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LONG-LIFE COLD CATHODE STUDIES FOR CROSSED-FIELD TUBES

PROGRESS REPORT

by

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OCTOBER 1967

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RAYTHEON COMPANY
MICROWAVE AND POWER TUBE DIVISION
Waltham, Massachusetts

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Technical Report ECOM-01698-7 October 1967

LONG-LIFE COLD CATHODE STUDIES FOR CROSSED-FIELD TUBES

Seventh Quarterly Report

15 April to 15 July 1967

Report No. 7
Contract No. DA28-043-AMC-01698(E)
DA Project No. 7900-21-223-12-00

Prepared by

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For

U. S. Army Electronics Command
Fort Monmouth, N. J. 07703

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ABSTRACT

A 200Å boron nitride film on a molybdenum substrate was subjected to electron bombardment at 0.16 A/cm^2 and 1.2 kv for 3 hours and as a result δ_{max} decreased from 1.75 to 1.55.

The high stress Electron Bombardment Vehicle was operated at 4 A/cm^2 and 2.5 kv and the polished copper target showed thermal etching effects.

Two 4-1-1 barium-calcium-aluminate impregnated tungsten samples were subjected to electron bombardment at varying current levels at 1.2 kV energy, corresponding to average current densities of 0.2 and 0.4 A/cm^2 for 23.5 and 19 hours respectively. δ_{max} levelled off to an asymptopic value of approximately 2.2 to 2.3 for both samples.

Cathode emission life test of model No. 8A was terminated after 58 hours. This model was rebuilt as No. 8B with a 1.680 inch diameter aluminum cathode. Other design changes were also incorporated and this tube has been designated for long life cathode emission evaluation.

FOREWORD

Long-life cold cathode studies for crossed-field tubes are authorized by the United States Army Electronics Command, Fort Monmouth, New Jersey, under DA Project No. 7900-21-223-12-00. The work was prepared under the support of the Advanced Research Projects Agency under Order No. 345 and is conducted under the technical guidance of the U. S. Army Electronics Command, Fort Monmouth, N. J. 07703.

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1. INTRODUCTION

The objective of the present cold cathode study program is to achieve long life cold cathode performance for crossed-field amplifiers. This program is being performed for the United States Army Electronics Command, Fort Monmouth, New Jersey, under contract DA-28-043-AMC-01698 (E).

In this study, selected cold cathode materials will be evaluated as to: their secondary emission properties, their ability to withstand environmental factors expected in a crossed-field amplifier, and their crossed-field amplifier performance. Based on the above experimental information and pertinent theoretical calculations, a life prediction chart will be established for a number of cold cathode materials.

The program is divided into two concurrent phases, Phase A being concerned with the measurement of various pertinent properties of cold cathode materials outside of the tube environment, and Phase B involving the evaluation and life testing of selected cathodes in a crossed-field amplifier.

The first quarterly report of this contract (Technical Report ECOM 01698-1) contains a discussion of the objectives and plans for the over-all program. Quarterly report no. 5 contains a description of the CFA test vehicles used in this program.

2. PHASE A - MATERIALS EVALUATION

2.1 Boron Nitride Film. Another boron nitride film was evaluated in the Electron Bombardment Vehicle. This was a 200Å film deposited by CVD technique on a molybdenum (Mo) substrate, as were the previous films tested in this program. The results are shown in Figure 1. δ_{max} was low (approximately 1.75 at the start) and decreased slightly under 3 ma electron bombardment at 1.2 kv. The high δ_{max} of 4.3 observed for a previous boron nitride (BN) film in the SEE test vehicle has not been repeated as yet.

2.2 Secondary Emission Measurements. To ascertain the relative significance of the impregnant and tungsten regions in contributing to secondary emission, a set of impregnated tungsten samples were fabricated of varying porosity and impregnant composition. Measurement of δ vs primary energy was performed in the SEE test vehicle, and the values of δ_{max} after system bakeout are shown in Table I.

