RB-101

LIGHT OUTPUT OF AN ELECTROLUMINESCENT CELL EXCITED BY SHORT VOLTAGE PULSES

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1 OF 12 PAGES

APRIL 30 1957

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This bulletin describes an investigation of the light output characteristics of electroluminescence excited by short voltage pulses. Total light output has been measured and output waveforms obtained for a green electroluminescent cell excited by short pulses of voltage. The phosphor is a ZnSe:ZnS solid solution type embedded in a 0.5-mil plastic layer. Rectangular pulses and pulses having one or both edges of exponential shape between 2- and 40-μsec in duration were applied. Reddish light is emitted during and after both the rise and fall of the pulse while bluish light is emitted predominantly after the pulse starts to fall. With a slowly-decaying pulse the light associated with the decay is delayed until the pulse is nearly zero. Slowly rising pulses excite relatively more blue light and slowly falling pulses more red light. The light obeys an exp $(-bV^{-1/2})$ law for all colors and all pulse shapes investigated. Cell current flow and loss data are also presented.

Introduction

Most investigations of electroluminescence (EL) have been made with sine-wave excitation. Recent information has, however, been obtained with long rectangular pulses[1,2] and with pulses as short as 40 μsec in duration[3,4]. Waymouth and Bitter[1] excited a green ZnS:Cu:Pb phosphor with long pulses ($\approx$30 sec) and observed that most of the light was produced after the pulse was terminated. They found only a slight dependence of the light on the rise and fall times of the pulse. In their later paper[2] they found that the color of the light emitted depends upon the pulse length, the color shifting toward yellow as the pulse in made longer. Nudelman and Matossi[3], also using the same type of phosphor, observed that with shorter rectangular pulses the short-wavelength light was emitted in equal quantities at the rise and fall of the pulse, while more of the longer-wavelength light was emitted at the beginning than after the termination of the pulse. They found, however, that the rate of emission of long-wavelength light was the same at the beginning and at the termination of the pulse. They also found that the total or integrated light output (ILO) decreased as the pulse was shortened.

EL is generally assumed to result from excitation of luminescent centers by collisions with moving charges under the influence of an electric field. One would not expect to observe light after the field has returned to zero. However, light is observed and to explain this it has been assumed[4] that polarization of the phosphor takes place while the pulse is applied, generating an internal field which can persist after the pulse ceases. The motion of the relaxing polarization charges in this field can excite the luminescent centers to produce light. The decrease in ILO with decrease in pulse duration is explained[4] as resulting from incomplete polarization of the phosphor by short pulses. At the beginning of the pulse, before polarization charges can move, a large internal field is expected and light generation should result. Matossi and Nudelman[3] observed light, but Waymouth and Bitter[1] did not. These latter investigators concluded that carriers excited into the conduction band during the excitation process are swept out of the active region of the phosphor by the field, preventing de-excitation and light emission until the field returns to zero.

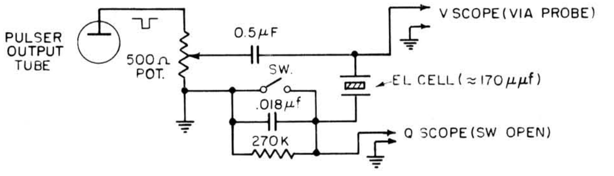
The differences in emission of long- and short-wavelength light have been qualitatively explained by assuming several modes for de-exciting luminescent centers. The light of short wavelength is thought to result from direct transitions of an excited center to the ground state. This process occurs immediately after excitation and therefore the light resulting from it is expected to follow variations of the internal field. Matossi and Nudelman[4] calculated a possible form for the decay of the internal field at the end of the pulse and found that the light did decay in a similar manner. The long-wavelength light does not follow the internal field, however. This can be explained, qualitatively, in terms of de-excitation of excited centers via trapping levels. Subsequent emptying of a trap leads to delayed emission of light of longer wavelength. The increase in long-wavelength light observed as the pulse length is increased has been explained as resulting from thermal emptying of traps[2]. The observations of Nudelman[3] and Matossi that the rate of emission of long-wavelength light was the same at the beginning and at the end of the pulse has also been explained in terms of traps.

In this work information has been obtained for shorter pulses between 2 and 40 μsec in duration of rectangular and exponentially rising or falling shape. The data have been obtained with a more complex phosphor (0.6 ZnS: 0.4ZnSe: Cu(0.1):Br)[5] which makes comparison with data for the simpler phosphors difficult. The present data are presented mainly for those workers interested in the characteristics of EL cells for application purposes. However, points of agreement or disagreement with other data are mentioned.

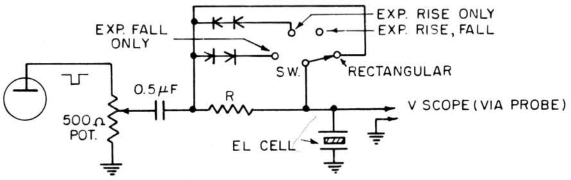
Experimental Method

EL was detected by a type 6217 multiplier phototube which has an S-10 type photo-response. This response is quite uniform to all colors of light emitted by the phosphor. The tube was operated at room temperature with a total dynode voltage of 1000 volts. The repetition rate of the light pulses was maintained at 600 pps and the resulting average and peak anode currents in the multiplier tube were small enough to avoid fatigue effects. ILO data were obtained by measuring the average anode current with a vacuum-tube microammeter adequately bypassed with capacitance. The dark current was sufficiently small and stable that ILO data over a range of four or five decades could be obtained. The EL cell was located two inches in front of the photosurface, with light filters intervening. The cell was ¼-inch square and was behind glass of 5/16-inch total thickness. A ¼-inch square hole masked the outer surface of the glass against which the filters were directly placed. A yellow (5720Å) and blue (4970Å) interference filter and a red glass filter were used as well as a special filter which, with an S-10 photosurface, approximates the response of the human eye. This filter was composed of a Corning No. 3307 and 9788 filter in series.

