THE PROCEEDINGS OF THE INSTITUTION OF ELECTRICAL ENGINEERS

A NEW SECONDARY CATHODE

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SUMMARY

One of the main difficulties in the use of secondary-emission multiplier stages in thermionic valves is the instability of the secondary cathode, which is usually characterized by a gradually decreasing secondary-emission ratio during its useful life. In this paper, experiments are described showing that this instability is due to the bombardment of the secondary cathode by the primary electron beam, and it is shown that this bombardment causes disintegration of the surface layer. A new type of secondary cathode, formed from a mixture of magnesium oxide and barium carbonate, has been found to have a stable life of over 1 000 hours, when operating at 400° C and with a primary bombarding current density of 20 mA/cm². The use of this secondary cathode has made possible the development of a single-stage thermionic electron-multiplier valve, with a mutual conductance of 20 mA/volt.

(1) INTRODUCTION

The ratio of the mutual conductance of a valve to its input capacitance is of great importance in many circuit applications, especially in broadband amplifiers, where it sets an upper limit to the possible gain per stage. Very high ratios of mutual conductance to capacitance have been achieved by special manufacturing and assembling technique; e.g. the American 1553 has a mutual conductance of 50 mA/volt at 10 mA anode current and an input capacitance of $9 \cdot 5$ $\mu\mu$F, and the 2C39 has a mutual conductance of 10 mA/volt at 10 mA and a capacitance of 6 $\mu\mu$F. In large-scale production, modern valves are made with mutual conductances of $6 \cdot 5$ mA/volt at 10 mA anode current and capacitances of 8 $\mu\mu$F (e.g. the British Z77), and any substantial improvement in these figures can be achieved only by considerable increases in the difficulty of manufacture and in the cost of the valve.

It is clear that, for a fixed cathode current, the use of a secondary-emission multiplier stage will increase the mutual conductance of a valve in direct proportion to the multiplication ratio δ, where δ is defined as the ratio of the primary bombarding current to the secondary current collected by the anode. Jonker and van Overbeck[1] have shown that for a constant anode current the mutual conductance is increased in proportion to $\delta^{0 \cdot 6}$. Since the use of a multiplier stage or stages does not necessitate

any increase in input capacitance, and may even allow some decrease, the use of secondary-electron multiplication can result in a greatly improved ratio of mutual conductance to input capacitance. For example, Wagner and Ferris[2] describe a thermionic valve with a single stage of multiplication which has a slope of 15 mA/volt at 12 mA anode current, and an input capacitance of $4 \cdot 5$ $\mu\mu$F.

Despite these advantages, valves using secondary-electron multiplication have not been made available commercially, and preliminary experiments by the authors confirmed the impression received from a study of the literature that one of the main difficulties in the use of secondary-electron multiplication is in obtaining a secondary cathode whose secondary-emission ratio would remain stable for a sufficiently long time to be of commercial value. Jonker and van Overbeck[1] describe the gradual decrease in secondary-emission ratio with life, and attribute the decrease to contamination of the secondary cathode by material evaporated from the primary cathode. By suitable design they prevent this contamination and state that the decay is reduced. Zworykin, Ruedy and Pike[3] use an alloy of silver and magnesium as a secondary cathode and state that a stable life can be obtained by special processing. This paper will be concerned mainly with an investigation of the decay in secondary-electron multiplication ratio with life, the development of a stable secondary cathode and the application of this secondary cathode to a single-stage thermionic multiplier.

(2) THE NATURE OF THE DECAY PHENOMENA

Pure metals are known to have a low secondary-emission ratio ($\delta = 0 \cdot 5-1 \cdot 5$), and any apparent exceptions to this rule have always been traced to contamination of the surface. Secondary cathodes of the Cs–CsO–Ag type used in photo-electric multipliers are capable of high secondary emission, but the use of caesium in thermionic valves brings very severe difficulties in manufacture. Bruining and De Boer[4] have shown that some metallic oxides, e.g. magnesium oxide and aluminium oxide, have a high capacity for secondary emission, and it was decided to carry out tests on this type of secondary cathode.

Secondary cathodes of magnesium oxide on a nickel base were prepared by the following process:

(a) Clean and de-gas the nickel electrode at 1 200° C in vacuum by means of an internal heater.

(b) After allowing the electrode to cool, coat with magnesium by evaporation to a thickness about 1 μ.

