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RAYTHEON

Technical Report

PT-2249

THERMIONIC CATHODE EVALUATION STUDY

INTERIM REPORT NO. 7

MICROWAVE AND POWER TUBE DIVISION

MICROWAVE TUBE OPERATION, WALTHAM, MASS. 02154

RAYTHEON COMPANY
Microwave and Power Tube Division
Waltham, Massachusetts

INTERIM REPORT NO. 7
THERMIONIC CATHODE EVALUATION STUDY

NASA Prime Contract No. NAS7-100
Subcontract No. 951810

January 1 - March 31, 1969

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ABSTRACT

During the seventh interim period of thermionic-cathode evaluation, diodes using pore-dispenser cathodes have completed at least 12781 hours of satisfactory life burning at cathode temperatures of 950°C to 1100°C and at current densities of 0.2 A/cm^2 to 1.6 A/cm^2.

Diodes using standard oxide cathodes have completed life burning cycles varying from 9638 to 11958 hours. The diodes are showing cathode emission slump at current densities above 0.15 A/cm^2 and cathode temperature of 825 and 850°C.

Six lots of diodes (24 total) were constructed and exhausted with three different cathode nickel alloys with oxide and coated-particle coating according to the specifications under Modification No. 1 of the contract.

The cathode coating peeling problem was eliminated in these diodes by the addition of a powdered nickel layer between the cathode face and the coating layer.

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1.0 INTRODUCTION

The Materials and Techniques Group of Raytheon's Microwave and Power Tube Operation is performing a study of the life capabilities of three different types of thermionic emitters under varying cathode temperature and current loading conditions for the Jet Propulsion Laboratory, California Institute of Technology.

The life capabilities of the following electron-tube cathodes are being evaluated for extended periods of time.

a. Pore-Dispenser Cathode
b. Coated-Particle Cathode
c. Standard Oxide Cathode

The life burning results, for this interim period of study, are reported in Section 2.0 (Pore-Dispenser Cathode) and Section 3.0 (Standard Oxide Cathodes,

The construction and exhaust of diodes using three different cathode nickel alloys with coated-particle and oxide coatings according to the requirements of Modification No. 1 of the study are reported in Section 4.0.

2.0 LIFE BURNING AND TESTING OF PORE-DISPENSER CATHODES

The test diodes constructed with pore-dispenser cathodes and operating under T1, T2, and T3 life-test conditions have completed 13048 hours as of the end of the seventh interim period of study, March 31, 1969.

The test diodes under T4 conditions have completed 12781 hours of life burning. The life-test results are shown in Tables 1 (T1), 2 (T2), 3 (T3), 4 (T4).

The last three sets of readings for each diode are the readings for the months of January, February, and March, 1969.

As noted in the tables, at each interval of life burning, the diodes are tested for cathode current at a specified constant anode voltage and cathode temperature. The cathode current is also recorded for ± 20% of the specified anode voltage.

The diodes are removed from the life test racks, at each test interval, and are read for dip temperature at the specified operating current and for current at 95% of the operating temperature according to the procedures described in the First Interim Report, Thermionic Cathode Evaluation Study, January 1 - June 30, 1967.

The diodes operating under T1 conditions (950°C, 0.2 and 0.4 A/cm^2) have not shown any significant changes in life burning or test conditions up to 13048 hours.

The diodes operating under T2 conditions (985°C, 0.4 A/cm^2) have not shown any changes in characteristics up to this point of life burning. The diodes operating at T2 conditions (985°C, 0.8 A/cm^2) have shown a slump of 12.4% and 15.5% up to this point of life burning.

