THE DEPENDENCE OF BRIGHTNESS AND THRESHOLD VOLTAGE OF MEMORY ZnS:Mn THIN FILM ELECTROLUMINESCENT DEVICE UPON ITS THICKNESS

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ABSTRACT

Thin film electroluminescent devices made from ZnS:Mn can be designed to exhibit an inherent hysteresis in the luminance vs. applied voltage characteristics. This memory behavior offers attractive advantages for efficient operation of displays with very large information content. Additionally, such memory devices can also be switched by light or electron beams, making possible such applications as image storage and a CRT with an active faceplate. If the device is driven near the threshold voltage, a pronounced hysteresis effect in the brightness vs. pulse width response curve also occurs. The dependence of brightness characteristics, as well as the threshold voltage and response time on the film thickness of the ZnS:Mn layer is reported. The experimental results are in good agreement with the theoretical prediction.

1 INTRODUCTION

AC thin film electroluminescent (ACTFEL) devices based on ZnS doped with Mn active material, are now enjoying a growing interest since this technology has opened the way to design large-area, flat-screen displays [1]. Much effort is now spent on scaling up of the panel area, and higher resolution in display technologies. This is motivated by the growing demand for various portable terminals.

Memory ACTFEL devices show hysteresis in their brightness-voltage (B-V) response curve [2]. The hysteresis voltage margin, ΔV, and saturation brightness B_s, can be considered as the figures of merit for memory ACTFEL displays. In operating a memory ACTFEL device, we usually apply a sustaining AC voltage, V_s (root-mean-square value), which is normally adjusted so as to be in the vicinity of the centre portion of the hysteresis region [3]. Initially, the device has low brightness operating at V_s. It can be turned 'on' by increasing the excitation voltage to $V_{ON} \sim V_s + V_0$ and turned 'off' by reducing V_s, at voltage V_0. The optimum value of V_0 is usually chosen so that V_{ON} reaches the 'knee' point voltage in the device's B-V response curve.

From a device and even an equipment point of view, hysteresis in B-V response curve is the most important advantage of ACTFEL devices for large-area applications. In spite of the fact that the brightness of a memory-type EL, in general, is lower than that of non-memory ones [4], their advantage lies in the possibility of operating on an arbitrary number of pixels in the matrix addressing mode at the same brightness level as the one-pixel device. Thus, memory devices are potentially more suitable for large area display operation.

A pronounced hysteresis effect in the brightness vs. pulse width (B-W) response curve for memory ACTFEL devices driven near the threshold voltage has also been found and its use to address memory EL displays was suggested. Therefore, on the basis of these investigations we have inspected the dependence of the B-W characteristics on the film thickness of the ZnS:Mn layer. The variations of the response times with respect to these parameters were also studied. The first results are reported in this paper.

2 EXPERIMENTAL

The studied ACTFEL devices represent the structure composed of layers of SiO_2 (150 nm), Y_2O_3 (300 nm), ZnS:Mn (various thickness from 200 to 900 nm), Y_2O_3 (300 nm), SiO_2 (150 nm) deposited onto an indium-tin-oxide (ITO) coated glass substrate.

The experimental setup used in the measurement is shown in Fig. 1. The samples were mounted in a thermal chamber, and driven by the voltage provided by the high-voltage pulse shaper. DC or AC pulses with variable durations and voltages could be generated.
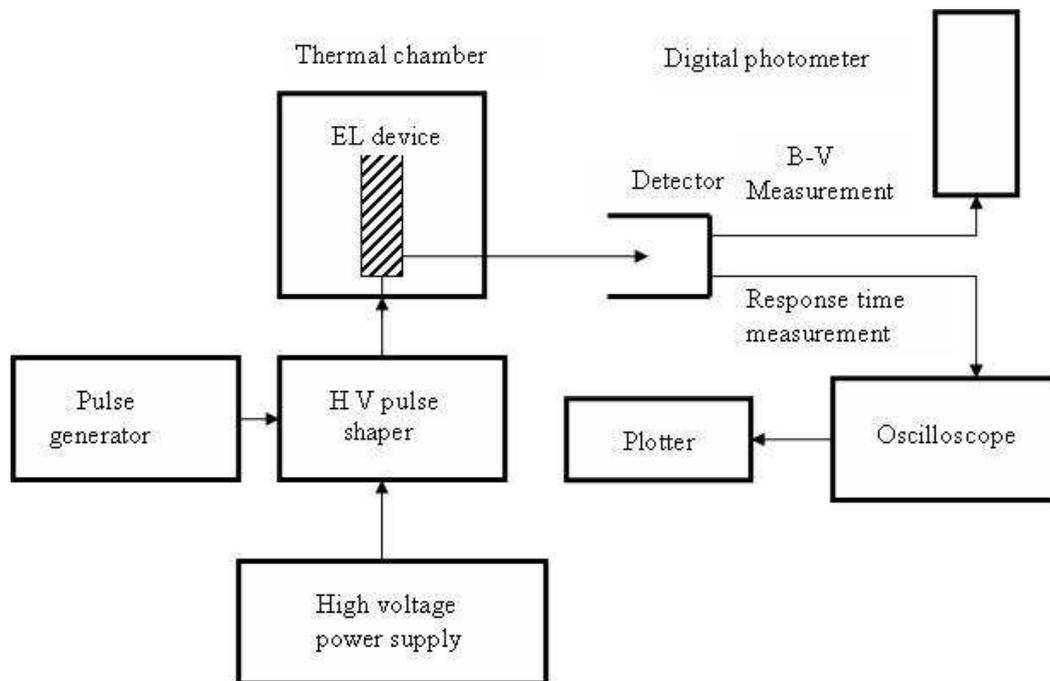