These are preliminary measurements only; therefore no conclusions will be drawn at this stage. Sufficient thermal activation for the high porosity samples was impossible, due to a poor thermal contact between each sample and the Mo cup in which it was contained. New high porosity samples are being made and the measurements will be repeated.

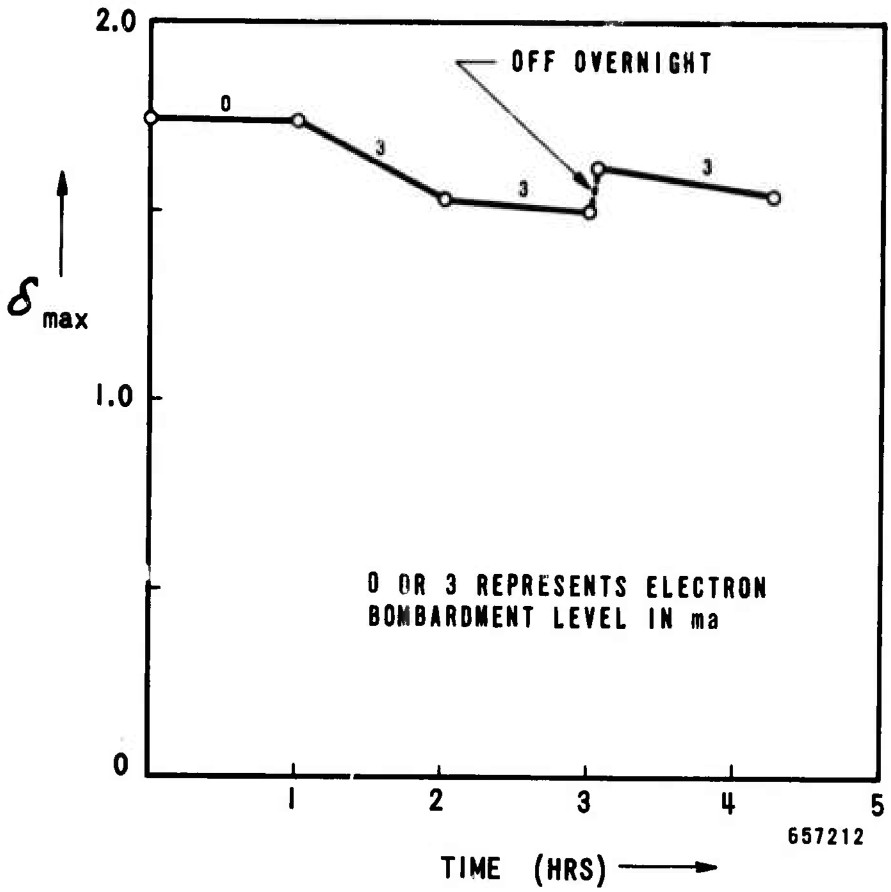

FIGURE 1. δ_{max} vs Electron Bombardment Time in EBV for 200 Å CVD BN on Mo Substrate

TABLE I

δ_{max} of Impregnated Tungsten Samples after System Bakeout at 400° C.

Sample Porosity* (%)	Impregnant Composition**	δ_{max}
20	4-1-1	1.91
20	4-1-1	1.78
40	4-1-1	(insulator)
40	4-1-1	(insulator)
40	2-1-1	1.66
20	2-1-1	2.13
20	2-1-1	1.94

* % porosity = 100 x impregnant volume fraction.

** Numbers in this column denote molar parts $BaCO_3$, $CaCO_3$ and Al_2O_3, respectively

2.3 High Stress Electron Bombardment Testing. The Sixth Quarterly Report described initial tests on a polished copper target undergoing electron bombardment at 1.5 kv and 2 A/cm^2. This copper target was subsequently subjected to bombardment at 2.5 kv and 4 A/cm^2 for 8 1/2 hours, corresponding to a power density at the target surface of 10 kw/cm^2. After removal the copper target was microscopically examined at a magnification of 50. As shown in Figure 2, there was evidence of thermal etching; the dark spots appear to be pitted areas.

