CHAPTER VII

BRIGHTNESS WAVES
7.1 Introduction

The term brightness waves is applied to the curves which give the light emission as a function of time during a cycle of variation of the potential applied to an electro-luminescent condenser. The fact that the light output varies periodically with twice the applied frequency was first reported by Destriau.\(^{(1,2)}\) The study of brightness waves provides an insight into the mechanism of recombination in electroluminescence. Brightness waves were originally obtained by means of a rotating disc device,\(^{(3)}\) while now a days photomultiplier and oscilloscopes are used.

7.2 General Review

The shape of the brightness waves is not in general symmetrical when stimulated by a sinusoidal field. A disturbance, which may be either an inflection or sometimes a small secondary peak, often occurs later in time than the main peak. The maximum of the light emission (the main peak) is not in phase with the applied potential and moreover, the two main peaks which occur in each cycle are unequal, and the slope of the curve differs according to whether the brightness is increasing or decreasing.

The brightness waveforms can be characterized by
(Fig. 7.1) :-

(i) a shift of the brightness wave as compared to the potential wave (phase angle \( \varphi \))

(ii) a disturbance at \( M \) and \( M' \), where the brightness is either \( B_2 \) or \( B_2' \), the prime sign indicating the half cycle when the transparent electrode, through which the observation is made, is positive.

(iii) a difference between the brightness \( B_1 \) and \( B_1' \) reached at the two successive main peaks \( A \) and \( A' \).

The modulation ratio \( m \) is equal to \( 2 \frac{B_1 - B_1'}{B_1 + B_1'} \).

\( m \) can be positive or negative.

The disturbance ratio \( d \) is given by \( B_2/B_1 \) or \( d' = B_2'/B_1' \)

The brightness waveforms characterized by three constants \( \varphi \), \( m \) and \( d \) are dependent of many factors \( (4) \) :

(i) The ratio \( a/b \) between the average thickness 'a' of the phosphor layer and the average thickness 'b' of the insulator.

(ii) The thickness of the phosphor layer.

(iii) The field strength.

(iv) Nature of metal electrode
The significant characteristics of a brightness wave showing the primary and secondary peaks.
(v) The frequency.
(vi) The temperature.

Besides these factors, the brightness waveforms are dependent on the nature of the cell i.e. whether it is symmetric or asymmetric. In the case of symmetric cells e.g. the phosphor layer between the two plates of conducting glass, the shape of the waves become quite simple. In the case of asymmetric cells the brightness waves have additional points of inflection. In the case of asymmetric cells the brightness waveforms are also dependent on the nature of metal electrode and its position i.e. whether it is in contact with the phosphor or separated from it by only a thin layer of insulator. The phase angle $\varphi$, modulation ratio $m$ and disturbance ratio $d$ are all different according to the electronic function of the metal backup.

The two peaks which normally occur during each cycle of the applied voltage do not generally have the same height. The polarity which corresponds to maximum brightness does not appear to be consistently defined. Some of the powder phosphors embedded in a dielectric show not only two main or 'primary' peaks of emission per cycle of alternating voltage but also two generally much smaller minor or 'secondary' peaks. The secondary peak may appear either on the descending side of one primary or on the ascending side of the following primary. It is also reported that with increase in voltage the secondary peak may shift from the
descending position to the ascending position of the primary. (6,7)

A shift of the secondary peak with temperature has been observed by some workers. (8-11) If the frequency is kept constant and the temperature lowered, the secondary peak moves continuously from the descending side of one primary peak to the ascending side of the next primary. (8,11) Keeping the temperature constant if frequency is decreased an opposite behaviour is observed. (9,10)

Irradiation of the phosphor by ultraviolet rays can also cause the secondary peak to disappear. (12-14) The secondary peak also disappears normally at high temperatures where the life time of trapped electrons is very short and at very low temperatures where the life time is very long. (11,15) Destriau (7) has observed that it also disappears at high frequency. The secondary peak may grow in height and then disappear more than once with the change of temperature corresponding to traps of different depths as observed by Hahn et al. (10)

The secondary peak is not normally observed in ZnS : Cu, Mn phosphors. (11,16,17) It is also found to be absent in those phosphors which have small trap depths (15) and in organic materials (6) or SiC (18) and red emitting ZnS : Cu phosphors. But it is very pronounced in phosphors containing oxygen (19,20) which is known to introduce deep traps in ZnS. (21,22)
There exists no fixed phase relation between brightness waves and the applied voltage. Generally the brightness waves are not in phase with the applied voltage but usually leads it. The phase angle is found to be a function of voltage and frequency. The higher the voltage, the greater is the phase angle, while it decreases with increasing frequency. According to Destriau (3, 6, 19) the brightness wave leads the voltage wave at low frequencies in ZnS : Cu phosphors, both are in phase at about 2 kHz whereas at high frequencies above 2 kHz the brightness wave lags behind the voltage wave. Zalm (20) and Thornton (16) have reported that the brightness wave never lags behind the voltage wave but can almost be in phase with it.