The EL cell was of plastic dielectric design with an evaporated aluminum rear electrode and a nearly transparent conductive layer mounted on glass as front electrode. The dimensions of the cell were sufficiently small that resistive losses in this front layer were negligible. The dielectric-phosphor film was about ½ mil in thickness; the dielectric was Araldite plastic. Pulsing this cell in humid weather caused breakdown to occur at a voltage less than one-half of the value possible when the cell was dry. For this reason the cell was hermetically sealed in a box containing CaSo$_4$ drying agent. Even then a freshly-made cell would appear to be short-circuited when the voltage was first applied. The phosphor density in the cell is high enough that conductive bridges between the electrodes can probably be formed by activated phosphor grains touching each other. These bridges must be burned away by a 'forming' process. This is accomplished by applying a progressively increasing d-c voltage via a series current-limiting resistance to the cell. Considerable twinkling of the phosphor at spots occurs during this process, accompanied by erratic current flow, but these effects decay with time as the limiting voltage is reached (about 180 volts in in this case). A steady state is finally reached in which a steady current of about 10 μa flows; after this, pulses of the order of 200-300 volts can be applied to the cell without causing breakdown. It was also found helpful to eliminate the possibility of d-c current flow in the cell while pulsing by using a large series capacitor in the circuit as shown in Fig. 1. With the capacitor in the circuit even higher pulse voltages can be applied to the cell without danger of breakdown.



(a) CIRCUIT ARRANGEMENT FOR RECTANGULAR PULSES



(b) CIRCUIT ARRANGEMENT FOR GENERATING PULSES WITH EITHER OR BOTH EDGES EXPONENTIAL IN SHAPE

Fig. 1 – EL cell excitation circuits.

Rectangular voltage pulses of variable duration were generated by a source having negligible output impedance. The rise and fall times of the pulse with the EL cell in the circuit were 0.3 μsec and were independent of pulse amplitude. The charge flow into the cell was measured by observing the voltage developed across another capacitor in series with the cell as shown in Fig. 1a. The voltage developed across this capacitor during the pulse was small compared to the EL cell voltage and the time constant of decay was much larger than the longest pulse used. Exponential edges on the pulse waveforms were generated by the circuit of Fig. 1b. Exponentially rising and falling pulses could be obtained by introducing series resistance into the EL cell circuit. Exponentially rising and fast falling, or fast rising and exponentially falling, pulses could be obtained by shunting this resistance with diodes as indicated. Two type 1N38A diodes in series were used in each branch. Pulse voltage amplitudes were measured with a Tektronix type 513 D oscilloscope having a voltage calibrator. The calibrator was in turn calibrated by an accurate slide-back type peak voltmeter and a correction curve was obtained.

Light output waveforms were obtained by amplifying the output appearing across a 470-ohm resistance in the anode circuit of the mulitplier phototube with a Tektronix type 121 preamplifier followed by the amplifier of the above-mentioned oscilloscope. The linearity of the ILO measurements was checked by comparing ILO data obtained with and without a 100-to-1 light attenuating aperture placed between the EL cell and light filter. Typical ILO versus pulse voltage curves were found to be identical over three decades of brightness in both cases.

Results

Light Output Waveforms with Rectangular Pulses

Figs. 2 and 3 are light output waveforms obtained with rectangular pulse excitation. Waveforms for the blue and red filter are representative of the extreme limits of the spectral distribution of the light. Waveforms for the yellow filter, which transmitted a band nearer the center of the spectral range, were observed to be combinations of these two extreme cases. The amplifier gain was changed frequently in obtaining the data; therefore no comparisons can be made of relative waveform amplitudes. With the blue filter, most of the light is emitted after the pulse is terminated. Only a small percentage of the light is emitted during the pulse itself. This percentage is independent of pulse voltage and increases only slightly as the pulse duration is increased. The decay of light at the end of the pulse is faster the shorter the pulse, as found by previous investigators.

The waveforms for the red filter are more complicated. More of the light is emitted during the pulse in this case. For a given duration of pulse, the relative amount of light emitted after the pulse is terminated increases with pulse amplitude. As the pulse duration is increased, for a fixed pulse voltage, this trailing spike of light becomes more prominent, maintaining the same peak value with respect to the base line. For small pulse voltages the trailing spike disappears completely; it disappears at lower voltages as the pulse duration is increased. The possibility that this red-light trailing spike results from leakage of blue light through the red filter was considered. The best evidence that this is not the case is afforded by the fact that no red-light spike is observed for short pulses whereas the blue-light spike for such pulses is still prominent. It seems unlikely that the red light could decay so abruptly at the end of the pulse that the rapid increase of blue light could be masked. Another piece of evidence against filter leakage is the fact that both the red and the blue ILO increase with voltage at nearly the same rate (see Fig. 8), whereas the trailing spike of red light increases faster than the leading pulse of red light as shown by the waveforms of Fig. 3. The relative amplitudes of the leading and trailing pulses of red light can be compared by considering the waveforms of Fig. 3 and the 40-μsec rectangular pulse waveform of Fig. 12 for red light, which was obtained with a higher pulse voltage than were the waveforms of Fig. 3. With increasing pulse voltage the trailing spike, initially absent, increases in amplitude relative to the leading pulse until it exceeds the leading pulse. This result differs from the findings of Nudelman[3] and Matossi who found that the two peaks had about the same amplitude.

