

Sept. 28, 1937.

H. GEFFCKEN ET AL

2,094,450

GAS DISCHARGE DEVICE

Filed June 29, 1933

2 Sheets-Sheet 1

Fig. 1

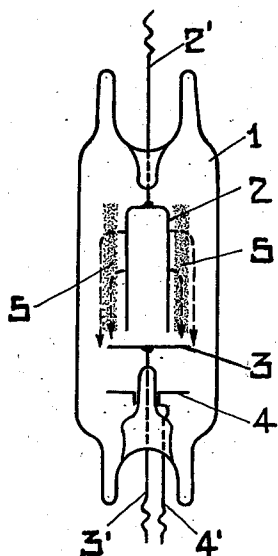


Fig. 2

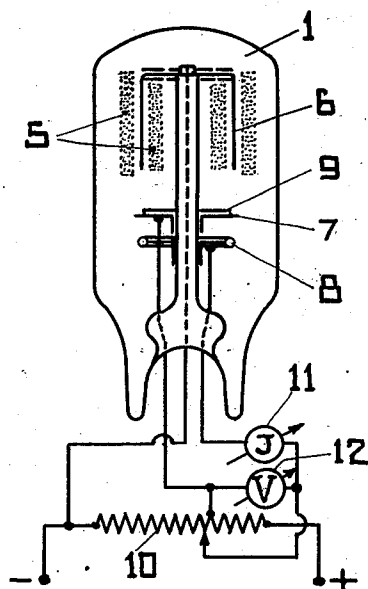


Fig. 3

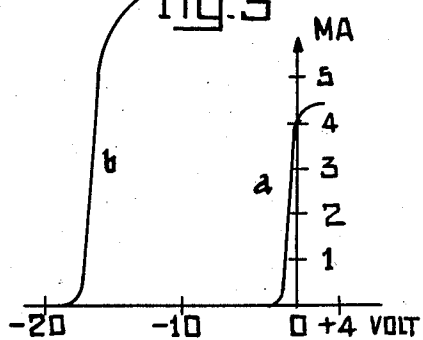


Fig. 4

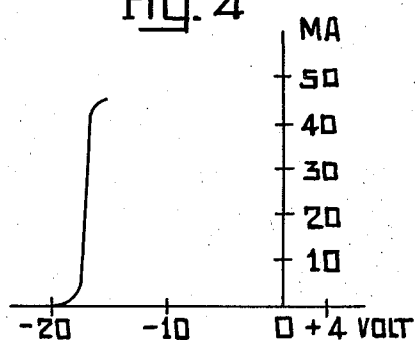
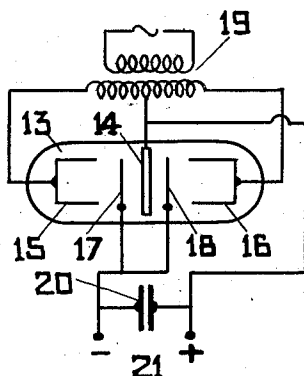


