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FABRICATION AND OPERATING CHARACTERISTICS OF SINTERED THORIA CATHODES

SEYMOUR GOLDBERG

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Seymour Goldberg

Abstract

Sintered thoria cathodes, 3 inches long and 0.860 inch in diameter, have been prepared by subjecting a mixture of thoria and tungsten or molybdenum powder to 115 tons/inch^2 pressure, and then sintering the resulting compact at 1750°C for one-half hour. The use of a split-segment die as developed by Raytheon seems to be best for the process. A volume concentration of conducting powder to thoria exceeding 0.212 is required to make the sintered cathode conducting and capable of being heated directly.

The operating characteristics of two cathode mixtures, one containing 30 percent tungsten and 70 percent thoria and the other 18 percent molybdenum and 82 percent thoria (by weight), were investigated. The cathode resistivity was found to decrease markedly as the cathode was first brought up to temperature, but once the highest operating temperature was reached no further appreciable decreases occurred. Considerable emission may be obtained at temperatures exceeding 1600°C (brightness); however, the cathode may be activated for short periods of time by flashing to a high temperature. In this manner over 1 amp/cm^2 was obtained at 1600°C (brightness). The period of activation was found to be much longer for the molybdenum mixture; it approached 100 hours. The activation time for the tungsten mixture never exceeded 15 hours.

FABRICATION AND OPERATING CHARACTERISTICS OF SINTERED THORIA CATHODES

I. Introduction

One of the main obstacles encountered in the development of higher powered pulsed and c-w magnetrons is the limitation imposed by the cathode. These difficulties are: first, those of an engineering nature; and second, the inherent limitations of the cathode material itself. Of the first kind are such things as heating power requirements, mounting problems and activation requirements. The inherent limitations include the available electron emission, sparking tendencies, and ability to withstand high-energy electron bombardment. The operating requirements of a magnetron cathode are perhaps the most stringent encountered in all vacuum tube work. They include sufficient primary emission to allow build-up of oscillation without mode skip, ability to withstand considerable high-energy electron back bombardment, sufficient secondary emission to supply the currents required during oscillation, and a minimum of sparking tendencies at high electron emission and at high potential gradients. From the production viewpoint it is desirable to have a cathode requiring no activation and having a corresponding ease of preparation, handling, and processing; and yet capable of operating satisfactorily at moderate temperature.

As the best compromise, oxide coated cathodes have been used almost universally. They do not satisfy all of the above-mentioned conditions; that is, they require activation and very careful handling; they have, at high fields and currents, sparking tendencies which become worse with age and as the duty cycle is increased. Also because of the low (800-900°C) normal operating temperature of oxide cathodes they cannot withstand much back bombardment without raising the cathode temperature to an excessive value. This effect is particularly noticed in c-w magnetrons, and places a severe limitation on the maximum output power. The back bombardment heating power is from 5 percent to 10 percent of the input power; thus, to design a 5-Kw c-w magnetron the cathode area would have to be about 100 cm^2 to dissipate this power without overheating an oxide cathode. Such a value is quite impractical, and in the case of a 10-cm tube, is far from the cathode area of about 5 cm^2 as given by application of the scaling laws.

As a more satisfactory compromise efforts have been made to introduce thoria as an emitting material for magnetrons. Although a thoria cathode requires higher operating temperatures, and thus greater heating power demands, it has several compensating advantages. Because of its higher operating temperature, a special heating problem is posed. One method of application is to coat a refractory-metal cylinder with powdered thoria

and to heat the cylinder indirectly by use of a tungsten heater coil. Since the cathode must operate at about 1700°C (and thus the heater at several hundred degrees more), the problem of insulating the heater from the cathode sleeve becomes very difficult. There is also the problem of making the thoria coat adhere to its base under operating conditions. A second method, proposed by Pomerantz (1) of the Bartol Laboratory, was to prepare a sintered thoria compact in which is imbedded a coil of tungsten wire serving as a heater. Trouble was encountered with the cracking of the cathodes because of expansion differences, and with the burning out of the tungsten coils. The method also presented many constructional difficulties. The third method first tried successfully by the Raytheon Company, and further investigated in this research, is to include with the thoria powder sufficient conducting powder to make a sintered compact that will conduct electricity. Thus heating may be accomplished by passing current directly through the cathode as is done with a filament type cathode.

In his research Pomerantz noted six advantages obtainable with thoria cathodes: "ability to provide high electron emission densities for long periods of time; sparking properties superior to those of Ba-Sr oxide-coated cathodes; ability to withstand violent punishment accorded by sparking, bombardment, and other destructive phenomena; greater stability, freedom from activation procedures, and corresponding ease of preparation, handling and processing; ability to operate at higher temperatures and to dissipate exceptionally high back bombardment powers; freedom from decay, and applicability to longer pulse length or c-w operation of magnetrons."

It would thus appear that a thoria cathode would be ideal for magnetron operation.

The purpose of this research was to devise a method of fabricating a conducting sintered-thoria cathode for use in a 10-Mw, 10-cm, pulsed magnetron now being developed at the Research Laboratory of Electronics, and also to gain a further understanding of its operating characteristics.

While the results of this research are to be applied to magnetrons, it is quite likely that other applications exist, such as in high-powered-transmitting tubes where the use of sintered thoria cathodes would be advantageous.

II. Cathode Fabrication

The first consideration in the fabrication of sintered thoria cathodes is the cathode mixture itself, that is, to determine how much conducting powder must be added to the thoria to make the sintered cathode conducting.

The basic constructional problem is that of devising a system whereby pressure sufficient to form a reasonably strong and uniform "green" compact

may be applied to the cathode mixture in a mold suitably shaped and capable of allowing removal of the compact after the pressing operation. Baking, to sinter the powders forming the cathode, completes the constructional work.

A discussion follows of these factors as applied to the fabrication of a cathode 0.865 inch in diameter, 2.70 inches long, and with a thickness of 0.060 inch.

Cathode Mixture. Considering the high operating temperatures of thoria cathodes (1600-1900°C), the choice of conducting metals is limited to the refractories, tungsten, molybdenum and tantalum. Tantalum was not considered since it would require sintering in a vacuum furnace, facilities for which were not conveniently available. The average particle size of all powders used was approximately 10 microns. In the case of tungsten, cathodes containing 27 percent of this metal (by weight) were found to be nonconducting while those containing 30 percent were conducting. This corresponds to a volume concentration of tungsten to thoria of 0.212. Because of the lower density of molybdenum only 18 percent was required to allow conduction. This corresponds to the same conduction volume concentration required with tungsten. The powders were mixed for 24 hours prior to use to assure even distribution.