The shape of the brightness waves is influenced by the impurity content and the method of preparation of phosphor. (10) Goldberg (23) has studied the effects on the brightness waves of the addition of Ni or Co to ZnS : Cu, Cl phosphors.

7.3 Experimental Procedure

The brightness waves have been studied by means of a double beam oscilloscope, the description of which has already been given in Chapter III, Sec. 3. A simplified block diagram of the apparatus used is shown in Fig. 7.2.

The powder phosphor was mixed with araldite in equal proportion and was sandwiched between a metal (electrode) disc and
EXPERIMENTAL ARRANGEMENT FOR STUDYING BRIGHTNESS WAVES
a thin mica sheet. This pellet was put in the cavity of the cell. A drop of castor oil was put on the mica sheet and the conducting face of the conducting glass was placed on top of it. The metal disc and conducting glass served as the electrodes. After applying the electric field the emission was received by a photomultiplier tube screwed on the collar of the cell. The voltage developed across a resistance in the anode circuit of the photomultiplier was amplified and applied to one pair of Y plates of a CRO. The exciting voltage was fed to the other pair of Y plates. Well insulated leads were used to avoid stray capacitance. Brightness waves were obtained on the screen of the CRO along with the waves of the exciting voltage. The photographs of these waves were taken first by changing the voltage and keeping the frequency constant and then by varying the frequency at a constant voltage. The photographs of these brightness waves were taken for CaO:RE phosphor having optimum concentration of Eu, Tb and Sm.

7.4 Results

CaO : Eu (0.5%) : 

(1) Two primary peaks are observed per cycle of applied field. Therefore the frequency of brightness wave is twice that of the applied field (Figs. 7.3 and 7.4).
Brightness waves of CaO : Eu (0.5%) Phosphor

Fig. 7.3 \( f = 300 \text{ Hz} \)
\( V = 450 \text{ volts} \)

Fig. 7.4 \( f = 1000 \text{ Hz} \)
\( V = 600 \text{ volts} \)
(ii) At a low frequency (300 Hz) the EL intensity rises rapidly at first followed by a slower rise. The intensity decreases slightly from its maximum value before increasing again to give a second peak. From this point there is a decrease in intensity which is followed by a pronounced shoulder. After this stage the intensity drops rapidly and once again reaches zero value. Thus the intensity goes to zero only after a full cycle and not twice per cycle as would be expected in a symmetrical curve.

(iii) At higher frequency or voltage the pattern undergoes some modification as far as the central dip is concerned but essentially the zero of intensity is reached only after a full cycle.

CaO : Tb (1.5%)

(1) At low frequency there is first an increase in intensity followed by a slight decrease before a second maximum is reached. The intensity then falls to zero in two stages leading to the appearance of a slight shoulder on the fall off side.

(ii) At higher frequency there is no central dip but the shoulder on the fall off side is present.
Brightness waves of CaO : Tb (1.5%) Phosphor

Fig. 7.5  \[ f = 300 \text{ Hz} \]
\[ V = 1000 \text{ volts} \]

Fig. 7.6  \[ f = 500 \text{ Hz} \]
\[ V = 900 \text{ volts} \]

Fig. 7.7  \[ f = 1000 \text{ Hz} \]
\[ V = 900 \text{ volts} \]
(iii) As in the case of Eu activated phosphors, the intensity falls to zero after a complete cycle.

CaO : Sm (1.5%)

In this case the structure in the brightness waves is absent except for an almost imperceptible shoulder on the fall off side. The brightness reaches zero intensity after a complete cycle giving the impression of a single brightness wave per full cycle.
Brightness waves of CaO : Sm (1.5%) Phosphor

Fig. 7.8 $f = 300$ Hz
$V = 600$ volts

Fig. 7.9 $f = 1000$ Hz
$V = 600$ volts

Fig. 7.10 $f = 1000$ Hz
$V = 900$ volts


(19) Destriau, G.  -  Phil. Mag. (7), 38, 700, 774, 800, 885 (1947).


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