Studies on Grid Emission*

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Summary—This paper is concerned only with the study of primary grid emission of various types of grid materials resulting from the evaporation products of *L*, impregnated, oxide-coated, and thoriated tungsten cathodes. The factors contributing to grid emission are analyzed. A detailed discussion of the performance of titanium, which exhibits excellent grid emission inhibiting properties, is included.

In our investigation a planar triode construction was used, the grids of which consisted of a two-terminal loop of 0.010 inch diameter wire. In the assembly and processing utmost precautions were taken to insure minimum contamination of the various elements. The methods of assembly and processing are fully described in the paper.

These tubes were tested using pulsed and dc techniques, and a discussion of the testing methods is included.

The work function of a tungsten grid exposed to the evaporation products of the L, impregnated, and oxide-coated cathodes varies from 1.2 to 2.0 ev, the final value depending upon the past history of the cathodes, namely, the nature of the surface of the grid and the temperature and length of exposure to the cathodes.

INTRODUCTION

THE SUBJECT of grid emission studies has been undertaken by many investigators since 1921. A large number of articles have been written and numerous patents have been granted in this field. Most of these patents cover the use of specific metals and alloys, oxides or carbides of specific metals and alloys, and roughened dark surfaces to increase the radiation area of the grid.

In this paper we will discuss only the primary grid emission of various types of grids resulting from the evaporation products of *L*, impregnated, oxide-coated, and thoriated tungsten cathodes. Primary grid emission is essentially thermionic emission. The factors affecting grid emission include: the rate of supply of emitting material (Ba, BaO) from the cathode, the binding energy of the grid surface material for barium and barium oxide, the presence of gases (particularly oxygen), poisoning, and the temperature of the grid. Primary grid emission can be reduced through the choice of materials which give a resultant high work function surface when exposed to the evaporation products of the cathode. It is also controlled by designing a grid which operates at a sufficiently low temperature where primary grid emission is negligible, or at a temperature high enough to vaporize the evaporation products from the cathode but low enough for negligible emission from the grid metal to be a factor. It is also known in the art that, if a grid is exposed to a hot cathode, the grid emission varies with time in such a

manner that it increases to a maximum value and then declines to an equilibrium value.

TUBE DESIGN AND PROCESSING

In our investigation the tube consists of a planar triode construction, as indicated in the isometric drawing in Fig. 1. The anode is a closed end molybdenum cylinder.
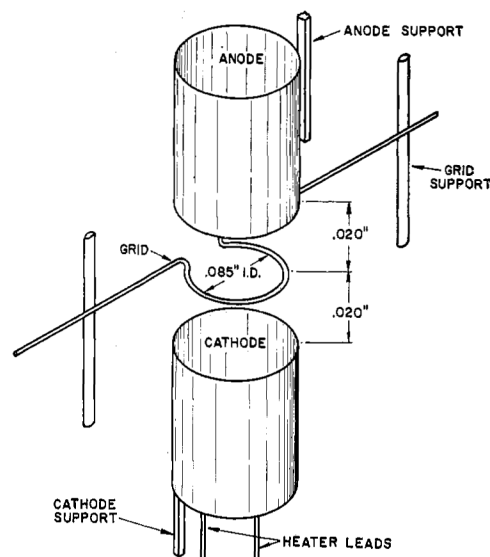

Fig. 1—Grid emission test structure.

The cathode has the same dimensions and is heated by an internal heater. The grids consist of a two-terminal loop of 0.010 inch diameter material assembled by means of a jig midway between the anode and the cathode which are 0.040-inch apart. An additional diode, consisting of a tungsten filament and a molybdenum plate, is included in the structure. This diode is used to determine the quality of the vacuum in the tubes by measuring the thermionic work function of the tungsten filament. Zirconium and batalum getters also are incorporated into the structure. Nonex glass stems and bulbs are used on all tubes. Two types of triode structures are used in measuring grid emission, the one being a single-ended structure where the grid emission is greater than 0.20 ma peak, and the other a double-ended structure with the grid and anode terminals brought out at the end opposite the cathode terminal for the cases where grid emission is less than 0.20 ma peak. This latter design increases the leakage path between the grid and cathode and prevents leakage current from contributing to the grid emission current.

In the assembly of the triodes utmost precautions are taken to insure maximum cleanliness of all parts, since even minute contaminations contribute greatly to an erratic behavior in the primary grid emission characteristic. All stem leads are cleaned electrolytically in hot 4 per cent solution of sodium hydroxide, rinsed in clear water, followed by a dip in distilled water. All molybdenum and tungsten parts are degreased prior to hydrogen firing and assembling. Only tungsten, molybdenum and tantalum are used for the tube structure. Grids may consist of other materials to be tested. Precautions are taken to avoid copper deposits from the electrode welding materials by employing welding tips consisting of tungsten. Tantalum strips are used as a flux when required. Stem leads consist entirely of molybdenum.

