The emission spectrum is mainly an orange band that peaks at 585 nm, which is characteristic of the Mn^{2+} ion. It

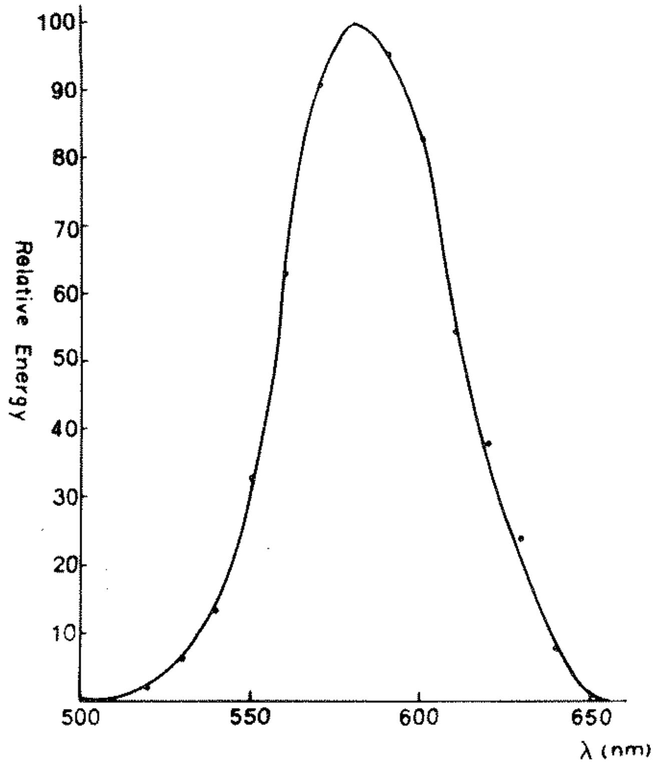

FIG. 1. Emission Spectrum of DCEL Panel.

is the same as that under dc excitation, and does not change with voltage or frequency (Fig. 1).

The brightness waveform was measured with a photomultiplier tube R562 from the Japanese firm Hamamatsu. The response time of the whole instrument is estimated to be less than 1 μsec. The light output under sinusoidal excitation has two peaks per cycle. No secondary peak is observed, i.e., only one peak appears per half cycle instead of two, which is usually observed in a Destriau cell. There is a "continuous" component, i.e., the light output never becomes zero at any instant. It increases steadily with frequency and becomes more and more important the higher the frequency. Obviously, the continuous component is correlated with the long decay time of the Mn^{2+} ion which is on the order of 1 msec, as measured with pulse excitation and cathode ray excitation (Fig. 2).

The current waveform consists of a pronounced in-phase peak (Fig. 3). It corresponds to the conduction or resistive current and is much larger in one polarity than in the other, indicating that the resistance is not symmetrical.