Some attempts to diffusion bond (pressure and temperature) aluminum to copper were made, but these were only partially successful, i.e., only portions of the area were bonded.

The following materials to be used in further electron bombardment studies have been procured:

1. aluminum alloy 6061 (approximately 97.5% Al)
2. aluminum allow 1100 (99.0 + % Al)
3. 98+ % pure beryllium.

Targets will be fabricated from these materials for 1 A/cm^2 and 4 A/cm^2 bombardment. Targets for 1 A/cm^2 bombardment will be threaded (easily removable) in the early EBV tests. Targets for the 4 A/cm^2 tests will depend on the diffusion bonding technique. In future work it is planned to operate two EBV's simultaneously.

Figure 2. Polished Copper Target After High Stress Electron Bombardment (50X magnification)

2.4 Impregnated Tungsten Samples in Hot/Cold EBV. Three impregnated tungsten samples of standard (4-1-1) impregnant composition and porosity were prepared. Two of these were tested during the present quarter.

The results for sample no. 1 are shown in Figure 3 while those for sample no. 2 are shown in Figure 4. These figures show the effects on δ_{max} caused by heating for purposes of activation and by electron bombardment in the hot/cold EBV.

After disassembly both samples appeared clean, there being no apparent discoloration due to extraneous deposits nor to the electron bombardment stress nor to the activation heating.

Prior to the testing of sample no. 1 the target heater had been modified for greater thermal efficiency. Additional shielding of the target had been provided also, to prevent the deposition of foreign material on the target surface. These modifications appear to have been successful.

Both samples appear to stabilize to a δ_{max} of 2.2 - 2.3 after periods of electron bombardment. The activating effect of electron bombardment with the target negative relative to the anode was particularly noticeable; it also caused de-activation in only one case. The maximum value of δ_{max} observed was 3.3 in the case of sample no. 1 and 2.6 for sample no. 2. These are lower than a value of 4.4 reported in Quarterly Report No. 2 for a similar sample at best activation. Further attempts will be made to obtain a higher δ for additional samples of impregnated tungsten.

