HIGH-CURRENT-DENSITY CATHODE-RAY TUBE ELECTRON SOURCE

Report #2

Second Quarterly Progress Report

1 July 1964 - 1 October 1964

Contract DA 28-043 AMC-00021 (E)
DA Task No. 1P6-22001-A-055-03

U. S. Army Electronics Laboratories
Fort Monmouth, New Jersey

PICKUP TUBE OPERATION
TUBE DEPARTMENT
GENERAL ELECTRIC
Syracuse, N. Y.

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HIGH-CURRENT-DENSITY CATHODE-RAY-TUBE ELECTRON SOURCE

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1 July 1964 - 1 October 1964

Objective: To develop an electron source of extremely high current-density for ultra-high-resolution cathode-ray tubes

Contract DA 28-043 AMC-00021 (E)
Technical Guidelines dated 15 August 1963
DA Task No. 1P6-22001-A-055-03

Authors:

M. Gibbons
M. Slivka

Pickup Tube Operation
Tube Department
General Electric Company
Syracuse, New York

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PURPOSE

The purpose of this contract is to conduct a program of research leading to the development of an electron source of extremely high current-density for ultra-high-resolution cathode-ray tubes. The high-current-density electron source will consist of a cathode or cathode-like structure suitable for use in an ultra-high-resolution cathode-ray tube.

These aims will be accomplished in five phases. Phase I will be devoted to the development and fabrication of the cathode. Phase II will involve testing of this cathode in diodes. In Phase III, life tests on the most-promising cathode compositions in cathode-ray-tube vacuum environments will be carried out. In Phase IV, life tests on the best cathode structure in cathode-ray tubes with FRM guns will be performed. In Phase V, tubes will be fabricated for shipment.

ABSTRACT

The life test of a large version of this cathode has passed 3500 hours and is still in progress. Space-charge-limited emission, being drawn at the set conditions of cathode temperature at 1000^{o}C and anode voltage at 120 volts, has diminished from 4.8 amperes per cm^2 at 1500 hours to 4.3 amperes per cm^2 at 3500 hours. However, emission capability, measured at a test temperature of 900^{o}C, has remained essentially unchanged, indicating the occurrance of a change in perveance of the life test diode.

Problems were encountered and overcome in the mounting of cathodes for emission testing in the demountable emission test diode assembly. Six of the cup-cone type of cathodes were incorporated in the diode assembly and tested for emission. Three that were fabricated by the technique described in the First Quarterly Report showed low emission and a propensity toward poisoning. One containing a heater internal to the cup-cone cathode could not be heated to required temperatures because of excessive thermal losses. Two cathodes were fabricated by a modified technique that opened the active material to the hydrogen during the sintering operation. These cathodes showed an improvement in emission; and, in one, space-charge-limited emission of about 15 amperes per cm^2 at 1100^{o}C was measured. This is equivalent to 3.5 amp/cm^2 at 1000^{o}C.

Production of the conical-bottomed sleeves with precise and sharp conical sections centered on the axes of the sleeves was emphasized. This will alleviate the problems that have been encountered in controlling spot size of the emitter portion of the cathodes and its centering in the face of the cathodes.

PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

None

FACTUAL DATA

Life Testing

A 0.359-inch-diameter cathode, placed on life test during the first report period, is still on test. This cathode, which is of the type presently used in cathode development and evaluation, has exceeded 3500 hours of operation. During this test, the temperature of the cathode has been controlled at 1000°C while d.c. potential of 120 volts has been impressed on the water-cooled anode.

Figure 1 shows how the emission current density of this cathode has varied with time. From the results of periodic emission tests, it is evident that the emission has been space-charge-limited throughout the life test. Figure 2 presents the periodic emission data taken at a test temperature of 900°C. (Note: For the purposes of extrapolating temperature-saturated emission values to higher temperatures, the values obtained at a given temperature can be doubled for each 50°C increase in temperature.)

Diode-Emission Measurements

A number of the cup-cone-type cathodes were tested for emission in an ion-pumped bell jar. This basic cathode assembly was chosen for the tests because the techniques for incorporating it into the existing diode structure and for obtaining controlled cathode-anode spacing already had been developed. However, mounting these very small cathodes into the existing diode test assembly presented a number of problems.

The first approach toward solving these mount problems was to weld the cathode to three tabs (each measuring 0.0625 inch by 0.008 inch). These tabs were brought out from the end of a conventional 0.359-inch-diameter molybdenum cathode sleeve and were a continuous

