June 12, 1934. J. D. LE VAN 1,962,159

GRID CONTROLLED GASEOUS DISCHARGE TUBE

Filed Aug. 25, 1930 2 Sheets-Sheet 1

Fig. 1.

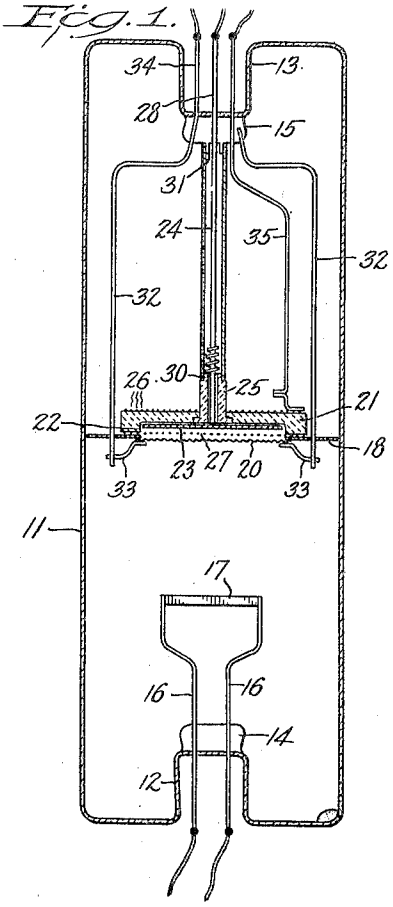


Fig. 4.

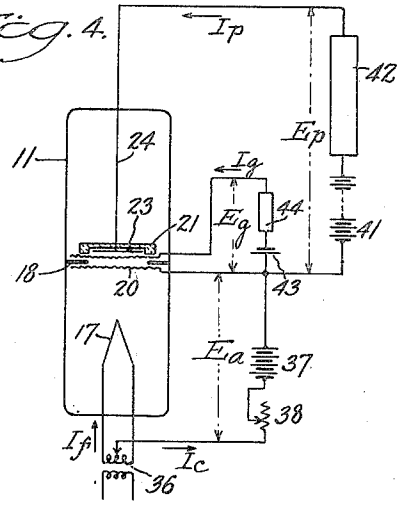
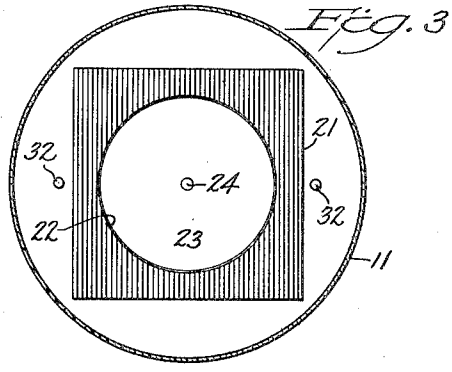


Fig. 3



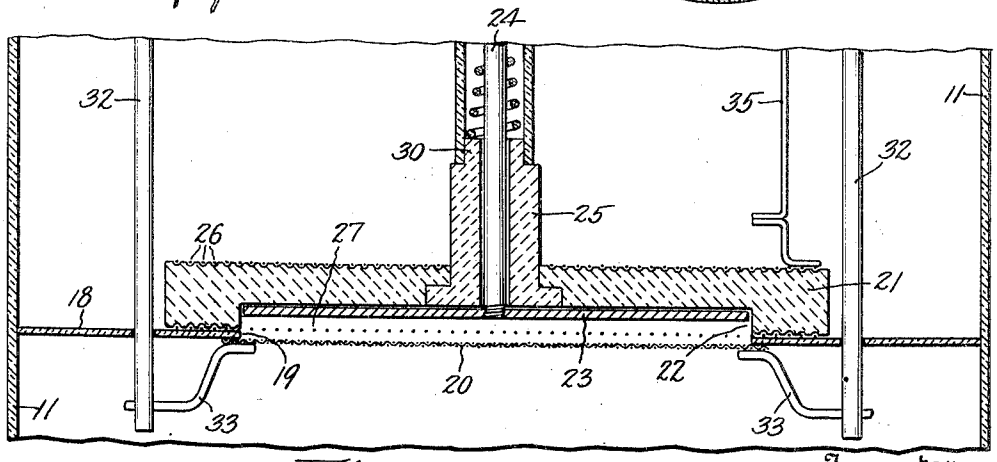


Fig. 2.