(c) Expose the electrode to air to oxidize the magnesium.

(d) Assemble in valve.

The preliminary vacuum cleaning was found to be indispensable, and any exposure to air of the electrode after cleaning, but before coating with magnesium, was also found to result in a low secondary-emission ratio.

These emitters were tested in an orbital-beam single-stage thermionic multiplier. The valve was processed in the normal way (bake, induction heat, activate cathode), and this was followed by electron bombardment to de-gas and activate the secondary cathode. It was known that exposure of a magnesium film to moist air results in the formation of some magnesium hydroxide as well as magnesium oxide, and experiments with a secondary cathode, in which the magnesium was oxidized in pure dry oxygen and needed no activation, suggested that the activation process consists of converting the hydroxide to the oxide. Care was necessary to avoid heating the emitter beyond the temperature required for activation (about 600° C), since excessive heating was found to reduce the ultimate multiplication ratio and sometimes to prevent activation entirely. These evaporated-magnesium secondary cathodes had a multiplication ratio between three and six, the variation between different valves being quite wide.

On life test, with the secondary emitter running at a temperature of about 400° C and a bombarding current density of 20 mA/cm², it was found that the multiplication ratio fell from its initial value of about 4 to below 1½ in times varying between 1 and 20 hours, the decay times again having wide variations from valve to valve. Typical life-test curves are shown in Fig. 1, and it will be seen that the decay is similar to that described by Jonker and van Overbeck[1] and Zworykin, Ruedy and Pike,[3] but that it takes place more rapidly.
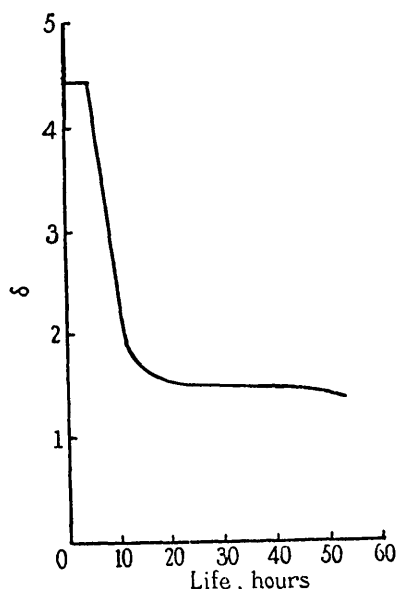

Fig. 1.—Variation of secondary-emission ratio δ of a thin-film magnesium-oxide secondary cathode with life.

(3) INVESTIGATION OF THE DECAY PHENOMENA

(3.1) Preliminary Investigations

Secondary cathodes similar to the magnesium-coated cathodes were made by evaporating aluminium and beryllium, and these showed a similar decay in secondary emission with life, while their multiplication ratios were rather lower. The decay phe-

nomenon is therefore not peculiar to one type of secondary cathode.

Considerable trouble was taken to achieve the best possible vacuum in the valve during processing and after sealing off, but no improvement in the methods of pumping and activating with a view to removing residual gases gave any consistent improvement in the life of the emitter.

Tests were made using platinum, molybdenum and gold-plated molybdenum as base metals for the secondary cathode, but no correlation could be found between the rate of decay of secondary emission and the nature of the base metal.

Contamination of the secondary cathode by direct evaporation from the primary cathode was prevented by the design of the valve, and while indirect contamination by rebound from other electrodes was possible, it did not seem probable.

(3.2) The Effects of Ionic and Electronic Bombardment

The destructive action of positive-ion bombardment of thermionic oxide-cathodes, and of negative-ion bombardment of fluorescent screens, is well known, and the possibility existed that the decay in secondary emission was due to bombardment by negative ions. The technique of Pearce and Broadway,[5] used by them for "black spot" experiments in cathode-ray tubes, gives a useful method of differentiating between the effects of electron and negative-ion bombardment. Experiments were therefore planned in which a beam of electrons and negative ions from an oxide cathode could be analysed magnetically and the effect of each component of the beam observed separately. A
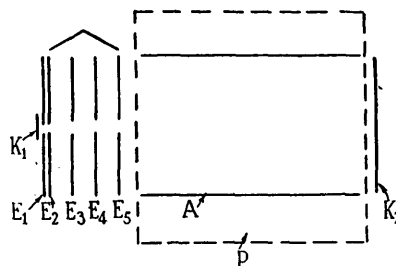