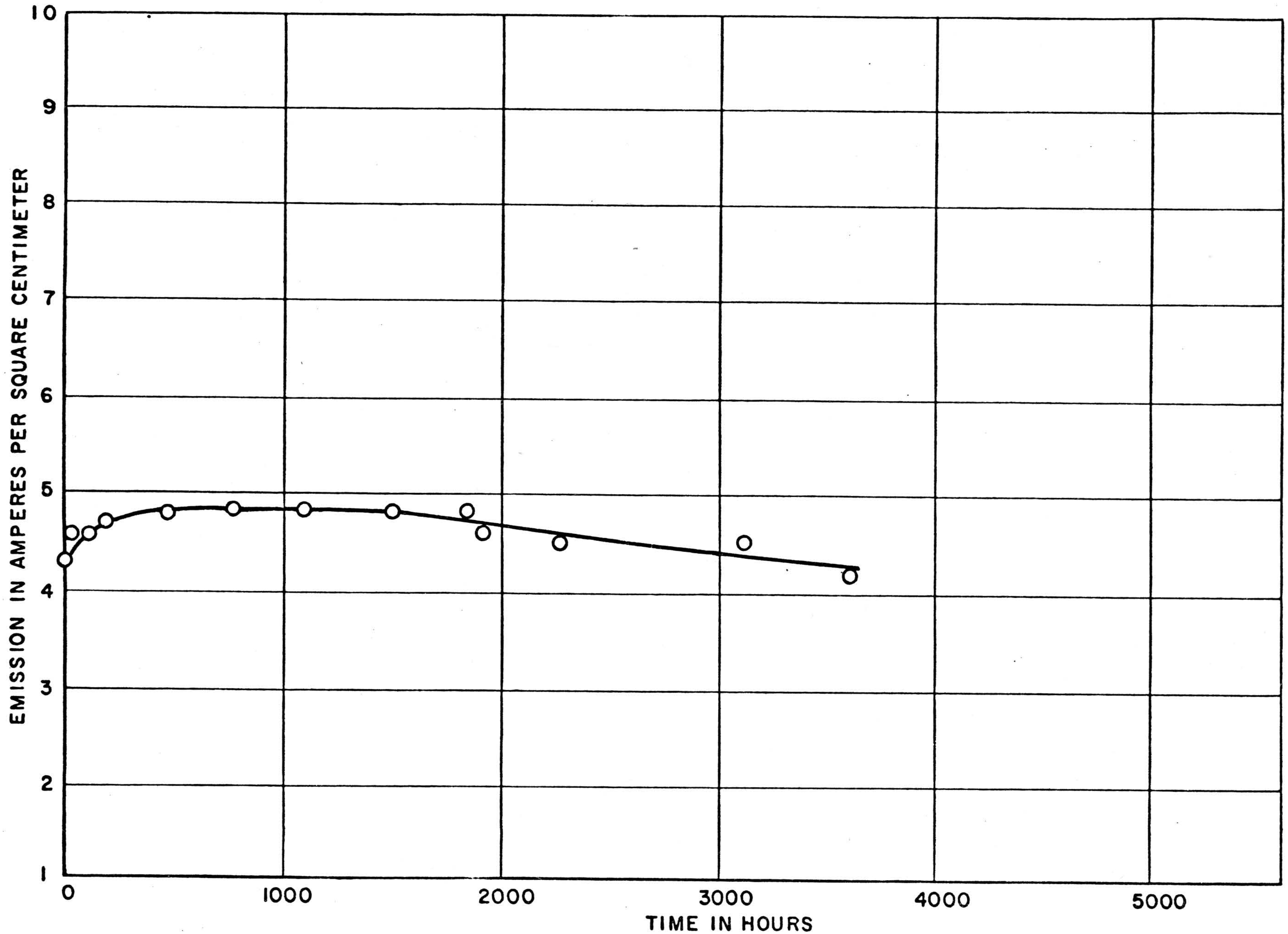

FIGURE 1. Emission Current Density Vs. Time of Life Test Cathode

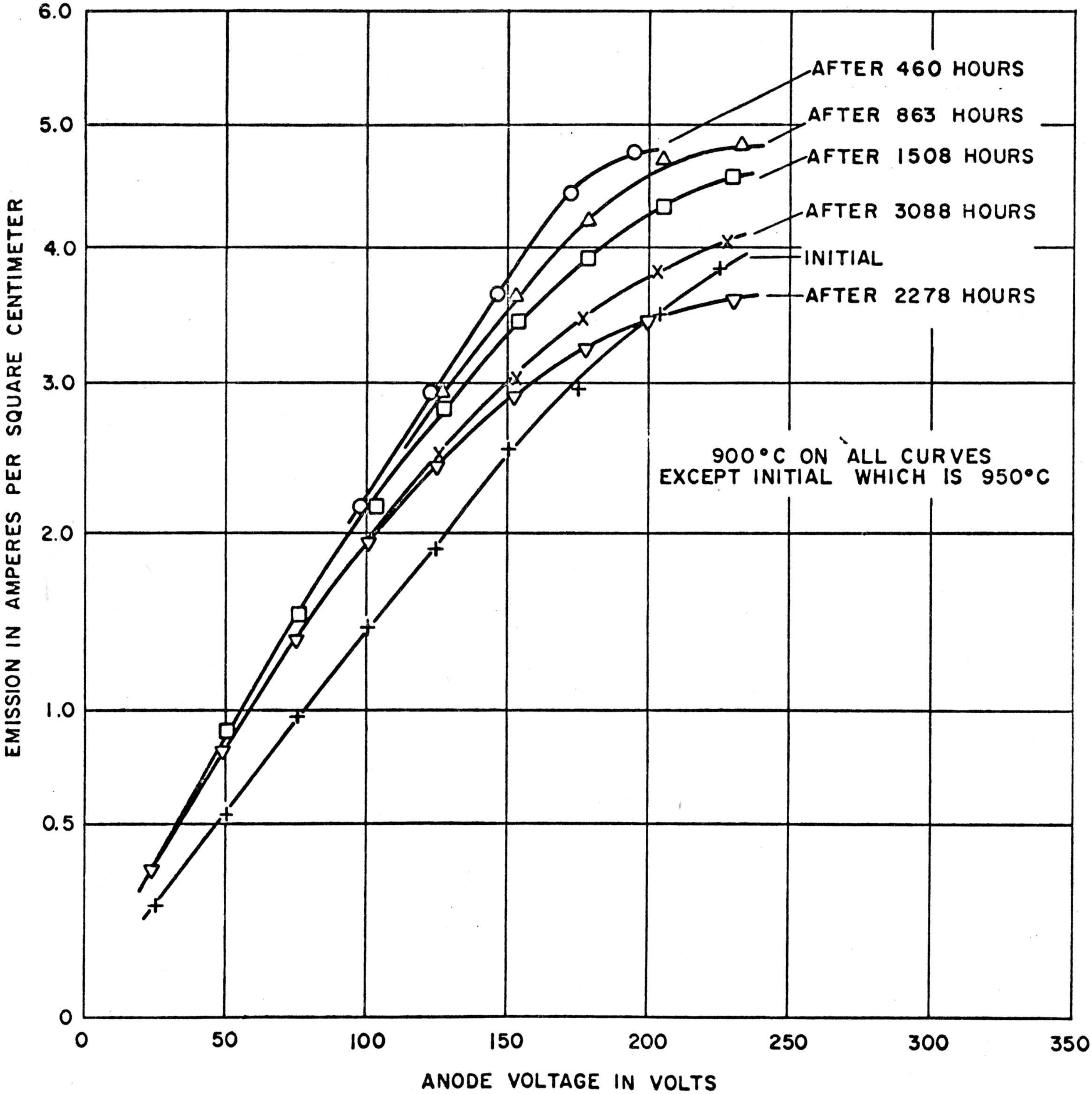

FIGURE 2

Emission Curves of Life Test Cathode

part of this sleeve. An intermediate flux (tantalum foil) was used in welding the cathode to the tabs. The heater, which was an alumina-coated tungsten helix, was attached inside the 0.048-inch (inside diameter) test cathode.

It was difficult to weld the support tabs to the cathode without producing deposits and splatter from the welding electrodes. Such deposits on the cathode proper could be injurious to emission. Nevertheless, a complete heater-cathode assembly was incorporated in the diode test assembly. When this assembly was placed in operation, the heater would not raise the cathode to the required emission temperatures, presumably because of excessive heat conduction along the support tabs.

To obtain emission test results quickly, this method of mounting and heating the cathodes was set aside temporarily (pending resolution of the thermal problem in the support structure); and an alternate approach was taken. In this alternate approach, the cathode is mounted as shown in Figure 3, using the 0.359-inch-diameter cathode sleeve and associated mounting technique. The test cathode is heated with a conventional heater, which fits inside of the sleeve. Cathode temperature is monitored by a platinum and platinum/13-per-cent-rhodium thermocouple (0.002" diameter) welded to the outside diameter of the cathode. All subsequent cathodes were assembled and heated in this manner.