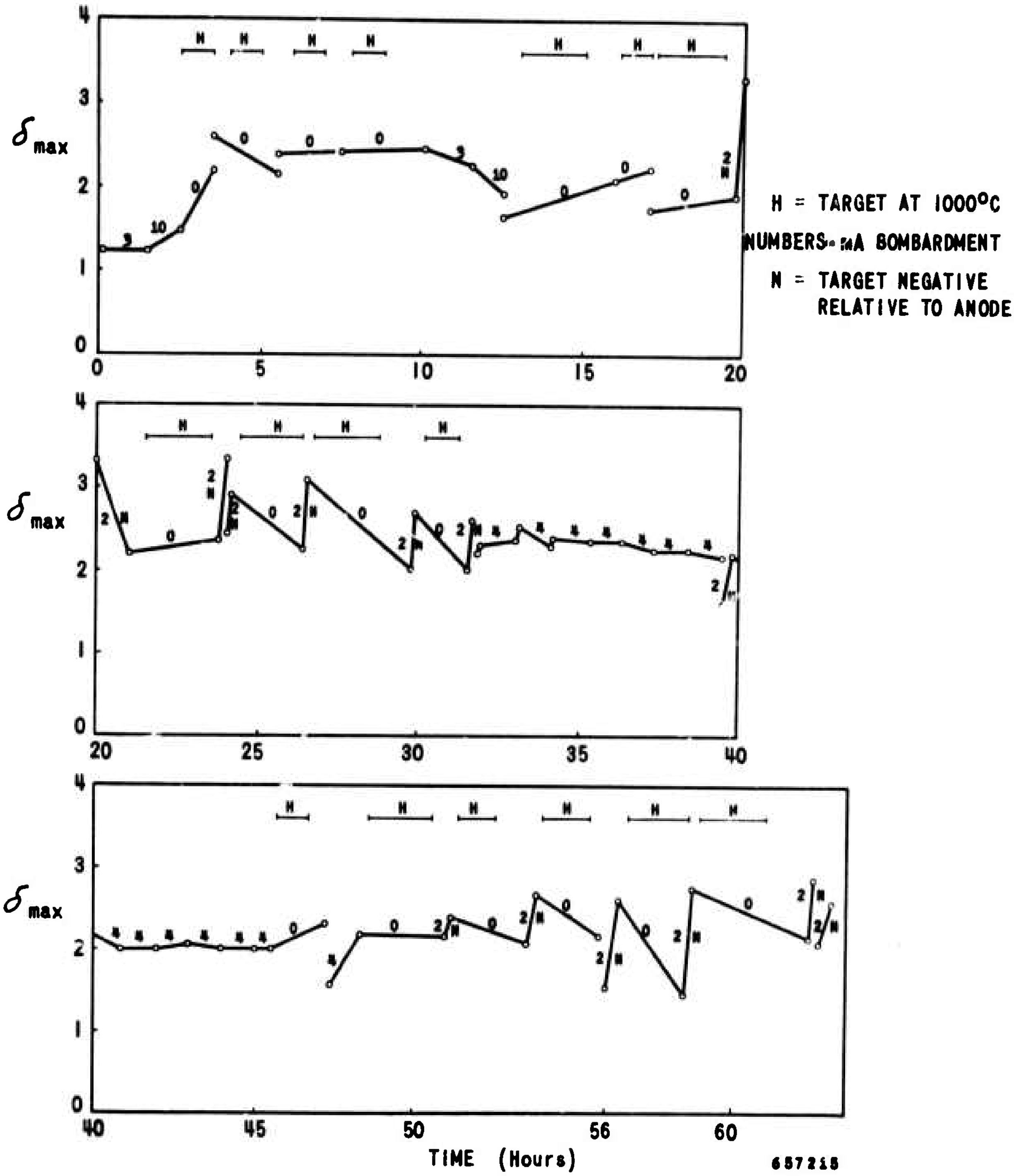

Figure 3. δ_{max} vs EBV Time for Impregnated Tungsten Sample No. 1

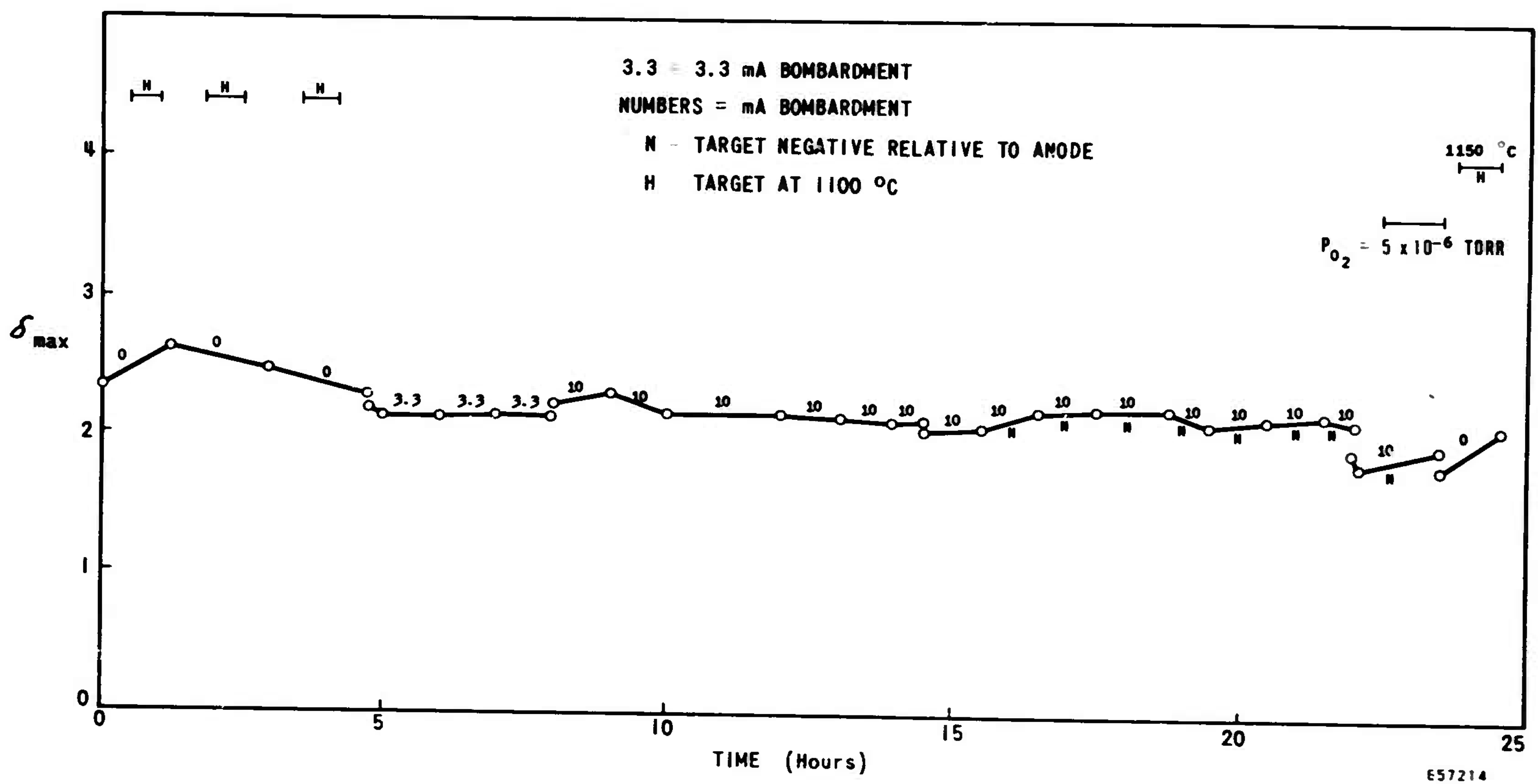

Figure 4. δ_{max} vs EBV Time for Impregnated Tungsten Sample No. 2

Sample no. 1 was electron bombarded for 23.5 hours at between 0.1 and 0.5 A/cm^2 (average value of 0.2 A/cm^2), interspersed with periods of thermal activation, during a total 64-hour period. Sample no. 2 was electron bombarded for 19-hours at between 0.17 and 0.5 A/cm^2 (average value of 0.4 A/cm^2) during a total 25-hour period. The δ values appear to oscillate about an ultimate asymptotic value of between 2.2 and 2.3 for both samples. The application of an oxygen pressure of 5×10^{-6} Torr to sample no. 2 resulted in no significant improvement in δ, contrary to expectations based on previous beneficial effects of O_2. The usual effect of electron bombardment with the target negative relative to the anode is an increase in δ. It is assumed that the cathode of the CFA also sees a similar sense of the electric field and is thus also subject to O^+ ion bombardment.

Some of the significant processes which may contribute to the surface condition of the aluminum cold cathode are:

1) dissociation of the oxide film due to electron bombardment, followed by:

   a) escape into the vacuum of oxygen atoms, either charged or neutral, from the first few atomic layers, and

   b) relaxation of the remaining depth of the electron range.

2) diffusion of aluminum deeper into the oxide from oxygen deficient superficial layers.

3) replacement of oxygen by adsorption of neutrals from the vacuum or perhaps (more effectively) by O^+ ion bombardment.

Some of the changes in δ observed such as occur during off-periods, may be due to diffusion and relaxation processes within the oxide.

Two Ni cermet samples were prepared during the present quarter and will be tested in the hot/cold EBV during the coming quarter.

