THEORETICAL APPROACH TO THE BRIGHTNESS OF A. C.THIN-FILM ELECTROLUMINESCENCE DEVICE

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ABSTRACT

An AC thin film electroluminescence device (ACTFELD) consists of a ultra layered structure of thin film of transparent electrode, insulator, phosphor, insulator, and metal electrode. Considering the fact that charge transfer from semiconductor to insulator layer causes electroluminescence excitation, an expression is derived for electroluminescence brightness. It is found that the brightness B of EL depend on several factors like such as efficiency η, insulator capacitance C_i, applied voltage V and voltage across the semiconductor U_s (t).

KEYWORDS: AC Thin Film Electroluminescence Device (ACTFELD), Brightness-Voltage Relations, Electroluminescence, Luminescence Emission, MISIM Structure

INTRODUCTION

An AC thin film electroluminescence device (ACTFELD) of the type pioneered by inoguchi and mito [1] consists of active ZnS:Mn layer sandwiched between two insulating layers of Y_2O_3 have now acquired the status of a reliable display element of very high brightness (>1500fL) and long life (~ 20,000 h)[1] . One main disadvantage of these device at present is its high operating voltage as compared with OLED. Effort are being made to reduce this voltage by using suitable dielectrics instead of Y_2O_3. The selection of this dielectric layer is done mainly on basis of the conclusion of Howard [2], that in order to obtain high brightness and high efficiency, the insulator film used must have the product of its dielectric constants and breakdown voltage at least three times higher than the corresponding value for the active ZnS:Mn layer. This implies that for low voltage operation without sacrificing the brightness or efficiency, insulator used should have high dielectric constant and breakdown strength. Based on this idea Okmato et al [3] have tried piezoelectric $PbTiO_3$ (ϵ=150) as insulator and found t,hat they can operate at 50 volts[3].

The main reason for the intensive attention being paid to thin film A.C electroluminescence devices, is the feasibility of realizing high quality flat panel displays [4-9] The film electroluminescence device have a multilayered structure of thin film of transparent electrode, insulator ,phosphor ,insulator and metal electrode. All these are important materials in fabricating and electroluminescence device, and offer numerous topics for research in areas such as electron transport processes and mechanism of excitation of luminescent centers [10-22]

In the present paper, a theoretical approach has been made to the brightness of thin film EL devices.

LIGHT–EMISSION MECHANISM

The light emission that is observed parallel to the charge transfer in doped with luminescence impurities is characteristic for the dopant (Fig.). For the most frequently investigated luminescence centres of ZnS-based ACTFELD) , the Mn ion (Mn^{2+}) and the Tb ion (Tb^{3+}), the emissions correspond to transitions of internal orbits. The two ions, Mn^{2+} and Tb^{3+} substitute for the Zn ion in the semiconductor. In order to compensate for the surplus charge of Tb^{3+} one often

introduces Tb as a complex centre such as TbF or TbF_3 in the ZnS matrix [23]

One important aspect of high-field EL concerns the nature of the excitation process of the luminescence centres. In fact, there are two possible ways for the charge carriers to excite the dopants: (i) direct excitation per (inelastic) impact, or (ii) indirect exciation (the incident charge carrier excites a centre of the accepter-donor type, which subsequently recombines). The recombination energy is then transferred to a close luminescent centre. The latter process is important with ZnS : Mn, Cu powder EL (PEL) samples [24], but for ACTFELD direct impact excitation seems to be the dominant mechanism . In the case of ZnS:Mn, Tanaka et al. [25] compared to the photoluminescence (PL) powder efficiency η_{PL} (Mn luminescence stimulated by band to band excitation 3.6 eV/illumation input power) with the EL power efficiency η_{EL} (luminescence/power). They concluded that the values of η_{PL} and η_{EL} are incompatible with an indirect –excitation mechanism for EL. In case of Tb, the evaluation is complicated by the nature of the centre complex (TbF, TbF_3). [26] Showed by means of time-resolved spectroscopy that at least in $ZnS:TbF_3$ samples, impact excitation prevails.