Pressing Die. In the early stages of research on sintered thoria cathodes, pressing dies of the type shown in Fig. 1 were used for the fabrication of tubular cathodes. This type has two great disadvantages. First, the stress in the die bore when full pressure is applied, is extremely high; and second, considerable difficulty is encountered in ejecting the compact after being pressed. Lame's analysis of thick-walled cylinders gives the tangential stress at the bore as a function of internal pressure p, bore radius r_1, and outer radius r_2.

$$S_t = p \frac{r_2^2 + r_1^2}{r_2^2 - r_1^2}$$

Even if r_2 is made very large S_t cannot be less than p. Thus, when pressures of the order of 100 tons/inch^2 (as are required) are applied to the powder, this stress exceeds the ultimate strength of most available steels. The stress may be reduced somewhat by shrinking on the die an additional jacket so as to cancel partially the stresses caused by pressing, but such a procedure presents many constructional difficulties.

Two difficulties are encountered in ejecting the compact from this type of die. First, one must continuously "crack" the frictional bond between the compact and the die walls as the cathode is pressed out. In

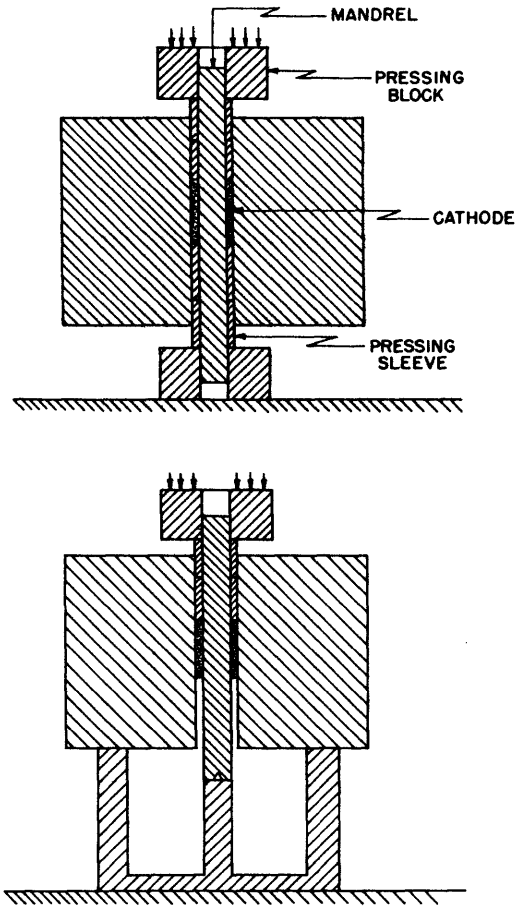

Fig. 1. (above) Pressing cathode.
(below) Ejecting cathode.

spite of the use of die wall lubrication, the motion is accompanied by chattering that may cause cracks in the compact. The second difficulty occurs when the compact is just coming out of the die. Here part of the cathode is restrained by the die while part of it is free to expand. The strains induced, in many cases, cause circumferential cracks to appear in the compact. Both ejecting difficulties may be alleviated somewhat by tapering the die bore and mandrel, but they would still exist in a large part, especially where the compact desired is almost 3 inches long.

Because of these disadvantages, work on a split-segment type die was initiated following receipt of information from Raytheon that they had successfully used such a structure. Figure 2 illustrates this type of die as set up for the pressing operation. The construction is such that after the compact has been formed the inner portion of the die containing the three segments, mandrel, pressing sleeves, and compact, may be removed. The segments may then be removed and the pressing sleeves and cathode slipped off the mandrel. The cathode expands enough when pressure and restraints are removed to allow it to be easily slid off the mandrel. In this manner no undue stresses are placed on the relatively fragile compact. The stresses in the split-segment die are also considerably less than in

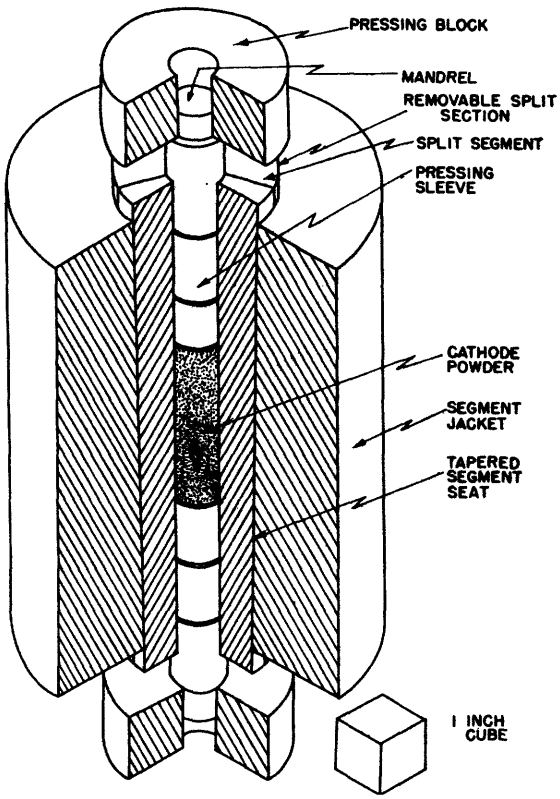

Fig. 2. Cathode pressing die.

the solid die since the radial pressure in the bore is distributed through the segments to the segment seat which has a larger area than the bore.

The die was made of hardened and tempered 18-4-1 high-speed steel (18 percent W, 4 percent Cr, 1 percent V) throughout. This steel has excellent abrasion-resisting properties and an ultimate strength exceeding 250,000 lb/inch^2. The main constructional difficulty encountered was in fashioning the three segments to fit together precisely when in the seat. A cylinder was first rough-machined to the approximate dimensions of the split-segment section, and then placed on an index head and sawed in three 120°-segments. Because of the width of the saw cut, the bore and outer diameter then had to be re-machined. The segments were next hardened and tempered by the method recommended by the steel manufacturer, i.e., by heating to 2350°F, oil quenching, then drawing to 1050°F for 2 1/2 hours and air cooling. The tempering was repeated (air cooling again). For accurate grinding, the bearing faces of adjacent segments were mounted on a semi-triangular brass rod as shown in Fig. 3. The adjacent bearing faces were then "wiped" with opposite sides of an under-cut grinding wheel. A perfect fit of the segments was thus assured when they were assembled in the die with adjacently-ground faces bearing upon one another. The faces were then numbered to insure proper assembly. After this operation the tapered outer diameter was ground to fit the segment seat in the die jacket.