TABLE 1

LIFE - TEST RESULTS

PORE - DISPENSER CATHODES

Test	Diode	Hours	Ip (ma)	Volts	Ip + 20% V	Dip T°C	Ip @ 95%I
T1-950°C 0.2 A/cm^2	M1 Ef=9.0v	0	10.0	39	8.4 - 12.0	880	8.75
		2688	11.0		8.9 - 13.2	891	8.00
		11046	11.0		9.0 - 13.1	891	8.69
		11722	11.0		9.0 - 13.0	846	8.75
		12486	11.0		9.0 - 13.2	--	---
		13048	11.0		9.0 - 13.2	848	8.90
	M-4 Ef=9.0v	0	10.0	26	8.3 - 12.5	888	8.81
		2688	10.0		8.4 - 12.2	906	8.25
		11046	9.9		8.2 - 11.9	904	7.87
		11722	9.9		8.2 - 11.9	867	7.87
		12486	9.8		8.2 - 11.9	--	---
		13048	9.8		8.2 - 11.9	820	8.90
T1-950°C 0.4 A/cm^2	M-2 Ef=9.0v	0	20.0	49	15.1 - 27.3	916	19.3
		2688	21.2		16.1 - 25.9	896	17.5
		11046	20.1		16.0 - 23.9	895	17.6
		11722	20.0		15.9 - 23.9	874	17.5
		12486	20.4		16.0 - 24.2	--	---
		13048	20.6		16.4 - 24.4	838	18.8
	M-3 Ef=9.0v	0	20.0	35	16.5 - 27.0	897	15.0
		2688	20.7		16.2 - 25.2	907	16.6
		11046	20.2		16.0 - 23.9	880	17.6
		11722	20.2		16.0 - 23.9	909	17.5
		12486	20.2		16.0 - 23.9	--	---
		13048	20.2		16.0 - 24.2	870	17.6

TABLE 2

LIFE - TEST RESULTS

PORE - DISPENSER CATHODES

Test	Diode	Hours	Ip (ma)	Volts	Ip + 20% V	Dip T°C	Ip @ 95%I
T2-985°C 0.4 A/cm^2		0	20.0	34.5	16.8 - 27.5	899	19.3
		2688	20.0		15.8 - 24.4	957	16.6
		11046	23.9		18.8 - 29.9	945	17.5
	M-7	11722	23.9		18.8 - 30.0	943	18.2
	Ef=9.0v	12486	23.0		18.0 - 28.7	--	---
		13048	23.2		18.2 - 28.8	906	18.2
		0	20.0	40	14.6 - 28.5	910	18.8
		2688	22.5		15.9 - 29.1	935	17.7
	M-9	11046	21.8		15.6 - 27.8	941	17.1
	Ef=9.0v	11722	21.4		15.4 - 27.3	946	17.8
		12486	21.5		15.4 - 27.8	--	---
		13048	21.9		15.8 - 28.1	908	18.1
T2-985°C 0.8 A/cm^2		0	40.0	65	32.0 - 49.5	964	28.0
		2688	37.5		30.8 - 45.8	979	30.3
		11046	35.5		29.7 - 41.2	946	35.0
	M-11	11722	34.2		28.6 - 39.4	979	30.5
	Ef=9.0v	12486	34.8		29.0 - 40.3	--	---
		13048	34.8		30.2 - 40.3	964	33.4
		0	40.0	54	31.0 - 50.0	913	38.0
		2688	37.0		29.2 - 45.0	957	32.0
	M-12	11046	33.8		27.2 - 39.9	910	34.5
	Ef=9.0v	11722	31.9		25.8 - 37.2	947	32.0
		12486	32.1		26.0 - 37.7	--	---
		13048	32.1		26.0 - 37.9	891	35.3