A flow of dry nitrogen is applied at all times during the sealing-in of the glass envelope to the triode structure and care is taken to reduce excessive heating during the sealing process. All triodes are processed on a vacuum system having a three-stage mercury diffusion pump with a liquid nitrogen trap between the manifold and the mercury pump. All tubes are baked out at 720°K for one hour. Parts are degassed simultaneously with the vacuum pressure always less than 1.0×10^{-5} mm of Hg until the temperatures indicated below have been reached:

L and impregnated cathodes	— 1,500°K
Oxide cathodes	— 1,300°K for 30 secs,
then at	— 1,200°K
Zirconium getter	— 2,000°K
Tungsten grids and filaments	— 2,700°K
Molybdenum parts	— 1,900°K
Gold plated molybdenum	— 1,200°K.

The batalum getter is glowed below flashing temperature. The vacuum pressure before sealing off is less than 5.0×10^{-7} mm of Hg. After sealing the tube off, the elements are seasoned to the above indicated temperatures for 10 minutes prior to flashing the batalum getter.

After flashing the getter, the impregnated and L cathode tubes are then seasoned at a cathode temperature of 1,500°K for 100 hours, while oxide-coated tubes are seasoned for the same time period at 1,100°K. Before the tube is measured for primary grid emission, the auxiliary tungsten filament is heated to 2,700°K for 20 minutes and its work function measured. The tungsten control grid is also heated at 2,700°K for 20 minutes to remove all contamination products that have come from the cathode. Tests are made for cold and hot leakage. If these factors are present, they are eliminated by sparking with an rf source. Thermionic emission tests are also made on the cathode. The entire tube is allowed to stand overnight and the work function of the auxiliary filament is again taken to check any deterioration in the vacuum condition. If this work function is higher than 4.5 ev, the tube is rejected.

Methods of Measurement

The method of testing these tubes was selected after a study was made of the previous methods[1-3] used for measuring primary grid emission. In Fig. 2, we note four of these methods.
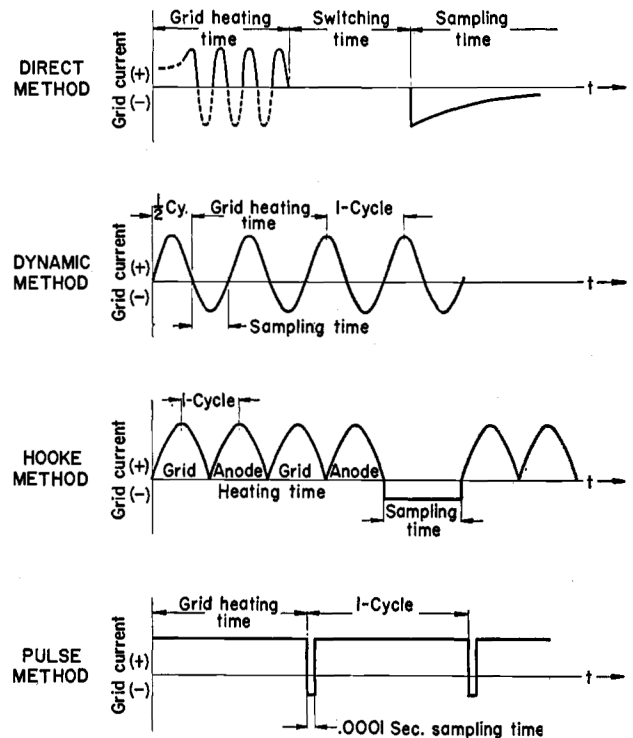
Fig. 2—Methods of measuring primary grid emission.

In the Direct Method, the tube is operated under its rated voltages for a sufficient time to insure normal temperature conditions. By means of a switch, the cathode voltage is made positive with respect to the grid, and the electron current from grid to cathode is recorded.

In the Dynamic Method, the grid of the tube under test is heated from a 60 cycle source on every alternate half cycle. On the reverse half cycle, a sensitive meter in series with a rectifier indicates the primary grid emission.

In the Hooke Method, the grid emission is measured after the grid and anode are heated to their normal operating temperatures by two sets of alternate pulses. This is a specific tube test for a given triode in which grid emission is measured by applying dc voltages during the sampling time indicated.

[1] "Standards on electron tubes; methods of testing, 1950," Proc. IRE, vol. 38, pp. 917–948; August, 1950, and pp. 1079–1093; September, 1950.
[2] I. E. Mouromtseff and H. N. Kozonewski, "Grid temperature as a limiting factor in vacuum tube operation," Proc. IRE, vol. 24, pp. 447–454; March, 1936.
[3] A. H. Hooke, "A method of measuring grid primary emission in thermionic valves," *Electronic Engineering*, vol. 18, pp. 75–80; March, 1946.

The difficulties with the above methods are that the Direct Method is not continuous, the Dynamic Method implies reading grid emission with a nonsinusoidal grid heating current, while the Hooke Method involves complicated switching with a nonsinusoidal grid and plate heating current.

For these reasons, we prefer to use the Pulse Method developed by R. A. La Plante of our Laboratories, in which the grid is heated continuously either by direct conduction or by electron bombardment, and the grid emission is measured every 1/60 second by applying a 100 microsecond pulse at a sufficiently high voltage so that saturation temperature limited currents are obtained.