Fig. 2.—Experimental apparatus for ionic bombardment investigation.

diagram of the experimental apparatus is shown in Fig. 2, where K_1 is an oxide cathode, E_1 is a current-control electrode, E_2, E_3, E_4 and E_5 are focusing electrodes, A is the anode and K_2 is the secondary cathode. The electron-gun system produced a line focus less than 2 mm wide and 12 mm long at a beam current of 0·2 mA. The secondary cathode K_2 measured 30 mm by 12 mm and was heated, during de-gassing and activating, by radiation from a tungsten filament, suitable heat shields being arranged to ensure uniform and efficient heating. The focused beam could be deflected $\pm$ 15 mm along the length of the emitter by an electromagnet whose pole pieces P are indicated in the Figure. The focus obtained with this system was thought to be sufficiently good for preliminary tests, although not sufficiently narrow to differentiate between the effects of ions of similar atomic weight. Experiments with this apparatus were performed in a demountable apparatus so that the secondary cathode could rapidly be changed.

Fig. 3 shows the variation in secondary-emission ratio, along the length of the secondary cathode, immediately after the activation of the secondary cathode. This curve was obtained by measuring the secondary-emission ratio of the emitter as the beam is moved across it by successive increases in the magnetic field. The dimensions of the apertures in the electron gun were such that direct evaporation was possible from the primary cathode to the central area of the secondary cathode, and the
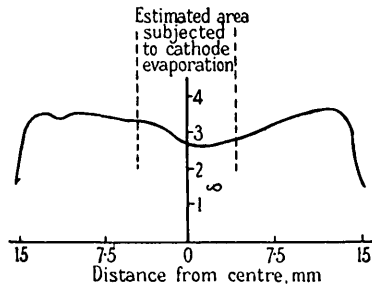
Fig. 3.—Variation of secondary-emission ratio δ along the length of a thin-film magnesium-oxide secondary cathode after activation by heating.

multiplication ratio over this area is about 30% lower than over the rest of the emitter. This indicates that, under the conditions of this experiment, contamination of the secondary cathode from the primary cathode can take place and that it results in some decrease in multiplication ratio. Some recovery of the multiplication ratio was possible, either by heating the secondary cathode or by electron bombardment, and this recovery was usually accompanied by loss of primary emission, possibly through re-evaporation back to the primary cathode. The decrease in multiplication ratio due to evaporation from the cathode was, however, different from the decay under investigation, in that it was observed immediately after activation and did not vary with time in any regular manner.
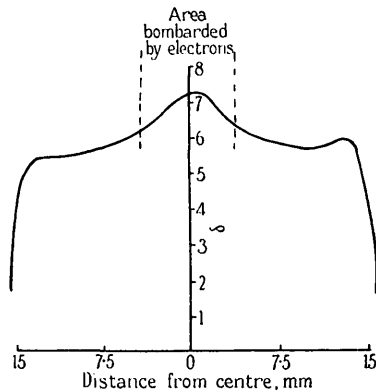

Fig. 4.—Secondary-emission ratio δ along a thin-film magnesium-oxide secondary cathode after activation by heating and electron bombardment.

By suitable processing, this decreased multiplication can be prevented; Fig. 4 shows the variation in multiplication ratio along the secondary cathode, after activation by heating with simultaneous bombardment of the centre of the secondary cathode. It will be seen that the secondary-emission ratio is highest at the centre, showing not only that electron bombardment has prevented the contamination of the secondary cathode, but also that it has actually increased the multiplication factor in this area.

A further example of the effect of electron bombardment is shown in Fig. 5, which shows the secondary-emission ratio of the secondary cathode after two hours' bombardment of one selected area. The secondary cathode in this experiment was cold, and it is clear that, in the bombarded area, the secondary-emission ratio has been maintained at its initial value, and that elsewhere it has decreased.

By observing the field required to produce a given deflection of the electron beam, it is possible to calculate the field required to bring an ion beam, emitted from the cathode, to a selected position on the secondary cathode. In view of the "black spot"
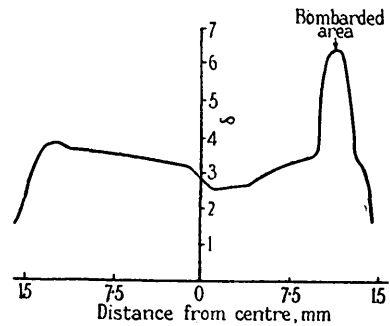

Fig. 5.—Secondary-emission ratio along a thin film magnesium-oxide secondary-cathode after 2 hours of electron bombardment.

experiments of Pearce and Broadway,[5] it was considered that ions of chlorine and oxygen were most likely to be present. No effects could be found due to these ions, however, nor to any other ions, after 6 hours' bombardment. Although the current density used was lower than in sealed-off valves, some effect would have been expected had ion bombardment been a major cause of decay.