Fig. 1: *Experimental setup for measuring the electro-optical characteristics of TFEL devices.*

All electro-optical measurements are taken by using our standard experimental setup, in which the ACTFEL device is placed in series with a resistor and a large sense capacitor. For

brightness-pulse width (B-W) measurements, a 150 Hz AC voltage with square-pulse widths ranging from 20 µs to 200 µs was applied (waveform generator Agilent 33220A in conjunction with a high-voltage operational amplifier 7265 DSP). The emitted light brightness was measured as a function of the pulse width, for a given peak-to-peak voltage, using an Ocean Optics PR-650 digital photometer. For the response-time measurements, a Hamamatsu type R928 photomultiplier tube (rise time ~ 25 ns) was used to detect the pulsed-light output. The voltage pulse and optical response were monitored on an Agilent 54621A digitizing oscilloscope and the results were plotted on a recorder [5].

3 RESULTS AND DISCUSSION

As an example of obtained results, the measured relations of the B-W response curves at various peak-to-peak voltages for the ZnS:Mn film thickness of 600 nm are shown in Fig. 2. As can be seen, a pronounced hysteresis effect is observed for the device driven near the threshold voltage.

Let the brightness margin, ΔB, be defined as the hysteresis width at pulse width 20 µs, the observed variations of ΔB and the threshold voltage with respect to the ZnS:Mn film thickness are shown in Fig. 3. It is noted from Fig. 3 that the hysteresis appears only if the ZnS film is thicker than 200 nm. Above it, the hysteresis width ΔB increases with the film thickness.
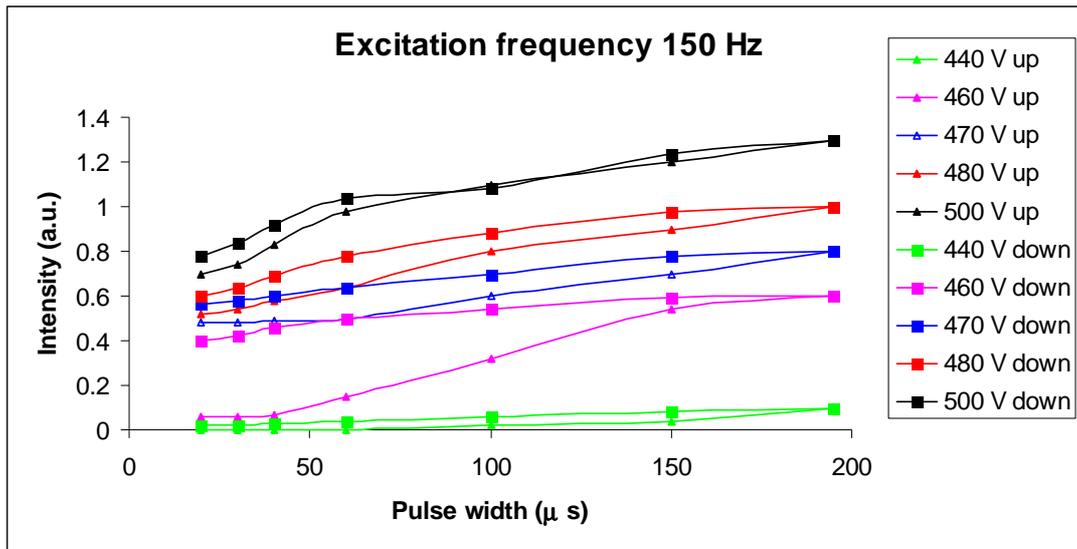

Fig. 2: *The measured relation of the brightness versus pulse width (B-W) at various peak-to-peak voltage of the memory EL device at excitation frequency 150 Hz.*