In cases where the grid emission is less than 0.20 ma peak, it is necessary to abandon the Pulse Method, because of the sensitivity limitation of the oscilloscope, and use an alternate method as indicated in Fig. 3.
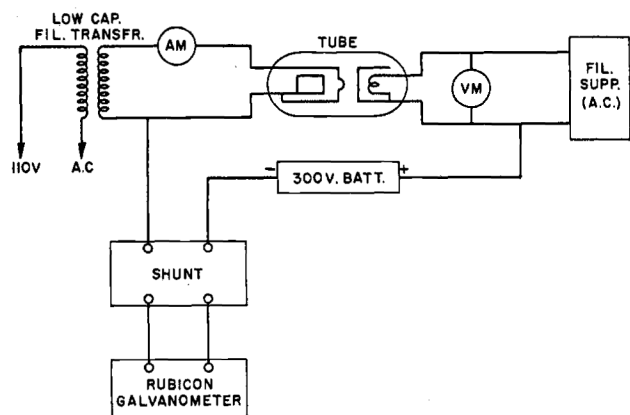

Fig. 3—DC method of measuring grid emission.

Measurements on Grid Emission

In our measurements, definite temperatures were established at which all grid emission measurements were made. All L and impregnated cathodes were operated at

while other studies were made on the variation of the grid emission with respect to grid temperature at the end of a given time. As for grid materials, a large number of tests were made using tungsten grids which were operated from ambient temperatures to 2,300°K, most tests being conducted with grids operating at 1,200°K. Other grid materials investigated include molybdenum, gold plated molybdenum, zirconium and titanium. It has been determined by other experimenters[4] in our Laboratories that the only materials detected in the evaporation products were barium and barium oxide. Since barium evaporates appreciably fast from clean tungsten at 1,200°K, it was decided to run a series of tests at this temperature.

As mentioned previously, these triodes were seasoned for 100 hours in order to obtain stable cathode conditions. The L and impregnated cathodes were glowed at 1,500°K and the oxide-coated cathode at 1,100°K. No current was passed to the grid during this time, and hence, the only heat it received was by radiation from the cathode. In the course of this seasoning, the evaporation products of the cathode built up layers on the grid. The evaporation products were removed by glowing the grid at 2,700°K for 20 minutes while the cathode was not heated. This treatment caused some of the evaporation products to be redeposited on the surface of the cathode. The redeposited material is very likely evaporated and redeposited upon the grid sometime between the initial and maximum grid emission reading. We note that grids in tubes having impregnated cathodes have approximately the same initial grid emission but the final grid emission is lower than with both the oxide-coated and L cathodes. It is believed that the evaporation product present at the end of a test is largely barium oxide. Hence, there appears to be less barium oxide evaporated from impregnated cathodes then from L and oxide cathodes. For the case of a tungsten grid (Table I), the maximum grid

TABLE I

Grid Emission for Tungsten at 1200°K.

Cathodes Used	Cathode Temp. Degrees Kelvin	Initial Grid Emission (ma Peak)	Max. Grid Emission (ma Peak)	Final Grid Emission (ma Peak)	Time Required to Reach Max. Grid Emission (Hours)
Impregnated Type A	1 275°	2.0	17.0	2.6	1.0
Impregnated Type B	1275°	1.1	20.0	5.1	1.0
"L"	1275°	2.1	50.0	17.0	18.0
Oxide	1100°	3.7	54.0	8.0	25.0

REMARKS: 1) Grid voltage applied only during measurements.

1,275°K and all oxide-coated cathodes were operated at 1,100°K. Some studies were concerned with observing how the grid emission varied with respect to time while the grid temperature was maintained at a constant level,

emission was obtained within an hour for impregnated cathodes, in less than 20 hours for L cathodes, and after approximately 25 hours for the oxide-coated cathodes.

[4] E. S. Rittner and W. C. Rutledge, private communication.

TABLE II
Emission for Gold-Plated Molybdenum Grids at 1100°K

Cathodes Used	Cathode Temp. Degrees Kelvin	Initial Grid Emission (ma Peak)	Max. Grid Emission (ma Peak)	Final Grid Emission (ma Peak)	Time Required to Reach Max. Grid Emission (Hours)
Impregnated Type A	1275°	0.70	1.10	0.28	2
"L"	1275°	0.21	1.8	0.21	5
Oxide	1100°	0.6	2.8	0.21	25

Remarks: 1) Grid voltage applied only during measurements.

These times are all short compared to the lifetime of a vacuum tube and hence are of no significance in the lifetime operation of the tube, but give information as to the nature of the evaporation products.

In the case of gold plated molybdenum grids (Table II, above), the maximum grid emission was reached in 5 hours for L cathodes, in 2 hours for impregnated cathodes, and in 25 hours for oxide-coated cathodes. Unfortunately, the gold plated molybdenum grids could not be cleaned prior to any tests since the gold would evaporate if the temperature is raised above 1,100°K. The data shown in Table III give the stable equilibrium values of grid emission for the listed materials.