Apart from the luminescence owing to intentionally introduced impurities such as Sm or Tm one can observe a broadband light emission extending from around 330 nm to the red spectrum region. This emission is also observed in undoped sample and has a very short decay time (< 50 ns), which implies that it is only observable during the charge transfer across the ZnS . Owing to its emission maximum in blue region, it is often called blue emission, but one has to stress that the spectrum is not identical to the well-known PL spectrum of the blue self-activated emission in ZnS [27]. EL emission is referred to in the following as ZnS emission. The ZnS-emission intensity is very weak compared to the luminescence observed for centre such as Sm or Tm. Its absolute intensity decreases with increasing concentration. It is not probable that the activator-donator centres are involved in this luminescence emission because of the constancy of the spectrum in time-resolved spectroscopy. It has been suggested that the emission is due to interband transition of high – energy electron [28], but its nature is not completely understood.

THEORY

The schematic of an ACTFELD matrix showing the MISIM structure is given in Fig 1(a) and (b) shows the equivalent circuit of one pixel. As r and C_s are in parallel. Their equivalent resistance R is given by

$$\frac{1}{R} = \frac{1}{r} + \frac{1}{\frac{1}{j\omega C_s}} \tag{1}$$

$$R = \frac{1}{j\omega C_s}$$

Below threshold voltage for light emission r>>1 ,and therefore equivalent resistance is given by

$$R = R' + \frac{1}{j\omega C_s} \tag{2}$$

It is evident from Fig .1 that C_i and R are in series therefore , equivalent resistance is given by

$$R' = \frac{1}{j\omega C_s} + \frac{1}{j\omega C_i} \tag{3}$$

Thus, the voltage developed across the semiconductor by the applied voltage U may be expressed as

$$U_s = \frac{\frac{1}{j\omega C_s}}{\frac{1}{j\omega C_s} + \frac{1}{j\omega C_i}} . U = \frac{C_i}{C_i + C_s} . U$$

Or $U_s = \alpha U$ $\tag{4}$

$$\text{Where } \alpha = \frac{C_i}{C_i + C_s}$$

Where Below threshold voltage UT, Us will be given by equation (4). However, above threshold voltage, the current flowing through r will transfer voltage from the semiconducting S- layer to the insulating I - layer C_i and the voltage across semiconductor Us(t) may be written as :
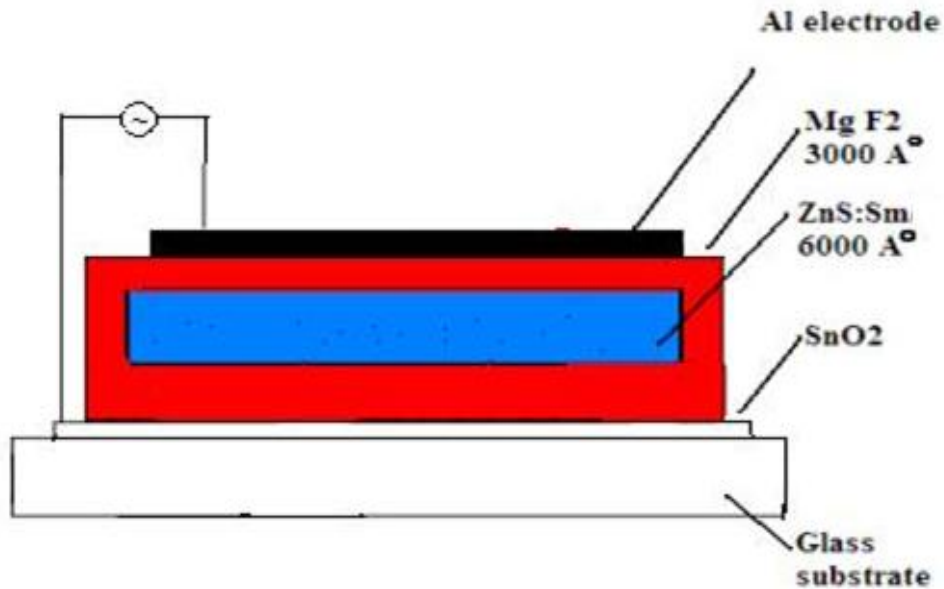

