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Title: Cutoff Variations Due to Barium Evaporation from Dispenser Cathodes

CUTOFF VARIATIONS DUE TO BARIUM EVAPORATION FROM DISPENSER CATHODES

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Abstract

Evaporative deposits of barium compounds from dispenser cathodes can produce a drift in CRT cutoff voltage over life. A build-up of these deposits can result in a reduction of the G1 aperture diameter as well as K/G1 spacing. Problems associated with the deposits can be reduced by proper selection of cathode operating temperature, grid spacing, aperture diameter, barium ratio, cathode handling and storage, and tube processing.

Introduction

Background

Driven by the requirements for higher resolution and longer life, the CRT industry is experiencing an ever increasing demand for the use of dispenser cathodes. Although oxide cathodes have a low work function (~1.5 eV), they are not suitable for high current density (10 A/cm²), high-brightness applications due to the relatively high resistivity of the coating (giving rise to a voltage drop and Joule heating at high current density). (1)

Dispenser cathodes (~ 1.8 eV work function) can produce the required current densities, but must operate at temperatures of 150 - 200 °C higher than oxide cathodes. As a result, the CRT manufacturer must cope with the side effects of increasing the cathode operating temperature.

Today's modern impregnated dispenser cathode (typically referred to as an I4 type in the CRT industry) described by Cronin [2] is comprised of a porous tungsten matrix impregnated with a mixture of barium calcium aluminate (BaO, CaO, Al₂O₃), and is typically overcoated with a thin layer of osmium/ruthenium or iridium. When the cathode is heated, barium is produced in the pores of the tungsten matrix by the reaction of the impregnant with the tungsten.

Another version of dispenser cathode, which utilizes a barium calcium aluminate pellet behind a precise laser drilled foil of refractory alloy, is the CPD or controlled porosity dispenser cathode. Proper electron emission depends on the equilibrium established between the rate of arrival of barium at the emitting surface and the rate of evaporation of barium from the surface. As a result, both barium and BaO are evaporated from the cathode as a function of temperature.

Investigative feedback on CRT test results over the past 2 years has exposed two areas of concern when dealing with the evaporative products from a dispenser cathode:

1) Stray emission (SE). The higher operating temperature of a dispenser cathode in close proximity to the G1 electrode may cause an increase in the temperature of the G1/G2 structures due to thermal radiation. Coupled with an increase in the barium evaporation from a dispenser cathode, the electrodes may produce excess stray emission.

Control of SE is best achieved by a thermally efficient cathode support structure to minimize conduction losses to the surrounding gun, as well as a minimum of radiating surface area of the cathode in order to reduce total input filament power. Specifics of the SE problem are not addressed in this report.

2) Cutoff voltage drift. Several sources have reported an observed cutoff drift or change as a function of tube life. The cutoff drift was found to be a direct result of excess barium deposits on the internal G1/G2 electrode areas of the gun between the cathode and G1 surface and on the inside of the G1/G2 apertures. Sometimes these changes were measured on the G1 (Investigator A) as a decreasing negative voltage (e.g., from -60V, to -55V), and in other cases the cutoff was measured on the G2 (Investigator B) as a positive voltage increase (e.g., from +150V, to +160V).

Objective

The goal of this effort was to gather and evaluate information related to the CRT cutoff variations and to try and determine the governing factors which produced the observed effects.

Investigator

Investigator A

Initial discovery of the cutoff problem in a monochrome tube by Investigator A resulted in a study of the mechanical structure and a measurement of K/G1 spacing on destructive physical analysis (DPA) samples which had exhibited a cutoff drift during the first several hundred hours. The results of the measurements confirmed that there was no change in spacing of the cathode in relation to the G1 electrode, and thus a mechanical movement over time was ruled out. The aperture diameter in these tubes was 0.4 mm and the cathode was a CPD with a 4:1:1 (xBaO : xCaO, XAl₂O₃) ratio of impregnant materials.

Observations made during the same DPA of the electron guns revealed evaporated deposits from the cathodes on the inside of the G1-G2 electrodes and on the inside of both apertures. Most of the deposition, however, was confined to the inside of the G1 electrode. Since barium readily forms an oxide/hydroxide upon exposure to air, it was difficult to determine the quantity of original deposit.

Subsequent observation of actual working tubes under a microscope revealed a "whitish" deposit on the G1 area when viewed through the glass stem and through a hole in the G1 cup. Several tubes (at 500 hrs. life) were RF bombed in the G1 region of the gun at 700 OC for 20 - 30 seconds in an attempt to remove the deposits. When the tubes were retested, a full recovery of cutoff to the original values was observed.

Figure 1 shows a graph of cutoff on one tube before and after bombing which illustrates the removal of deposits in the G1 area.