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GRID CONTROLLED GASEOUS DISCHARGE TUBE

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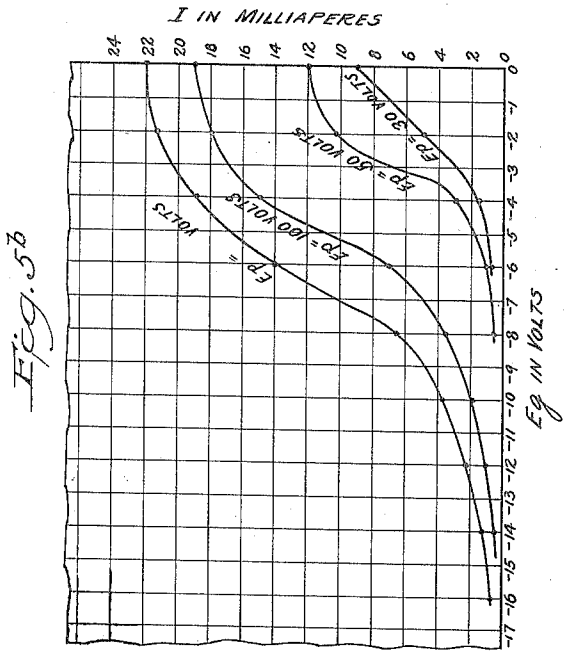