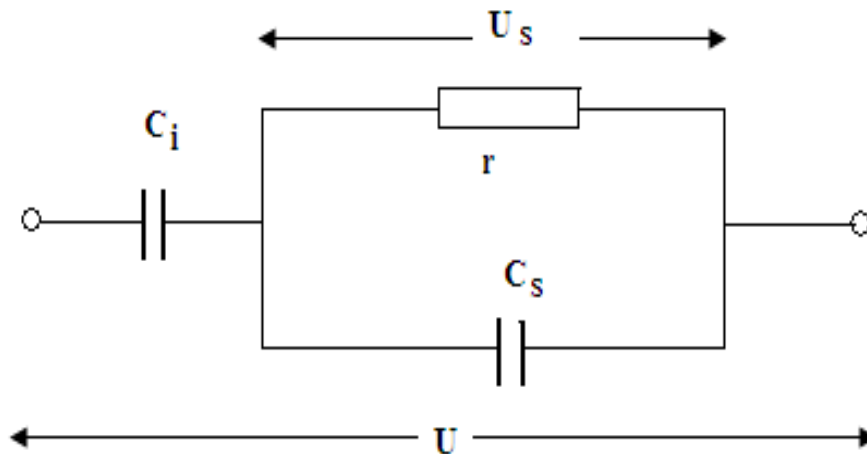**Figure 1: Structure of thin Film EL Device Fabricated**

Figure 2: Equivalent Circuit Diagram of One Pixel

(1-Metal Electrode (A1),2-Insulating layer(` 2000A$^0$),3-Active Layer (Zns:Sm`/Tm 5000A^0),5-Transparent Electrode (SnO2) and 6-Glass substrate).Where Below threshold voltage U_t, U_s will be given by eqn.(4).However ,above threshold voltage ,the current i_r flowing through r will transfer voltage from the S-layer to the I –layer (C_i) and the voltage across the semiconductor U_s(t) may be written as :

$$U_s(t) = \alpha\, U(t) - \frac{1}{Ci} \int_0^t i_i \ dt'$$

or $\qquad U_s(t) = \alpha\, U(t) - \dfrac{1}{C_i} Q_i\,(t)$ $\hspace{4cm}$ (5)

It is seen from fig. That i_r the current flowing through r will be the difference between the current i_i flowing through the insulator and the current i_s flowing semiconductor, thus, we get

$$i_r = i_i - i_s$$

or $\qquad i_r = C_i\, \dfrac{dU_i}{dt} - C_s\, \dfrac{dU_s}{dt}$ $\hspace{4cm}$ (6)

As $\qquad dU_s = - dU_s$, we get

$$i_r = C_i\, \dfrac{dU_s}{dt} - C_s\, \dfrac{dU_s}{dt}$$

$$i_r = -\dfrac{dU_s}{dt}\,(C_i + C_s)$$ $\hspace{4cm}$ (7)

Thus, charge Q_r flown through r may be expressed as

$$Q_r = i_r\,.dt = - dU_s(C_i + C_s)$$

or $\qquad Q_r = \dfrac{(C_i + C_s)}{C_i}\,.Q_i$ $\hspace{4cm}$ (8)

Where $- dU = \dfrac{Q_i}{C_i}$.

The brightness B, i.e. the photon flux produced in each half period of the excitation voltage of peak voltage V may be expressed in terms of electrical energy N supplied in to the S-layer per half period. The energy supplied to the input into the S-layer per half period will be equal to the charge $Q_r = C_i \left[V - \dfrac{U_s\,(t)}{\alpha}\right]$ times voltage across at the S-layer. Thus we get

$$B = \eta\,.N$$

or $\quad B = .\; C_i \left[V - \dfrac{U_s\,(t)}{\alpha}\right].U_s\,(t)$ $\hspace{4cm}$ (9)

Where η is the conversion efficiency in lumen / watt. Equation (9) indicates that B should depend on: (i) η , (ii) $U_s\,(t)$, (iii) V , (iv) α , and $(v)\, C_i$

It has been found that different semiconductors used as active material give different brightness. This fact indicates that brightness depends on the efficiency η.