3. PHASE B - CFA TESTING

3.1 <u>QKS1397 Test Vehicle</u>

3.1.1 <u>Model no. 8A.</u> Evaluation of cathode emission life of model no. 8A was continued during the report period. The tube was operated at 0.001 duty factor, with a peak drive power of 125 kw, a magnetic field of 3075 gauss, and at a frequency of 3350 MHz. In Figure 5, the solid curve shows the peak tube current, while the dashed curve shows the oxygen source heater power, both as a function of time. The oxygen source heater power was initially 59 watts, but was later raised to 60 watts (after approximately 34 hours of cumulative operating time) to increase the peak current emission. At this level of oxygen source heater power however, the peak current emission could not be maintained, and had decreased to 67 amperes by 38 hours of cumulative operating time. The test vehicle was now operated with only rf drive power and oxygen dispenser heater power (60 watts) present, to recondition the cathode emitter surface for higher peak current

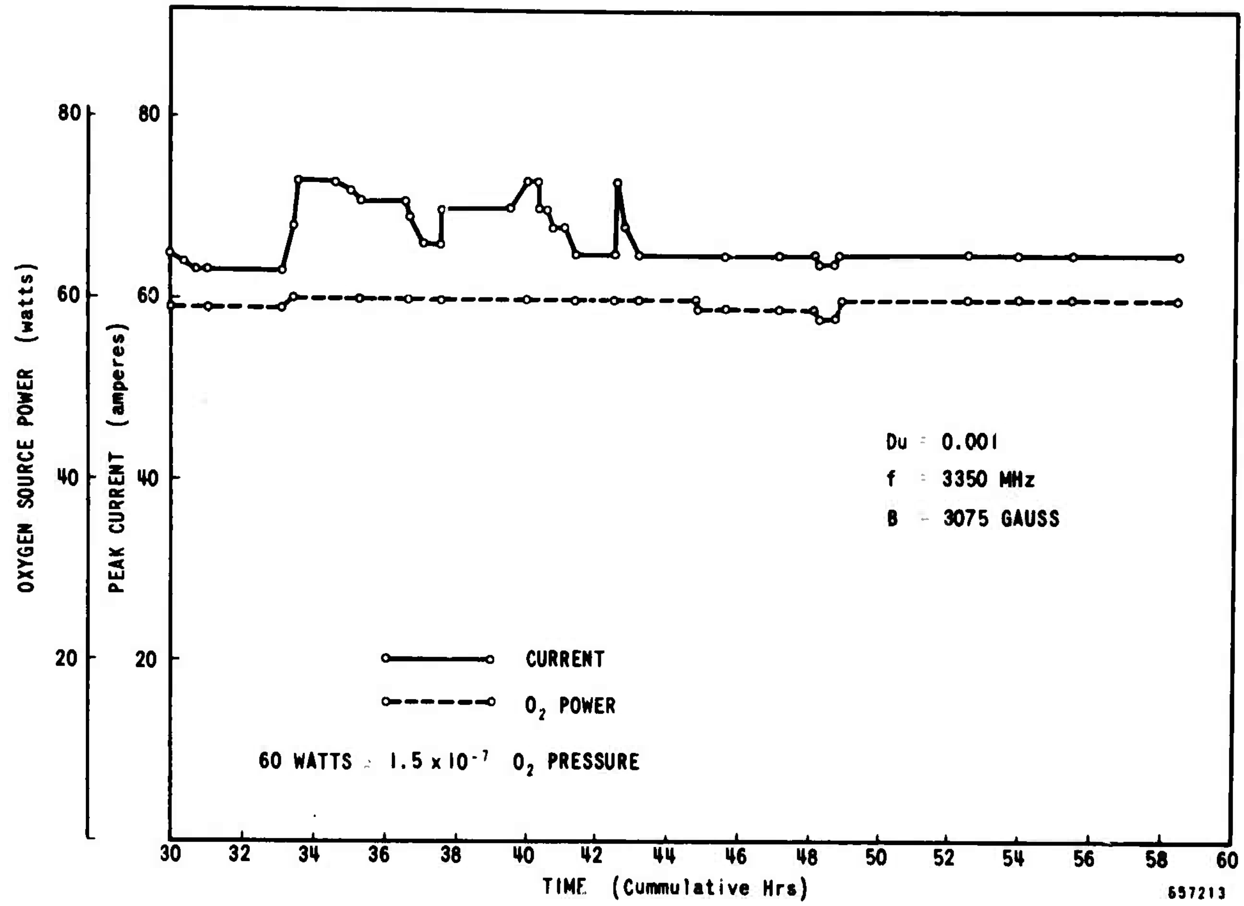

Figure 5. QKS1397 No. 8A Life Test

emission. The peak current emission did indeed increase, but could not be maintained; after 43 hours of cumulative operating time the peak current emission had decreased to 66 amperes. A second attempt to recondition the cathode emission was similarly unsuccessful in maintaining peak current obtained; 44 hours of cumulative operating time, the peak current had decreased to 66 amperes. It then stabilized at this level for the remainder of the life test period. This current level represents a cathode stress level of approximately 3.6 amp/cm^2, with a peak output power level of 1 Mw and 900 watts of average power added by the CFA test vehicle. A reduction of the oxygen source heater power to 59 watts showed no decrease in the peak cathode emission, but a further reduction of heater power to 58 watts did show an immediate effect (after approximately 48 hours of cumulative operating time). The effect of an oxygen source heater power level higher than 60 watts was not investigated because of the higher partial O_2 pressure.

Cathode emission life test of model no. 8A was terminated after a total accumulated time of 58 hours to rebuild the test vehicle with a modified aluminum cathode emitter and supporting structure design for improved performance.