The activation and test procedures utilized in testing the cathodes are the optimum procedures normally used in the testing of

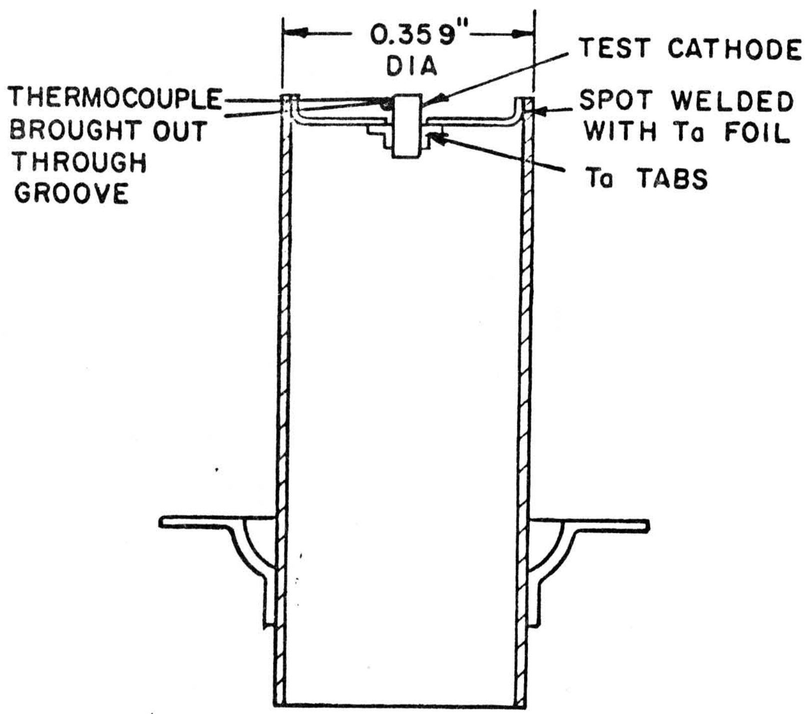

FIGURE 3

Cathode Test Assembly

FACTUAL DATA (Continued)

similar dispenser cathodes. In this procedure, the following operations are performed:

1. Initial outgassing of the heater-cathode assembly with a mercury diffusion pump and a liquid-nitrogen trap. The pressure range is 2-to-3 x 10^{-5} Torr.
2. Final outgassing and pressure stabilization. An ion pump (the mode of pumping used throughout the test) maintains a pressure in the range of 1-to-5 x 10^{-7} Torr. The temperature is 1100°C; the anode voltage is 25 volts.
3. Flashing at 1200°C for 10 minutes, holding the anode voltage at 25 volts.
4. Activation and stabilization of the cathode at 1050°C for a minimum of 16 hours with 150 volts applied to the anode. This normally draws 4-5 amperes per cm^2 from the cathode.
5. Test at 950°C and at other required temperatures. This is done by controlling the cathode temperature at the selected value while increasing the anode voltage in 25-volt steps, starting at 25 volts and continuing until saturated emission is clearly indicated, or until the limit of anode dissipation ability is reached (indicated by boiling of the cooling water). In the latter case, the temperature is lowered 50°C; and the process is repeated.
6. Plot anode-volts versus cathode-current, using 2/3-power graph paper and determine the temperature-saturated

emission at the test temperature. This is the point at which the plot departs from a straight line.