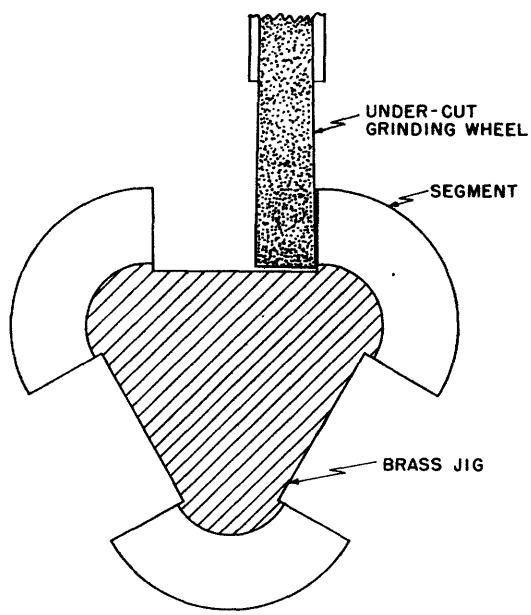

Fig. 3. Grinding segment faces.

The bore was ground and diamond-lapped with the segments firmly seated in the die jacket, and the center mandrel was diamond-lapped. The remainder of the die was machined by conventional methods.

The finished dimensions of the die were: outer die diameter 6 inches, jacket length 8 inches, segment seat taper 1° 40' (included), segment section length 8.25 inches, segment section diameter 2.662 to 2.424 inches, bore diameter 0.910 inch, and mandrel diameter 0.783 inch.

Pressing Technique. One of the most important techniques of the pressing operation is that of lubrication. Lubrication was applied in the form of a thin wax coat on all surfaces against which the powder bears during pressing. Without lubrication the powders were found to bind against the die walls, producing a compact with a powdery middle portion; and the abrasion was sufficient on the die walls to produce scoring. It was necessary to wax the segment seat to facilitate removal of the segments after pressing. A mixture of 40 grams of Carbo-wax in 130 cc of ethyl alcohol was found to work well. The mixture was warmed to dissolve all the wax in the alcohol. It is best to apply the wax hot because it will deposit a harder, denser coat on the surfaces. A saturated solution of Glyco-wax in carbon-tetrachloride was found to be satisfactory, but it has the disadvantage of reacting with the cathode when sintered in the hydrogen furnace, thus requiring thorough cleaning before being fired. The Carbo-wax apparently vaporizes off the cathode with no chemical effects.

The segment seat was lubricated by rubbing a cloth saturated with the hot wax solution over the outside of each segment. If the cloth is rubbed rapidly over these surfaces a thin, hard coat may be obtained. If this coat is too thick, the segments slip from their seat during pressing. The segments were then placed in the die jacket and firmly seated by applying about 5 tons' force to the top of the split section.

The mandrel was waxed by immersion in a test tube full of the hot lubricating mixture; the inner die bore was lubricated by stopping up one end of the bore, filling the whole bore with lubricant and then draining. It was found best to apply two thin coats of wax to the bore and mandrel. To make each coat thin, the wax mixture was applied for only 30 to 40 seconds for each coat, and allowed to dry thoroughly between coats. Small blowers expedited the drying. In drying, the alcohol evaporates leaving the hard wax on the coated surface.

After the die is lubricated the parts may be assembled for loading as shown in Fig. 4. The die length was made sufficient to receive all the loose powder required for a compact 3 inches long (about 70 grams) with a 1.5-inch pressing sleeve inserted in the lower end. The loose powder then occupies a space about 6.5 inches long, so that the powder is compressed by

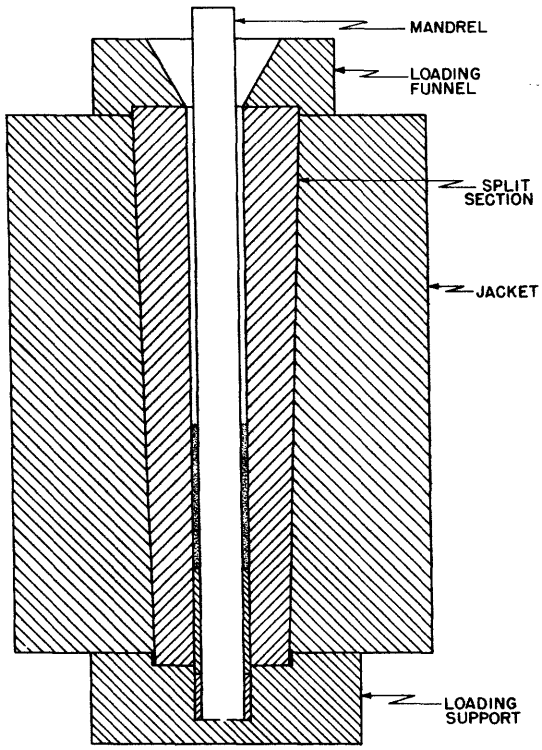

Fig. 4. Loading die.

a factor of about 2 when pressure is applied. To assure even distribution of the powder, the die is tapped with a brass mallet as the powder is poured into the loading funnel. The top pressing sleeves and pressing block are then slid on and pressure applied to the top of the powder only, with the bottom of the die still resting on the loading support. There are two reasons for first pressing on the top of the powder only. First, if the die were supported by a pressing block and sleeve before the powder is compressed, the weight of the die (about 80 pounds) would be sufficient to cause the die to slide down the mandrel until it rests on the pressing blocks, forcing powder out of the top of the die, and leaving a protruding length of mandrel which would be insufficient to hold a pressing sleeve and block safely. Second, it is desirable that one of the two sleeves in contact with the powder move as short a distance as possible, because when the pressing sleeves move, powder collects and becomes jammed between the pressing sleeve and mandrel. This makes the removal of the pressing sleeves very difficult when the die is taken apart after pressing. It was thought that this difficulty could be alleviated by making the pressing sleeves fit very closely over the mandrel. In spite of these efforts, there was always sufficient space between the two to allow a few grains of powder to collect and become jammed. In fact, the jamming was found to be worse with close-fitting sleeves than with those having a clearance of about 0.010 inch.