3.1.2 Tube model no. 8B. The test vehicle was rebuilt as model no. 8B with a smaller diameter (1.680 inches) aluminum cathode. This cathode diameter conformed more closely to the "standard" QKS1397 design, which has shown practically no π-mode oscillation. In addition, the following design changes were incorporated in the cathode structure:

1. Axial height was made equal to vane tip height for increased emitter surface activity.

2. Molybdenum end shields were brazed to the cathode support structure for improved heat dissipation.

3. Mechanical bond was improved between the aluminum emitter and the support structure.

4. Copper-clad pole pieces were used to eliminate vaporized iron deposits on the emitter surface due to arcing during initial tube processing.

5. Surface edges were extensively rounded smooth to reduce the likelihood of arcing during initial tube processing.

The rebuilt test model has been bake-out processed; initial test evaluation procedure will remain as before and will be conducted with a conventional pulse modulator. This tube model has been designated for long life cathode emission evaluation.

4. CONCLUSIONS

4.1 Phase A - materials evaluation. Barium-calcium-aluminate impregnated tungsten appears to approach an asymptotic value of δ_{max} of approximately 2.2 after considerable electron bombardment at up to 0.5 A/cm^2 and 1.2 kv.

4.2 Phase B - CFA testing. Life test of the QKS1397 CFA test vehicle for more than 50 hours has shown a stabilized cathode emission of an aluminum cold cathode through the use of oxygen in the pressure range of 10^{-6} - 10^{-5} torr. The stabilized emission level was reached at an electron back-bombardment level of approximately 3 amps/cm^2 at a duty cycle of 0.001.

5. PROGRAM FOR NEXT INTERVAL

5.1 Phase A

1. Evaluation of impregnated tungsten and/or Ni cermet samples in hot/cold EBV.

2. Evaluation of Al and Be samples in EBV at 1 A/cm^2.

3. Evaluation of Al and/or Be samples in high stress EBV.

5.2 Phase B.

1. Evaluate QKS1397 model no. 8B with a "normal" diameter (1.680 inches) aluminum cathode emitter.

2. Life test QKS1397 model no. 8B at highest stabilized cathode emission level with the use of oxygen in the pressure range 10^{-6} - 10^{-5} torr.

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