AGING STUDY OF EVAPORATED ZnS:Mn ALTERNATING-CURRENT THIN-FILM ELECTROLUMINESCENT DEVICES

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ABSTRACT

A study of the aging characteristics of evaporated ZnS:Mn alternating-current thin-film electroluminescent (ACTFEL) devices is undertaken by monitoring the capacitance-voltage (*C-V*) characteristics at various temperatures as a function of aging time. Short-term ACTFEL aging is characterized by a rigid shift in the *C-V* curve to higher turn-on voltage with aging time. Additionally, the insulator and phosphor capacitances are found to be independent of aging time, the internal phosphor threshold voltage increases slightly with aging time, and the conduction and polarization charges are observed to decrease with aging time.

1 INTRODUCTION

The importance of the aging characteristics of alternating-current thin-film electroluminescent (ACTFEL) devices is underscored by the fact that device stability and aging were major focal points in the paper by Inoguchi [1] which ushered in the modern age of ACTFEL technology. Much work has subsequently been reported regarding ACTFEL aging characteristics, mechanisms, and process modifications to improve device stability. Most of this work has involved characterization of the luminescent properties of the ACTFEL devices as a function of aging time. The purpose of the work discussed herein is to report an investigation of the aging properties of evaporated ZnS:Mn ACTFEL devices which were fabricated by Planar Systems. This study is unique in that the aging characteristics are monitored, as a function of temperature and aging time, using the capacitance-voltage (*C-V*) technique. The *C-V* technique offers several advantages for ACTFEL aging studies. First, the technique can be readily automated. Second, a wealth of device physics data can be acquired which leads to a better understanding of the internal electrostatic modifications associated with aging and, hence, of the physical mechanisms of aging. The obvious disadvantage of the *C-V* technique is that it exclusively monitors the electrical properties of the ACTFEL whereas the device performance must ultimately be assessed optically. Temperature-dependent *C-V* aging studies yield an aging activation energy of approximately 0.2 eV. ACTFEL aging is also characterized by a turn-on voltage which increases with aging time, a *C-V* transition which shifts rigidly with aging time, phosphor and insulator capacitances which are independent of aging time, a phosphor field which increases slightly with aging time, and conduction and polarization charges which decrease with increasing aging time. These experimental observations lead to a model for ACTFEL aging in which hot-electron-mediated atomic migration near the insulator/phosphor interfaces gives rise to the creation of defect complexes which act as deep level traps and increase the interface fixed charge density. The atomic rearrangement is envisage-d to occur very close to the interface (within perhaps 100 Å), to most likely involve the presence of sulfur vacancies, and to probably occur by nearest-neighbor hopping.

2 EXPERIMENTAL

The ACTFEL devices are fabricated at Planar Systems and consist of an evaporated ZnS:Mn active phosphor layer which is sandwiched between two sputtered silicon oxynitride insulator layers. Aluminum and indium-tin oxide (ITO) electrodes are employed as contacts. Briefly, *C*-*V* analysis is accomplished using the circuit shown in Fig. 1. An arbitrary waveform generator (Agilent 33220A) in conjunction with a high-voltage operational amplifier (7265 DSP) generates the small duty cycle bipolar pulse waveform which drives a series resistor, R_s the ACTFEL device, and a current sense resistor, R_c as shown in Fig. 1. R_s is chosen to be 1.25 kΩ and R_c is chosen to be 10 Ω. $v_2(t)$ and $v_3(t)$ are obtained using a digitizing oscilloscope (Agilent 54621A). The standard waveform consists of symmetric, bipolar pulses of trapezoidal shape with 5 μs rise and fall times and a pulse width of 30 μs where rise and fall times are defined as the time between 0 % and 100 % of the maximum amplitude and the pulse width is defined as the duration during which the pulse is at its maximum amplitude. The frequency of the waveform is 1 kHz.