A pressure of about 70 tons/inch^2 is needed to seat the powder firmly against the lower pressing sleeve for a 3-inch compact. (For shorter lengths, the pressure needed was proportionately less. A 1.5-inch compact requires only 35 tons/inch^2.) After this preliminary pressing the loading support may be removed, a pressing block placed on the bottom, and full pressure applied to both the top and bottom of the compact as shown in Fig. 2. In applying full pressure, the lower pressing sleeve was found to move only about 1/4 inch. The amount of pressure required to form a uniform cathode varied between 80 and 115 tons/inch^2, depending on the length

of the compact. Part of the vertical pressure applied must be expended in overcoming the frictional bond between the compact and the die wall and mandrel. The magnitude of the force needed to counteract friction is proportional to the surface area of the compact in frictional contact. It is thus a function of the length and the inner and outer diameters of the compact. The 3-inch compacts had a total area of about 95 cm^2 in frictional contact and required a pressure of 115 tons/$inch^2$ to form a uniform cathode. If less pressure is used, the compacts develop an hour-glass shape on sintering. This happens because the center portion of the compact, prior to firing, has less density than the ends and thus is free to contract more on sintering. The 1.5-inch compacts required only 80 tons/$inch^2$ pressure. The difference of applied force in these two cases is about 5 tons and represents the additional frictional resistance presented by the longer compact.

The next step in the compacting procedure was to press out the split-segment section of the die; about 6 tons force was usually required. The segments, however, were not found to be free of the compact at this point. The wax film effectively cemented the compact to the segments and any attempt at their removal resulted in cracking the compact at the segment junctions. To relieve this bond the whole die, after the segments had been cracked free from the die jacket but not entirely removed, was set in an oven which operated at about 200°F for 1 hour. This oven treatment serves two purposes. It melts the wax bond between the compact and segments; and it melts any wax that may have jammed, with the cathode powder, between the pressing sleeves and mandrel, allowing the compact to expand along the mandrel, and relieving any strains in the compact. The segments were then slid completely out of the jacket and removed from the mandrel containing the compact and pressing sleeves. The sleeves and cathode were removed, and the pressing procedure was completed.

Sintering. The last step in preparing a cathode is the sintering operation. Firing in a hydrogen furnace at 1750°C for 30 minutes was found to be sufficient to sinter the compact to a strong, dense cathode. To avoid thermal shock the furnace was gradually brought to temperature, and then gradually decreased to room temperature after the sintering time. The compact shrinks considerably when sintered; there was a net decrease of 5 percent between the diameter of the die bore and the diameter of the sintered cathode. The effectiveness of the sintering may be judged from the fact that density measurements indicated about 1 percent porosity in the sintered cathode.

In general, the pressing die and technique outlined here proved quite satisfactory. Once familiarity was established with the proper technique,

several cathodes were made in succession without a failure. It is estimated that the percentage of failures to be expected on a semi-production basis, is about 10 percent.

III. Operating Characteristics of Thoria Cathode

The power requirements, resistance, and thermionic properties of two cathode mixtures were investigated as functions of temperature. Temperature measurements were made by means of a Leeds and Northrop optical pyrometer. This instrument measures brightness temperature in centigrade degrees by matching the brilliancy of a calibrated filament with that of the surface being measured. The calibration is made for black-body emissivity, and since the emissivity of the cathode surface is less than 1 (meaning less emitted light power at a given temperature) a correction factor would have to be added to the observed brightness temperature (B) to obtain the true centigrade temperature. Since the emissivity of the sintered-cathode surface is not yet accurately known, and since the nature of the surface changes depend on the cathode activity, all readings are given as brightness temperatures. Probable correction factors would be of the order of plus 60° at 1800°B.

Cathodes containing 30 percent tungsten-70 percent thoria, and 18 percent molybdenum-82 percent thoria were tested. To simplify the experimental procedure, small rectangular cathodes (about 1/8 inch x 1/16 inch x 5/8 inch) were used in determining the basic operating characteristics. To obtain further correlation a large cylindrical tungsten-thoria cathode 0.860 inch in diameter, 1.125 inches long, with a 0.060-inch wall was mounted and operated in a test diode. This investigation also served to establish a mounting scheme applicable to the high-powered magnetron. The rectangular cathodes were obtained by cutting small sectors from a cylindrical cathode, and grinding them to rectangular cross sections. The cutting and grinding were readily accomplished with a carborundum saw wheel.

Diode Construction and Processing. Figure 5 illustrates the general construction of the diodes used for testing the small rectangular cathodes. The cathode was platinum-brazed to sheet molybdenum contact strips which in turn were spot-welded to the two tungsten cathode leads. Platinum foil was required as a flux in making the molybdenum-to-tungsten spot-weld. The tube containing the tungsten-thoria cathode had a tantalum anode while the molybdenum-thoria cathode was tested with a molybdenum anode. This choice of anodes was made for the investigation of certain anode effects which will be discussed later. Both anodes were 1 inch long, 0.375 inch in diameter and 0.005 inch thick.

For testing the full-sized cathode, a water-cooled copper diode was

constructed as shown in Fig. 6. It simulates the mounting and physical operating condition which would be encountered in the high-powered

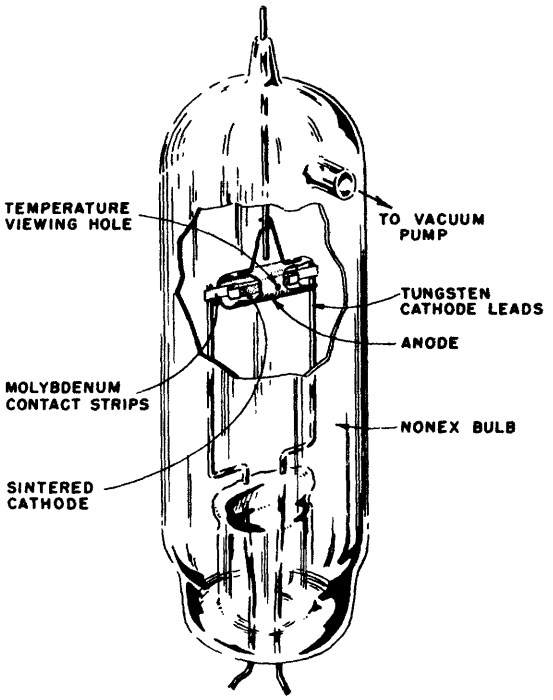

Fig. 5. Test diode for rectangular cathodes.