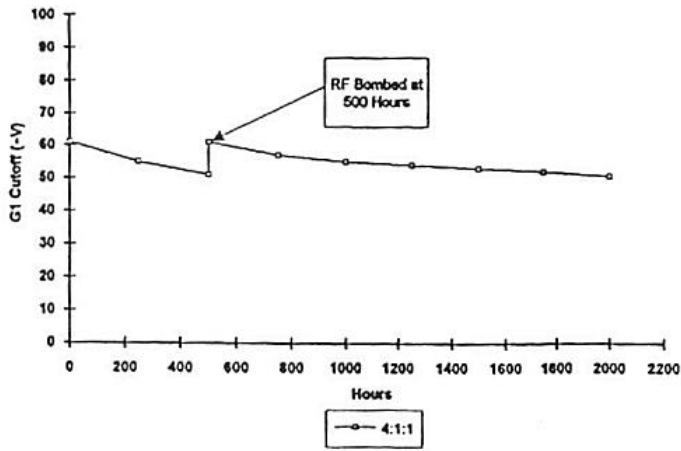


Figure 1. Cutoff change in a CRT showing effects of RF bombing the G1 area to remove barium deposits.

After testing for the restored cutoff condition, the G1 areas of the guns were again observed under the microscope. The whitish deposits were virtually eliminated in the G1 area and greatly reduced on the G2.

To confirm the observations, two tubes (one tube RF bombed and the 2nd tube not bombed) were dismantled at the Semicon laboratory under controlled atmospheric conditions. Using the aid of a microscope, the tubes were disassembled inside of a glove bag filled with dry argon gas.

Figure 2 Illustrates the comparison of results of the two CRTs.

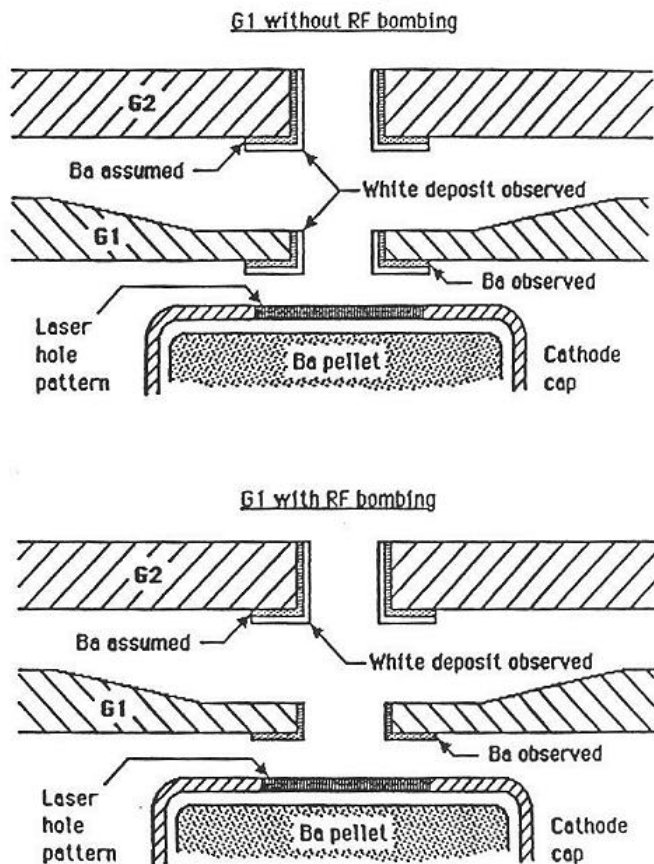


Figure 2. Schematic comparison of observed deposits on G1/G2 electrodes. (Top) G1 without RF bombing. (Bottom) G1 after RF bombing.

Both G2s had whitish deposits on the side facing the G1 cup (and cathode). No deposits were found on the outside of either the G1 or G2 electrode. A whitish deposit was observed on the inside aperture of both the G1 and G2 of the gun that had not been bombed. On the other gun (with RF bombing), the same deposit was observed only on the G2 area.

It was concluded that the whitish deposits were barium hydroxide ($\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$). Barium hydroxide has a higher vapor pressure than barium, and barium is higher than barium oxide. Since barium metal was remaining on the inside of the G1 cup, the conclusion was that the deposit is most likely barium hydroxide which is depositing from the cathode or is forming as a result of moisture in the cathode or tube. The volume of barium hydroxide is much greater than that of Ba or BaO.

Subsequent changes in tube processing parameters and cathode impregnant mole ratio (from 4:1:1 to 5:3:2) have shown significant Improvements after further testing, resulting in a reduction of the cutoff drift with life.

Figure 3 shows a comparison of the cutoff drift for a 5:3:2 and 4:1:1 barium pellet in a CPD.

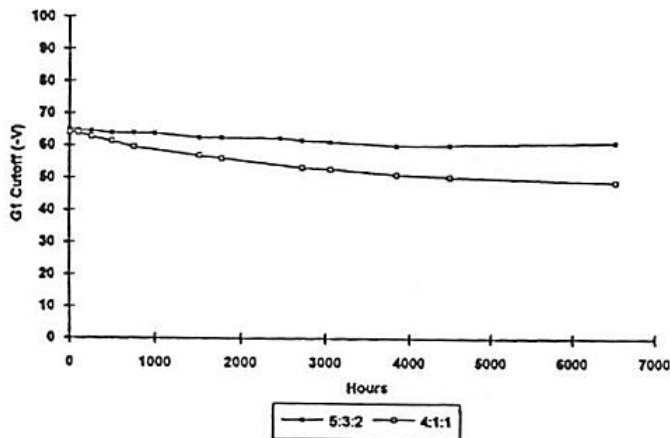


Figure 3. Cutoff drift versus life comparison for a 5:3:2 and 4:1:1 mole ratio of barium calcium aluminate.

