ELECTRON BEAM PHOSPHOR AGING

Robert L. Donofrio
Display Device Consultants, Ann Arbor , MI 48105

ABSTRACT

This paper is a review of electron beam phosphor/phosphor screen aging studies for CRT and FED displays. We show a number of models describing the aging relationship and some phosphor screening process/preparation methods will be described which have shown aging improvement.

INTRODUCTION

The fall off of luminance as the screen is bombarded with the electron beam is called aging. This effect is due to two main factors; **1**.The thermal quenching of the phosphor luminescence and **2**. Generally, a non-reversible phosphor aging. In reality, the effect is even more complicated as the phosphors are usually on a glass substrate and the electron beam also darkens the glass substrate through a form of (in part) solarization in which metal oxides in the glass are reduced. Experiments have shown that plotting the luminance fall off as a function of accumulated charge is good method to allow discussion of aging and aging models and evaluate improvements which reduce aging.

MODELS

One of the early models of aging was the model first used by Birks & Black in 1951 (ref 1) in their investigation of the deterioration of anthracene luminescence with bombardment of alpha particles. They showed that the relationship,

1) $I = Io/(1+AN)$

could be used to mathematically define the luminance fall off. Where Io = initial intensity of the scintillation pulses, I = the mean intensity after a total dose of N alpha particles per square cm . They showed that the half intensity level achieved when A =1/N is an important parameter. A somewhat different model was proposed by Broser and Warminsky (1951) for CdS;

$$L_N/Lo = 1- \log(1+a/N)^{N/a}$$

and is described in Curie's text (ref 2). In 1958, Hanle and Rau used this method for ZnS phosphors bombarded with alpha particles and in 1960 Pfhanl applied this relationship to CRT phosphors under electron bombardment.

PFHANL'S METRIC (1961)

For completeness, Pfhanl's metric is given as equation 2.

Where; I = the cathodoluminescent light intensity after an accumulated charge of Q (Coul/cm^2)

Io = the initial cathodoluminescent intensity

N = 0.625 x 10^{19} (electrons/coul) times Q (coul/cm^2)

2) $I = Io / (1+CN)$

IMPROVED METRICS

The need for a better understanding of a phenomena and the use of the right tools is mandatory in any technology. The same logic is true in our area of electron beam bombardment of a phosphor screen.. If we were to solve equation 2 for the Pfhanl's burn parameter C, we find that;

3) $C= [(Io/I) -1]/N$, for $I/Io = ½$ then $C= 1/N_{1/2}$

and $N_{1/2}$ is the accumulated number of electrons/cm2 for which the ½ Io is reached.

This is relationship is the same as used by Birks & Black, where the half luminous intensity point then here $C=N^{-1}$. It is important to note that Pfhanl's relationship is by definition, true for one point (the half intensity point). However, *i*f we try to use Pfhanl's relationship to determine the functional behavior of an aging phosphor we will see that it does not always agree with experiment. If we plot C (using equation 2) vs the accumulated charge. We will thus see that "C" is not always a constant, but appears to be a function of the accumulated charge. The experimental measurements made on 12" monochrome CRTs using P4 and P31 phosphors were reported by Donofrio (ref 8).

A number of methods have been proposed to simplify the problem. These models are associated with a number of investigators, such as Donofrio, Rengan, Cappels and Bechtel.

DONOFRIO MODEL (Two Parameter – 1981)

3) $I/Io = 1/(1+ NB/Q^D)$

In this relationship (ref 8), in order to agree with experiment , the pfhanl's constant is replaced by a term which is a function of accumulated charge. Where,

4) $C = B/Q^D$

Equation 3, reduces to Pfhanl's when D=0 and C then equals B. This method was developed to evaluate the short term aging of the CRT screen. Here we are concerned the aging relationship for charge accumulation up to with one coulomb. We found this to be important for our studies on CRTs.

RENGAN (2 parameter Model – 1984)

5) $T = A e^{(-Y/m)}$

where T = Coulombs/cm^2 and for P45, for T < or =3 coul/cm2 m = 4.76 (initial rapid decay) for T> or = 3 coul/cm2 m = 1.02 (slower decay). This study (ref 9) of projection tube aging dealt mainly on the mechanisms of glass aging but showed the two component aging as discussed in reference 8.

CAPPELS (Three parameter Model – 1996)

6) $\mathrm{Eff} = \mathrm{Eff}_0/((1+CN - (L / (1+SN)) * (1+L))$

Cappels and La presented (ref 10) their model in 1996 to determine how the blue CRT phosphor behaves with aging. Their data showed Pfhanl's model to be adequate to predict the behavior of the green phosphors. They stated that the model of red phosphor also probably should be modified to their model to get good agreement with experimental results. The C, L & S terms are determined by curve fitting. Their model reduces to the Pfhanl model when L=0. Cappels in private communications has stated that equations 3 and 9 give similar results. (In a private note Cappels stated that Equation 3 appeared to give similar results to their model)

BECHTEL (Gaussian spot aging Model – 1997)

7) $I/Io = (Q_{50\%}/Qo) \ln (1+(Qo/Q_{50\%})$

Bechtel (ref 13) states that $Qo = 20 * Q_{av}$ and $Q_{50\%}$ is the charge dose for which the efficiency of the aged phosphor is halved. This work was developed with the advent of the new Philips' thin CRT.