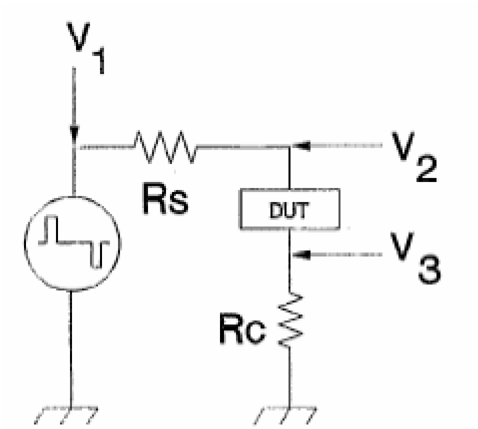

Fig. 1: *Circuit used for ACTFEL electrical characterization*

Referring to fig. 1, the current through the ACTFEL device is obtained from the voltage across the sense resistor, R_c, e.g. $i(t) = v_3(t)/R_c$. The capacitance is equal to the current divided by the derivative of the voltage across the ACTFEL device, so that

$$c(v_2 - v_3) = \frac{i(t)}{d[v2(t) - v_3(t)]/dt} \tag{1}$$

The *C*-*V* curve is obtained by plotting $C(v_2\text{-}v_3)$ vs $[v_2(t) - v_3(t)]$.

A typical *C-V* curve is shown in Fig. 2. C_t refers to the total capacitance prior to breakdown while C_i is the insulator capacitance. Since the *C-V* transition is nonabrupt, we denote three turn-on voltages, V_{to1}, V_{to2}, V_{to3}, which refer to the onset of conduction, the midpoint of the *C-V* transition, and the field-clamping voltage, respectively. V_{to2} is found to correspond very well to the normal *Q-V* threshold.

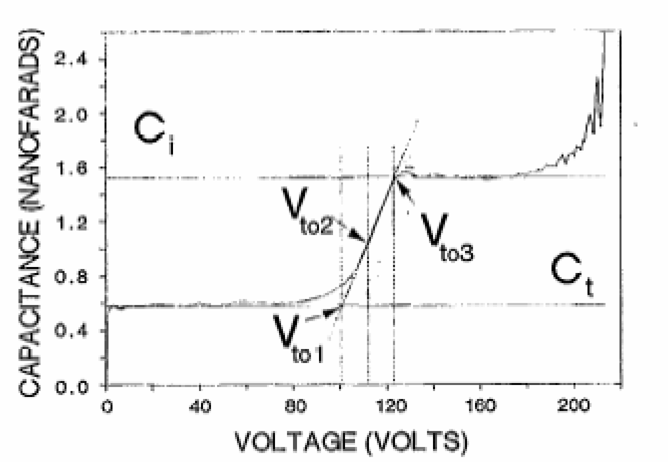

Fig. 2: *C-V curve for ZnS:Mn ACTFEL device*

3 RESULTS AND ANALYSIS

The results of ACTFEL aging experiments are summarized in figs. 3–5 for the following temperatures: -50 °C, -10 °C, 0 °C, 20 °C, 60 °C, and 80 °C. The family of selected *C-V* curves shown in fig. 3 are for the 60 °C experiment. These *C-V* curves show characteristics typical of all aging experiments at various temperatures.

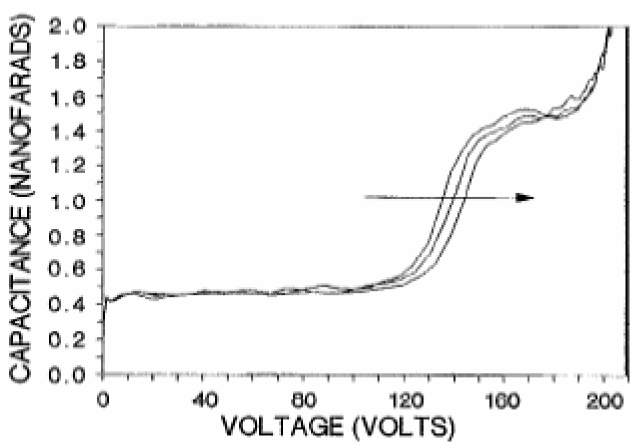

Fig. 3: *C-V curves for 60 °C experiment. Arrow indicates direction of increasing aging time. Aging times of curves shown are 1 second, 20 minutes, and 9.5 hours*

In general, it is observed that the turn-on voltage shifts rigidly with operating time and that C_t and C_i remain constant, to within experimental error, with aging time. As can be observed from figs. 4 and 5, the aging characteristics can be classified into four regimes: (1) incubation period, (2) logarithmic aging, (3) saturation, and (4) long-term aging.