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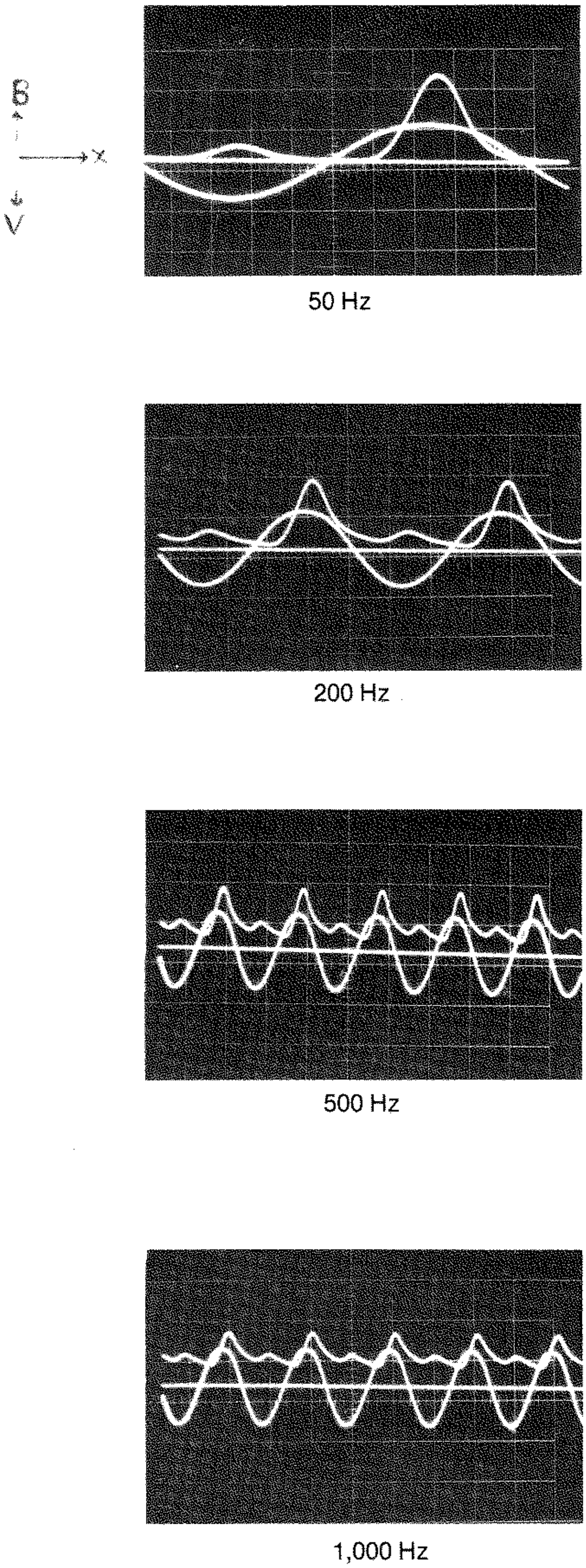

FIG. 2. Brightness Waveforms at Different Frequencies. Voltage Applied, 75 V. Horizontal Line, Zero Light Output; Sine Curve, Voltage Applied.

There is, in addition, an out-of-phase component which leads the voltage by $\pi/2$. It is correlated with the capacitive current.

The absence of a secondary peak in the brightness wave seems to imply that only excitation and de-excitation of Mn^{2+} ions are involved in the luminescence process. Careful inspection of the photographs shows that the light peak lags behind the voltage peak. This is difficult to explain if recombination of charged carriers is not considered. Since Cu ions have been doped in the phosphor and there is evidence that they act as sensitizers[4], it is expected that Cu ions may participate in the light-emitting process. The excitation and luminescence of Cu ions usually involve the generation of electron-hole pairs and the recombination of a conduction band electron with a hole trapped at the Cu center. The maximum rate of recombination does not necessarily coincide with the peak of the applied voltage, as is well known in the case of Destriau cell. Thus it would seem reasonable to assume that recombination of charged carriers also plays some role in the luminescence process. This assumption is supported by the observation that the emission spectrum of the DCEL panel consists of a very weak (more than 100 times weaker than the Mn^{2+} band) Cu band and that a flash of this Cu emission is produced at the trailing edge of a rectangular voltage when it is used to excite the panel[5].

Figure 4 shows the voltage dependence of the luminescence intensity B. It can be represented by $B = B_0 V^n$. The parameter n depends on the condition of forming and aging.

The variation of the current I with voltage is given in Fig. 5. $I = I_0 V^m$ is a good approximation.

Figure 6 shows the variation of luminance and current with frequency. The light output B_{dc} increases only by a factor of 2 while the frequency changes by two orders of magnitude. This is quite different from a Destriau cell which is also ZnS activated by Mn and Cu and of which the luminance-frequency relation is given in the same figure for comparison. The dependence of current on frequency is also plotted for both the DCEL cell and the Destriau cell. It can be seen that the current I_{dc} of the DCEL cell increases much more slowly than that of the ACEL cell. I_{dc} consists of a capacitive current as well as a resistive current. The capacitive current increases with frequency. If it is deducted from I_{dc}, the resistive current would increase even more slowly than I_{dc}. In contrast with the Destriau cell, of which the EL light output depends strongly on the polarization field, the emission of DCEL panel is mainly determined by the conduction current. The slow variation of the resistive current explains the slow increase of the light output of the DCEL panel with frequency.

Figure 7 shows the decrease in light output during long periods of operation. The applied voltage is 110 V at 50 Hz. The luminence after 1,000 hours of operation is still above 20 ft-L. By extrapolation, it is expected that the luminance should be around 10 ft-L after 10,000 hours.