Fig. 5b

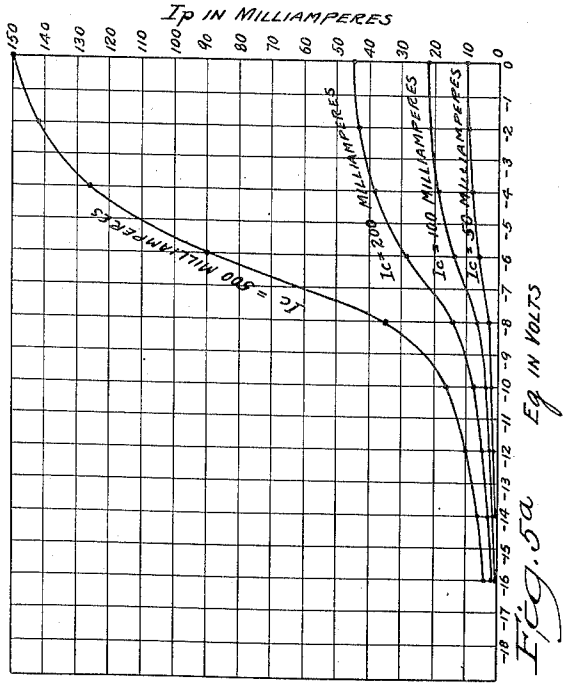


Fig. 5a

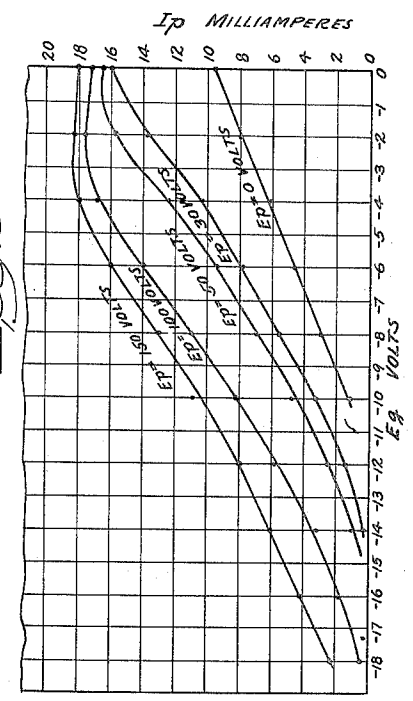


Fig. 6b

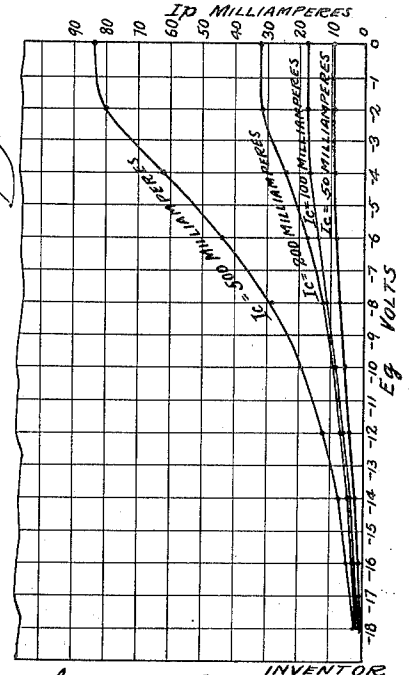


Fig. 6a

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Patented June 12, 1934

1,962,159

UNITED STATES PATENT OFFICE

1,962,159

GRID-CONTROLLED GASEOUS DISCHARGE TUBE

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Application August 25, 1930, Serial No. 477,495

2 Claims. (Cl. 250—27.5)

This invention relates to grid-controlled gaseous discharge tubes and it has among its objects the provision of highly efficient gaseous conduction tubes suitable for large power operation in which the space current flow is under control of a grid having an effectiveness similar to grids in high vacuum devices.

The objects and novel features of the invention will be best understood from the following description of exemplifications thereof, reference being had to the accompanying drawings wherein

Fig. 1 is a sectional view of a tube embodying the invention;

Fig. 2 is an enlarged detail, sectional view through the electrode assembly of the tube in Fig. 1;

Fig. 3 is a bottom view of a portion of the electrode assembly of the tube in Fig. 1;

Fig. 4 is a diagram of one of the circuit connections in which the tube of Fig. 1 may be used;

Figs. 5*a* and 5*b* are curve diagrams illustrating the performance of the tube in Fig. 1 when employed with a helium filling;

Figs. 6*a* and 6*b* are curve diagrams illustrating the performance of a tube like Fig. 1 having a filling of mercury vapor.

As is well known, the high vacuum grid-controlled electron tubes now generally used as amplifiers, oscillators, etc. are restricted in their output due to the space charge effect and the limited electron emission of the thermionic cathodes which supply the electrons serving as current carriers in the tube. For years those skilled in the art have been making endeavors to devise a gaseous conduction tube in which the conduction could be subjected to a control action similar to that exercised by the grids in high vacuum tubes. Gaseous conduction tubes have an advantage over high vacuum pure electron tubes in that the current conduction and the current carriers are chiefly supplied by the ionization of the gas in the tube, which is not limited by the electron emissivity of the cathode. Much greater currents at lower losses may thus be obtained from such gaseous conduction tubes and they are, therefore, by their very nature, specially adapted for use in large power applications.

Furthermore, in gaseous conduction tubes the space charge effect of the electrons which limits the conductivity in high vacuum tubes is substantially fully neutralized by the positive ions produced in the ionized gas, thus greatly reducing the impedance and the loss in the gas-filled tubes as against high vacuum pure electron tubes.

As far as I am aware, no one has heretofore made a gaseous conduction tube in which the current carriers are produced by ionization of a gaseous filling of the tube and in which the current conduction could be controlled at will by varying the charge on a grid interposed in the discharge path. This inability to control the current flow in gas-filled tubes has been explained by the fact that the positive ions in the gas form a sheath around the negatively charged grid, thus neutralizing any control effect which the charge might otherwise have on the current conduction. The tube of my invention overcomes these difficulties and secures positive control of the current flow in a gas-filled tube.

In order that the invention may be readily practiced by those skilled in the art, I shall first describe in detail the gaseous discharge tube shown in Figs. 1 to 4 as actually built and used by me and give the operating characteristics determined by tests with such tube.

As seen in the drawings the tube is made in the form of an elongated cylindrical envelope 11. The tube as actually built by me was about six inches long and two inches wide. On the two opposite ends, the tube has reentrant stems 12 and 13 terminating in presses 14 and 15, respectively. In the lower press 14 of the tube are sealed two lead-in wires 16 which hold an auxiliary cathode 17 in the form of a ribbon of nickel covered with an electron-emitting coating, for instance of barium and strontium oxides. The cathode ribbon 17 in the tube under consideration may be shaped into a wavy member extending transversely across the tube.