The life-test curves in Fig. 1 were obtained in a valve operated with the secondary cathode at about 400° C; the experiments described above were therefore repeated with the secondary cathode at 500° C. Again no effect was found due to ion bombardment, but electron bombardment caused first a slight increase and then a strong decrease of multiplication ratio. Fig. 6 shows the decay in multiplication ratio with time of
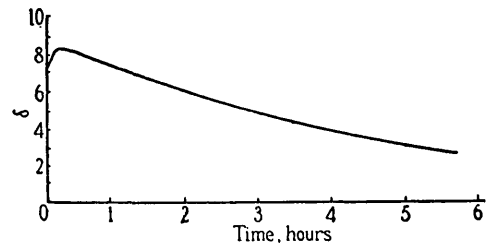

Fig. 6.—Decrease of secondary-emission ratio δ with time of bombardment of a thin-film secondary cathode operated at 500° C.
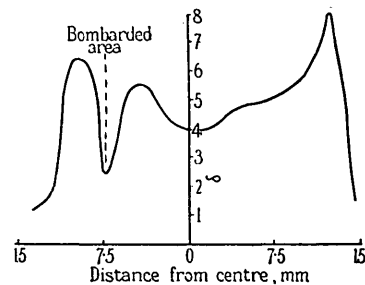

Fig. 7.—Secondary-emission ratio along a thin-film secondary-cathode after 10 hours of electron bombardment.

bombardment, while Fig. 7 shows the decreased multiplication ratio in the bombarded region. It will be noticed that this decreased multiplication ratio is not due to the temperature only, since only in the bombarded area does the decrease occur. The initial rise and subsequent fall of secondary emission shown in Fig. 6 is exactly parallel to the effects found during the activation and life of sealed-off valves.

(4) ELECTRON BOMBARDMENT PHENOMENA

The experiments described above show a considerable difference in the behaviour of a magnesium-oxide secondary cathode

operated at 500° C and at room temperature. With the secondary cathode at 500° C, the primary cause of the decay phenomena is the bombardment of the emitting surface by electrons. A possible result of this bombardment could be the dissociation of the magnesium oxide into its constituent elements, since the energy of formation of magnesium oxide is less than 5 eV and the energy of the bombarding electrons is 250 eV. Bruining and de Boer[4] have discussed an analogous effect resulting in the formation of colour centres in a secondary-emissive layer of sodium chloride.

If such dissociation does take place, evaporation of the oxygen would be expected whether the secondary-cathode temperature was 500° C or room temperature. Jacobs[6] has shown that bombardment of a metallic oxide liberates a gas which poisons the primary cathode and which can be assumed to be oxygen. The behaviour of the magnesium would depend on both the temperature of the secondary cathode and the vacuum conditions of the experiment. At 400° C the magnesium would probably be lost from the surface by migration or evaporation, while at room temperature it would probably remain on the surface sufficiently long to be re-oxidized.

At high temperatures, therefore, the secondary-emission ratio would be expected to fall with prolonged bombardment, since the loss of magnesium and oxygen from the surface would ultimately expose the base metal, which has a low secondary-emission coefficient. At low temperatures the secondary-emission coefficient might be maintained, provided that the magnesium formed by dissociation remained on the surface sufficiently long to be re-oxidized.

The theory that electron bombardment causes disintegration of the bombarded surface also explains the results shown in Figs. 4 and 5. Under the conditions of these experiments, the emitting surface is liable to contamination both by residual gases and, in the centre, by material evaporated from the cathode. If, in the bombarded area, this contamination is continually removed by disintegration and evaporation, electron bombardment will improve the activation as shown in Fig. 4 and, with the secondary cathode cold, will maintain the secondary ratio as shown in Fig. 5.

With the very thin film of magnesium oxide used in these experiments, it was not possible to observe visually any loss of coating. With thicker layers (see Section 5.1), an examination of the secondary cathode after life testing showed that the magnesium oxide had been stripped completely in the bombarded area, as shown in Fig. 8, where the dark patch on the right of the secondary cathode is the base metal exposed by 50 hours of electron bombardment.