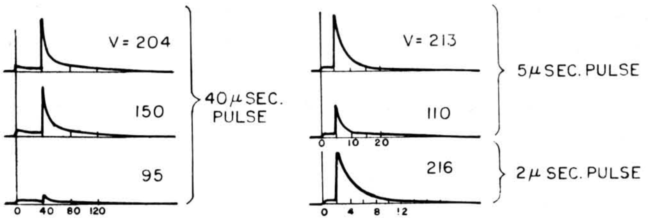


Fig. 2 – Light output waveforms. With rectangular pulse excitation and blue filter.

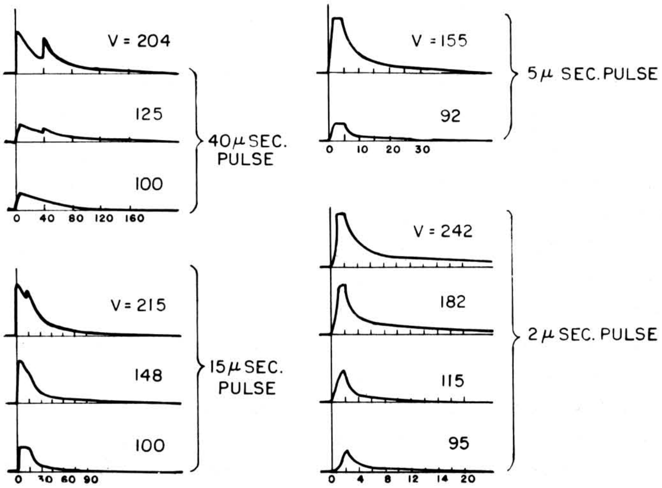


Fig. 3 – Light output waveforms. With rectangular pulse excitation and red filter.

The decay time constant of the red-light trailing spike is about the same as that of the blue-light trailing spike. The rates of decay of light during the pulse itself also are about the same for the two colors, except for the shortest pulses. In the case of these pulses the red light for low pulse voltages continues to grow during the pulse, whereas the blue light peaks in about the time required for the pulse voltage to rise, and then slowly decays. For large, short pulses, however, the red light also begins to rise quickly, following the action of the blue light.

Light Output Waveform With Sine-wave Excitation

Light waveform data were also obtained (see Fig. 4) using 10-kc sine-wave excitation for comparison with other published a-c data[6]. The light maxima occur close to the points of maximum external field excursion when the rate of change of field is small. The light output minima occur close to zero external field when the rate of change of field is large.

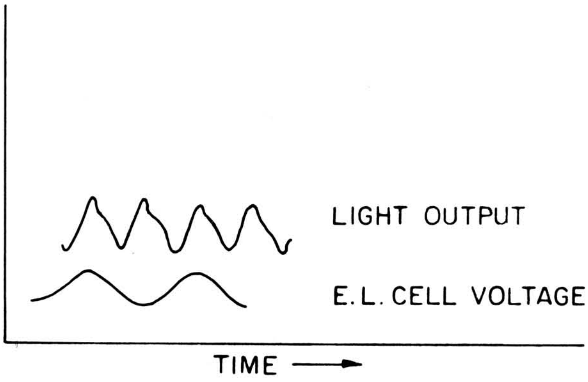


Fig. 4 – Light output waveforms with 10 k-c sine-wave excitation of 160 volts peak-to-peak value. No filter used.

Light Output Measurements With Rectangular Pulses

ILO measurements were made using the arrangement of Fig. 1a with the charge-integrating circuit shorted by the switch indicated. The results are given in Figs. 5, 6, 7, 8 and 9. Relative ILO values for each filter were obtained; because the filter attenuation factors were not measured ILO values for the various filters cannot be compared. Absolute brightness was measured for a pulse of 183 volts and a pulse duration of 40 μsec in the green region of the spectrum. The brightness obtained was 1.4 foot lamberts for 600 pps repetition rate. The curves of ILO versus pulse voltage are not straight lines on the log-log plots of Figs. 5, 6 and 7, but have slopes which decrease with increasing pulse voltage, V. Less ILO is emitted with shorter pulses, the decrease being greatest for the red filter and least for the blue filter. In Fig. 8 the same data are plotted as log ILO versus $V^{-1/2}$; the curves are nearly all straight lines in this case. The law,