AGING FACTORS

There are a number of factors which effect aging . In the area of Phosphors there is Particle Size, Lattice Impurities, Reaction Products, Bond Strength, For Screening methods which effect aging there are Thin Layer, Cascaded Layers and Packing Density. There are process methods that effect aging such as Proprietary Phosphor Doping, Screen /Phosphor Coatings, Pre-Aging and then there is always the Substrate Composition

A. PHOSPHORS

Q0.5 Coul/cm2	Phosphors		
	P	#TYPE	Ref
0.1	P16(AA)	CaMgSiO4: Ce	4
10-25	P2.(GL), P4,(WW)	ZnS:	4
10-25	P7(GM), P31(GH) Z	nS :	4
15-39	P5(BJ), P15(GG)	CaWO4:[W], ZnO:[Zn](Oxides)	4
60-100	P1(GJ)	Zn2SiO4:Mn	4
>100 P49	(VA)	Zn2SiO4/YVO4	4
20- 50	P22 blue (X)	ZnS: Ag	11
>100	P22 red (X)	Y2O2S:Eu	11
>100	P47(BH)	Y2SiO5:Ce	11
>300	P53 (KJ)	Y3Al5O12:Tb	11

TABLE 1

A comparison of deposited charge per unit area (Q0.5) for aging to the half - luminance of various phosphors is seen in tables 1 (Data for two different sources ref 4 & ref 11)

We see here the trend reported by Leverence in that the phosphors with the higher melting points or stronger binding show less aging (this is a larger Q 50% value In table 1, the phosphors are shown with the two designation system numbering (P# & World Wide Designation System - ref 12)

PARTICLE SIZE

Some evidence exists that larger particle size (10 micron ZnS:Ag) phosphors may give reduced aging (compared to 5 micron ZnS:Ag). This work of J. Rottgardt was discussed in ref 2. However, this is appears contrary to newer data on the thin layer, high density and high thermal dissipation theories. It is known that if the small particle size was obtained by milling then the smaller (more milled) phosphor would show increased phosphor aging.

IMPURITY IONS IN LATTICE

Yamamoto in ref 7 discussed how addition of Arsenic ions in $Zn2SiO_4$:Mn increase the persistance of the phosphor but also causes it to age faster.

REACTION PRODUCTS

For example, (from ref 7) CaS:Ce is water soluble and shows severe aging. As per Leverenz use of water insoluble phosphors is best for aging.

BOND STRENGTH OF LATTICE

As per Leverenz, is the importance of higher melting point and harder phosphors for reduced aging.

SCREENING

Phosphor Screening plays an important role in screen aging. The thin film data implies that improved phosphor thermal contact with the faceplate will reduce aging. Shmulovich discussed sputtered gallium modified $Y_3Al_5O_{12}$:Tb^{3+} and found only 3% decrease in L.O. after 700 C/cm2. Also stated that single crystals of YAG did not show aging Cascaded layers of have been used by Sony to reduce aging (see section on coatings), High Packing Density improved heat dissipation.

PROCESS

Proprietary process/Doping SI Diamond Technology who is involved with the fabrication of FEDs has reported (ref 11) on a Doping method which significantly improves the aging of a phosphor screen. They report that the half intensity point for Y_2O_2S:Eu is about 100 C/cm^2 for the standard process and about 350 C/cm^2 for their proprietary doping process at 700 volts and 10ma/ cm^2. In CRT fabrication it has been reported that some phosphor surfaces are hydolyzed in the potassium silicate solution. In some cases the phosphors can be protected from this reaction with a silicate coating. Bechtel (ref 13) has shown that phosphors can be protected from aging by a Polyphosphate Coating.

THERMAL CONDUCTIVITY

It has been shown that the temperature of the phosphor screen is a function of the phosphors used and probably their thermal conductivity (ref 7). Dense packed screens are superior for aging to loose packed screens.

SCREEN/PHOSPHOR COATINGS

Reduced SiO2 coating gives improved aging. This method has been used by Tatsyama, Yamazaki and Teshima of Sony (ref 5) in the formation of cascaded screens in which the layer closest to the source of electrons has a third of the Silicate coating concentration as the panel side layer. Bechtel has reported on the use of a polyphosphate coating applied to the ZnS:Ag phosphor to inhibit aging. The results of their coating showed a four fold increase in L.O. at 40 C/cm^2 over the uncoated ZnS:Ag.

PRE-AGING

In order to limit the effect of the sudden fall-off of intensity for the user, some manufacturers of CRTs use Pre-Aging. In this process the entire screen is bombarded by the electron beam over some fixed period of time. During this time the sudden initial aging takes place before the final user operates the tube. However, not all phosphors need preaging, Yamamoto has shown that all or part of the short time aged L.O. can be recovered after cooling. They showed that after 15 minutes aging the $Y_3Al_5O_{12}$:Tb green phosphor recovered fully after cooling however, the $Y_3Al_3Ga_2O_{12}$:Tb phosphor recovered about 87% of its original L.O.

SUBSTRATE COMPOSIION

It is well known that a glass substrate darkens upon electron bombardment and that glass companies supply glass substrates which do not contain lead and have additives which suppress the glass darkening called “Browning”. It has been reported by Rengan that the raster scanned region shows a 50% to 75% depletion of K & Na. to at least 2 microns below the surface. They also state that Pantano reported that the ion migration of sodium goes to the bulk instead of desorption or vaporization. What is very interesting is that they reported on “Spotted regions” which showed the Sodium and Potassium concentrations to be almost an order of magnitude lower than the unscanned regions. Additionally the metals such as lead can be leached out of the glass (see reference 11). All which can give rise to color centers. What is less known is that the phosphor screen if of sufficient thickness can protect the glass substrate from damage by the electron beam.

CONCLUSIONS

1. There is a need for a Screen aging model which has factors for phosphor, temperature and substrate effects., **2**. In 1996, Cappels has shown that their model can be used to predict aging effects on the white color in a tri-color screen. **3**, Recent (1997) work by Bechtels et al with 4kV electrons show that a Polyphosphate coating can improve aging, Bojkov’s (1995) FED work with 700 volt electrons has shown that special doping can improve screen aging.

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