TABLE 3

LIFE - TEST RESULTS

PORE - DISPENSER CATHODES

Test	Diode	Hours	Ip (ma)	Volts	Ip + 20% V	Dip T°C	Ip @ 95%I
T3-1035°C 0.6 A/cm^2		0	30.0	45	22.5 - 38.5	965	29.2
		2688	30.0		23.9 - 39.8	961	26.4
		11046	32.2		24.2 - 40.1	972	24.2
	M-13	11722	32.8		24.2 - 40.4	980	26.4
	Ef=11.0v	12486	32.4		24.1 - 40.4	--	---
		13048	32.4		24.0 - 40.2	913	28.2
		0	30.0	48.5	21.5 - 38.0	949	29.2
	M-18	2688	30.0		23.0 - 37.8	1003	25.6
	Ef=11.0v	11046	31.7		24.7 - 40.0	1020	25.4
		11722	31.9		24.8 - 40.2	1005	25.4
		12486	31.8		24.8 - 40.1	--	---
		13048	31.8		24.7 - 40.1	961	27.8
T3-1035°C 1.2 A/cm^2		0	60.0	90	45.0 - 78.5	993	55.5
		2688	61.2		47.8 - 77.4	1020	51.6
	M-17	11046	63.2		51.2 - 78.8	1024	51.2
	Ef=11.0v	11722	63.2		51.4 - 78.8	1030	51.2
		12486	62.4		50.8 - 78.7	--	---
		13048	62.4		50.9 - 78.8	1013	53.6
		0	60.0	98	44.5 - 69.0	995	56.0
	M-14	2688	54.9		41.2 - 70.2	977	55.2
	Ef=11.0v	11046	53.7		40.1 - 68.4	999	54.8
		11722	54.0		40.9 - 68.4	988	54.4
		12486	60.2		42.0 - 76.4	--	---
		13048	60.9		42.0 - 76.9	965	53.6

TABLE 4

LIFE - TEST RESULTS

PORE - DISPENSER CATHODES

Test	Diode	Hours	Ip (ma)	Volts	Ip + 20% V	Dip T°C	Ip @ 95%T
T4-1100°C 0.8 A/cm^2	M-21 Ef=11.0v	0	40.0	67	23.0 - 52.0	957	37.6
		2521	46.4		28.8 - 59.5	1055	34.6
		10943	50.2		31.0 - 63.0	1048	29.0
		11413	51.0		31.4 - 63.9	1037	38.0
		12183	51.7		31.8 - 63.9	--	---
		12781	51.9		32.0 - 63.9	1016	34.5
	M-23 Ef=11.0v	0	40.0	73	24.0 - 51.0	997	38.0
		2521	37.2		23.9 - 45.8	1079	31.0
		10943	37.0		24.8 - 46.2	1100	29.0
		11413	39.2		27.8 - 46.3	1100	30.5
		12183	37.2		24.9 - 46.5	--	---
		12781	38.2		25.3 - 47.0	1100	29.5
T4-1100°C 1.6 A/cm^2	M-22 Ef=11.0v	0	80.0	106	59.0 - 100.0	1039	73.0
		2521	86.5		71.7 - 110.0	1051	66.0
		10943	86.3		74.1 - 110.0	1100	63.0
		11413	86.2		74.0 - 110.0	1100	66.0
		12183	86.4		74.1 - 110.0	--	---
		12781	86.8		74.4 - 110.0	1100	61.0

The diodes operating at T3 conditions (1035°C, 0.6 and 1.2 A/cm^2) are satisfactory in operating and test conditions up to this point in life burning.

The diodes operating under T4 conditions (1100°C, 0.8 and 1.6 A/cm^2) have not shown any significant changes in cathode test parameters for 12781 hours.

In summary, the pore-dispenser cathodes have been operating satisfactorily for 12781 hours from 950°C to 1100°C with the cathode current varying from 0.2 A/cm^2 to 1.6 A/cm^2.

3.0 LIFE BURNING AND TESTING OF OXIDE-COATED CATHODES

The test diodes with oxide-coated cathodes under T1 and T2 conditions have completed 9638 hours of life burning.

The test diodes with oxide-coated cathodes operating under T3 and T4 conditions have completed 11958 hours of life burning.

The life test results are shown in Tables 5 (T1), 6 (T2), 7 (T3), 8 (T4). The last three sets of readings for each diode are for the three months of this interim report.

The diodes operating under T1 conditions (800°C, 0.075 A/cm^2) have shown a change in cathode operating current from 8.8% to 25.0%.

The diodes operating under T2 conditions (825°C, 0.15 A/cm^2 and 0.30 A/cm^2) are showing a change in cathode operating current from 0% to 37.5%. It should also be noted that the dip temperature is 825°C (operating temperature).