It is to be concluded from these experiments that electron bombardment of secondary-emitting surfaces causes disintegration of the surface and that the observed decrease in secondary-emission ratio during life is due to the gradual exposure of the clean base metal.

(5) LONG-LIFE SECONDARY CATHODES

In view of the above conclusion, one obvious way to obtain a long life from a secondary cathode is to use a small primary current-density and a low operating temperature. This is, in fact, the technique used in photo-electric multipliers, in which the life is quite good. For a thermionic valve this solution is not acceptable, since a low bombarding current would result in a low mutual conductance, while increasing the size of the secondary cathode to increase the permissible bombarding current would result in increased inter-electrode capacitances.

It might be possible to produce an emitter in which the recombination efficiency is high, so that a thin-film emitter would
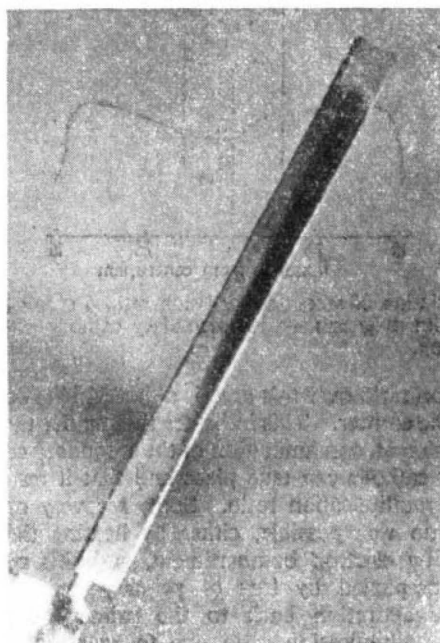

Fig. 8.—A thick magnesium-oxide secondary cathode after 50 hours of electron bombardment. The base metal exposed as a result of the bombardment can be seen as a dark strip on the right-hand side of the secondary cathode.

be continually re-formed. Zworykin, Ruedy and Pike[3] discuss the use of a silver-magnesium alloy as a secondary cathode which, after special processing, is claimed to have a long life under severe operating conditions. Experiments similar to theirs have been repeated by the authors, but the life so attained, though better than for evaporated-magnesium cathodes, was still not sufficient.

From a consideration of the heats of formation of oxides suitable for use as secondary emitters, it does not seem possible to prevent decomposition of the emitter surface by electron bombardment. Although it may be possible to prevent the rapid removal of the metallic element by operating at a low temperature, the residual clean metal film will have a low secondary-emission ratio. The possibility exists of operating the valve with a definite residual pressure of some element which would combine with the secondary cathode to re-form the surface continually. These, in fact, are the conditions which gave the results shown in Fig. 3, the temperature being such that the magnesium was not rapidly lost from the surfaces while the residual pressure of oxygen was sufficient to re-oxidize the surface. It is difficult to see, however, how these conditions could be arranged in a sealed-off valve without deleterious effects on the life of the primary cathode.

It might also be possible to have an emitter surface that is continually renewed, either by evaporation or diffusion from a suitable source in an analogous manner to the disperser cathode,[8] but this would hardly be practical in small receiving valves, where space and power dissipation are limited.

A solution which seemed practicable is to use a secondary cathode which has an emitting layer thick enough to withstand bombardment for a sufficiently long time before exposing the base metal. If the surface were such that considerable recombination of the disintegrated compound could take place, then the life would be further extended. It was therefore decided to investigate the possibility of using secondary cathodes with a magnesium-oxide coating 10^{-4}–10^{-2} in thick in the hope that their life would be adequate.

(5.1) Magnesium-Smoke Secondary Cathodes

Since it was thought necessary to prevent the formation of an oxide film on the base metal (cf. preparation of evaporated-magnesium secondary cathodes), platinum electrodes were used in preliminary experiments. It was found later that similar results could be obtained using nickel electrodes, provided that they were first magnesium coated as before. Experimental secondary cathodes were coated by holding the prepared electrode in the smoke from burning magnesium ribbon and, with some practice, an even coating could be obtained of any desired thickness. With a coating thickness of 0·003 in, the surface layer had a resistance so high that the value of the multiplication ratio could not be determined with any certainty. Owing to the high electric field set up across the coating, arcing and violent disintegration of the coating often occurred. With thinner coatings, sufficiently thin for the base metal to be just visible, the resistance of the coating was sufficiently low to be usable, the multiplication ratio being between three and five.

