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Brightness waves of electroluminescence in ZnO:Nd electroluminor

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Abstract. Brightness waves due to sinusoidal excitations for ZnO:Nd electroluminor have been investigated for a temperature range 93°K to 363°K. During each cycle of excitation it consists of two primary waves each associated with a secondary wave, which grow and disappear twice in this temperature range. These results have been discussed in terms of existing models.

Keywords. Electroluminescence; brightness waves; Nd doped ZnO.

1. Introduction

The variation of electroluminescence (EL) light emission during each cycle of excitation of varying electric field is known as brightness waves (BW). Study of BW provides an important tool to understand the mechanism of EL phenomena. Further, it is known (Zalm *et al* 1954; Matossi 1955) that traps play an important role in the development of BW. In continuation of our previous publications (Bhushan *et al* 1976–78) on rare earth (RE) doped ZnO system, this paper reports some results of BW of EL in ZnO:Nd electroluminor for the temperature range 93°K to 363°K.

2. Experimental

The preparation of electroluminor and EL cell, the experimental arrangements and the details of cryostat have been discussed earlier (Bhushan *et al* 1976, 1978a).

3. Results

3.1. *Effect of voltage and frequency*

The BW at two different voltages and two frequencies of the excitation field (EF) at 273°K are shown in figures 1 and 2. The primary and secondary peaks of BW are designated by P_1 and P_2 and S_1 and S_2 respectively. It is seen that the primary peak of BW always precedes the voltage maximum of exciting field (EF) and the phase difference ϕ increases with increase of excitation voltage and decreases with the increase in frequency. Further, the secondary peaks associated with each primary peak disappears with the increase in voltage and frequency (900 V or 2·5 kHz).

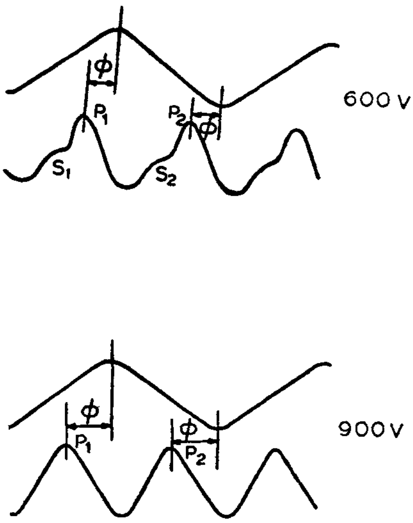

Figure 1. Brightness waves of ZnO:Nd electroluminor at different voltages ($f = 500$ Hz; $T = 273$°K)

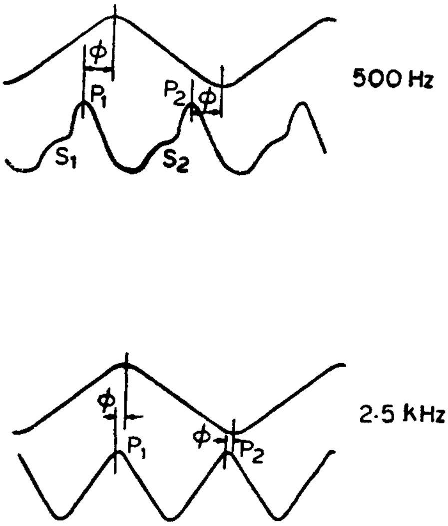

Figure 2. Brightness waves of ZnO:Nd electroluminor at different frequencies ($V = 600$ V; $T = 273$°K)

3.2. *Effect of temperature*

The BW at different temperatures between 93°K and 363°K at fixed excitation voltage and frequency are studied and some are shown in figure 3. It is found that the position of the primary peak remains fixed with respect to peak positions of EF with the change in temperature. Further, the secondary peaks associated with each primary peak grow and disappear twice in this temperature range. In the diagram the secondary peaks at lower temperatures have been marked by S_1 and S_2 while those at higher temperatures by S'_1 and S'_2. The temperature dependence of EL brightness in the range of 99°K to 293°K is shown in figure 4. From this curve two strong peaks—one at 142°K and the other at 266°K are seen. The temperatures (141°K and 263°K) at which the secondary peaks of BW grow more are very near to these peak temperatures.

The first secondary wave appears in the ascending arm of primary at about 113°K and with increase in temperature its height with respect to primary of BW goes on increasing and it also creeps in the preceding direction till it becomes most prominent and lies between two primaries (141°K). Further increase in temperature decreases its height and it disappears at about 173°K. A new secondary peak appears at about 243°K and becomes most prominent at about 263°K and disappears at about 353°K. It always remains in the ascending arm of the primary wave but the shift with temperature is in the same direction as that of the first one. However, the shift in the position of the above secondary waves with respect to primary peak position of BW are not the same in magnitude; the shift for the first secondary from 113°K to 173°K is about 47° while that for second one from temperature 248°K to 323°K is only 18°.