The diodes operating under T3 conditions, (825°C, 0.225 A/cm^2 and 0.45 A/cm^2) are showing cathode current slumps from 16.1% to 43.5%. The dip temperature is also up to 825°C (operating temperature).

The diodes operating under T4 conditions are showing cathode current slumps from 40.2% to 57.5%. The dip temperature is also at 850°C (operating temperature).

An analysis of the test results shows the diodes with oxide-coated cathodes to be slumping at current densities above 0.15 A/cm^2.

TABLE 5

LIFE - TEST RESULTS

OXIDE - COATED CATHODES

Test	Diode	Hours	Ip (ma)	Volts	Ip + 20% V	Dip T°C	Ip @ 95%T
T1-800°C 0.075 A/cm^2		0	6.0	19.5	4.7 - 7.9	722	4.13
		1371	6.0		4.9 - 7.4	666	5.14
	0-32	7600	5.2		4.2 - 6.0	732	4.95
	Ef=8.0v	8276	5.2		4.2 - 6.0	709	4.85
		9040	5.7		4.9 - 6.2	---	---
		9638	5.7		4.9 - 6.2	764	4.76
		0	8.0	18.5	7.1 - 9.7	750	4.13
	0-35	1371	7.8		7.2 - 8.9	740	5.14
	Ef=8.0v	7600	7.0		6.8 - 8.0	780	4.88
		8276	7.1		6.8 - 8.6	767	4.87
		9040	7.2		6.8 - 8.6	---	---
		9638	7.2		6.8 - 8.6	793	4.50
T1-800°C 0.15 A/cm^2		0	12.0	36	9.0 - 15.1	655	10.9
		1371	11.8		8.9 - 14.3	680	10.5
	0-39	7600	9.0		6.4 - 10.9	714	10.2
	Ef=8.0v	8276	9.0		7.0 - 11.0	719	10.7
		9040	9.0		7.0 - 11.0	---	---
		9638	8.9		7.0 - 11.6	738	10.1
		0	12.0	29	9.6 - 14.7	769	9.3
		1371	12.0		9.9 - 14.1	703	10.1
	0-40	7600	10.0		8.4 - 12.0	757	9.8
	Ef=8.0v	8276	10.0		8.3 - 12.0	748	10.3
		9040	9.8		8.3 - 12.0	---	---
		9638	9.9		8.3 - 12.1	770	9.8

TABLE 6

LIFE - TEST RESULTS

OXIDE - COATED CATHODES

Test	Diode	Hours	Ip (ma)	Volts	Ip + 20% V	Dip T°C	Ip @ 95%T
T2-825°C 0.15 A/cm^2		0	12.0	29	9.3 - 15.2	741	11.0
		1371	11.0		8.0 - 13.0	804	10.2
		7600	14.2		12.1 - 15.8	825	8.7
	0-38	8276	14.9		13.0 - 16.0	825	6.0
	Ef=8.0v	9040	13.0		11.1 - 14.0	---	---
		9638	12.0		11.2 - 13.1	825	5.6
		0	12.0	34	9.1 - 14.7	727	10.8
		1371	12.0		9.3 - 14.9	758	10.8
	0-41	7600	10.0		7.9 - 12.1	825	9.0
	Ef=8.0v	8276	9.9		7.9 - 12.0	825	9.5
		9040	9.2		7.2 - 11.0	---	---
		9638	9.0		7.0 - 11.0	825	8.8
T2-825°C 0.3 A/cm^2		0	24.0	45	19.0 - 30.4	787	21.0
		1371	20.9		16.2 - 25.4	825	20.8
	0-33	7600	16.9		15.0 - 23.0	825	17.2
	Ef=8.0v	8276	15.9		12.8 - 19.0	825	16.9
		9040	15.8		12.9 - 19.0	---	---
		9638	15.0		12.3 - 18.0	825	16.2
		0	24.0	56	19.1 - 30.7	735	22.6
		1371	21.0		17.0 - 24.7	825	18.0
	0-37	7600	20.0		16.9 - 23.3	825	20.1
	Ef=8.0v	8276	20.0		16.8 - 23.2	825	21.0
		9040	20.2		16.9 - 23.5	---	---
		9638	20.2		16.8 - 23.5	825	20.8