Figure 4 shows the 2/3-power plots obtained for the first cathode (No. 11-II-CA-1). In this case, the diameter of the emitter spot was 0.017 inch. This corresponds to an area of 1.46 x 10^{-3} cm^2, at which 10 amperes per cm^2 is equivalent to an emitted current of 14.6 ma. The maximum emission measured at 1100°C was 7.55 ma, which is equivalent to 5.18 amperes per cm^2. It was difficult to determine the start of saturated emission from the 2/3-power plots.

Note in Figure 4 that an abnormal reversal of slope occurred at the higher current levels as exemplified by the tests at 1050°C and 1100°C. Similar abnormal behavior occurred in tests on another cathode (No. 17-II-B-2) when high current levels were drawn.

In the next test (cathode No. 11-II-CA-2), the emitter spot diameter was 0.008 inch, which corresponds to an area of 3.24 x 10^{-4} cm^2. (For this area, 10 amperes per cm^2 is equivalent to an emitted current of 3.24 ma.) Promising emission was observed until the cathode was flashed at 1200°C. At the start of this step, the emission was 0.84 ma or 2.6 amperes per cm^2 with the anode set at 25 volts. During the holding period, however, the emission dropped abruptly to 0.02 ma. The higher emission could not be recovered during the activation procedure or during subsequent tests and operation of the cathode. Apparently, the emitter had become poisoned. Thus, the fact that smaller emitting areas may be more sensitive to poisoning is a potential hazard inherent in the operation of small emitters.

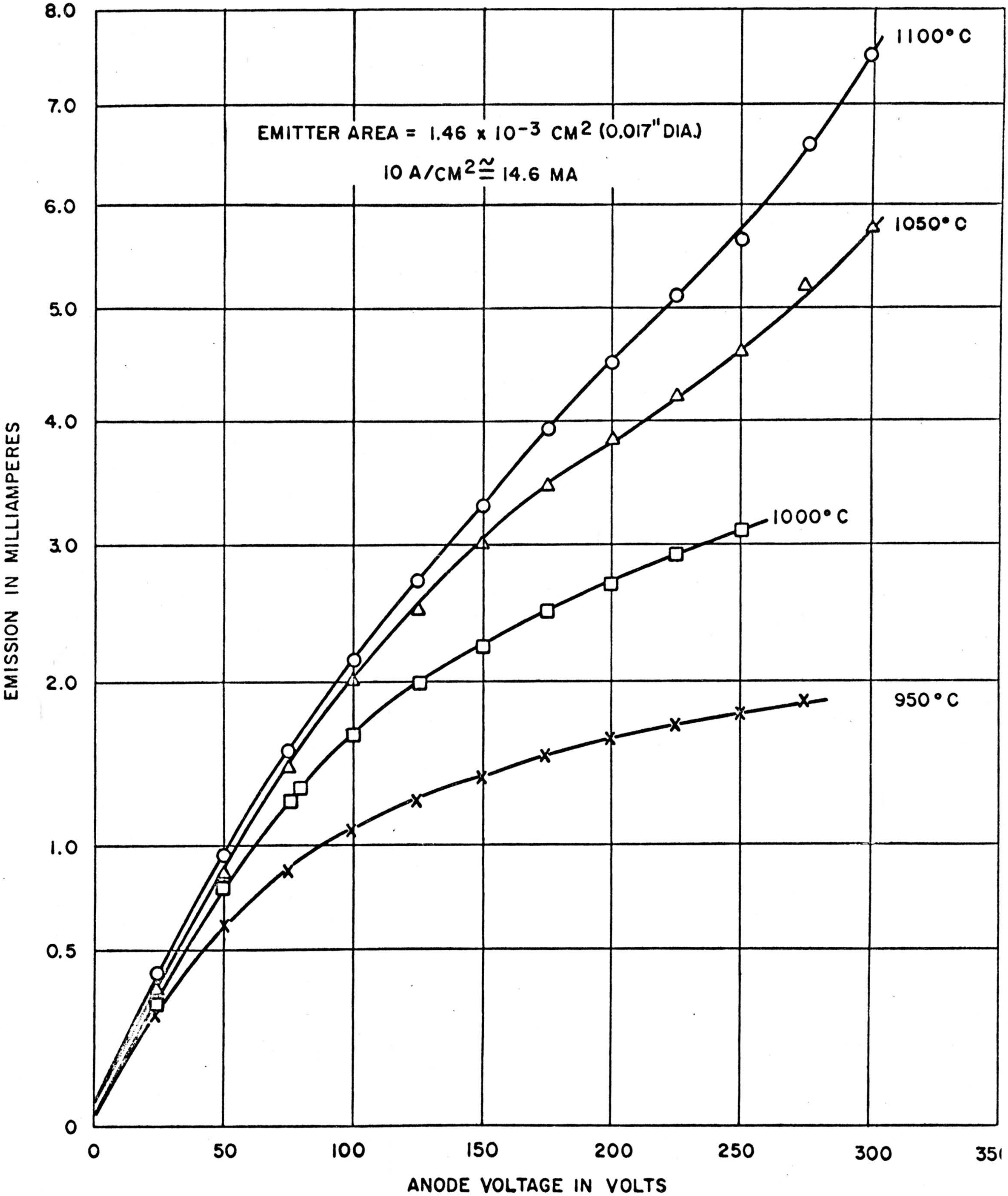

FIGURE 4. Emission Curves of Cathode No. 11-II-CA-1

FACTUAL DATA (Continued)

Low emission also was obtained when cathode No. 10-IV-CA-2 was tested. This cathode had a spot diameter of 0.012 inch or an area of 7.3×10^{-4} cm^2. For this area, 10 amperes per cm^2 is equivalent to 7.3 ma. The highest value measured at 1100°C was less than 1 ampere per cm^2.