TABLE III
Emission of Different Grid Materials for L-Cathodes at 1275°K

Grid	Temp. Degrees Kelvin	Emission Currents (μA)
W	1200°	414.00
Mo	1200°	300.00
Zr Ca Mg COATED Mo	1200°	24.00
Mn–Ni	1200°	24.00
Au Plated Mo	1100°	4.48
Zr	1200°	2.24
TiO₂	1200°	0.10
Ti	1200°	0.0004

REMARKS: 1) Oxide coated and impregnated cathodes values are of the same order of magnitude.

Fig. 4 shows how the grid emission varies with respect to time for the various grid materials indicated. L cathodes were used in all these tests. As noted from Fig. 4, titanium has the lowest grid emission of all materials investigated. In order to read grid emission currents in the order of 0.001 microamperes, it was necessary to use the double-ended triode structure described previously.

Clean, bright titanium or titanium plated molybdenum wire used for grids in these studies indicated grid emission currents several orders of magnitude lower than for grids made of molybdenum wire sprayed with titanium powder. The higher value in the latter case is probably due to the presence of titanium oxide in the powder. No correction
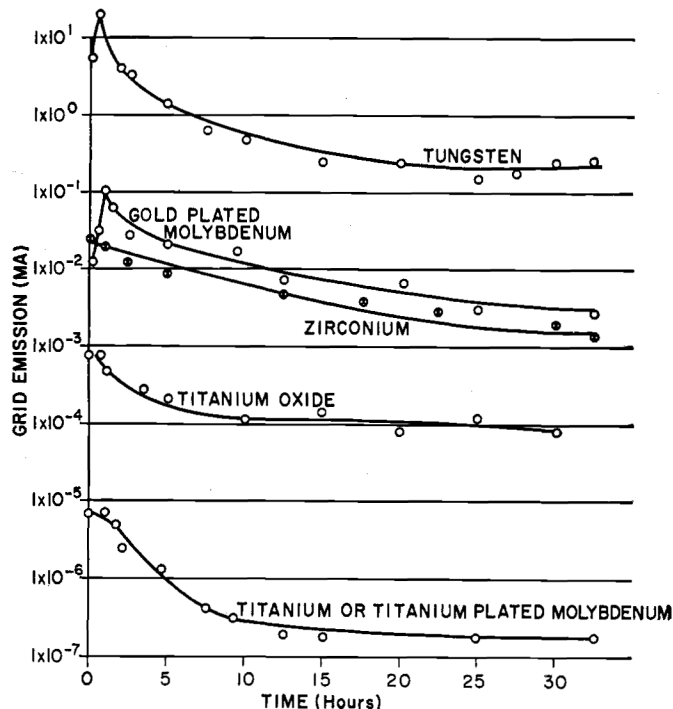

Fig. 4—Grid emission vs time for different grid materials. (L cathode run at 1,275°K; W, Zr, TiO and Ti grids at 1,200°K; Au plated Mo grid at 1,100°K).

was made for the increased surface area in the case of sprayed titanium powder. Comparative data from titanium oxide on titanium and bright titanium are shown in Fig. 5.

Fig. 6 shows plots of grid emission vs time for a titanium grid at various temperatures. Previous to these measurements the grid had been exposed overnight to a L cathode glowing at 1,500°K. During the measurements the cathode was maintained at 1,275°K. At the end of each run the titanium grid was cleaned by heating it at 1,175°K until the emission fell to the value for clean titanium. Therefore, only one run could be made in a day. It is noted that grid emission stability occurs after a few hours of operation in each case. During the measurements barium and barium oxide evaporated from the grid are being replaced by fresh materials from the cathode.
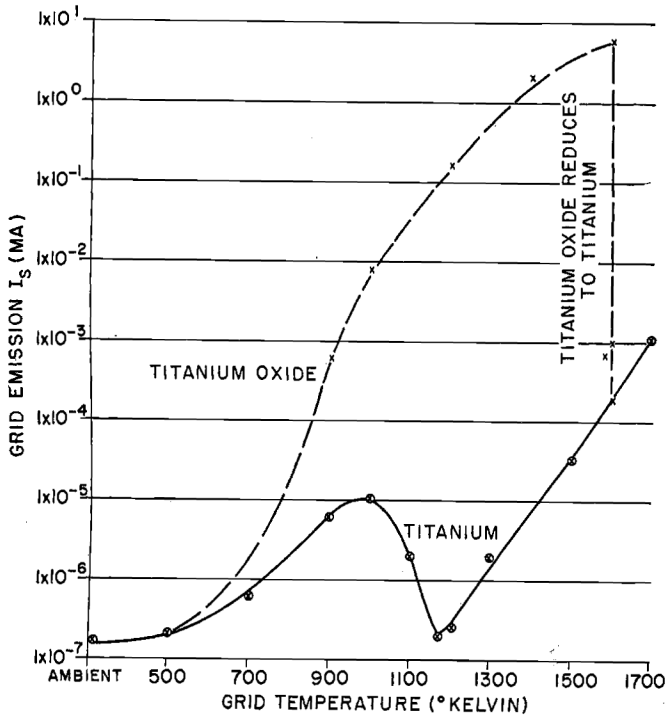
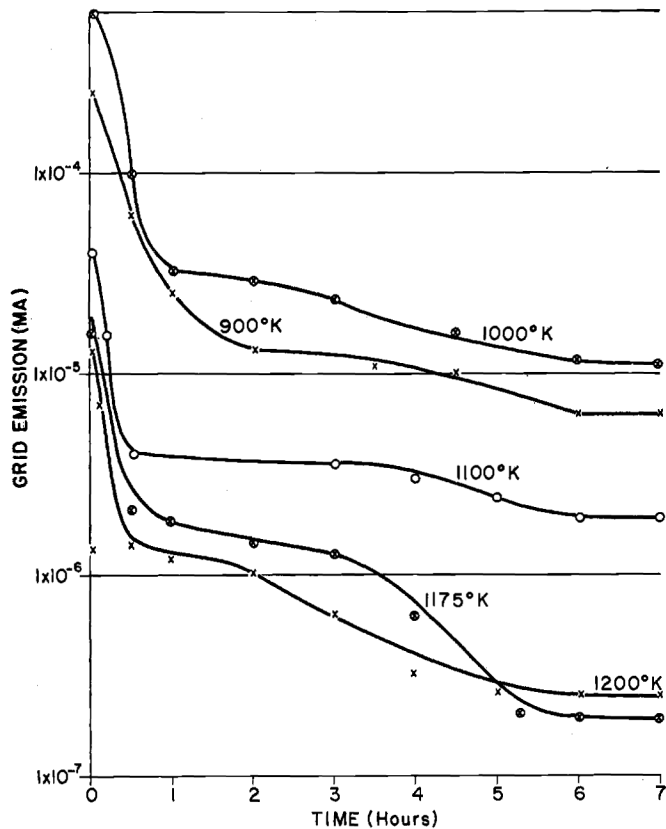Fig. 5—Grid emission of bright titanium vs oxidized titanium. (Covered with the cathode evaporant).