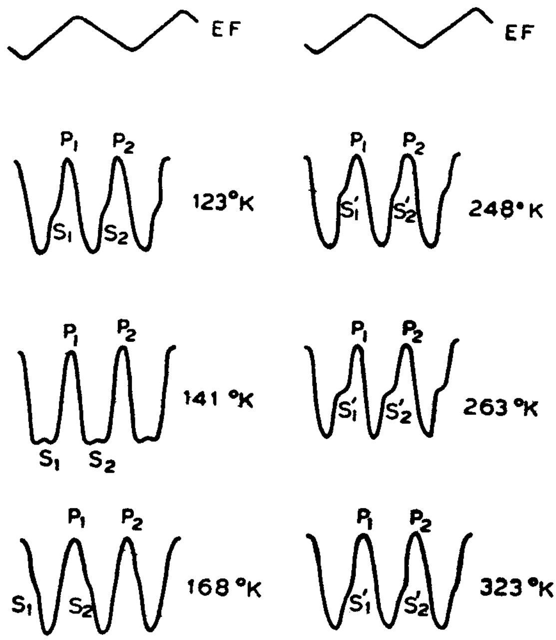

Figure 3. Brightness waves of ZnO:Nd electroluminor at different temperatures ($V = 500$ V ; $f = 500$ Hz)

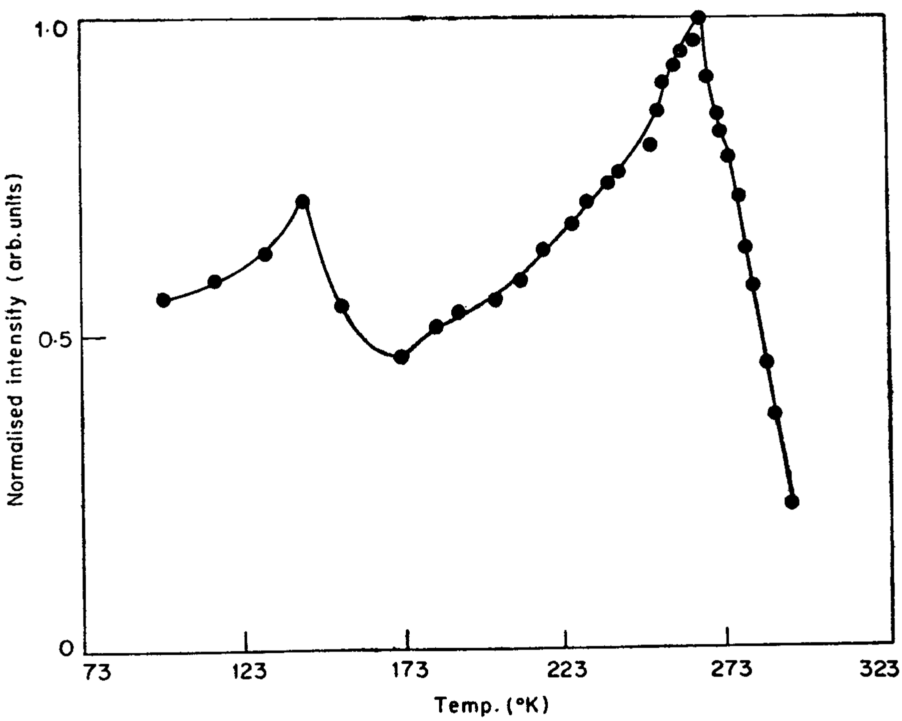

Figure 4. Temperature dependence of EL output for ZnO:Nd electroluminor ($f =$ 500 Hz; $V = 500$ V)

4. Discussion

The shift in the position of the primary peak with the voltage and frequency of the EF may be explained in terms of 'delayed nature of the recombination' (Zalm 1956). After the field is reversed the electron must return to empty luminescent centres for emission to occur which is facilitated if the driving voltage is higher and also if sufficient time is allowed. The emission peak, therefore, occurs earlier in the cycle for higher voltage and low frequency.

The secondary peaks may be attributed to electrons which are freed from certain centres in the presence of electric field and become trapped in some low field regions. These electrons may recombine only after the internal field is reversed. According to Haake (1957), the time t_0 at which the maximum light intensity from secondary peak is observed, is a function of frequency (f) of EF and temperature (T) and is given by the relation

$$\frac{1}{t_0} \propto \frac{p}{w} = \frac{s}{2\pi f} \exp\left(-E/KT\right), \tag{1}$$

where p is the thermal release probability of electrons from traps, s the frequency of escape, E the trap depth and K the Boltzmann constant. From this relation it is clear that at constant frequency of EF decreasing the temperature T will increase the time t_0 and therefore the secondary peaks creep forward along the time scale. From figure 4 we find that two types of traps are effective in the present system. The two types of secondaries (S and S') may be associated to these traps. Because of the difference in the depths of the traps the shifts with the position of the two secondaries with temperature are different.

Further, the life-time of the trapped electrons is very short at high temperatures and very long at low temperatures (the absolute value depends on the trap depth), causing the disappearance of secondary peaks at the two extremities of temperature corresponding to each trap. At very high frequency the time becomes so small that the traps cannot hold the electrons and therefore the secondary wave disappears. At very high voltage it seems that the electrons responsible for the secondary wave find sufficient energy for acceleration and partake in primary emission and thus the secondary wave disappears.

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