$$\text{ILO} = ae^{-b/V^{1/2}}$$

which was found[6] to hold for a-c sine-wave excitation

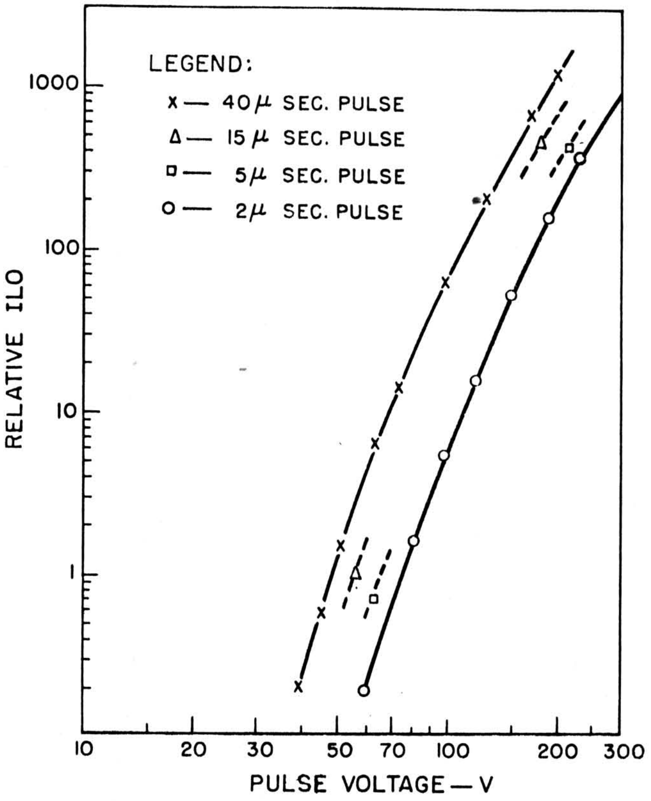


Fig. 5 – Relative ILO versus rectangular pulse voltage on log-log plot. Data for red filter. Note curvature of lines and decrease of ILO as pulse is shortened.

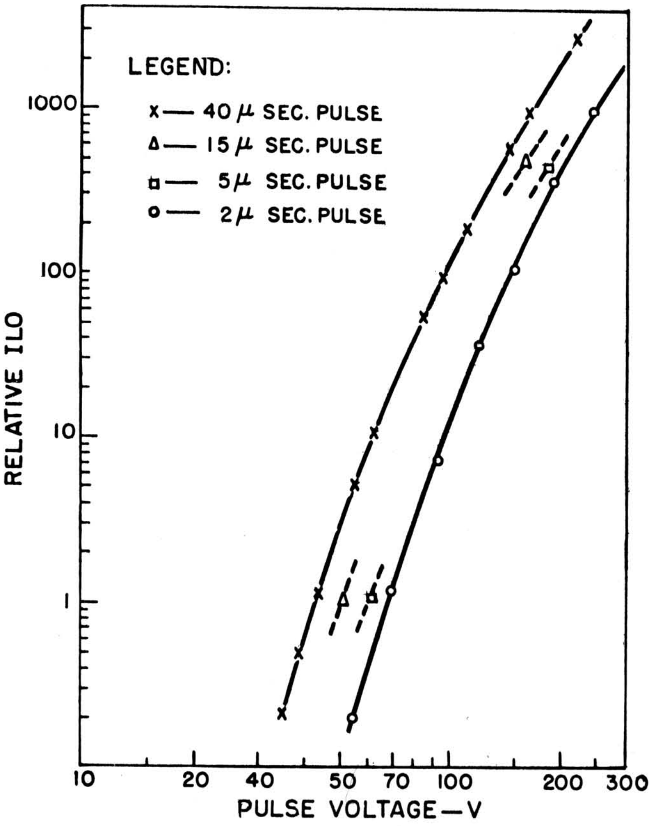


Fig. 6 – Relative ILO versus rectangular pulse voltage for yellow filter.

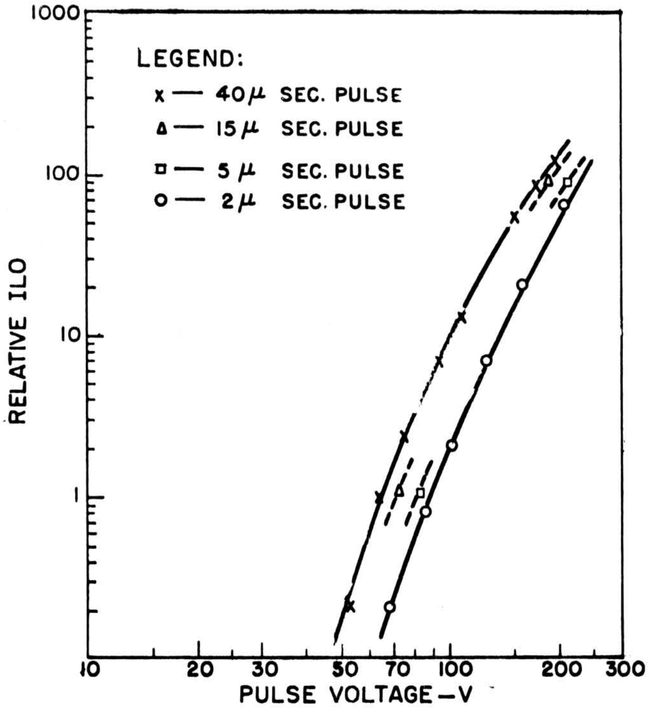


Fig. 7 – Relative ILO versus rectangular pulse voltage for blue filter. Note relative decrease in ILO for short pulses is less than in case of red or yellow filter.

can therefore be extended to include rectangular pulse excitation as well. The b values obtained from the slopes of the curves are listed in Table I. The slope is steeper the shorter the pulse and is almost independent of the color of the light, although b is slightly greater for red light. This implies that the spectral distribution is slightly voltage as well as pulse-duration dependent, the light becoming slightly redder as the pulse is increased in amplitude. In Fig. 9 similar curves are shown, one set for which no filter was used and another for which the filter was the special filter mentioned in the previous section which simulates a photomultiplier response approximating that of the human eye. The curves are again straight lines.

TABLE I

Values of the constant b in the equation for light output, ILO = $ae^{-b/V^{1/2}}$, for rectangular voltage pulses, V.