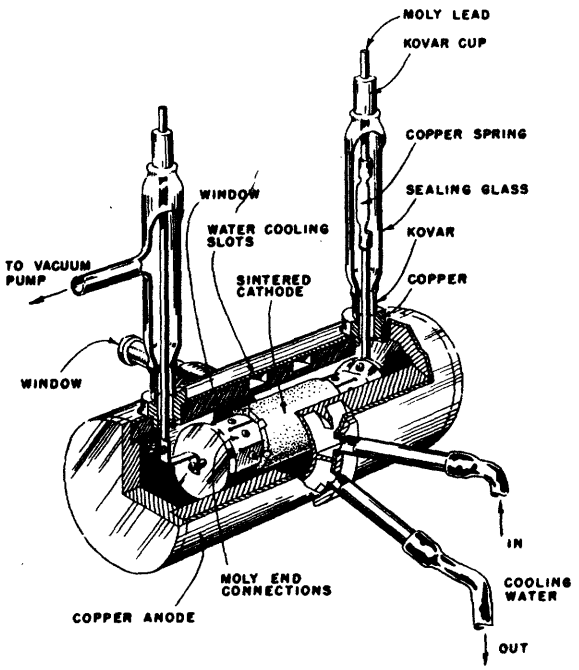

Fig. 6. Thoria cathode test diode.

magnetron. The cathode contact strips were fashioned from 0.005-inch sheet molybdenum. The holes and slots minimize heat conduction losses while maintaining adequate electrical conductivity. It was found necessary to provide several "fingers" on the contact strips to prevent them from pulling away from the cathode during the platinum-brazing operation. The cathode end caps were 1.125 inches in diameter as in the high-powered magnetron. Threaded holes (5-40) were tapped in each end cap for joining to the cathode-current lead-ins. The cathode contact assembly was joined to the cathode by platinum-brazing in a hydrogen furnace.

The cathode leads were made of 0.25-inch molybdenum rod. One lead was provided with a 0.030-inch sheet-copper spring to allow for cathode expansion. The spring and Kovar cup were brazed to the molybdenum lead with gold-nickel solder. The molybdenum was first nickel plated where the soldered joints were made so that the solder would flow better. The lead and lead-base were then joined with sealing glass. One of the lead assemblies was provided with tubulation for pumping.

The anode was made of OFHC copper, having a 1.4-inch ID and a 0.375-inch wall. Two water cooling slots, 1/2 inch x 3/16 inch deep were cut around the anode.

The small diodes were exhausted and baked at a temperature of 500°C until the gas pressure was about 4×10^{-7} mm of mercury. On cooling, the anodes were heated to about 1500°C by r-f induction until no further gas was evolved. It was found that, on first heating the cathode, considerable gas was given off. A large part of this gas was probably H_2 that had been absorbed during the sintering process. Most of it was evolved at temperatures below 1500°C. Before the tubes were sealed off the gas pressure, with the cathodes operating at 1950°C and full anode dissipation applied, was less than 1×10^{-7} mm of mercury.

The copper diode was processed similarly except that the baking temperature was 450°C because of the lower softening point of Kovar sealing glass. Electron bombardment alone was relied on to clean the anode. It may be noted here that the normal time required for activating an oxide cathode equal in size to this test diode is about 50 hours, while only one hour was required for outgassing the thoria cathode. No process other than this was required to prepare the cathode for operation.

Heating Power and Resistance Characteristics. The heating power requirements, as a function of temperature, are plotted in Fig. 7 for the three cathodes tested. As would be expected, they follow an approximate fourth-power relationship with the temperature in degrees Kelvin. The difference in the power required for the two rectangular cathodes is probably caused by slight differences in the emissivities. The decrease in the power needed for the large cylindrical cathode represents the decrease in conduction loss gained through use of hold-and-slot arrangement in the cathode contacts; and since the cathode was longer, the conduction losses represent a smaller proportion of the total cathode power, and thus the power required per square centimeter appears less.

It was found that on first heating the cathode, the resistivity followed an approximately linear relation with temperature up to a temperature of about 1400°C (brightness), whereupon the resistivity, at nearly constant temperature, decreased considerably with time. After a few minutes the rate of decrease of resistivity with time decreased markedly and attained an essentially constant value at this same temperature. The resistivity at all lower temperatures were likewise decreased a proportional amount. On a further slight increase of temperature the resistivity showed a normal rise when again the resistivity decreased. This continued to occur until the highest operating temperature was attained. At all temperatures below this value the resistivity curve remained constant over a considerable length of time.

Figure 8 indicates these irreversible resistivity changes observed in a 30 percent W-70 percent ThO_2 cathode, and the final resistivity of an

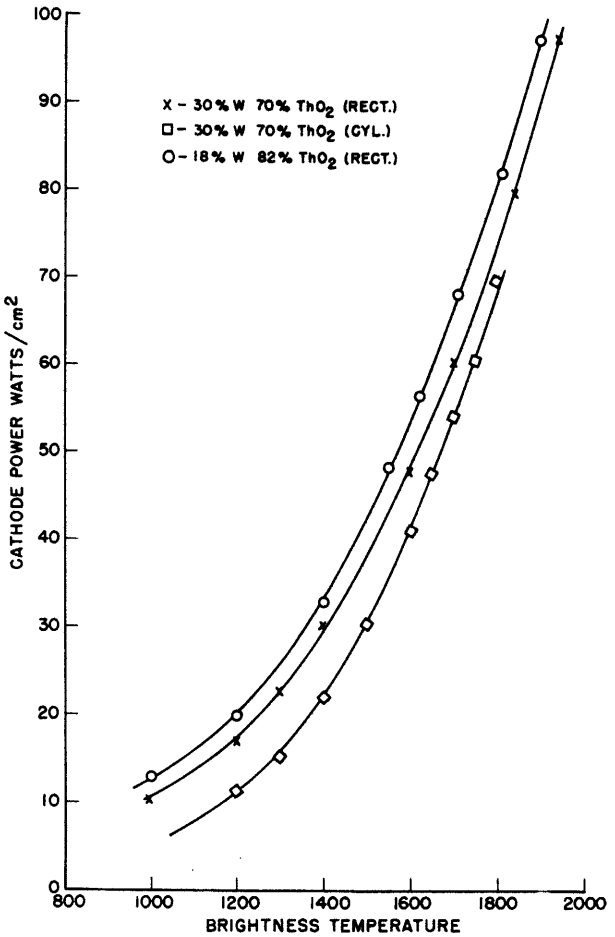

Fig. 7. Cathode power required.