A distance above the cathode there is mounted transversely across the tube an electrode assembly which is shown in detail in Fig. 2 of the drawings. This electrode assembly comprises a circular disk 18 of mica extending through the full width of the tube and touching with its edges the surrounding glass walls so as to entirely segregate the lower region from the upper region of the tube. The central part of the mica disk has a circular opening 19 which is covered on the under side by a special perforated electrode in the form of a wire screen 20, the edges of the screen 20 overlapping the edges of the mica disk to secure positive segregation of the tube space below the screen from the tube space above the screen. On the upper side of the disk opening 19 is mounted a block of insulating material 21 such as lava. This block may be of square shape and has on its under side a circular depression 22 directly above the opening 19 in the mica disk 18. Within this depression lies a flat circular metallic disk 23

which forms the plate or main anode of the tube, the plate being held, as by a threaded connection, on supporting rod 24 which extends upwardly through a perforation in an insulating bushing 25 of magnesium oxide seated in the center of the lava block 21.

The opposite sides of the lava block 21 have milled therein fine parallel grooves as shown in Fig. 3 and a thin wire 26 is wound around this block along the closely adjacent grooves so that the under side of this winding lying over the opening into the depression 22 in which the anode 23 is mounted constitutes a grid 27 by means of which the discharge between the screen electrode 20 and the anode 23 is controlled as explained hereinafter.

The upper end of the supporting rod 24 of the anode forms a lead-in wire 28, which is sealed through the upper press 15 of the tube, the supporting rod being confined within an insulating sleeve of glass which fits at its opposite ends over a tubular extension 30 of the bushing 25 and a tubular extension 31 on the press 15, respectively.

The screen electrode 20 and the mica disk 18 are held in proper relationship against the lava block 21 by means of two supporting wires 32 secured in the press 15 and extending downwardly through perforations in the mica disk 18 where they carry wire members 33 welded to the under sides of the screen 20. One of the supporting wires 32 is sealed through the press and forms a terminal connection 34 for the screen electrode 20. The terminal connection to the grid 27 is provided by a lead-in wire 35 sealed through the press 15 and joined at its inner end to the upper side of the wire screen forming the grid 27.

The tube is evacuated in accordance with the usual vacuum technique, by pumping the tube and heat-treating the various members in the interior of the tube to drive out occluded gases. After the tube has been evacuated, it is filled with a gas filling. I have used this tube with a filling of helium and also with a filling of mercury vapor over a relatively wide range of pressures. When using the tube with a helium filling I admit the necessary quantity of helium after the tube has been completely evacuated and before sealing of the tube. When using the tube with mercury vapor I admit a drop of purified mercury into the tube before the tube is sealed.

In order to facilitate the ready practice of the invention, I am giving below complete data about the several elements entering into the construction of the anode assembly. The screen electrode 20 was made of a 60-mesh nickel screen of .007 inch wire. The plate 23 was made of nickel, .014 inches thick, one inch in diameter. The grid 27 was made of .005 inch molybdenum wire, the adjacent wire centers being spaced from each other .015 inches. The mica disk 18 was .004 inches thick.

The spacing between the screen electrode 20 and the grid 27 was about .010 inches and the spacing between the plate 22 and the grid 27 was .025 inches.

I desire it to be distinctly understood that in giving here and elsewhere in the specification the precise data and details of construction of the specific tubes which I have built, I do so merely with a view to enable those skilled in the art to more readily duplicate the results obtained by me, and speedily learn to practice the invention. It is not my intention to limit my invention to these precise details, but, on the contrary, many other materials and many other constructions will suggest themselves to those skilled in the art for carrying out the arrangements and principles of the invention as herein described, and it is my desire that all such modifications and variations shall be embraced by the claims following hereinafter.

In operating a tube as described above for amplifying purposes it may be connected as shown, for instance, in the diagram Fig. 4. The filamentary cathode 17 is connected to a winding of a supply transformer 36 so as to be heated to a temperature at which the filament is in electron-emitting condition. In the aforementioned tube which I have built the filament operated on a voltage of about three volts with a filament current of about six amperes.