These magnesium-smoke secondary cathodes, although an improvement over the evaporated-magnesium cathodes, still had a life of only 50 hours, and it was realized that any layer of pure magnesium oxide thick enough to have a long life would have so high an insulation as to be useless. In the present series of experiments, no attempt was made to measure the resistance of the coating directly, but its effect was inferred from the current-saturation curve of the secondary cathode with increasing anode voltage. Such curves are shown in Fig. 9. The lack of saturation for the magnesium-smoke secondary cathode may be due
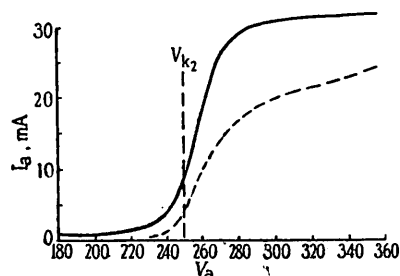

Fig. 9.—Anode-current/anode-voltage saturation curve of secondary cathodes.

——— Thin-film magnesium-oxide secondary cathode.
--------- Magnesium-smoke secondary cathode.

to other causes, e.g. roughness of coating, or localized difference of potential, but, since the thicker magnesium-smoke coatings showed their high resistance by disintegration, it seemed reasonable to assume that the lack of saturation was associated with a high resistance.

(5.2) Complex Emitter Coatings

A considerable amount of work was done on the problem of reducing the resistance of a thick layer of magnesium oxide (where "thick" means of the order of 0·001 in). Magnesium oxide mixed with finely divided metals, and mixtures of magnesium oxide with beryllium or aluminium oxide, were all tested, but they had either a high resistance or a low secondary-emission ratio. If a coating of magnesium oxide is prepared by cataphoresis from a suspension in acetone, the resistance of the processed secondary cathode, as shown by its saturation curve, is quite low, but its secondary-emission ratio is only two. This result, compared with that for the magnesium-smoke secondary cathodes is surprising and emphasizes the importance of the physical state of the surface.

(5.3) Magnesium-Barium Secondary Cathodes[9]

The resistance of the coating of thermionic oxide cathodes is known to decrease rapidly with increasing temperature, and tests were therefore made with secondary cathodes formed from a mixture of magnesium oxide and barium carbonate. An acetone suspension was prepared using a sintered mixture of 40% barium carbonate and 60% magnesium oxide, and emitters were coated with this suspension, to a thickness of 0·00025–0·002 in. Processing of the assembled valve on the pumps followed the normal technique, the secondary cathode being de-gassed in the same manner as the primary cathode.

These secondary cathodes were found to have adequate conductivity and a secondary-emission ratio which remained sensibly constant for over 1 000 hours at a value of about three.

As might be expected from its chemical composition, the magnesium-barium secondary cathode is capable of thermionic emission if the operating temperature is sufficiently high. Its secondary-emission ratio increases with temperature while its resistance decreases, so that, below the limit set by thermionic emission, the secondary cathode should be operated at as high a temperature as possible.

It has been found that use of an unsintered mixture of magnesium oxide and barium carbonate results in a secondary cathode which has a multiplication ratio of about six and a current saturation curve which indicates a high-resistance coating. With increasing temperature, the resistance and the secondary-emission ratio both fall, and the same result can be obtained by ageing the secondary cathode for 20 hours under normal operating conditions.

(6) APPLICATION TO SINGLE-STAGE THERMIONIC MULTIPLIERS

The magnesium-barium secondary cathode has been used in an orbital-beam single-stage thermionic multiplier which has a mutual conductance of 20 mA/volt for 25 mA anode current and input capacitance of 8 $\mu\mu$F.