Pulse Length (μ sec.)	Filter	b
2	Red Yellow Blue	119 117 111
40	Red Yellow Blue	99 94 92

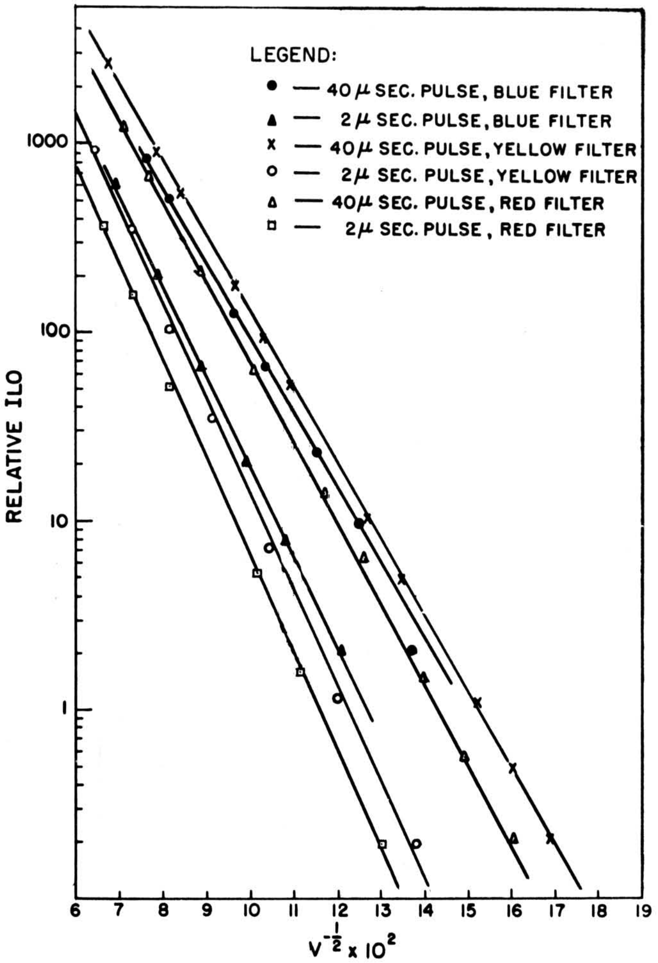


Fig. 8 – Log ILO versus $V^{-1/2}$ for rectangular pulses and red, yellow and blue filters. Straight-line plots appear to fit data well.

Results With Exponential Pulses

Exponentially rising and falling pulses were compared with fast rising and falling rectangular pulses. The circuit arrangement was that shown in Fig. 1b with the resistance only in series with the EL cell and pulser to slow both the rise and fall of the pulse. The value of series resistance was chosen to make the ratio of pulse decay time constant to pulse duration either of two arbitrary values, 0.15 or 0.38, for each of four pulse durations, 2, 5, 15 and 40 μsec. Light waveforms with the resistance were observed to be similar to those of Figs. 2 and 3 except for greater rounding of the peaks of light. Curves of ILO versus pulse duration for these two ratios are shown, together with a curve of ILO for rectangular pulses of 0.3 μsec rise and fall time for comparison, in Fig. 10. These data are for the red filter. The fractional decrease in light as a given ratio is introduced is nearly independent of pulse duration. With even the most rounded pulse used, more than 50 percent of the light obtained

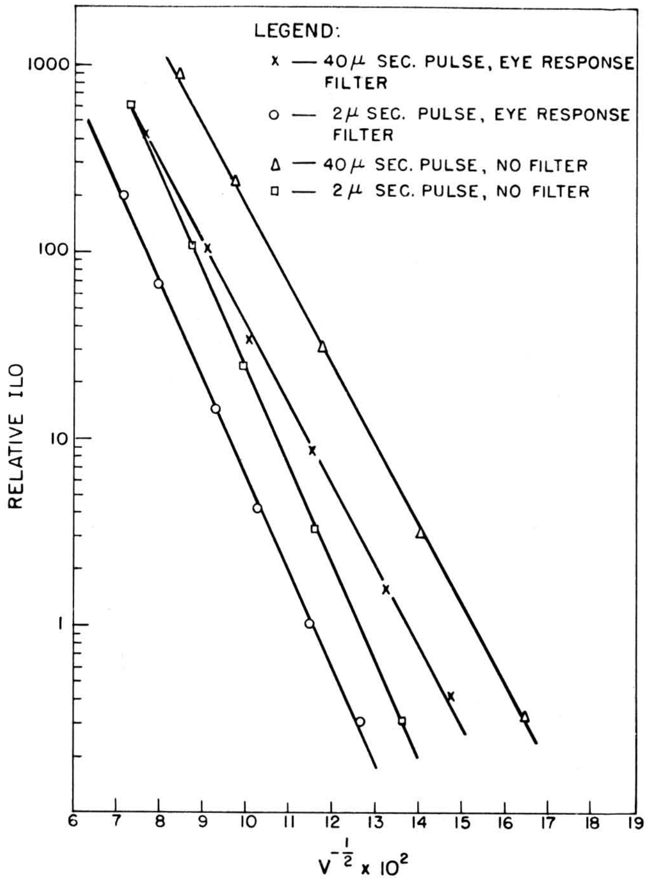


Fig. 9 – Log ILO versus $V^{-1/2}$ for rectangular pulses, with and without light filter. Light filter used produces a response approximating that of the human eye. Straightline plots are again obtained.

TABLE II

Ratio of red to blue light for pulses having exponential leading and trailing edges. Peak pulse voltage constant (143 V). For a given pulse length the ratio is nearly independent of τ/T.