Between the midpoint of the filament transformer 36 and the screen electrode 20 is connected a suitable source of current, for instance, a battery 37 for maintaining a gaseous discharge in the tube 11 between the cathode 17 and the screen electrode 20, the screen electrode being connected to the positive terminal of the source 37, a resistance 38 serving to control the current flow. The discharge between the cathode 17 and the screen electrode 20 produces thorough ionization of the gas in the part of the tube on the under side of the screen electrode 20, this screen electrode 20 acting with respect to the cathode 17 as an anode. Between the lead from the screen electrode 20 and the plate 23 is connected a plate circuit including a source of plate voltage, for instance a battery 41 having its positive terminal on the anode side of the circuit, and an output device 42 which may have, for instance, the form of an output transformer, loud speaker, or the like. The input circuit of the tube is formed by connecting between the lead from the screen electrode 20 and the grid 27 a source of biasing voltage, for instance in the form of a battery 43 and an input device 44 which may be for instance a phonograph pick-up coil, or the like.

The tube connected as aforesaid will operate as follows:

With the cathode filament 17 heated to an electron-emitting condition, the battery 37 will maintain a discharge between the cathode 17 and the screen electrode 20 which, as stated before, acts with regard to the cathode 17 as an anode. This discharge ionizes the entire space on the under side of the screen electrode 20, making the space an abundant supply of electrons due to ionization of gas molecules by collision with electrons, the electrons flowing towards the positive screen electrode 20. A large part of the electrons flowing towards the screen electrode 20 will pass through the screen openings, and once having gotten into the space above the screen, they will come under the influence of the field produced by the battery 41 connected between the screen electrode 20 and the plate 23. Under the influence of this field, the electrons will flow towards the positive plate 23, producing a flow of current in the plate circuit through the output device 42. In this discharge between the screen electrode 20 and the plate 23 the screen electrode 20 acts like a cathode supplying electrons for the discharge, the electrons coming from the ionized space below, just as if the screen electrode were a generator of electrons. Because of this dual nature of the screen electrode 20 acting with respect to the discharge from the auxiliary cathode 17 as an anode and with respect to the discharge to the plate 23 as a cathode, I designate it for convenience as a "kathanode".

The spacing between the anode 23 and the kathanode 20 is such that, under the pressure conditions existing in the tube, the distance between the opposing electrode surfaces is of the order of the mean free path of the molecules in the gas or, preferably, less. The lava block 21 covering the back of the anode eliminates also all long paths between the back surface of the anode 23 and the kathanode 20 and grid 27 so that all discharge paths between these electrodes of a length greater than approximately the mean free path are blocked and discharges along such long paths are made impossible.

Under such conditions the electrons which pass through the openings in the kathanode 20, on getting in the space between the kathanode and the plate 23, behave very similarly to electrons in a pure electron discharge device. A high potential may be applied by the battery 41 between the kathanode and the plate 23 without causing the electrons to produce substantial ionization by collision, the paths between the two electrodes being too short. The space current between the kathanode 20 and the plate 23 is accordingly substantially in the form of a pure electronic discharge and is readily controlled by the charge applied to the control grid 27 like in high vacuum electron tubes. Because of the construction and arrangement of the electrodes, there are not enough positive ions in the space between the kathanode 20 and the plate 23 to neutralize the control action of the charge impressed upon the grid 27, thus maintaining the control action of the control grid effective notwithstanding the fact that a high potential is applied to the place and the space is filled with gas.

A limited number of positive ions is generated in the space between the kathanode 20 and the plate 23, probably by electrons coming with an initial velocity through the openings in the kathanode screen. The limited number of positive ions thus present in the space between the kathanode screen 20 and the plate 23 is useful in the tube of my invention, serving to neutralize the space charge in the spaces and decreasing the impedance of the discharge path included in the plate circuit of the tube.

It is seen from the foregoing that the tube of my invention has two distinct sections. The lower section between the auxiliary cathode 17 and the kathanode 20 serves to maintain a discharge which ionizes the gas between these two electrodes producing an abundant supply of electrons. I designate the discharge between the cathode 17 and the kathanode 20 as the "exciting discharge".

The discharge between the kathanode 20 and the plate 23 is substantially purely an electronic discharge in which the current is carried by the electrons supplied from the exciting discharge path through the openings in the kathanode screen. This electronic discharge I designate as the "controlled discharge" since the electron flow in this space is maintained by the action of the potential applied by the source 41 in the plate circuit, this discharge being under the control of the grid 27.