TABLE 7

LIFE - TEST RESULTS

OXIDE - COATED CATHODE

Test	Diode	Hours	Ip (ma)	Volts	Ip + 20% V	Dip T°C	Ip @ 95%T
T3-825°C 0.225 A/cm^2	0-11 Ef=8.0v	0 3439 9720 10596 11360 11958	18.0 11.0 10.0 10.4 10.4 10.4	31	14.0 - 22.2 9.0 - 12.4 8.4 - 12.0 8.9 - 12.6 8.9 - 12.3 8.7 - 12.2	779 825 825 825 --- 825	16.4 11.6 12.6 12.4 --- 12.4
	0-15 Ef=8.0v	0 3439 9720 10596 11360 11958	18.0 14.2 12.4 12.7 12.7 12.5	28	13.9 - 23.5 11.3 - 18.0 10.2 - 15.0 10.2 - 15.0 10.2 - 15.0 10.0 - 14.7	769 825 825 825 --- 825	16.6 13.5 11.9 11.2 --- 11.3
T3-825°C 0.45 A/cm^2	0-7 Ef=8.0v	0 3439 9720 10596 11360 11958	36.0 20.0 11.0 11.0 16.2 17.3	34	28.0 - 45.5 17.0 - 22.4 10.9 - 14.3 10.9 - 14.3 14.0 - 18.9 14.5 - 20.4	783 825 825 825 --- 825	33.5 32.8 22.5 19.4 --- 23.0
	0-14 Ef=8.0v	0 3439 9720 10596 11360 11958	36.0 35.4 29.8 30.0 30.0 29.2	67	28.0 - 44.5 27.0 - 46.2 24.2 - 42.5 23.9 - 42.7 24.2 - 45.0 24.0 - 44.2	768 825 825 825 --- 825	31.7 29.3 28.4 23.6 --- 24.5

TABLE 8

LIFE - TEST RESULTS

OXIDE - COATED CATHODES

Test	Diode	Hours	Ip (ma)	Volts	Ip + 20% V	Dip T°C	Ip @ 95%T
T4-850°C 0.3 A/cm^2							
	0-22 Ef=8.0v	0 3439 9720 10596 11360 11958	24.0 15.8 11.5 10.9 10.5 10.2	46	19.7 - 28.0 13.1 - 21.2 9.9 - 12.3 8.9 - 11.9 8.9 - 11.8 8.9 - 11.2	775 850 850 850 --- 850	18.2 19.3 8.2 12.6 --- 13.8
T4-850°C 0.6 A/cm^2	0-19 Ef=8.0v	0 3439 9720 10596 11360 11958	48.0 41.9 36.5 36.9 36.9 36.9	57.5	35.0 - 59.3 31.4 - 64.5 29.3 - 51.8 29.1 - 49.2 29.2 - 49.4 29.2 - 50.0	796 850 850 850 --- 850	42.0 36.0 28.5 33.0 --- 31.8
	0-20 Ef=8.0v	0 3439 9720 10596 11360 11958	48.0 41.4 28.3 28.4 29.8 28.7	70	36.8 - 60.0 32.0 - 55.3 23.1 - 36.4 23.1 - 36.6 24.4 - 32.9 23.9 - 31.9	769 850 850 850 --- 850	42.6 37.5 31.2 29.0 --- 30.0

4.0 BEHAVIOR OF OXIDE-COATED AND COATED-PARTICLE CATHODES WITH THREE DIFFERENT CATHODE ALLOYS

The cathode coating peeling problem that was encountered in the construction and exhaust of diodes using three different cathode nickel alloys with oxide and coated-particle coating was solved by the addition of a powdered nickel underlay between the nickel cathode face and the coating.

The cathodes were fabricated and the diodes were constructed as described in Interim Report No. 5, Thermionic Cathode Study, July 1 - September 30, 1968.