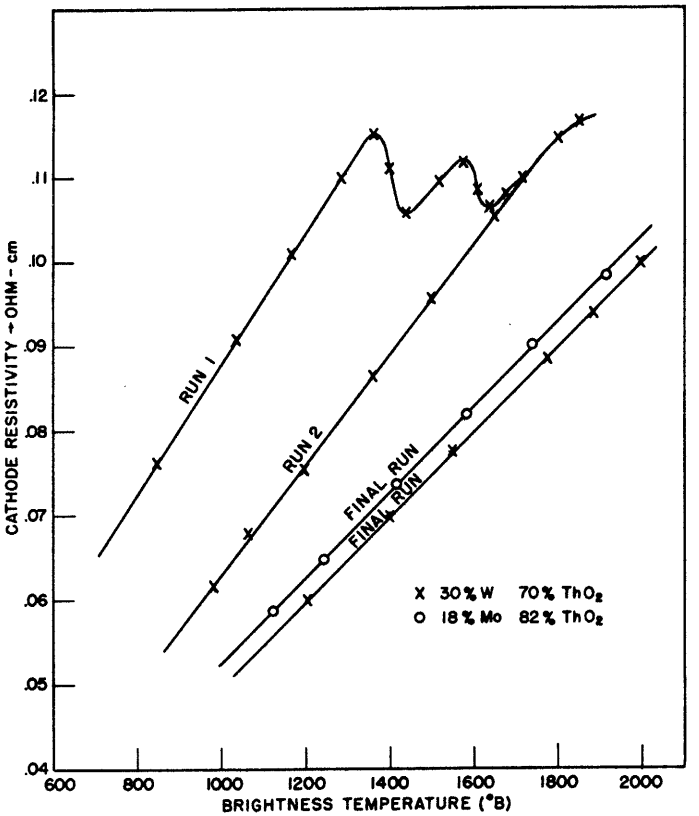

Fig. 8. Resistivity of sintered thoria cathodes.

18 percent Mo-82 percent ThO_2 cathode. The final values of resistivity were measured after the cathode had been operated for several hours at 1950°C (brightness) and no further change of resistivity was observed. Both cathode mixtures had a volume concentration of conducting powder to thoria of 0.212, and since the resistivity of molybdenum is approximately the same as that of tungsten both sintered cathodes had about the same resistivity.

It is believed that the resistivity decreases are caused by intense and extremely local heating in parts of the cathode that have been imperfectly compacted or sintered. Such heating would tend to establish more conducting paths and thus a decrease of resistivity. This conclusion has been borne out by the fact that several small cathodes, pressed with a solid die and containing minute cracks scarcely visible under a microscope, exhibited a very much larger change in resistivity, decreasing from several hundred ohm-cm to a fraction of an ohm-cm. The resistivity observed by Henry (1) on a cathode pressed in this manner showed similarly a much greater change than has been observed here and a higher final resistivity for the same cathode mixture. Cathodes pressed with a solid die are subject to much more abuse during pressing, and the likelihood of such stray cracks is increased.

Thermionic Properties. The final phase of this research is concerned with the thermionic properties of sintered thoria cathodes. The basic circuits used for making emission measurements are shown in Fig. 9. D-c measurements were made in the conventional manner. Because of anode dissipation considerations, these measurements could only be made at comparatively low temperatures where the temperature-limited emissions are not great. At 1600°C (brightness), however, the pulse measurements coincided exactly with the d-c emission, indicating that, with an anode capable of dissipating the high d-c power, the pulse measurements may be extended to apply in the case of d-c.

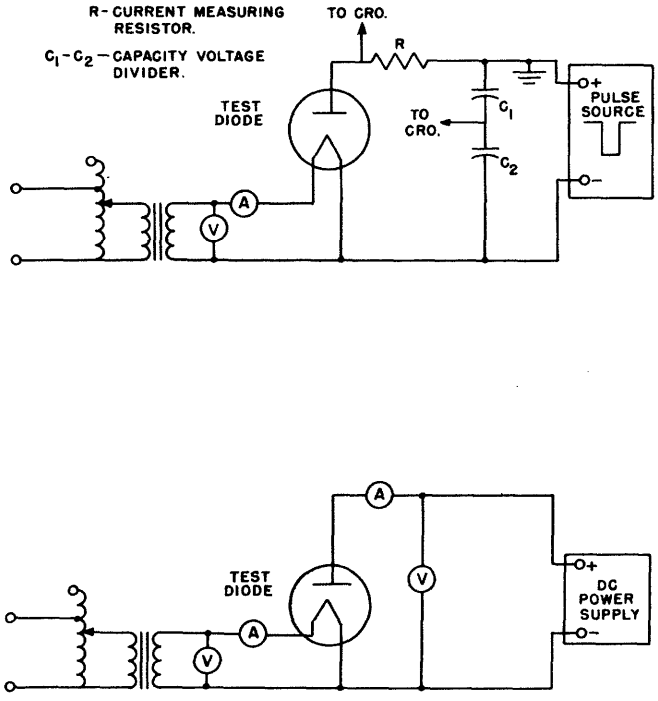

Fig. 9. (above) Circuit for pulse measurements. (below) Circuit for d-c measurements.

A magnetron modulator was used as a pulse power supply in making the pulse tests. Anode voltage was measured by means of a capacity voltage divider; the current, with a small resistor placed in the anode ground return. The voltages from these sources were observed on a calibrating synchroscope, thus allowing the anode voltage and current to be determined. The synchroscope also supplied the trigger for the modulator. The Child's law plots, made on 2/3 power paper, are shown in Figs. 10 and 11. The results in Fig. 10 were obtained with the rectangular cathodes. Because of this cathode geometry the space-charge-limited emission does not follow a straight line with voltage. However, if two straight lines are plotted, one corresponding to the emission from a cylindrical cathode of diameter equal to the longest cross-sectional dimension of the rectangular cathode, and the other corresponding to the shortest dimension, the space-charge-limited emission boundaries will be obtained; and where the plotted emission curve crosses the lower boundary, the maximum space-charge-limited emission is obtained. These lines are indicated in Fig. 10.