EXPERIMENTAL SUPPORT TO THE PROPOSED THEORY

As reported by Patel [4] (2000) has reported that fig.3 shows the plot between brightness B versus applied voltage U_p. It is seen that the EL emission takes place only after a particular value of the applied voltage. Such fact has been observed in our proposed theory.

Fig. 3 also indicates that the brightness B increases with the applied voltage and than its tend to attain a saturation value. The dependence of brightness on the voltage is indicated by equation (9) the saturation value of the brightness for higher value of the applied voltage may be due to the transfer of all charges from the
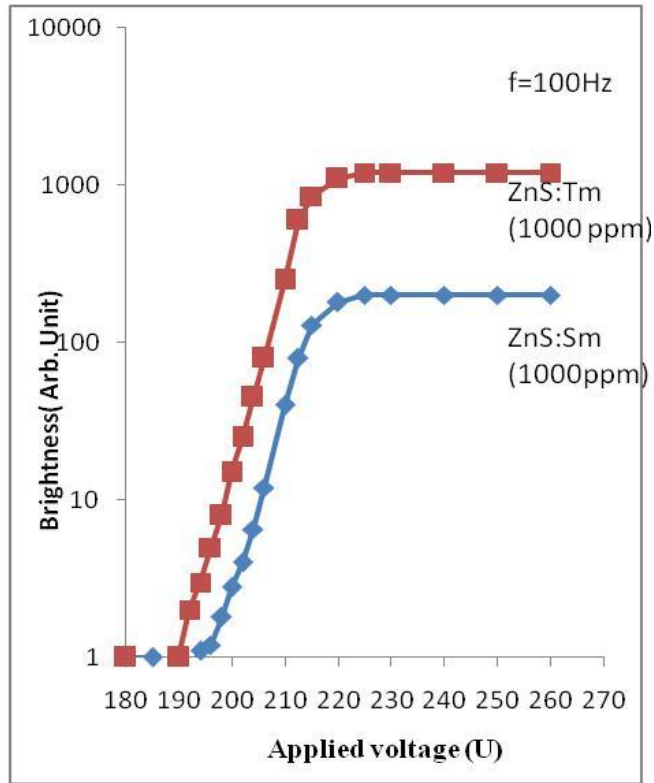
Figure 3: Brightness (B)- Voltage(U) Characteristics of ZnS:Sm (1000 ppm) and ZnS:Tm(1000 ppm) Electroluminescent Devices
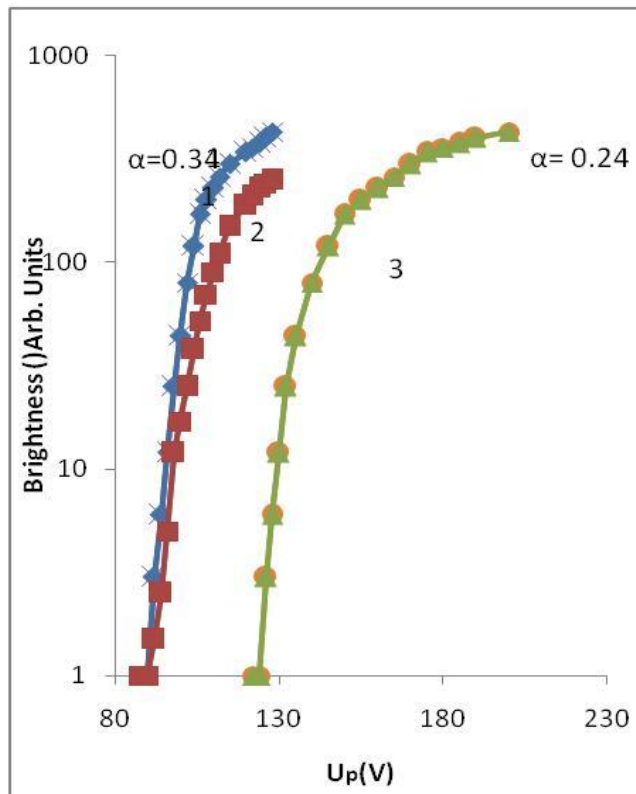