The only difference in the cathode fabrication was the addition of the nickel underlay on the cathode surface. The three different cathode alloys were sprayed with a very porous layer of Monel nickel to a thickness of 0.003 inch to 0.005 inch. The powdered nickel layer was sintered at 1140°C for ten minutes in wet hydrogen.

The diodes were exhausted on the double vacuum bakeout system in groups of four diodes each. The exhaust procedure for the diodes is described in Interim Report No. 6, Thermionic Cathode Study, October 1 - December 31, 1968.

The diodes, which were constructed with three different cathode alloys according to the specifications described in Table 9, Life Test Procedures, Modification No. 1, showed no sign of cathode coating peeling.

Six lots of diodes were constructed with the cathodes and coating as described in Table 10.

The diodes are presently being aged for 24 - 100 hour periods at 800 - 825°C cathode temperature and anode voltage at 50 Vdc.

The test lots of diodes will be tested and placed on life burning during the next interim period of this thermionic cathode study.

TABLE 9
LIFE TEST PROCEDURES
MODIFICATION NO. 1

CATHODE	LIFE TEST TEMP.	REQ'D UNITS	CURRENT DENSITY ma/cm^2
Oxide Cathode	T_2	1	150
Using 220 Alloy	T_2	1	300
Nickel Base	T_3	1	225
(4 Units)	T_3	1	450
Oxide Cathode	T_2	1	150
Using Cathalloy	T_2	1	300
A-33 Nickel Base	T_3	1	225
(4 Units)	T_3	1	450
Oxide Cathode	T_2	1	150
Using 0.1% Zr in	T_2	1	300
Ni-pure Nickel Base	T_3	1	225
(4 Units)	T_3	1	450
Coated Particle	T_2	1	275
Cathode Using Cath-	T_2	1	550
alloy A-33 Nickel Base	T_3	1	415
(4 Units)	T_3	1	830
Coated Particle	T_2	1	275
Cathode Using 0.1%	T_2	1	550
Zr in Ni-pure Nickel Base	T_3	1	415
(4 Units)	T_3	1	830

TABLE 10

CATHODE DESCRIPTION - DIODE LOTS

DIODE LOT NO.	CATHODE	COATING
9	220 Ni-Alloy	Oxide-coating C51-3
10	0.1% Zr in Ni-Pure Nickel Alloy	Oxide-coating C51-3
11	0.1% Zr in Ni-Pure Nickel Alloy	CPC Coating
12	A-33 Ni-Alloy	Oxide-coating C51-3
13	A-33 Ni-Alloy	CPC Coating
14	A-33 Ni-Alloy	CPC Coating

5.0 PLANS FOR THE EIGHTH INTERIM PERIOD

During the next interim period of study from April 1 - June 30, 1969, the following program will be followed:

a. Continue life testing of pore-dispenser cathodes now on life burning.

b. Continue life testing of oxide cathodes now on life burning.

c. Pretest new diodes according to specifications outlined in Table 9.

d. Start life testing of new diodes according to specifications outlined in Table 9.

6.0 CONCLUSIONS AND SUMMARY

The Raytheon Materials and Techniques Group, in conducting a study of the life capabilities of the pore-dispenser cathode and the oxide cathode, has drawn the following conclusions from 18 months of life burning under the conditions noted in Tables 1 through 8.

a. The pore-dispenser method is suitable for dc operation for at least 12781 hours at current ranges of 0.2 A/cm^2 to 1.6 A/cm^2 and temperatures ranging from 950°C to 1100°C.

b. The standard barium/strontium-oxide cathodes are showing emission slump at current densities above 0.15 A/cm^2 from 9638 to 11958 hours. Though the emission level in these diodes is decaying, they should not be counted as failures at this point of life.

c. The diodes constructed with the cathode alloy modifications listed in Table 9, have been reconstructed with a nickel underlay between the cathode face and the cathode coating, thus eliminating the cathode coating peeling problem.

d. At this point, the only candidate for satisfying the objective of 1 A/cm^2 is the pore-dispenser cathode.