The high maintenance of the DCEL panel under ac appears to be correlated with the negatively applied

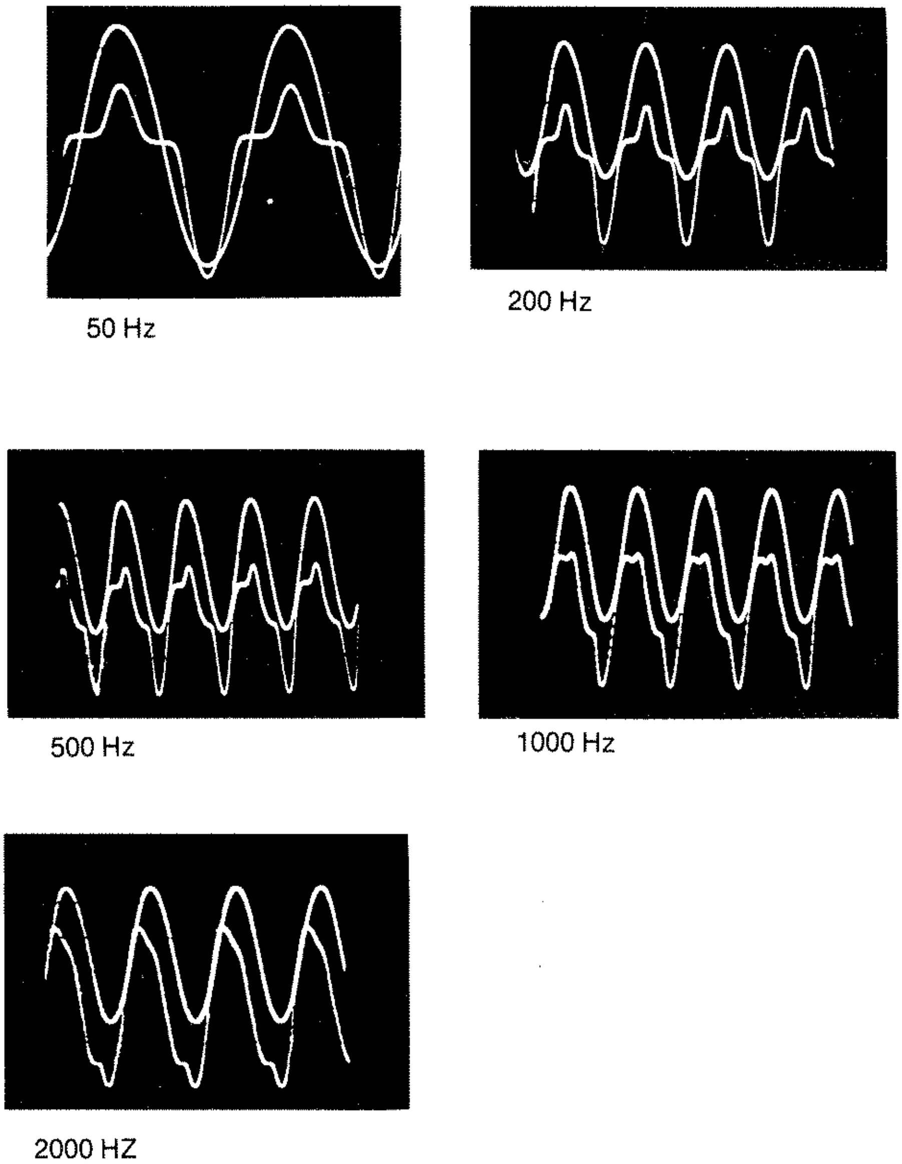

FIG. 3. Current Waveforms at Different Frequencies. Voltage Applied, 80 V.