Pulse Length (μsec.)	$\frac{\tau}{T} < 0.07$	$\frac{\tau}{T} = 0.15$	$\frac{\tau}{T} = 0.38$
40	8.9	9.1	8.8
15	6.8	6.7	6.8
5	4.6	4.7	4.7
2	3.8	3.8	4.0

with rectangular pulses is still emitted. Curves for the blue filter (not shown) were found to be similar to those for the red filter. For a fixed shape of pulse the ratio of red light to blue light was measured for different pulse durations. This information was obtained by taking all the data completely for one filter before taking data for the second filter. It was found necessary to obtain the data this way because the filters could not be removed

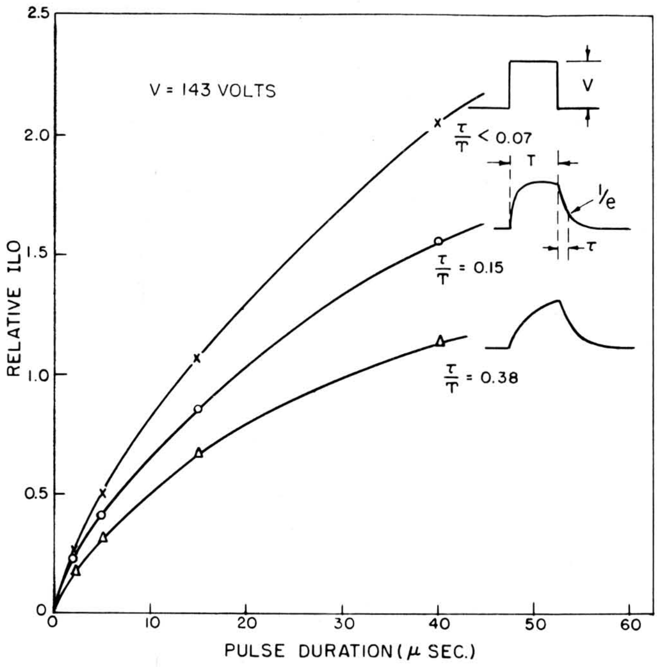


Fig. 10 – ILO for pulses of exponential shape versus pulse duration. ILO for rectangular pulses included for comparison. Red filter used.

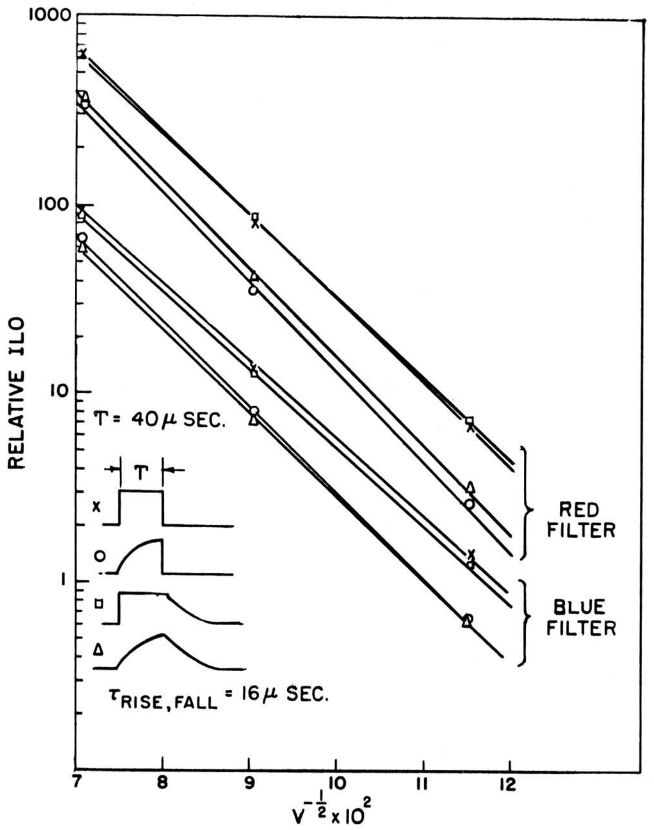


Fig. 11 – Log ILO versus $V^{-1/2}$ for four different pulse shapes. Exponential portions of each pulse have same time constant.

TABLE III

Values of b and red/blue light ratios for different shape pulses having the same peak amplitude. Compared to a rectangular pulse, pulse type (2) generates a greater fraction of blue light and has a greater b value, Pulse type (3) also has a greater b value but generates relatively more red light. Pulse type (4) has about the same red/blue ratio as the rectangular pulse, but a greater b value. Data for 40-μsec pulses.

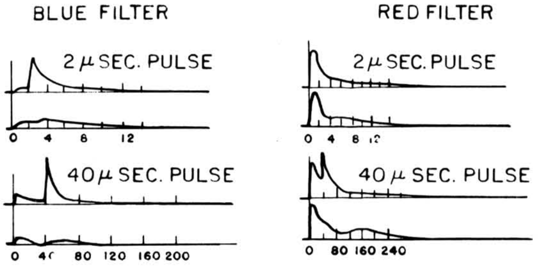
Pulse Type	b		Ratio Red/Blue Light Output For Pulse Voltage		
	Red Filter	Blue Filter	V = 199	V = 123	V = 75.5
Rectangular(1)	103	96	6.5	5.7	4.8
Exp. Rise, Fast Fall (2)	111	106	5.1	4.5	4.1
Fast Rise, Exp. Fall (3)	105	97	7.1	6.4	5.7
Exp. Rise, And Fall (4)	108	103	6.3	5.7	5.4

and replaced accurately enough to maintain the same attenuation factor if the filters were changed more frequently. Using this method the attenuation factor between filters remained constant. The red-to-blue light ratio was found (see Table II) to be constant to within about five percent which is just within the precision of the measurements. This implies that for all three pulse shapes the spectral distribution is the same for a given pulse duration. This is a surprising result in view of the rather large dependence of the spectral distribution upon pulse duration.