Fig. 6—Titanium grid emission vs time for various grid temperatures. (L cathode at 1,275°K during this test. Exposed to cathode for 16 hours prior to each run).

Fig. 7 indicates a plot of grid emission vs grid temperature after a titanium grid has been exposed to an L cathode glowing at 1,500°K for two hours. It may be noted that the stable values of the grid emission at the several temperatures indicated in Fig. 6 fall on the curve of Fig. 7. When the grid is heated, the grid current remains below 1.0×10^{-6} ma for temperatures ranging from ambient to about 600°K. Between 600°K and 1,175°K a noticeable change in the grid emission characteristic takes place with a maximum grid current of 1.0×10^{-5} ma occurring at approximately 1,000°K. At 1,175°K a minimum value of grid emission is again reached. Increasing the grid temperature beyond this point yields the thermionic emission typical of titanium. If the data are taken by beginning with the grid above 1,175°K and reducing the grid temperature to the ambient temperature, the grid current reading is much less than 1.0×10^{-6} ma throughout this entire range.
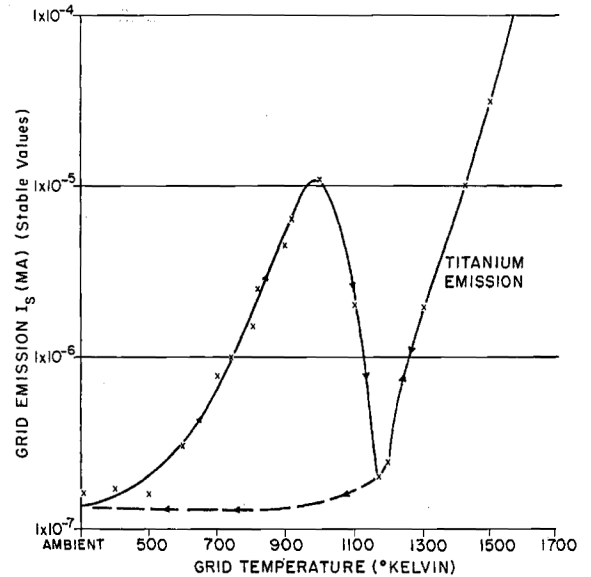
Fig. 7—Titanium grid emission vs grid temperature. (L cathode run at 1,500°K for two hours before reducing to 1,275°K for this test).

Subsequent exposure of the grid to the cathode for a definite time period and a rerun of the data will result in a curve having the same general shape as Fig. 6. The value of the maximum grid emission current will depend upon the temperature of the cathode and the length of time the unheated grid is exposed to the cathode.

The phenomenon of the rise and fall of grid emission between 600°K and 1,175°K is probably due to the following sequence of events. The grid is covered with barium and barium oxide from the cathode previous to these observations and the cathode is then cooled to 1,275°K. In heating the grid between 600°K and 1,000°K, the grid is activated by barium oxide and some remaining barium though a considerable amount of evaporation of barium is taking place.