In the orbital-beam valve suggested by Jonker and van Overbeck[1] the anode is relatively large, and it was thought that, by modifying their suggested electrode structure, the primary beam could be brought to a narrow focus on the secondary cathode. By this means, the secondary cathode and anode could be relatively small and have small inter-electrode capacitances. One line of approach to this problem was to try to produce an electron-optical analogue of the elliptical mirror, the primary and secondary cathodes being placed at the corresponding focus of the electron-optical system. Investigations were made using the rubber membrane technique,[10] in which a rubber sheet under tension is given vertical displacements proportional to the potential distribution in the valve, and a small ball rolling on the rubber traces out the electron paths. Surrounding the cathode by an accelerator grid at one focus of an elliptical electrode and surrounding the secondary cathode by a gridded anode at the other focus were not successful. After some experimenting, it was found that putting the primary and secondary cathodes at suitable points on the minor axis of the elliptical focusing electrode gave an electron-optical system in which electrons emitted from the primary cathode were brought to a line focus on the secondary cathode. With this arrangement, not only is the focus obtained in practice very good, but also its position and size are nearly independent of the anode voltage, provided that it is greater than the accelerator-grid potential.

Fig. 10 shows the final design of the valve.[11] The cathode K_1, control grid G_1 and accelerator grid G_2 are those used in the valve CV1091. The shield S_1 is the focusing shield, A is the anode and K_2 the secondary cathode. A photograph of the complete
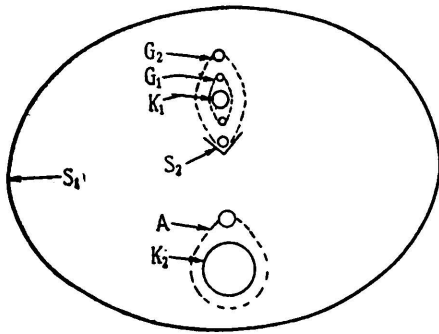
Fig. 10.—Electrode arrangement of orbital-beam single-stage
electron-multiplier.

valve is shown in Fig. 11A, while Fig. 11B is a photograph of
a valve with the focusing electrode cut away to show the internal
electrode structure. The anode is relatively small, while the
anode/control-grid capacitance is considerably reduced by means
of shield S_2. This reduction in anode/control-grid capacitance
is so marked that the residual capacitance in the actual valve is
determined almost entirely by the arrangement of the pins in the
valve base and holder.

The valve is normally operated with a primary bombarding

Fig. 11B.—Valve structure with focusing electrode cut away
to show internal electrodes.

Total capacitance of anode to other
    electrodes   ..   ..   ..   8 $\mu\mu$F.
Total capacitance of grid to other ·
    electrodes   .'.   ..   ..   5 $\mu\mu$F.
Anode/control-grid capacitance   ..   0·008 $\mu\mu$F.

Characteristics of the valve are shown in Figs. 12 and 13.

Fig. 11A.—Orbital-beam single-stage electron-multiplier.
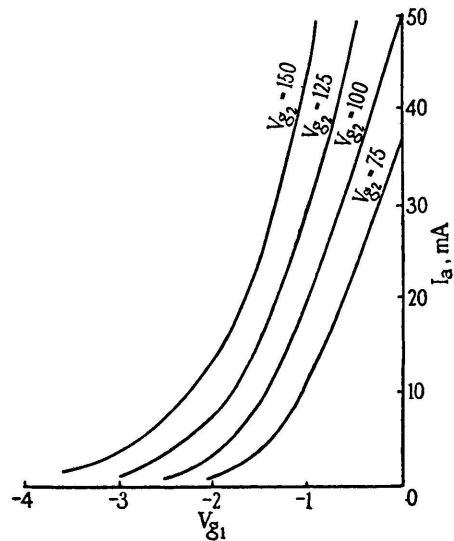
Fig. 12.—Anode-current/control-grid characteristics of single-stage
multiplier.

current of 8 mA at 250 volts, which maintains the secondary
cathode at about 400° C. Under these conditions the thermionic
current from the secondary cathode is very low, and the multipli-
cation ratio is between 3·0 and 3·5, giving final anode current of
25 mA. The normal operating conditions are as follows:

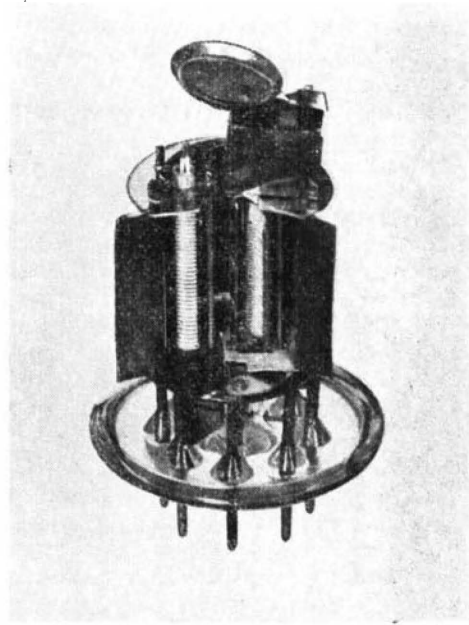|	
Heater	6·3 volts, 0·3 amp.
Control grid	−1·25 volts.
Accelerator grid	125 volts, 1·3 mA.
Focusing shield	Cathode potential.
Secondary cathode	250 volts.
Anode	350 volts, 25 mA.
Mutual conductance	20 mA/volt.