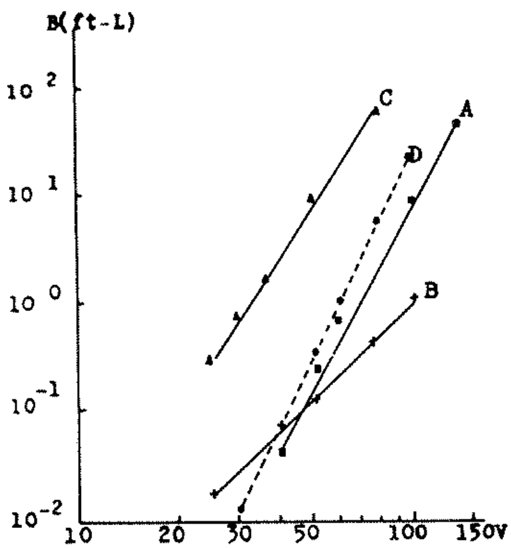

FIG. 4. Voltage Dependence of Light Output of DCEL Panel. Frequency, 50 Hz.

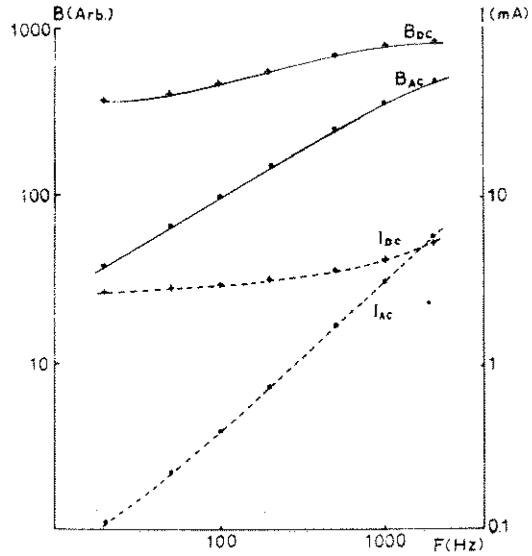

FIG. 5. Voltage Dependence of Current of the DCEL Panel. Frequency, 50 Hz.

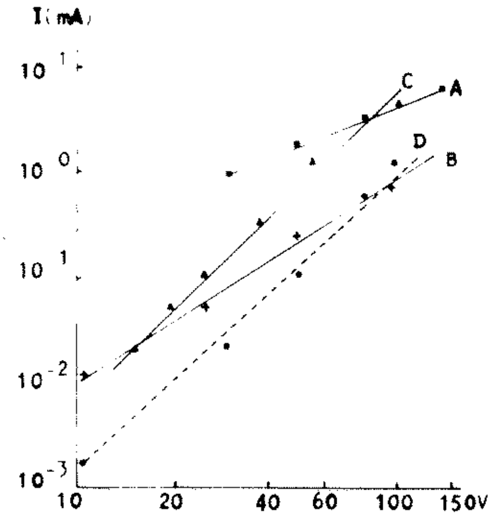

FIG. 6. Frequency Dependence of Light Output and Current of DCEL Panel and of Destriau Cell. I_{dc}, Current through DCEL Panel; I_{ac}, Current through Destriau Cell; B_{dc}, Light Output of DCEL Panel; B_{ac}, Light Output of Destriau Cell.. Voltage Applied, 80 V.

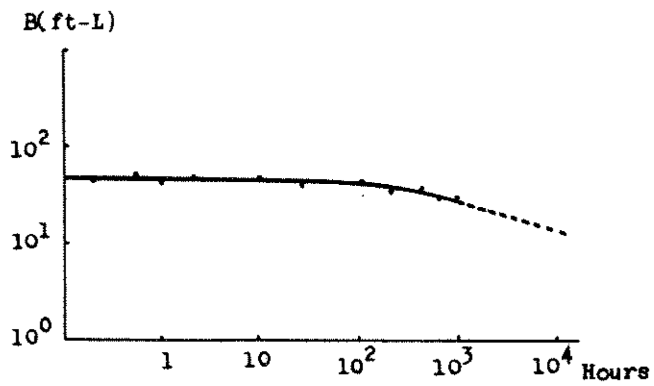

FIG. 7. Variation of Light Output with Time. Voltage Applied, 110 V; Frequency, 50 Hz.