It thus was apparent that a change was needed in the cathode processing. Previously, the cathodes had been fabricated by pressing the emitter powder mix inside the conical-bottomed molybdenum sleeve, sintering, and then machining the face of the cathode to expose a spot of emitter material at the center of the face. Experience with similar dispenser cathode structures indicates that best emission results are obtained when the emitter material is processed with maximum exposure to the hydrogen atmosphere in which the sintering is performed.

Cathode No. 17-II-CB-1 was fabricated by machining the face of the cathode sleeve to expose a 0.008-inch-diameter hole in the face. Then the emitter powder mix was pressed in the sleeve, the assembly was sintered, and the face of the cathode was machined in the usual manner. The resultant emitter spot had a diameter of 0.011 inch and an area of 6.12×10^{-4} cm^2. For this area, an emission density of 10 amperes per cm^2 is equivalent to 6.12 ma. The emission test results are shown in Figure 5.

An additional modification was made in the fabrication of cathode No. 17-II-CC-2 by changing the conditions near the apex of the cone during the pressing operation. The emitter powder mix was pressed

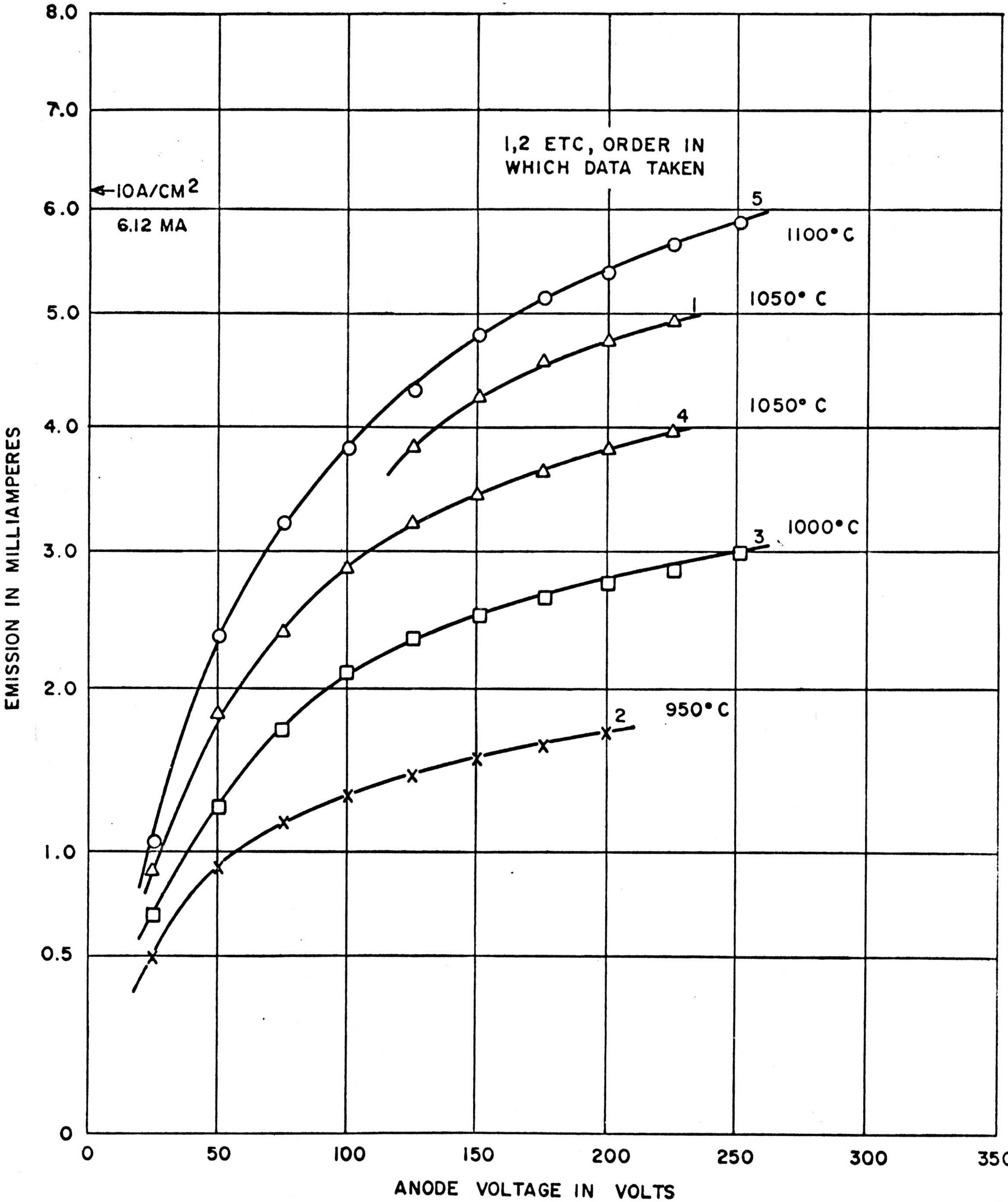

FIGURE 5. Emission Curves of Cathode No. 17-II-CB-1

in the conical-bottomed sleeve, and then the face of the cathode was machined to expose an undersized spot of emitter material. Following this, the cathode was sintered and finally machined in the normal manner. The area of the final emitter spot was 9.93×10^{-4} cm^2, which for an emission density of 10 amperes per cm^2 is equivalent to an emitted current of 9.93 ma. The thermocouple was left off when Cathode No. 17-II-CC-2 was mounted for test, to determine whether poisoning effects were arising because of deposits left on the cathode during the thermocouple welding operation. During test, the temperature was measured with an optical pyrometer. These brightness-temperature readings were converted to true temperatures by using a previously plotted calibration curve.

Figure 6 shows the emission results obtained with Cathode No. 17-II-CC-2. An abnormal, and as yet unexplained, activation phenomenon or increase in emission occurred (at a constant temperature and anode voltage) when high-voltage high-current conditions were allowed to remain in effect for a period of time. On returning to low-voltage low-current conditions, the reverse effect would occur; and the cycle could be repeated. Thus, different voltage-current values were obtained when the voltage was increased after a stay at low voltage and when the voltage was decreased after a stay at high voltage. A typical cycle of activation and deactivation is shown in Figure 7. Note the changes in emission that occurred with time when the cathode was held at a constant temperature and the anode voltage was changed from one extreme to the other, with stays at each extreme.