Above 1,000°K the evaporation products of the cathode are evaporated rapidly from the grid and the grid emission current falls to the value typical of clean titanium. Some X-ray diffraction analyses were made to determine the presence of barium titanate in the case where a titanium grid was exposed to a cathode which evaporates barium or barium oxide. No titanates were found.
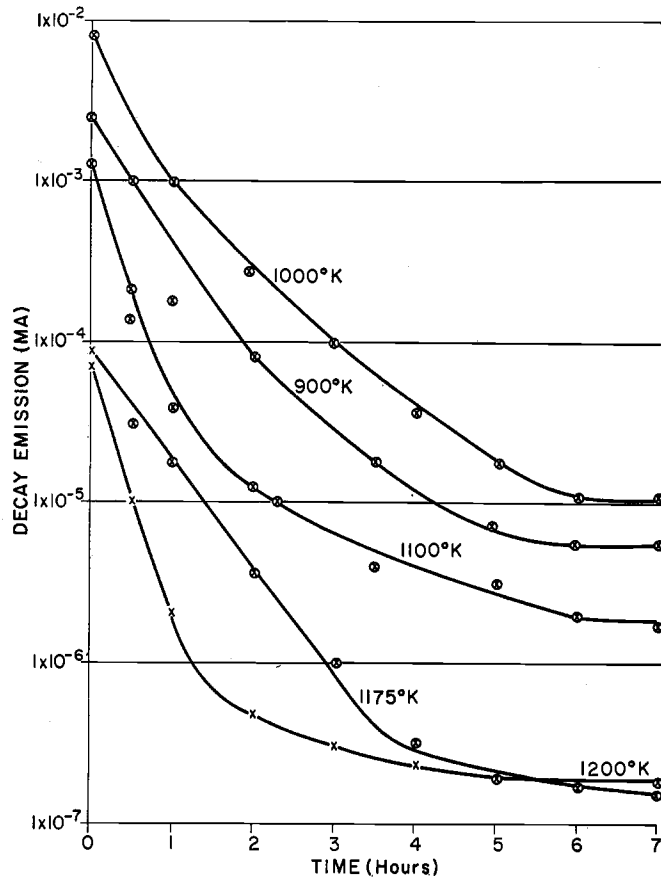

Fig. 8—Titanium grid decay emission vs time at various grid temperatures. (Exposed to cathode for 16 hours at 1,500°K prior to each run).

Fig. 8 shows the results of the decay of emission from a titanium grid with a cold cathode after the grid has been exposed while cold to the evaporation products of the cathode at 1,500°K for 16 hours before each temperature run. Table IV indicates how the emission decays for various grid materials treated as were those used for Fig. 8. The tungsten, zirconium, and titanium grids are operated at 1,200°K while the gold plated molybdenum grid is glowed at 1,100°K. The time required to reach the final stable emission is 28 hours for tungsten, 10 hours for gold plated molybdenum, 6 hours for zirconium, and 1 hour for titanium. The rapid evolution of the evaporation products from the cathode by the titanium grid is consistent with the data given in Table III.

Fig. 9 shows a plot of grid emission vs grid temperature for various grid materials after the grids have been ex-

TABLE IV
DECAY EMISSION FOR DIFFERENT GRID MATERIALS
L-Cathode
Grid Temperature 1200° Kelvin

Grid Used	Decay Emission	
	Initial (ma)	final (ma)
Tungsten	39.00	1.7
Gold Plated-Molybdenum	9.6×10^{-3}	3×10^{-3}
Zirconium	5.4×10^{-3}	2.2×10^{-3}
Titanium	6×10^{-4}	3×10^{-7}
Titanium-Oxide	2×10^{-3}	5.8×10^{-5}

REMARKS: 1) The cathode was run over night before every run. 2) Comparative values were obtained for the oxide and impregnated cathodes.

posed to a cathode glowing at 1,500°K for 16 hours. The dip in the grid emission characteristic for zirconium and tungsten occurs at 1,600°K and 1,900°K, respectively. The dip is not as great for zirconium or for tungsten as it
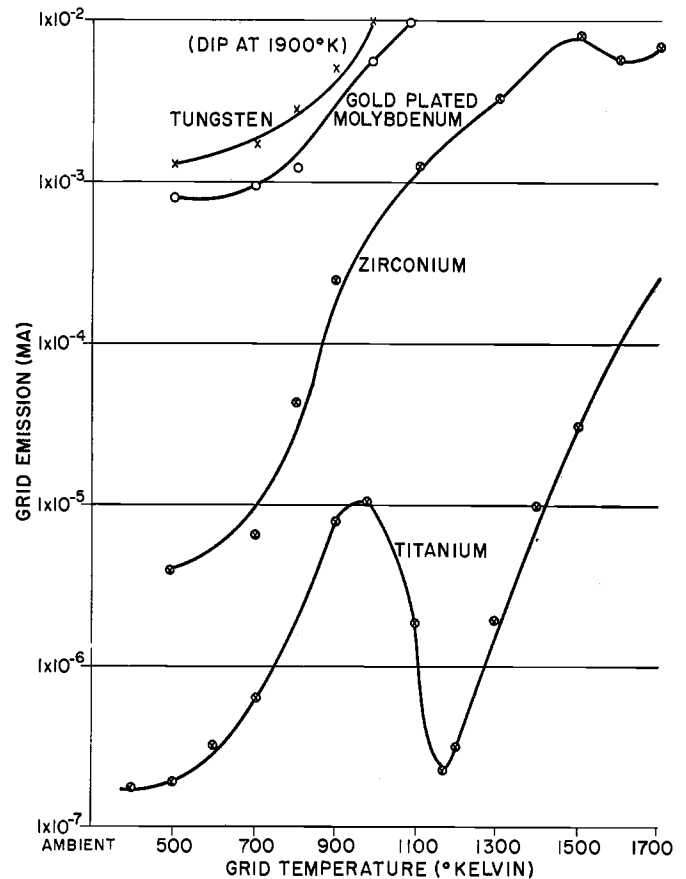