With the foregoing arrangement, electrical impulses applied from the input device 44, which may for instance be a phonograph pick-up, to the control grid 27 will vary the electron flow between the kathanode 20 and the plate 23 producing corresponding variations in the current flowing in the plate circuit through the output device 42 in a manner similar to the effect of impulses impressed on the input circuit of a high vacuum tube on an output device connected in the output circuit of such tube.

In order to secure a wide field of usefulness of tubes of the foregoing character, it is important that the grid control of the current flow in the space between the kathanode 20 and the plate 23 be maintained with relatively high voltages applied to the plate. The useful power output of such tube depends first on the magnitude of the current changes produced in the plate circuit, and on the magnitude of the voltage changes in the output circuit, these voltage changes being directly limited by the maximum voltage that can be applied to the plate without destroying the control action in the discharge path between the kathanode and the plate.

The arrangement of the kathanode and the plate with the enclosed grid so as to eliminate and block all long discharge paths and prevent penetration of the ionized gas discharge into the plate discharge path enables the use of high voltages in the plate circuit. Since the electrons for the plate discharge path are derived from a body of ionized gas, it is readily possible to provide an abundant electron supply for the plate discharge path, thus overcoming the limitations of the restricted electron supply from a thermionic cathode as is the case in high vacuum tubes. The neutralization of the space charge effect by the limited number of positive ions in the plate discharge space reduces the impedance of the plate discharge path, making the losses in the tube smaller than in pure electron discharge tubes. All these effects combined make it possible to secure with such tubes an extremely high degree of amplification with a high mutual conductance and great power output.

In actual operation of a tube constructed as described above, with a filling of helium at a pressure of 1.17 millimeters mercury column, the tube had a mutual conductance of about 27,000 microohms corresponding to a variation of plate current from 40 milliamperes to 95 milliamperes on varying the grid potential between −7.8 volts and −5.8 volts. The tube operated with a cathode filament current of 5.7 amperes at a filament voltage of 2.6 volts. The exciting current between the kathanode and the cathode was 500 milliamperes at an applied voltage between the kathanode and the cathode of 38 volts. The plate voltage was 130 volts. As will be seen from the foregoing data, the tube had within the operating range in question a plate impedance of about 1700 ohms and an amplification factor of about 10. A full set of performance data of such tubes is given in the curves of Figs. 5*a* and 5*b*, 6*a* and 6*b*.

The curves in Figs. 5*a* and 5*b* are based on operating results of a tube as shown in Fig. 1 filled with helium at a pressure of 1.17 millimeters. The curves of Fig. 5*a* give the variations of the plate current in response to variations of the grid voltage for four different values of the current in the exciting discharge path, namely 50, 100, 200 and 500 milliamperes, the tube operating with a filament current of 5.7 amperes, cathode-kathanode voltage E_a=28 to 38 volts, and plate voltage E_p=130 volts. The meaning of the various symbols used is indicated by the arrows applied to Fig. 4, I_f designating the filament current, E_f the filament voltage, I_c the current to the filament 17, E_a the filament-kathanode voltage, I_p the plate current, E_g the grid voltage and I_g the grid current.

As will be seen for instance from the curve for the exciting current I_c=500 milliamperes, there

is a substantially straight-line curve portion for the plate current range between 40 milliamperes and 95 milliamperes, corresponding to the grid voltage variation between −7.8 volt and −5.8 volts. In order to operate on the straight part of the characteristic curve within the aforesaid range, the biasing battery 43 in the grid circuit will under such conditions be made equal to −6.8 volts and the applied control voltages would be caused to vary between plus and minus one volt, maintaining thus the variations of the grid potential between −5.8 and −7.8 volts.

The curves in Fig. 5*b* give the plate current I_p as a function of the grid voltage for different values of the plate voltage, the tube being operated with a cathode current I_c of 100 milliamperes at a voltage in the exciting circuit of about 50 volts.