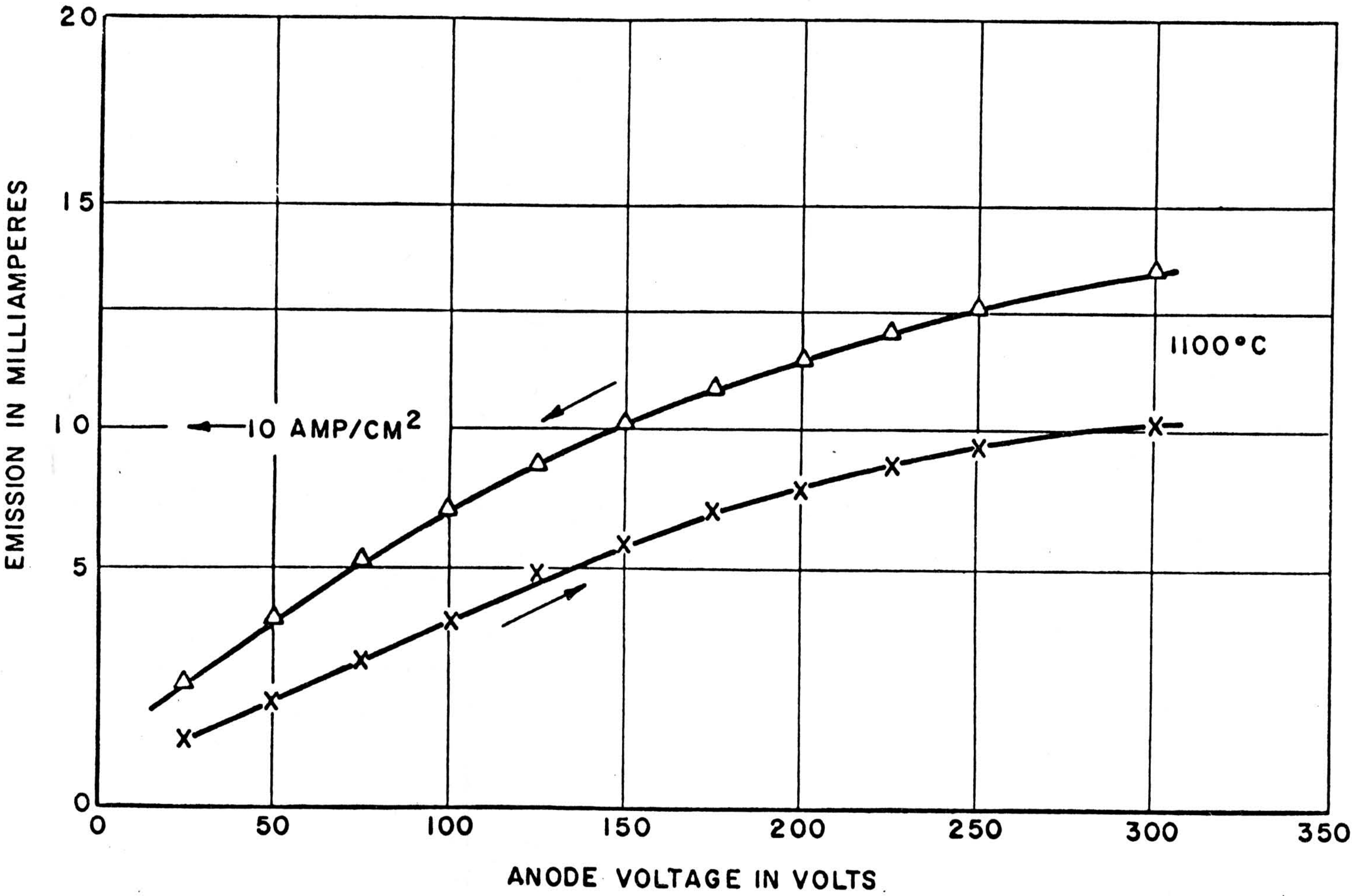

FIGURE 6

Emission Curves of Cathode No. 17-II-CC-2

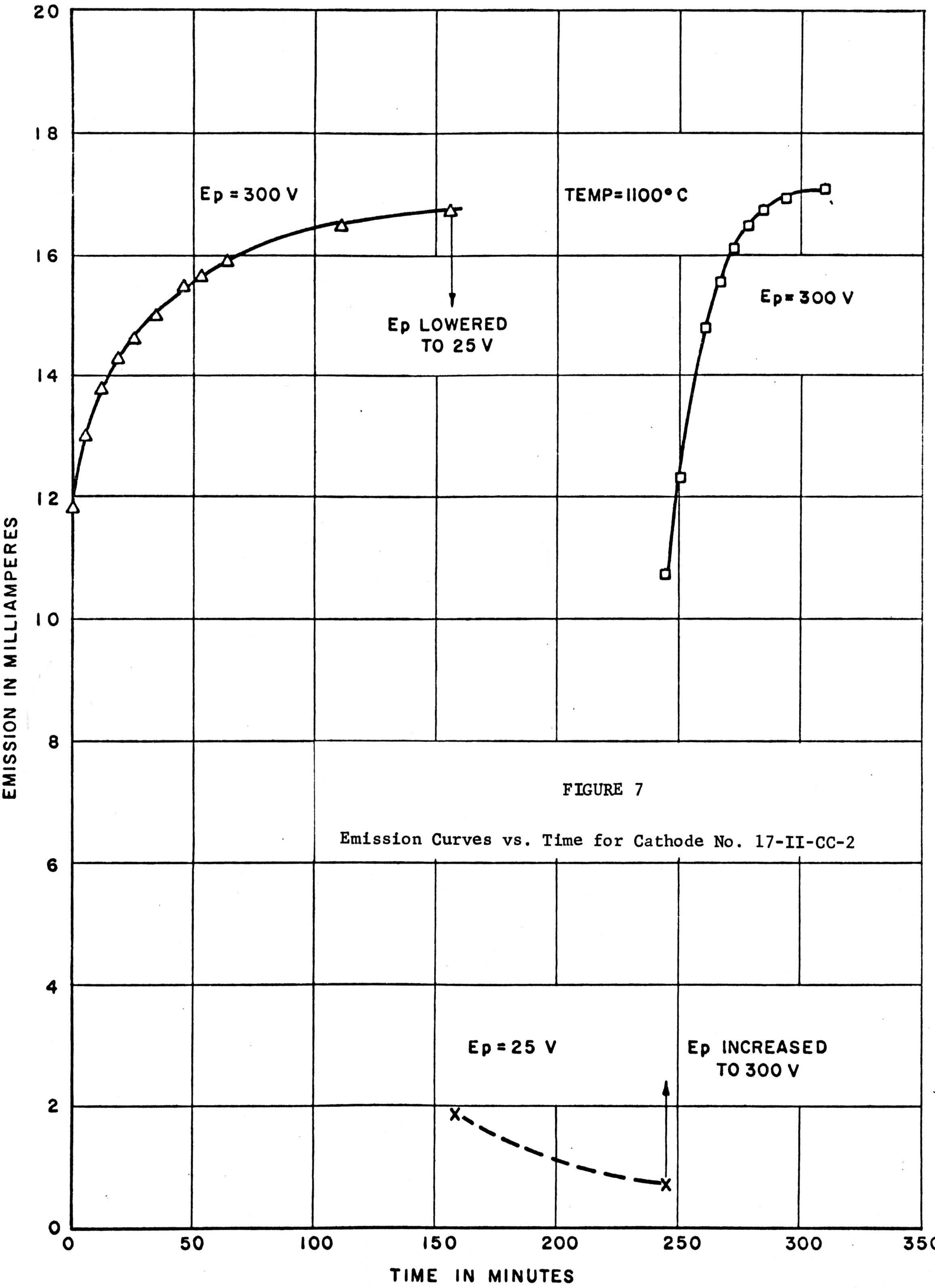

FIGURE 7

Emission Curves vs. Time for Cathode No. 17-II-CC-2

FACTUAL DATA (Continued)

Cathode Fabrication

Several mechanical processing problems remain to be solved. One problem is control of the final emitter spot diameter; another is the proper centering of the emitter spot in the face of the cathode.

Two factors make it difficult to control the spot diameter. One is the appearance of the emitter spot after the final machining operation. The appearance of this spot is so similar to the surrounding molybdenum area on the face of the cathode that it is difficult to define the outline of the spot, even under a high-power microscope. In addition, it has been difficult to produce truly conical cathode sleeves having a sharp apex; some have had a blunt apex. In these cases, an accurately controlled cut on the face of the cathode has produced an abnormal enlargement of the hole.

Effort is being concentrated on producing sleeves having:

1. the axis of the cone coincident with the axis of the sleeve and
2. a sharp apex on the cone.

To assure quality in these respects, the sleeves are now being x-rayed during their manufacture. Only sleeves having sharp, precise cones will be used. To improve control of spot size further, the sleeves currently being produced will be made with an initial 0.006-inch-(±0.001 inch) diameter hole in the center of the face of the cathode. In the final machining operation, this hole will be enlarged to the desired spot size by controlling the depth of the cut into the conical section.

FACTUAL DATA (Continued)

Evaluation

Emission tests were made on two groups of cathodes in diode structures using titanium anodes. The small cathodes were spot-welded to three 0.005-inch molybdenum support wires. The other ends of the wires were welded to a cathode support cylinder similar to that used in conventional electron guns.