Fig. 9—Grid emission vs grid temperature for different grid materials. (L cathode).

is for titanium, and it is believed that at these temperatures the barium oxide is reduced to barium which is evaporated from the surface of the grid while the oxygen combines with the base metal. This conclusion is reached
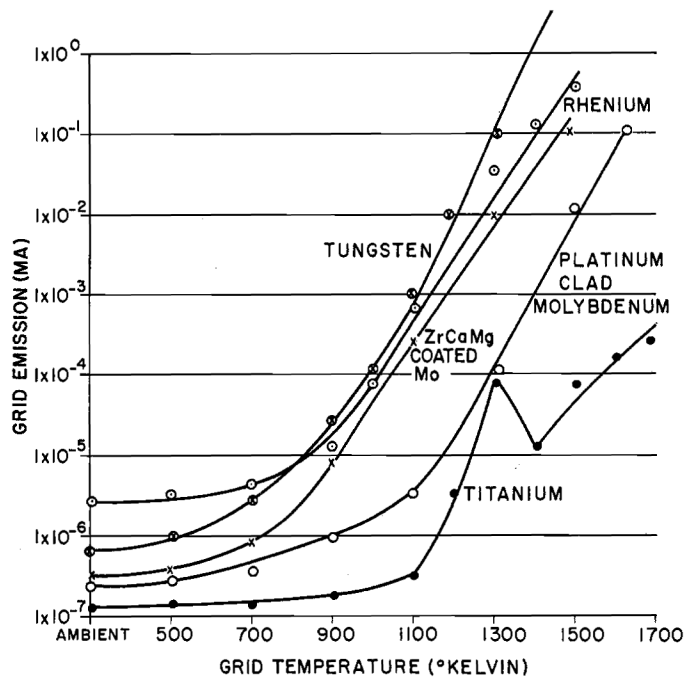
Fig. 10—Grid emission vs grid temperature for different grid materials. (Thoriated tungsten cathode at 2,200°K).

Fig. 11—Grid emission vs time at grid temperature of 1,200°K. (Thoriated tungsten cathode run at 2,200°K).

because the subsequent grid emission is not that which is characteristic of clean tungsten or of clean zirconium.

WORK FUNCTION DETERMINATIONS

In the case of a tungsten grid, the deposited materials from all these cathodes were largely barium and barium oxide, and the resultant work functions measured varied from 1.2 to 2.0 ev, depending upon the ratio of barium to barium oxide in the evaporation products. If the grid is heated to 1,200°K, barium is evaporated from the grid and the resultant work function was found to be between 1.2 and 1.6 ev, indicating that the remaining material is largely barium oxide. Operating the grid at 2,700°K for ten minutes removed all oxides and the work function was 4.5 ev, the accepted value for clean tungsten.

Attempts to measure the work function of titanium grids contaminated with the evaporation products from the cathode have been unsuccessful due to the fact that barium continually evaporated from the surface at temperatures as low at 600°K. All values of work functions measured were approximately 4.1 ev, which agrees with published values for clean titanium.

GRID EMISSION IN TUBES WITH THORIATED TUNGSTEN CATHODES

A further study was made comparing the grid emission properties of titanium with those of other materials.

The tube was of a planar triode construction. The cathode consisted of a 0.0095 inch diameter wire looped into a single turn whose inner diameter was 0.085 inch;
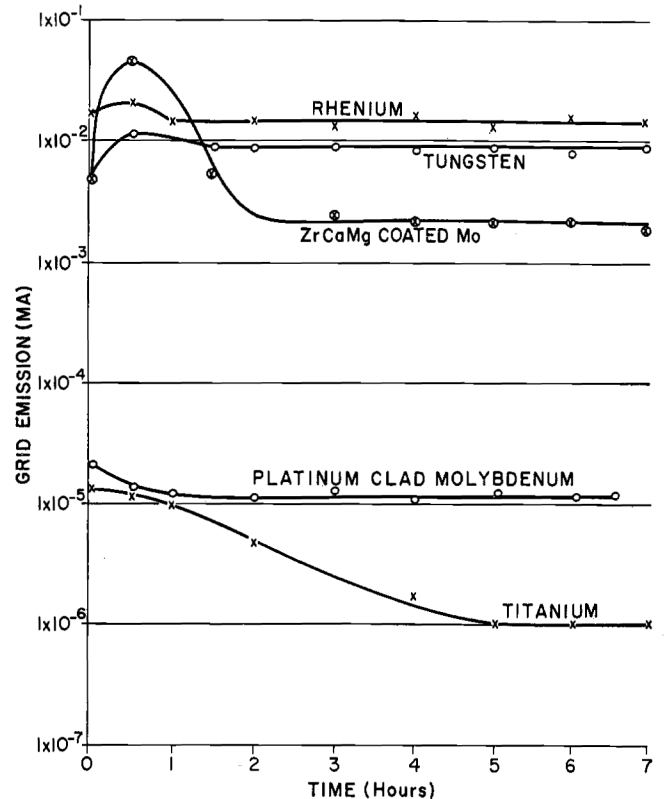
the wire was formed in the same way as the grids under test. The cathode was carburized in the conventional manner.