Life-test results with this valve have shown that a stable life of
well over 1 000 hours can be expected. Fig. 14 shows a life-test
curve obtained with the valve operating under the conditions
specified above.

(7) DISCUSSION OF EXPERIMENTAL RESULTS

The life of the magnesium-barium secondary cathode is more
than 20 times that of the magnesium-smoke cathode, and,
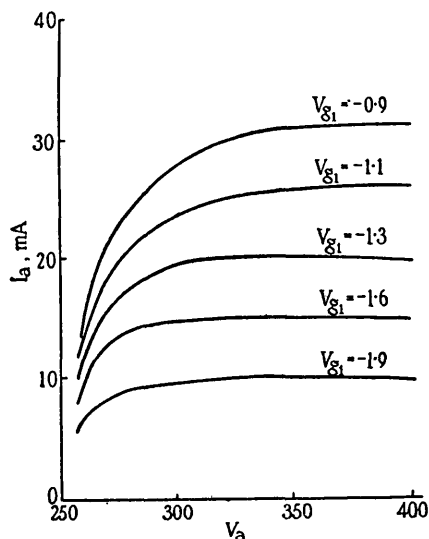although the coating thickness of these cathodes cannot be

Fig. 13.—Anode-current/anode-voltage characteristics of single-stage multiplier.
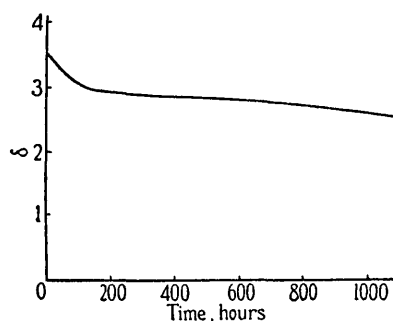

Fig. 14.—Life-test results of magnesium-barium secondary-cathode showing variation of secondary-emission ratio δ during life.

determined accurately, the magnesium-barium cathode appears to be only three or four times thicker than magnesium-smoke cathode. This suggests that the magnesium and oxygen ions liberated as a result of electron bombardment have a smaller chance of recombining in the magnesium-smoke emitter, possibly because the high electric field across the coating causes rapid separation of the oppositely charged oxygen and magnesium ions. There may, in fact, be some relationship between the life of a secondary cathode and the electrical resistance of its coating.

Although the barium carbonate was introduced into the emitter with the object of lowering its resistance, it is clear that this is not its only function, since magnesium oxide alone, deposited by cataphoresis, also appears to have low resistance (see Section 5.2). Activation of the secondary cathode is similar to the activation of a primary cathode, so that the processed secondary cathode should have a low work-function. The dependence of secondary-emission ratio on the work function has been discussed previously by Treloar[13] and Coomes,[14] but

the evidence does not appear conclusive. Preliminary experimental work has shown that the secondary-electron velocities are much lower for the magnesium-barium secondary cathode than for pure metals, so that the importance of the work function may depend on the type of surface used. The increase of secondary-emission ratio with temperature in connection with primary cathodes used as secondary cathodes has been investigated,[15,16] but some doubt exists as to whether the effect is real or not. The magnesium-barium secondary cathode normally has a secondary-emission ratio which increases with temperature, owing in part to the decreased coating-resistance at higher temperatures.

(8) CONCLUSION

The magnesium-barium secondary cathode described in this paper is of considerable importance both practically and theoretically. From the practical point of view, the properties of this emitter should result in a new range of valves of which the present valve is only one example. From the theoretical point of view, it is clear that the phenomena observed with this emitter cannot be fully explained in terms of existing theories of secondary emission. Further investigations, including the measurement of the effect of work function and coating resistance, will be necessary before a satisfactory theory of secondary emission from thick films can be developed.

(9) ACKNOWLEDGMENTS

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