These tubes were processed on an oil-diffusion pump with the pressure in the low 10^{-7} mm range. The Schottky method was used to obtain zero field emission. The first cup-cone cathode, in which the emission material was pressed into the cone-shaped closed-end of the cathode body (described in the first quarterly report), yielded 0.3 amp/ cm^2 at $1000^{o}C$. The cathode body described, in which the surface was machined back to expose part of the emissive surface to the hydrogen gas during firing, yielded 0.36 amp/cm^2 at $1000^{o}C$. These data are based on an assumed diameter of 0.010 inch for the emitting surface. Both emission levels appear stable.

One of the cup-cone cathodes was mounted in an emission microscope, that is, an image of the cathode surface was projected on a phosphor screen. The emission pattern was not uniform, having emitting and non-emitting areas. There appears to be some migration beyond the original emitting surface. This emission, which spreads a few mils beyond the boundary, is more uniform but of less intensity than the emission area.

More tests will be made, using the emission diode and electron microscope tubes. The microscope tube will be used to study migration of emission material, which, if it occurs, can cause a problem in specifying the current density capability of these cathodes. It does not appear troublesome with regard to the resolution of aperture-limited display tubes. Since the emission microscope tubes are miniature cathode-ray tubes, these tests can be used also to study the display tube environmental effect in the cathodes.

CONCLUSIONS

Life testing of the proposed emitter material in a larger-sized cathode has continued successfully through 3500 hours of operation. At the end of this time, the cathode had a space-charge-limited emission capability of about 12 amperes per cm^2 at $1000^{o}C$. However, these life-test results need to be supplemented by a test in which a full 10 amperes per cm^2 are drawn at $1000^{o}C$ or lower. Effort is currently being exerted to fabricate a diode in which this will be accomplished. This diode will use a cathode having a smaller emitter area and will have a water-cooled copper anode to handle the dissipation.

There is an urgent need to improve emission from the actual cup-cone cathodes used in cathode-ray tubes and to understand fully the parameters for cathode reproducibility. It is felt that the processing peculiar to the small-area test cathodes has been detracting from their emission capability compared with the emission obtained with the same material used in large cathodes. This was demonstrated during this report period when a decided improvement in emission was realized after the cathode sleeves were machined so that both ends of the cathode were exposed to the hydrogen atmosphere during sintering. Other processing steps, including the final pressing and machining operations, may also be adversely affecting emission.

Additional refinements in the fabrication of the conical-bottomed sleeves are required to assure control of the size and the centering of the emitter spot on the face of the cathode. These refinements are being incorporated in fabricating a quantity of sleeves that will have exact conical sections assured by x-ray examination.

PROGRAM FOR NEXT INTERVAL

The life test of the large-sized cathode will be continued at 1000^{o}C, with periodic tests for emission being made at 900^{o}C. A second life test diode will be constructed and started on life test. This diode will contain a small area cathode and will allow a continuous current of 10 amperes per cm^2 to be drawn.

Emission tests on the cathode-ray-tube cathodes will be continued, the objective being a space-charge-limited emission of 10 amperes per cm^2 at 1000^{o}C or lower. Modifications in the processing of the cathodes will be evaluated for an understanding of the parameters in order to fabricate reproducible emission cathodes. Samples of the best up-dated cathodes will be evaluated and tested in cathode-ray-tube environments.

IDENTIFICATION OF PERSONNEL

Second-Quarter Manpower Hours

	Hours
M. D. Gibbons, Project Engineer	105
M. J. Slivka, Project Engineer	150
R. J. Bondley	10
TOTAL	265

R. J. Bondley

Manager - Tube Technology
Schenectady Tube Operation
Tube Department

Education

1930	B.S.E.E., Ohio Northern University
1950	M.S.E.E., Union College

Experience

1933 - 1944	General Electric Company, Vacuum Tube Engineering Department and Electronics Laboratory
1944 - Present	General Electric Company, Research Laboratory and Tube Department

Fields of Experience

Research and development on electron-tube and vacuum devices; planar tubes; magnetron field; L-128 klystron. Internationally recognized expert in development of the titanium hydride ceramic sealing processes.

Patents

29 patents

Other Pertinent Data

Has published many papers.
Received General Electric Coffin Award for pioneering work on all-metal radio and industrial tubes in 1936

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This contract is supervised by the Special Tubes Branch, Electron Tubes Division, ECD, USAEL, Fort Monmouth, New Jersey 07703. For further technical information, please contact Mr. I. Stein, Project Engineer, telephone ext. 201-59-61205.

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Contract # DA 28-043 AMC-00021(E)

Unclassified Report

The life test of a large version of this cathode has passed 3500 hours & is still in progress. Space-charge-limited emission, being drawn at the set conditions of cathode temperature at 1000oC and anode voltage at 120 V, has diminished from 4.8 amps per cm^2 at 1500 hours to 4.3 amps per cm^2 at 3500 hrs. However, emission capability measured at a test temperature of 900o C has remained essentially unchanged, indicating the occurrance of a change in perveance of the life test diode. Problems were encountered & overcome in the mounting of cathodes for emission test diode assembly. Six of the cup-cone type of cathodes were incorporated

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Production of the conical-bottomed sleeves with precise & sharp conical sections centered on the axes of the sleeves was emphasized. This will alleviate the problems that have been encountered in controlling spot size of the emitter portion of the cathodes and its centering in the face of the cathodes.

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