This discrepancy spurred further investigation. ILO data were obtained for an exponentially rising, fast falling pulse and also for a fast rising, exponentially falling pulse. The results are shown in Fig. 11; log ILO is plotted versus $V^{-1/2}$ in the usual manner. Rectangular pulse and exponentially rising and falling pulse data obtained at the same time are also included. Again the curves appear to be straight although the number of data points are not sufficient to prove this conclusively. Values of b obtained from these curves are given in Table III together with corresponding red-to-blue light ratios. In obtaining these ratios the same precautions were observed to maintain the filter attenuation factors constant, i.e., to obtain all the data for one type of filter before changing filters. Because of the difficulty of reproducing filter positions, the red-to-blue ratios of Tables II and III are not the same for the rectangular pulses, but differ by a constant factor. As indicated in Table III, a slowly rising, fast falling pulse excites more blue light than does a rectangular pulse of the same length. The variation of light also exhibits a greater b value. Light waveforms for these pulses were observed to be similar to those for rectangular pulses except for a less rapid increase of initial light, as expected. The combination of greater b value and bluer light is what one observes for shorter rectangular pulses. From the data of Fig. 5 and also the data of Table I, b has the value one would expect for a rectangular pulse of about 15-μsec duration. The red-to-blue ratio is about 20 percent less than it is for a 40-μsec rectangular pulse and, from Table II, this ratio is about that expected for a 20-μsec rectangular pulse. The absolute light output with the red filter is about 50 percent less, which also is about that expected for a 15-μsec rectangular pulse. The light-generating characteristics of this slow rising, fast falling pulse of 40-μsec duration are therefore equivalent to those of a rectangular pulse of 15- to 20-μsec duration of the same peak amplitude. Sufficient data were not obtained to extend this analogy to pulses of different durations.

A fast rising, slowly falling pulse excites more red light but has about the same b value as a rectangular pulse of the same duration. Because b remains unchanged it is not possible to correlate this type of pulse to an equivalent longer rectangular pulse. Light waveforms for these pulses are shown in Fig. 12. The light generated during the decay of the pulse is delayed until the decay is nearly complete. This effect is observed for both the red and the blue light. The ILO for this shape of pulse compared to a rectangular pulse is only slightly changed, being reduced slightly in the blue and increased slightly in the red. The opposing effects of a slow rise and a slow fall of the pulse upon the spectral distribution explain the relatively small spectral shift observed when both the rise and the fall of the pulse are exponential in shape. The shift toward the blue resulting from the ex-

(a) VOLTAGE WAVEFORMS OF EXPONENTIALLY DECAYING PULSES



(b) OUTPUT LIGHT WAVEFORMS OF RECTANGULAR AND EXPONENTIALLY – DECAYING PULSES COMPARED

Fig. 12 – Light output waveforms for fast rising, exponentially falling pulses, compared with waveforms for rectangular pulses of the same amplitude and flat-topped duration. The lower of each waveform pair is for the exponentially-decaying pulse. Note that the light tends to be delayed until the pulse has decayed.

ponential rise of the pulse is counteracted by the shift toward the red resulting from the exponential fall of the pulse. The value of b with this pulse shape is greater than that for rectangular pulses of the same length, however.

Charge Flow Into The EL Cell

Measurements were made of the total charge per pulse, Q, flowing into the EL cell while exciting the cell with rectangular voltage pulses. The circuit is shown in Fig. 1a. The switch indicated in the figure was open and an additional oscilloscope was connected to measure the integrating capacitor voltage which is proportional to Q. Typical waveforms of Q are shown in Fig. 13. Initially the charge rises quickly at the same rate as the pulse and then continues to increase at a slower rate while the voltage remains constant. When the pulse voltage becomes zero again, charge continues to flow in the reverse direction for a short time. In Fig. 13a this action is compared with the charging curve for a dummy low-loss capacitor having the same small signal a-c capacitance as the EL cell. Fig. 13b shows charging curves for different pulse durations. The curves fall on top of each other, showing that the cell does not exhibit hysteresis effects. With the longer pulses the rate of charging tends to become constant near the end of the pulse, and the cell then presents a nearly constant resistance to the pulse source.

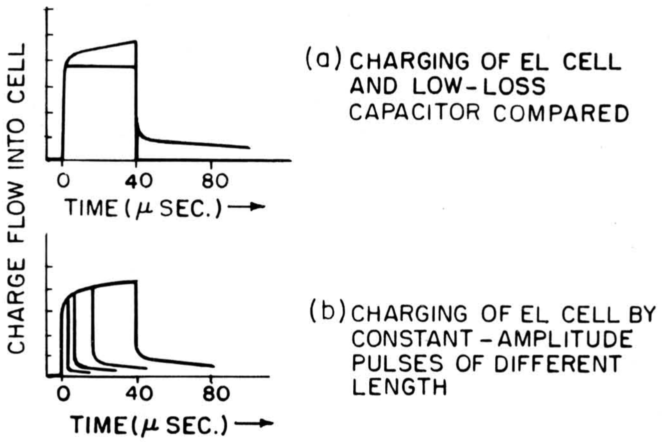


Fig. 13 – EL cell charging waveforms.