The assembling and processing of these triodes were the same as described previously with the exception that the thoriated tungsten cathode was operated at 2,200°K. In the assembly of the triodes precautions were taken to insure maximum cleanliness of all parts.

The grid emission was measured by using a dc battery supply in series with a Rubicon galvanometer or an RCA microammeter. A block diagram of the apparatus is shown in Fig. 3.

The measurements were taken in the same manner as described previously with the exception that the cathode was operated at 2,200°K. Data showing how the grid emission varied with respect to time and to grid temperatures were taken. The results obtained are shown in Figs. 10 and 11. The evaporation products from thoriated tungsten emitters consist chiefly of thorium and thorium oxide.

Results indicated that the most satisfactory grid material for inhibiting grid emission is clean crystalline titanium. The decay curves (Fig. 12) show that titanium loses most of the materials which have been deposited upon it when the grid temperature is 1,200°K. These decay curves are consistent with the emission curve data taken.
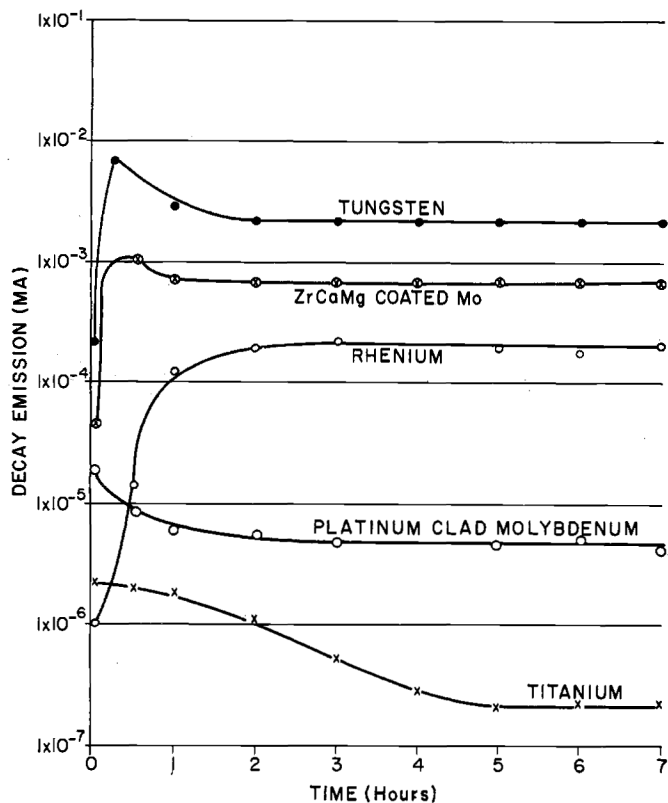
Fig. 12—Decay emission vs time at a grid temperature of 1,200°K. (Exposed to thoriated tungsten cathode at 2,200°K prior to each run).

CONCLUSION

In conclusion, let us summarize the essential facts concerning primary grid emission resulting from the exposure of a grid to the evaporation products of *L*, impregnated, and oxide-coated cathodes.

The work function of a tungsten grid varies from 1.2 to 2.0 ev for all cathodes, the final value depending upon the past history of the cathode, the temperature and the length of exposure to the cathode and the condition of the surface of the grid before exposure to the evaporation products of the cathode.

Primary grid emission from tungsten grids exposed to the oxide-coated cathode is approximately an order of magnitude higher than for similar grids exposed to L and impregnated cathodes. The higher grid emission is probably due to a higher percentage of barium oxide in the evaporation products from the oxide-coated cathode.

For tungsten grids, emission decay studies indicate that as the temperature of the grid is raised, barium is evaporated from the grid at approximately 1,200°K. Barium oxide starts to evaporate at 1,300°K and it is not completely removed until the wire is glowed at 2,700°K for a few minutes.

The most satisfactory metal for inhibiting grid emission is smooth, clean, crystalline titanium which appears to lose barium by evaporation at temperatures as low as 600°K and converts barium oxide to barium at temperatures ranging from 1,000°K to 1,175°K. The barium evaporates completely at 1,175°K.

Of all grid materials tested to date in tubes with thoriated tungsten cathodes, the most satisfactory material for inhibiting grid emission is titanium.