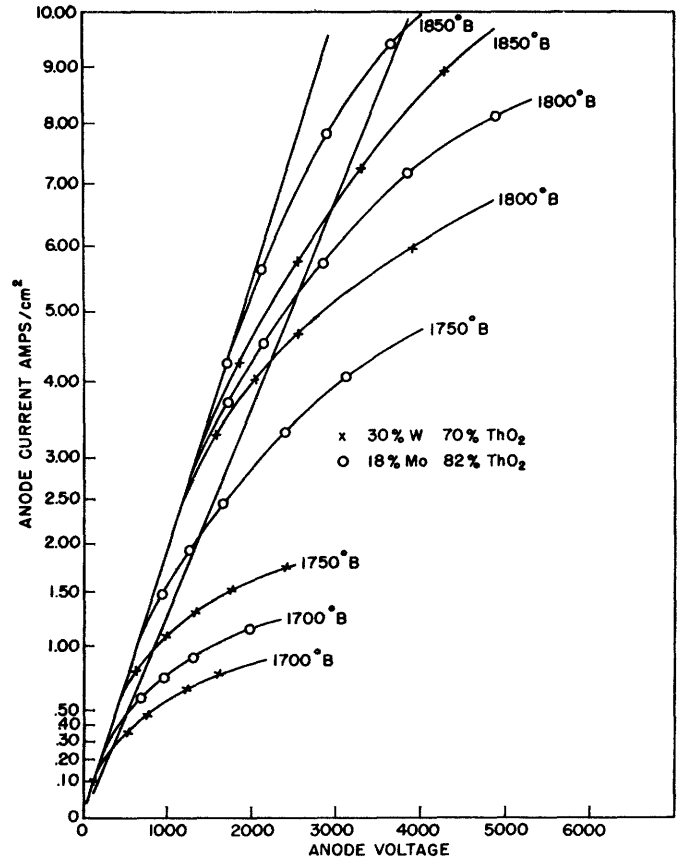

Fig. 10. Pulsed emission from rectangular sintered thoria cathodes.

The data presented in Fig. 11 were obtained from the large cylindrical W-ThO_2 cathode and thus follows a straight line until the cathode becomes

temperature-limited.

All of the above measurements were taken after sufficient time had elapsed at each temperature for the cathode to reach an equilibrium condition. The anode voltage was left on only long enough to take each reading, so that no anode effects would enter.

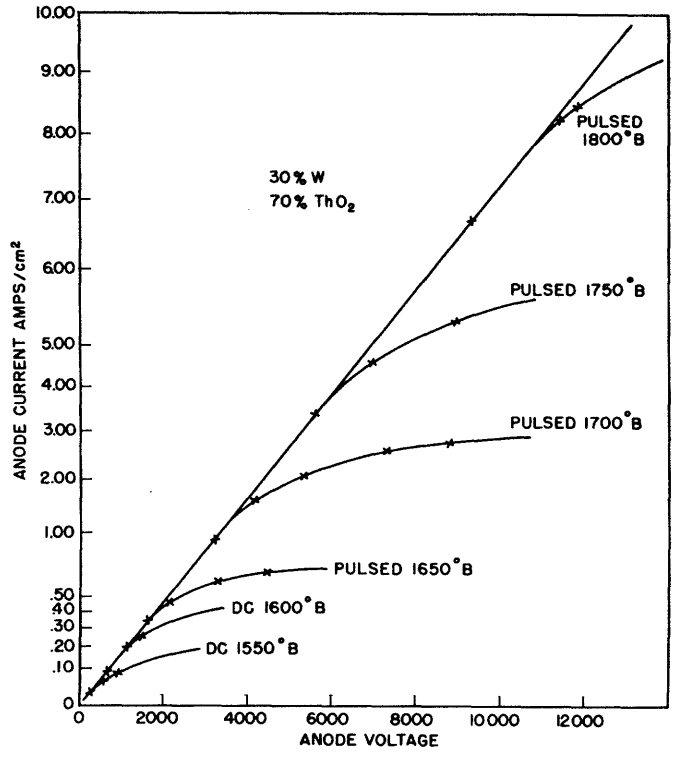

Fig. 11. Emission from a cylindrical sintered thoria cathode.

Two particular phenomena were observed in the thermionic properties of the sintered thoria cathodes. First, the thermionic activity of the cathode at a given temperature, was found to depend on the temperature history of the cathode; that is, until sufficient time had elapsed for equilibrium to set in at the new temperature. Secondly, there appeared a marked decay in emission when pulsed current was drawn continuously to the anode. This was observed only in the W-ThO_2 cathode using a tantalum anode.

The first effect is most apparent when the cathode temperature is suddenly decreased after being allowed to dwell long enough at the higher temperature for equilibrium to occur. The emission was observed to start out at some high value, which depended on the higher temperature, and then to decrease slowly with time, approaching the normal equilibrium emission for the lower temperature. Typical plots of this phenomena are shown in Fig. 12. Fan (3) explains this on the basis of formation, diffusion and evaporation of free thorium. At the higher temperature, at equilibrium

emission, an equilibrium of these three factors is observed; but when the temperature is suddenly decreased, the rate of evaporation decreases markedly, and since there is still within the cathode a considerable "stock-