voltage. Experiments regarding the effect of negatively applied dc voltage have been carried out, and the results are summarized in Table I. The panels chosen for the measurement have different histories of aging. The luminance B_0^+ and the current I_0^+ were measured at 100 V. The capacitance C_0 was measured by a bridge circuit with the panel subjected to a voltage of 15 V at 500 Hz. The panel was then negatively biased with a voltage of 60–70 V for a few minutes. The luminance B^- is higher than B_0^+, although the magnitude of the negative voltage is much less than 100 V. After the application of a negative voltage, the capacitance C was measured again under the same condition, i.e., 15 V at 500 Hz. When the voltage was switched back and increased to +100 V, both the luminance B^+ and the current I^+ increased significantly. It took quite a long time (hours) for the luminance to drop back to the original value B_0^+. This process of applying a negative voltage intermittently may be repeated as many times as one likes. The lifetime of the panel can be prolonged appreciably in this way.

IV. DISCUSSION

It is well known that as soon as a dc voltage is applied to the panel, copper ions migrate away from the conducting glass electrode which is positive. A thin copper-depleted layer with high resistance is formed adjacent to the conducting glass. This is the so-called forming process. DCEL light emits from this layer. The migration of the Cu ion continues so long as the positive voltage is applied. Thus, the forming process proceeds incessantly and appears to be responsible for the aging of the panel. As a result, the high-resistance layer should become thicker and thicker. This is confirmed by the experiment in that the capacitance of the panel decreases as the device operation time increases.

When a negative voltage is applied to the glass electrode under appropriate condition, i.e., with a current that is not too large, and for a short period, light emits from the same

TABLE I. Results of Experiments to Determine the Effect of Negatively Applied dc Voltage.

	Panel 5-1	Panel 11-2	Panel 2-27(1)	Panel 2-27(4)
History of panels	Aged at 120 V for > 500 hrs	Aged at 120 V for > 500 hrs	Aged at 120 V for a few hrs	Aged at 120 V for a few hrs
Luminance B_0^+ at 100 V (arb. unit)	60	45	56	42
Current I_0^+ at 100 V (mA)	0.4	0.6	0.3	0.2
Capacitance C_0 (nF)	3.99	3.66	4.09	4.95
Negatively Biased Voltage (V)	−60	−70	−70	−60
Maximum Luminance B^- (arb. unit) (negatively biased)	70	60	86	52
Maximum Current I^- (mA) (negatively biased)	9.2	12	3.4	4.9
Time for Being Negatively Biased (minutes)	5	2	10	10
Luminance B^+ at 100 V (arb. unit) (after being negatively biased)	150	80	130	220
Current I^+ at 100 V (mA) (after being negatively biased)	8	1.2	2	3.6
Capacitance C (nF) (after being negatively biased)	4.13	3.72	4.16	5.02
$\Delta C = C - C_0$ (nF)	0.14	0.06	0.07	0.07
$\Delta C/C_0 \times 100$	3.4	1.8	1.9	1.5

layer as when the panel is positively biased. This implies that at either biased state a change in the panel characteristics takes place in the same region. The increase of light output and the decrease of panel resistance after the panel has been negatively biased are processes opposite to those that occur during forming. It is proposed that when a negative voltage is applied to the conducting glass, copper ions migrate in the reversed direction, i.e., toward the conducting glass. This partially renews the panel. When ac is used to drive the panel, the panel becomes negatively biased and is renewed once every cycle, thus improving maintenance.

The reversed migration of the copper ion would result in a decrease in the thickness of the copper-depleted layer. The capacitance of the panel should increase after having been negatively biased. This is confirmed by the results of capacitance measurement given in Table I. For all four panels it can be seen that the capacitance increases by 1–3%.

The result obtained can be applied to a panel for a matrix display. In a panel which has been operated by unidirectional voltage pulses for a long period of time, it is observed that the luminance of light-emitting elements increases significantly if it has been operated by pulses of reversed polarity for a short period of time. It is expected that if the panel is operated by ac pulses instead of unipolar pulses, the maintenance of the display device would be improved considerably.

V. CONCLUSIONS

A DCEL powder panel can be driven by a power line with high luminance and good maintenance. Its behavior can generally be understood by investigating the properties of the panel under dc with positive and negative voltage. The maintenance of the panel is closely related to the negatively biased voltage. Evidences show that the forming process, which has been considered irreversible thus far, appears to be partly reversible. The result obtained can also be applied to the devices driven by voltage pulses.

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