The curves in Fig. 6*a* correspond to the curves in Fig. 5*b* and give the performance data of a tube in which instead of helium, a filling of mercury vapor was used. The mercury vapor in the tube was produced by placing a drop of mercury in the evacuated glass vessel as explained before. The operating data from which the curves in Figs. 6*a* and 6*b* were obtained were derived while operating the tube at a temperature between around 40° centigrade and 60° centigrade, the vapor pressure within the tube being probably between .006 and .030 millimeters mercury column, the cathode-kathanode voltage 11 volts, the plate voltage 100 volts and the filament current 6 amperes.

The curves of Fig. 6*b* correspond to the curves in Fig. 5*b*, likewise using a mercury vapor atmosphere instead of helium as the tube filling, the tube operating under conditions given in connection with Fig. 6*a*, with the cathode-kathanode current equal to 100 milliamperes.

In the foregoing I have given a full, detailed disclosure of the actual construction of a practical tube of my invention and the operating characteristics of such tube, although much better results may be readily obtained by more careful construction of the tube, as will suggest itself to those skilled in the art. I shall now explain what I at present believe are some of the essential features of construction and arrangement of the tube by means of which its special operating characteristics are secured.

In the first instance, the kathanode screen and its mounting in a tube are such as to prevent the ionized gas discharge in the lower part of the tube from entering into the upper part of the tube. To secure this result, the two discharge spaces of the tube should be entirely segregated and the screen which forms the kathanode 20 and the associated barriers must be of such construction as to prevent the gaseous discharge from extending through the perforations into the part of the discharge space between the kathanode and the plate. To make the kathanode screen 20 effective, I have found that the width of the openings between the screen wires or in general the perforations in the kathanode screen must not exceed certain limits. If the openings are too large, the resulting electrostatic field produced by the high voltage applied between the plate and the kathanode will cause the ionized gas discharge on the under side of the kathanode to be drawn into the plate discharge path. When this takes place the discharge usually, instead of being spread out over the whole lower kathanode surface, becomes spotted on a limited portion or point of the kathanode, penetrates into the space above the kathanode and provides intense ionization in the plate discharge path, entirely destroying the control action of the grid. The kathanode should not be made with too small openings, because in such case the electron supply in the space between the kathanode and the plate becomes small and a much higher plate voltage is necessary in order to obtain an appreciable plate current. It is difficult to give any definite data about the size of the openings in the kathanode screen, but if the foregoing considerations are kept in mind it is easy to determine in connection with each design what size of openings will be satisfactory.

In operating with a tube as described above with a helium pressure of the order of a few millimeters, I have found that a screen having openings of about ¼ of an inch wide produces ready spotting of the discharge at the kathanode screen and penetration of the gaseous discharge in the plate discharge path, and causing destruction of the grid control action. Screens having openings of about 10 mill widths have been found very satisfactory. The size of the required kathanode screen openings can be readily determined by varying the width of the screen openings until under the given pressure conditions and the given plate voltage, the discharge does not spot through the kathanode screen but remains distributed on its under side.

In the construction of the kathanode screen it is desirable to make the screen wires relatively thin so that a relatively large portion of the kathanode screen area shall be formed of openings. This prevents excessive collection of electrons on the kathanode screen and secures ready passage of the large number of electrons from the exciting space below the kathanode into the control space above the kathanode.

To secure effectiveness of the kathanode screen it is also essential that it be so mounted within the tube that the gaseous discharge in the exciting space cannot get into the plate discharge path by passing around the border of the screen. In the construction of my invention this is secured by the provision of the mica disk overlapping the kathanode screen edges and fitting against the walls of the tube. Such separation and segregation of the discharge spaces can be secured in other ways as will suggest itself to those skilled in the art.

Another important feature for securing operativeness of the tube of my invention under high plate voltages resides in the elimination of long discharge paths between the kathanode and the plate. Unless this is carefully taken care of, as by the arrangement of the lava block shown in Fig. 1, or by some other construction, the application of a high voltage between the plate and the kathanode screen will result in a gaseous discharge in the plate discharge space or parallel thereto, notwithstanding the short path spacing between the main part of the plate surface and the kathanode surface. If a long discharge path between for instance the back side of the plate and an edge portion of the kathanode screen remains unblocked, the application of a substantial voltage to the plate will produce a gaseous discharge which will render the action of the control grid ineffective and make the tube inoperative for the purpose intended.