Figure 4: Brigntness (B) – Voltage (U) Characteristics of an AC TFD with (1) α = 0.34, (2) α = 0.24 Same as in (1) but α Reduced by an External Capacitor; (3) Curve (2) Shifted to Make B Coincide at low Brightness for Comparison Only
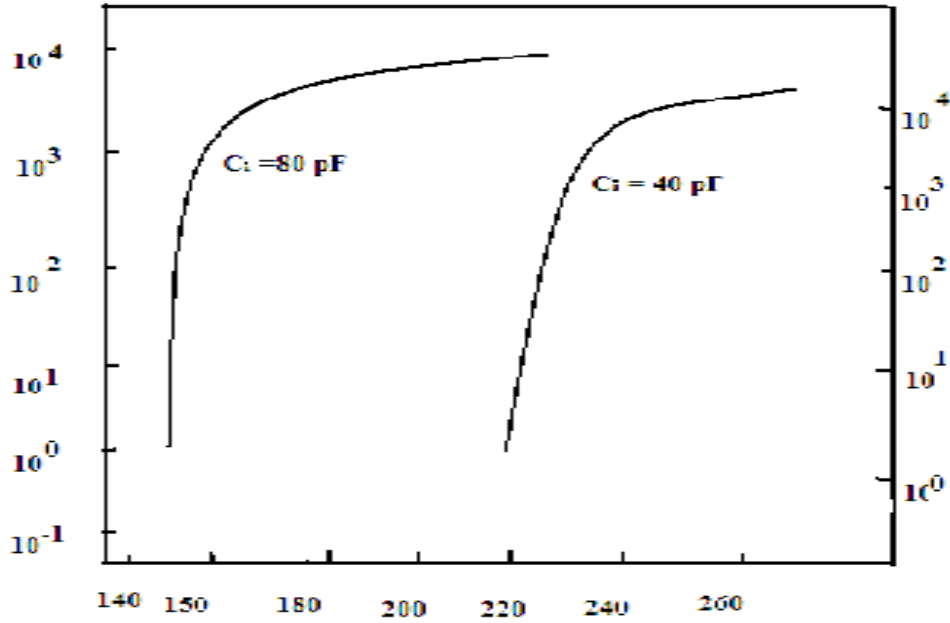
Figure 5: Evidencing the Influence of C, or α on B(U) in the Simplest Model Calculation

Muller [8] has reported that for higher value of α less value of the threshold voltage is needed to cause the electroluminescence emission fig 4 such fact is indicated by eqn..9

Muller [8] as also reported that low value of threshold voltage is needed for the EL device having higher value of C_i fig.5 this may be understood in a following way. Substituting $\alpha = C_i \,/(C_i + C_s)$ equation (9) may be expressed as:

$$B = \eta C_i \left[V - \frac{U_s(C_i + C_s)}{C_i} \right] U_s(t)$$

or $\qquad B = \eta C_i \left[V - U_s\,(t)\left(1 + \frac{C_s}{C_i}\right) \right] U_s(t)$ $\qquad\qquad\qquad\qquad\qquad$ (10)

It is evident from equation (10) that for lower value α the value of product $U_s\,(t).\left(1 + \frac{C_s}{C_i}\right)$ will be higher, therefore, higher value of U will be needed to cause the EL emission, on the other hand for the higher value of α the value of product will be low and consequently lower value of applied voltage will be needed to cause the EL emission.

Fig. 4.15 shows that for the higher value of α the threshold voltage is less and for lower value of C_i the threshold voltage is high this result is also in accord with the proposed model.

CONCLUSIONS

An expression is derived for the brightness of EL devices which is as given below:

$$B = \eta \,.\, C_i \left| V - \frac{U_s\,(t)}{\alpha} \right| .U_s\,(t)$$

Where η is the conversion efficiency in lumen / watt, above expression indicates that B should depend on: (i) η , (ii) $U_s\,(t)$, (iii) V , (iv) α , and $(v)\ C_i$. This equation is able to explain dependent of the brightness of electroluminescent device on different parameters. Thus, there is good agreement theoretical results with the experimental results.

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