It is also noted from Fig. 3 that the threshold voltage of these devices changes dramatically from one device to another. Within the experimental error, the threshold voltage was found to increase approximately linearly with the ZnS film thickness. This result is understandable. Experimentally, it has been proven that the excitation mechanism in ZnS:Mn EL devices is due to the direct impact excitation of the activator ions of Mn^{2+} by 'hot' electrons [6]. These electron s were originally trapped at the active (ZnS)-insulator (Y_2O_3) interface states. At high enough applied voltages, they tunnel from the interface states into the conduction band of the active layer. They are subsequently accelerated by the high electric

field and the impacts excite the activator ions, Mn^{2+}. Light is emitted as the ions undergo radiative decay from the excited state to the ground state [6]. As a result, the threshold voltage is related primarily to electron tunneling which is induced by the electric field ($E = V/d$) inside the layers. Therefore, the threshold voltage should increase as the thickness of the ZnS film increases.
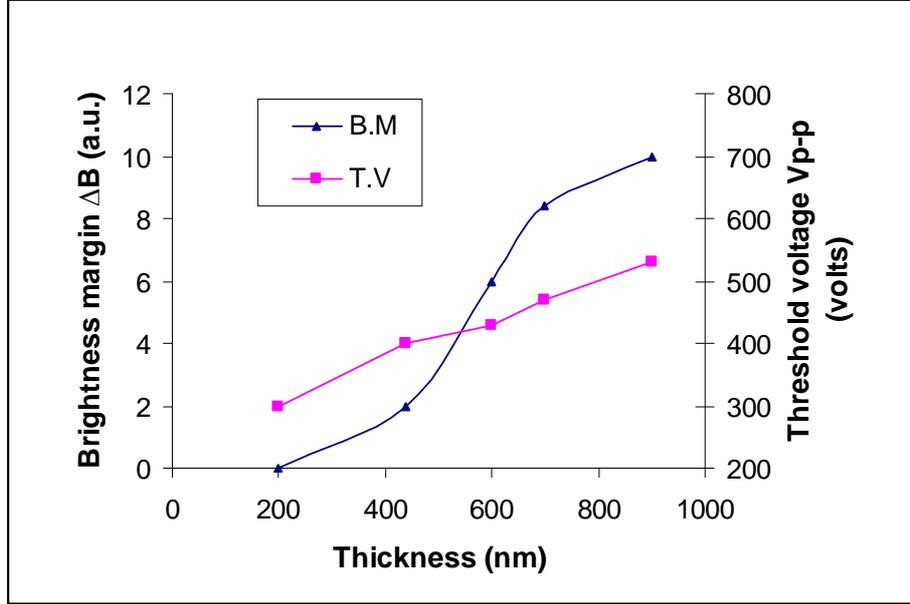

Fig. 3: *The observed variations of brightness margin, ΔB (curve BM) and threshold voltage V_{p-p} (curve TV) with respect to the film thickness of ZnS:Mn layer.*

It should also be noted from Tab.1 that the rise-time and the decay-time are not equal. It is known that the rise-time is controlled by the crystalline properties of the ZnS:Mn layer.

ZnS:Mn layer thickness (nm)	Device	T_r (μs)	T_d (μs)
200	D_1	75	105
450	D_2	81	111
600	D_3	80	100
750	D_4	84	105
900	D_5	78	108

Tab. 1: *The measured results of the rise-time (T_r) and the decay-time (T_d) for ZnS:Mn EL devices having various thickness of the active layer*

Electrons reach the excite-impact energy faster in large grained ZnS:Mn thus decreasing the device's rise-time. The decay-time, on the other hand, is determined by the radiation decay time of luminous centers Mn^{2+} from their excited state. According to this picture, the rise-time should be independent of the ambient temperature, and the decay-time should not. The decay-time T_d can be written as

$$\frac{1}{T_d} = \frac{1}{T_{ir}} + \frac{1}{T_{inr}} ,$$

where T_{ir} is the internal radiative decay-time, T_{inr} is the internal nonradiative decay time. The major nonradiative decay process for an excited Mn^{2+} ion is most likely due to energy transfer

to the 'killer' centers in the ZnS lattice [8]. These centers may be associated with impurity atoms, or with defects in the ZnS lattice (e.g. vacancies, dislocations, etc).

4 CONCLUSION

An experimental study of the brightness-pulse width characteristics of memory ZnS:Mn ACTFEL devices is presented, in which memory of the device is assessed by monitoring the hysteresis characteristics. From the obtained results we can conclude two important notices:

1) The hysteresis appears only if the ZnS film is thicker than 200 nm. Above it, the hysteresis width ΔB increases with the film thickness.

2) The threshold voltage is related primarily to electron tunneling which is induced by the electric field (E = V/d) inside the layers. Therefore, the threshold voltage should increase as the thickness of the ZnS film increases.

For further development in the 21st century, it is strongly expected to create new functional materials beyond a scope of conventional inorganic compounds. The targets of our ongoing research project are to create new organic-inorganic hybrid systems with new types of electronic and optical functions and to open the new frontiers of advanced applications, such as memory devices with a huge recording density and a light-emitting flat panel with high energy-conversion efficiency.

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