Investigator A is continuing to test both CPD and I-type cathodes from several sources as well. To date, all types are continuing to exhibit cutoff drift in various degrees.

Investigator B

During the same time frame, Investigator B was experiencing a similar situation in a color tube with a 0.4 mm diameter aperture. The cutoff drift in this instance was measured on the G2 as a positive voltage increase. After performing a similar series of experiments as Investigator A1 a similar conclusion was reached: The cutoff drift was attributed to deposits on the G1 aperture.

Another problem experienced by this source was slight k'G1 shorting from the volume of deposit which was forming as a result of moisture. Cathodes from another source have exhibited this same condition as well.

Investigator C

A third source using a projection tube with a 0.6 mm diameter aperture has reported little cutoff change in comparison to A and B. It is suspected that a combination of tube processing and larger aperture size are the main reasons for the difference.

Results and Discussion

The main factors which were found to influence the degree of cutoff change were:

Cathode Operating Temperature

One of the most important factors in reducing cutoff drift is to control the quantity of material evaporated from the cathode. Evaporation rate is exponential with temperature, so a slight reduction in temperature can be very significant for reducing the amount of deposition.

Cathode temperature is usually dependent on the current density requirement of the CRT gun and the electron work function of the cathode surface. If the surface has been optimized to the lowest work function possible (highest current density), then the operating temperature and the resulting evaporation rate will be minimized.

Cathode activity curves, which plot I_k as a function of temperature (or filament voltage), determine the transition from "temperature limited" to "charge limited" operation of a specific configuration and are very helpful for setting a minimum operating point above the "knee" in the space-charge region. The heater filament voltage can then be adjusted for this specific power level.

K/G1 spacing

The spacing between the cathode surface and the inside of the G1 cup is a factor in determining the rate of cutoff change (and/or the time required for a potential direct short between the cathode and G1) because deposits tend to reduce the available space. provided, and thus, may affect the electric field in the K(G1 area). The design configuration, therefore, for reduced cutoff drift would be to maximize the K/G1 spacing as much as possible for the desired beam parameters.

G1Aperture Diameter

The G1 aperture size is very important in determining how quickly and to what extent a problem might occur. Smaller diameters will be affected more than larger diameters, since, for the same thickness of deposit, a greater percentage change will occur in the smaller aperture. (e.g. if the aperture opening were 0.016 in. diameter compared to 0.024 in. then a .0005 in. thick deposit would reduce the small dia. by .001 in. total or 12% of the total area; whereas the larger aperture opening would be reduced by the same .001 in. but the total area reduction would be only 8%) Therefore a larger aperture is less affected by evaporative deposits.

Barium Supply Ratio

The mole ratio of the barium in the cathode impregnant is significant for two reasons. The first reason is that Ba/BaO evaporation rate increases with an increase in the BaO ratio in the impregnant.

The second reason is that the hygroscopic nature of the impregnant also seems to increase for a higher mole ratio of BaO and the reaction with moisture to form barium hydroxide is significant due to the relatively high vapor pressure of the hydroxide thus allowing material to easily evaporate from the cathode to

the surrounding structure. The volume of this resulting deposit is much greater than the metallic barium or BaO which is normally evolved during life.

Cathode Handling and Storage

Because of the hygroscopic tendency of dispenser cathodes, proper handling at the manufacturing and customer levels is equally important. Exposure to air during manufacturing should be kept to a minimum and storage during processing can be accomplished with a dry box or vacuum box container. Cathodes should be packaged in dry gas containers (eg., plastic coated mylar bags) for storage before and after shipping. Upon opening of the packages at the CRT assembly area, care must be taken in a similar manner to minimize exposure during assembly and to provide for dry storage during extended periods before final sealing into the CRT tube.

Initial CRT Processing

Controlling the atmosphere in the CRT during processing is very essential. Reducing the amount of residual moisture, which might otherwise remain in the tube after processing, will minimize the potential for formation of barium hydroxide later on during tube operation. Proper selection of conductive coating and phosphor materials and complete bakeout procedures can also contribute to improved results.

To further enhance cathode activity and reduce moisture in the cathode, a low level of filament power can be applied during the bakeout procedure.

Conclusion

Reduction of the unwanted variations in voltage cutoff due to barium compound deposition can be a significant factor for increased life (or time between service adjustments) of the CRT. Key factors in reducing cutoff drift are proper temperature control to reduce excess barium evaporation, selection of maximum grid spacing and aperture diameter, a minimum ratio of BaO in the impregnant material and minimum exposure of the cathode to moisture both before and after assembly into the CRT.

Dispenser cathodes have the potential for very long life at high current density, and anything that contributes to the overall improvement in performance will have a very significant impact.

Acknowledgements

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References

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