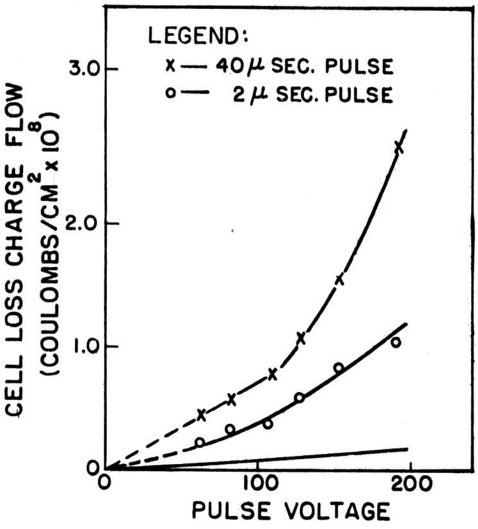


Fig. 14 – EL cell charge flow (minus capacitive component) versus rectangular pulse voltage. This charge flow difference is proportional to total cell loss. Expected loss of plastic dielectric alone is indicated by bottom curve.

The initial, or capacitive, charge flow into the cell was measured as a function of pulse voltage and was found to be proportional to the voltage up to the breakdown value of the cell within an experimental error of about three percent, indicating that this capacitance is quite linear. The total charge flow on charging the cell minus the charge flow associated with cell capacitance (per square cm of EL cell surface area) is plotted versus pulse voltage in Fig. 14 for a short and a long pulse. This charge difference is a measure of cell loss; the reverse charge flow after the pulse voltage has become zero returns little energy to the pulser because of the low output impedance of the latter, and can be neglected. The loss includes energy requirements of light production as well as heating. The lowest curve in Fig. 14 indicates the loss expected from the Araldite embedding plastic alone. The total loss with rectangular pulses greatly exceeds the dielectric loss. This loss for pulses of less than 100 volts is predominantly heating loss because the light output for such pulses is small. The loss for a 40-μsec pulse is about twice that for a 2-μsec pulse. On the other hand, the ILO for the longer pulse is about four times that of the shorter pulse, indicating a factor of two improvement in light efficiency for the longer pulse. For pulses shorter than 2-μsec in duration the phosphor loss would be expected to decrease compared to the plastic dielectric loss. Loss measurements made using a-c excitation of a frequency of 1 mc indicate that about 50 percent of the cell loss is due to the plastic at that frequency.

Conclusions

Useful light output can be obtained from thin plastic dielectric EL cells excited by short voltage pulses, even for pulse repetition rates of less than 10^3 per second, by employing higher peak voltages than would be used on the same cell with a-c excitation. For the ZnSe:ZnS phosphor used in this investigation and for a cell having an Araldite plastic dielectric, hermetic sealing and careful 'forming' of the cell with d-c voltage is necessary before the cell can withstand the higher pulse voltage without breaking down.

Under pulse excitation the waveform of the short-wavelength light differs greatly from that of the long-wavelength light emitted by the phosphor. The short-wavelength light is predominantly emitted after the pulse has started to decay and has a waveform which is pulse-amplitude independent. The long-wavelength light, on the other hand, is emitted in appreciable quantity before the pulse has begun to decay. The waveform of this light is pulse-amplitude dependent; for low pulse voltages the light is predominantly emitted during the pulse, but for higher voltages more of the light appears after the pulse has started to decay. These findings differ considerably from those of Matossi and Nudelman[3,4], but this may be because their phosphor was not of the type used here. For a slowly-decaying pulse most of the long- and short-wavelength light emitted after the pulse has started to decay is delayed until the pulse voltage has returned nearly to zero. This result confirms the hypothesis of Waymouth and Bitter[1] that excited carriers are swept out of the volume of the phosphor and rendered ineffective while the field is applied.

Measurements of total light output (ILO) as a function of peak pulse voltage show that an $\exp(-bV^{-1/2})$ law holds for the short-, medium- and long-wavelength components of light, both for rectangular pulses and for pulses which have exponentially rising or falling edges. For all these pulses the light increases more rapidly with voltage (b is greater) the shorter the pulse. Also, for all the pulses, relatively more short-wavelength light is emitted as the pulse is shortened. The ILO decreases as the pulse is shortened, but the fractional decrease in light is less than the fractional decrease in pulse length. For this reason, if the most light for a given pulse voltage is desired, shorter, more frequent pulses should be applied.

When exponentially rising, but fast falling pulses are applied to the cell the light becomes shorter in wavelength and increases more rapidly with voltage than it does with rectangular pulses of the same length and peak value. For a 40-μsec slow-rising pulse, these light characteristics were found to be equivalent to those of a shorter rectangular pulse of the same amplitude. For fast rising, exponentially falling pulses the light becomes longer in wavelength, but the rate of ILO increase with voltage remains the same as the rate for rectangular pulses having the same flat-top length. When both pulse edges are exponential in shape the shift toward short-wavelength light resulting from the rounding of the leading edge of the pulse is counteracted by a shift toward longer-wavelength light resulting from the slowly decaying trailing edge. The net shift is small if the time constants of the rise and the fall of the pulse are both the same.

The capacitance of the EL cell has been found to be constant to within a few percent over the normal operating range of voltage. Current continues to flow in the cell after capacitive charging is complete and the energy associated with this flow contributes to the cell loss. The total cell loss component increases as the pulse is lengthened and is considerably greater than the loss component of the Araldite plastic dielectric alone, even for the shortest (2-μsec) pulse used. The plastic loss may, however, be comparable to the phosphor loss for pulses shorter than 1-μsec or for frequencies greater than 0.5 mc. The increase in cell loss as the pulse is lengthened is accompanied by a more rapid increase in light output. The light efficiency for longer pulses is accordingly greater.

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