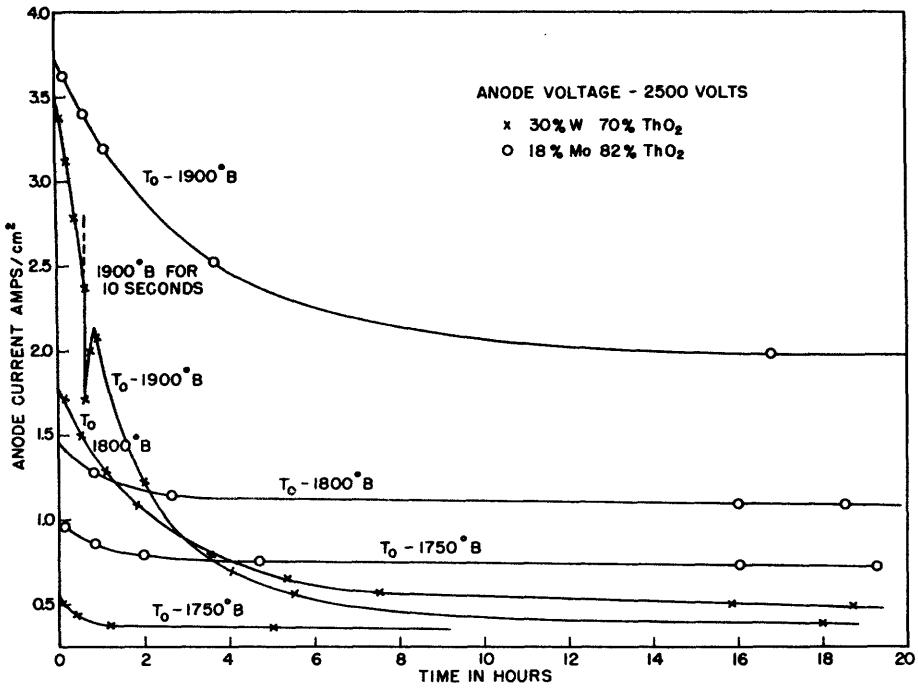

Fig. 12. Decay of cathode activity when temperature decreased from T_o to 1600°B. Anode voltage, 2500 volts.

pile" of free thorium formed at the higher temperature, there may appear on the cathode surface a greater amount of thorium than would normally appear at the lower temperature. When the temperature is momentarily increased during the decay period, as shown in the decay from 1900°C (brightness), and then returned to the lower temperature; the emission shows a marked decrease from the normal decay curve, and then slowly rises to continue the normal decay course. This occurs because at the higher temperature most of the thorium on the surface is evaporated. When the temperature is decreased again it takes a short time for more thorium to diffuse to the surface, and thus for the emission to build up.

It is interesting to note that the time constant of activity decay for the molybdenum-thoria cathode is much greater than that of the tungsten-thoria cathode. Since the deposits of cathode material on the anode of the tube containing the molybdenum-thoria cathode appeared to be much less, this is probably caused by a slower rate of evaporation of thorium from the "patched" molybdenum surface.

It was noticed that during the decay time the amount of power required to maintain the cathode at a constant brightness temperature decreases by

several watts as the cathode becomes deactivated. This gives further evidence of a change in cathode state as indicated by a change in spectral emissivity.

When the temperature was increased after the emission had reached an equilibrium value at a lower temperature, a time lag was again observed in the rise of emission. Here it takes time for the increased rate of formation and diffusion of thorium to catch up with the increased rate of evaporation. The time required to reach equilibrium in this case was only about 20 minutes for the tungsten-thoria cathode, and about 3 minutes for the molybdenum-thoria cathode.

The second phenomenon, the decay in emission observed when anode current is continuously drawn, is believed to be entirely an anode effect. It was observed only with the tungsten-thoria cathode when a tantalum anode was used. No trace of the effect was found with the molybdenum-thoria cathode using a molybdenum anode nor with the tungsten-thoria cathode mounted in the water-cooled copper anode. Plots of the observed decay are shown in Fig. 13. It is believed that this decay is caused by back bombardment of the cathode by material driven from the anode by electron

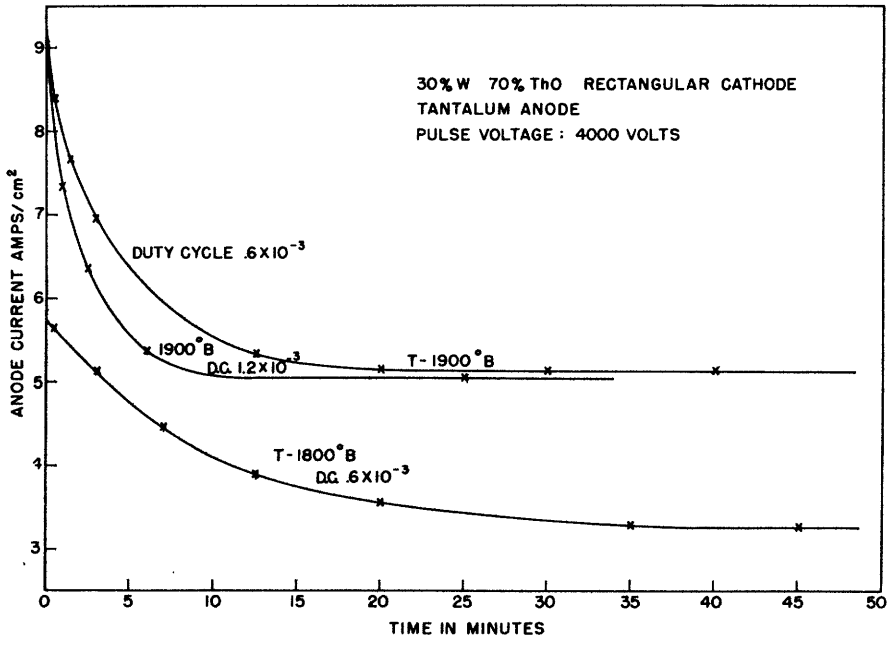

Fig. 13. Decay of emission under pulsed conditions. Tantalum anode. Pulse voltage, 4000 volts.

bombardment, since tantalum has a high affinity for absorbing and chemically reacting with residual gases. It is not a direct effect of gas pressure however, since the effect was observed while the tube was on the vacuum pump where the pressure was only 2 x 10^{-7} mm of mercury and when the

pressure was intentionally increased to 2 x 10^{-6} mm no change in the decay was observed.

IV. Conclusions

In general it appears that sintered thoria cathodes would serve ideally for magnetron operation. The molybdenum-thoria mixture is superior, giving slightly higher emissions, and having a much slower rate of activation decay. Emission densities of over 1 amp/cm^2 may be obtained at 1550°C (brightness) for over 100 hours after the cathode is flashed at 2000°C (brightness). To further increase the activation time the author suggests the addition of carbon (in the form of powdered graphite) to the cathode mixture, as in the preparation of thoriated tungsten filaments.

No sparking tendencies were observed at any point. The small tubes were successfully operated at anode potentials up to 33,000 volts and pulsed emission densities of 10 amps/cm^2 with no arcing. This anode voltage corresponds to a potential gradient, at the cathode, of over 150,000 volts/cm.

Furthermore, no particular care is required in handling the cathodes. The tubes were opened to air several times during the operating tests, and when evacuated and sealed again, showed no change in operating characteristics.

Acknowledgments

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