At lower temperatures there is an incubation period, in which the turn-on voltage is essentially constant; this incubation period is most clearly evident in fig. 5. This incubation period lasts 1 hour at the lowest temperature (-50 °C) and eventually disappears at and above room temperature (20 °C). The incubation period is followed by a period in which the turn-on voltage increases logarithmically with aging time. Next, the turn-on voltage approaches a saturated value which is temperature-dependent. Finally, the last aging regime is denoted long-term aging in which the turn-on voltage decreases slowly with increasing aging time. The logarithmic and saturation aging regimes are taken to collectively comprise what we denote the short-term aging characteristics. The incubation period is tentatively attributed to the fact that the warm-up and preaging occur at a higher temperature than that of the aging. Long-term aging kinetics will be the subject of future study. Thus, our present study of the aging kinetics will focus on short-term aging in which the kinetics are found, or extrapolated, to be logarithmic or saturated.

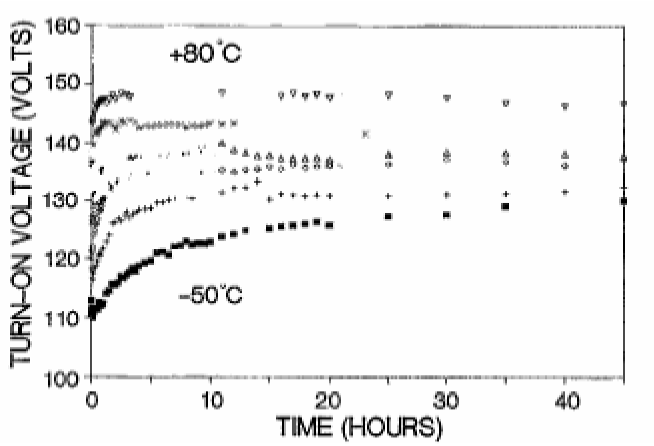

Fig. 4: *Turn-on voltage, V_{to2}, as a function of aging time at temperatures of -50, -10, 0, 20, 60, and 80 °C*

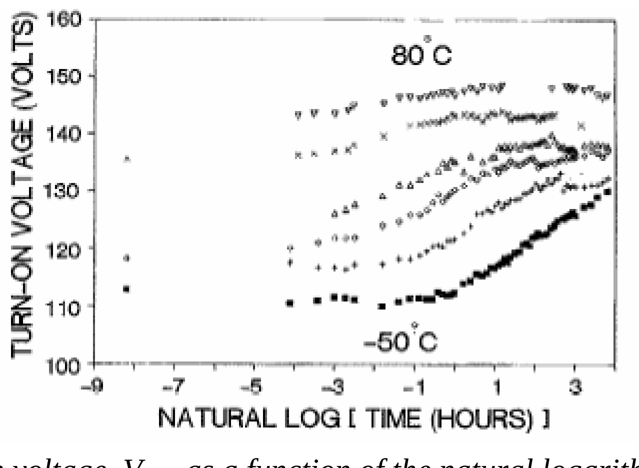

Fig. 5: *Turn-on voltage, V_{to2}, as a function of the natural logarithm of aging time at temperatures of -50, -10, 0, 20, 60, 80 °C*

4 CONCLUSIONS

An ACTFEL aging study is presented in which the *C-V* technique is used to characterize the electrical properties of evaporated ZnS:Mn ACTFEL devices at various temperatures as a function of aging time. The primary experimental findings of this study are the following:

1) The insulator and phosphor capacitances are constant with respect to aging time; this suggests that the perturbation in the electrostatic charge distribution which is responsible for aging occurs near the SiON/ZnS interfaces.
2) The C-V curve shifts rigidly with aging time; a rigid shift indicates that changes in the fixed charge density, not the interface charge density, give rise to aging.
3) The activation energy for short-term aging is found to be approximately 0.2 eV. These experimental observations lead to the following model for aging of evaporated ZnS:Mn ACTFEL devices. Atomic rearrangement at SiON/ZnS interfaces leads to the formation of deep level, fixed charge states which trap transported conduction electrons. Such electron trapping leads to a reduction of the conduction and polarization charges and an increase in the turn-on voltage. It is likely that atomic migration is stimulated by the thermalization energy dissipated by hot electrons after they impinge upon the SiON conduction band discontinuity. Also, it is likely that atomic migration at the interface is exacerbated by the presence of sulfur vacancies in the ZnS near the interface.

ACKNOWLEDGMENTS

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