Another important feature resides in the elimination of direct discharges between the control grid and the cathode. If such discharges are not limited, sufficient positive ions will be generated

near the control grid to cause it to lose is control action by some such effect as the formation of a positive ion sheath as mentioned before.

As seen in the drawings, the kathanode 20, the anode 23, control grid 27, and their leads are so arranged that electrons accelerated by the field acting on the gaseous discharge space between the cathode 17 and kathanode 20 cannot get into parts of the tube outside the short-path space between the anode and kathanode, or, in general, into spaces where long paths extend between parts of the anode, kathanode and grid.

The control grid is preferably made of thin wires in order to make the collecting area of the grid as small as possible. To secure efficient control action of the grid the wires should be spaced rather closely; the larger the spacing, the smaller the effectiveness of the control and the larger the grid voltage, that is required to secure a definite control action.

In operating the tube of my invention it is important that within the operating range the grid current shall be kept to a very low value so as to reduce as much as possible the power input necessary for obtaining a given power output. In the tubes of my construction as described before, I have found that with the control grid at zero potential, the grid would be collecting a small electron current indicating that a part of the electrons passing through the openings in the kathanode collect on the control grid. After raising the grid potential to a sufficiently negative value, positive ions from the relatively small number of positive ions in the plate discharge space begin to collect on the grid and when a sufficiently high negative voltage is applied to the grid, the amount of positive ions collected predominates the amount of electrons and a small positive grid current will flow in the input circuit. However, this positive grid current remains practically constant within relatively wide variations of negative potential applied to the grid. This is a very desirable characteristic because under all practical conditions the tube is operated with a negative grid voltage at which the grid current is in the range at which it does not substantially vary with the variations of the grid potential, thus making the ratio of the input power to the output power very small and efficiency of power amplification very great.

In the exemplification described above, the exciting discharge between the cathode and the kathanode was maintained by means of a thermionically emitting hot cathode. However, a tube like that shown in Fig. 1 will operate in accordance with substantially the same manner if the exciting discharge is maintained in the gaseous medium within the exciting space in some other way. For instance, the gas in the exciting space may be ionized by maintaining a glow discharge between the cathode 17 and the kathanode 20 in which case of course a higher voltage will be required between the cathode and the kathanode, but the use of a thermionically emitting cathode is preferable. Other forms of discharges for ionizing the gas in the exciting space may be used instead.

Many modifications of the tube construction shown and described above will suggest themselves to those skilled in the art and various materials and arrangements will suggest themselves to those skilled in the art as substitutes for those referred to in the description of the specific exemplification. It is accordingly desired that my invention shall not be limited to any specific details of construction or to any specific materials referred to but that it be accorded a broad construction commensurate with the scope of the invention within the art.

I claim:

1. A space current device comprising a gas-tight envelope containing a gas at a pressure sufficient to sustain an ionizing discharge therethrough, a screen electrode having perforations over its surface, an anode disposed on one side of said screen electrode and spaced therefrom by a gap sufficiently short to prevent gas ionization therebetween by the potential applied to the electrodes, a thermionic cathode, a control grid mounted between said anode and said screen electrode for controlling the electron flow to said anode, and insulating barrier means isolating said anode, grid and screen electrode against ionization from the region of said cathode.

2. A space current device comprising a gas-tight envelope containing a gas at a pressure sufficient to sustain a gaseous discharge therethrough, a screen electrode having perforations over its surface, an anode disposed on one side of said screen electrode and spaced therefrom by a gap of the order of the mean free path of a gas molecule or less, a thermionic cathode on the side of said screen electrode opposite said anode sustained gaseous discharge, a control grid mounted between said anode and said screen electrode for controlling the electron flow to said anode, and insulating barrier means isolating said anode, grid and screen electrode against ionization from the region of said cathode.

JAMES D. LE VAN.

CERTIFICATE OF CORRECTION.

Patent No. 1,962,159. June 12, 1934.

JAMES D. LE VAN.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 4, line 4, for "volt" read volts; page 5, line 1, for "is" read its; and line 124, claim 2, strike out the words "sustained gaseous discharge"; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 24th day of July, A. D. 1934.

Bryan M. Battey

(Seal) Acting Commissioner of Patents.