Fig. 5



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2 Sheets-Sheet 2

Fig. 6

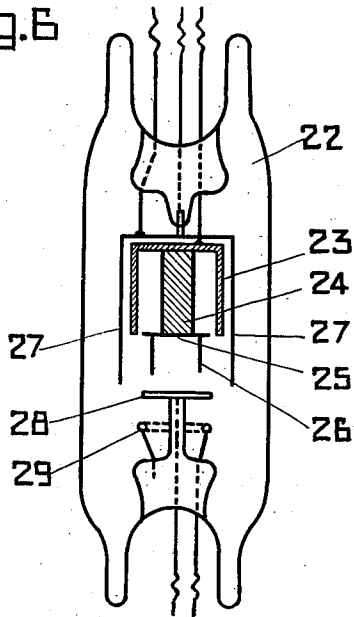


Fig. 7

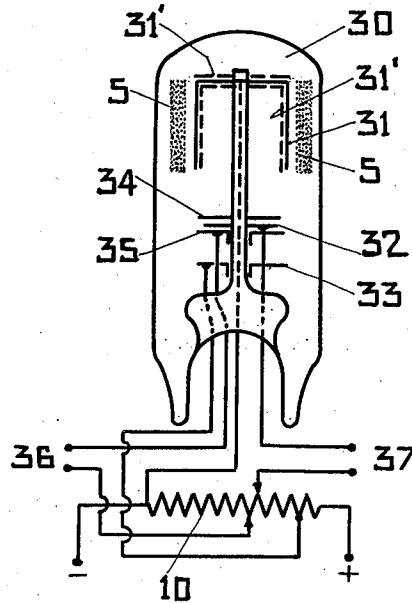


Fig. 9

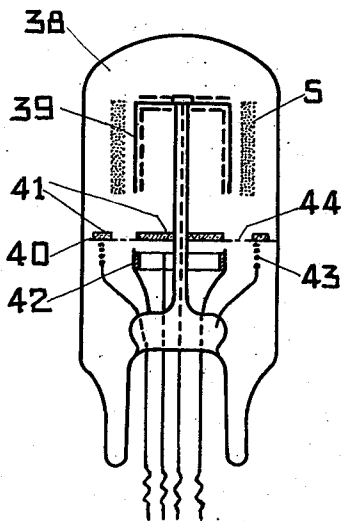


Fig. 10

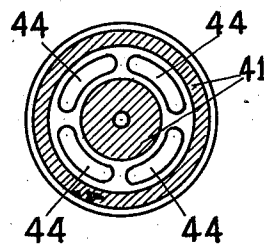
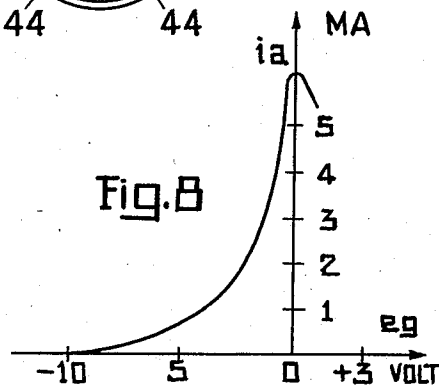


Fig. 8



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GAS DISCHARGE DEVICE

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16 Claims. (Cl. 250—27.5)

Our invention relates to electric discharge devices and more particularly to gaseous discharge tubes as used for amplification, rectification and generation of electric currents.

As is well known, gas discharge amplifiers differ from the known vacuum tube amplifiers by an increased discharge current due to the ionization of the gaseous atmosphere preferably a noble gas contained in the tube. A further advantage of tubes of this type resides in the absence of a hot cathode liable to burn out after a limited number of operating hours, thus making the life of gaseous discharge tubes practically unlimited.

In the usual construction, gaseous discharge tubes as used for amplification, rectification and similar purposes in the communication and power engineering art, generally comprise a vessel filled with a gaseous atmosphere preferably a noble gas and including a cathode and a first anode or positive electrode hereinafter referred to as the "discharge anode". An electric glow discharge is set up between the cathode and the discharge anode serving as a source of negative ions and electrons to be dissociated from the primary discharge and directed toward a second positive or anode electrode, hereinafter called the "operating" or "suction anode". In a discharge tube of this kind, the primary discharge between the cathode and the auxiliary or discharge anode may be likened to the hot cathode in a pure vacuum tube and serves as a source of pure negative discharge carriers (negative ions and electrons) travelling to the operating or suction anode and capable of being governed in a manner similar to vacuum tubes of known construction, such as by means of a grid or similar control electrode.

It is one object of our invention to provide a gas discharge tube of improved construction to secure a well defined and concentrated discharge stream consisting substantially of electrons and negative ions and capable of being easily and efficiently controlled.

Another object of our invention consists in a novel operation of and the provision of means for gas discharge control devices for increasing the sensitivity and efficiency as compared to similar devices known in the art.

Further objects and aspects of our invention will become more apparent from the following detailed description taken in reference to the accompanying drawings in which we have illustrated a few constructions of discharge devices embodying the novel features of the invention.

Figure 1 shows schematically a simple form of

electrode construction for a gaseous discharge device in accordance with the invention.

Figure 2 shows an improved electrode structure according to the invention.

Figures 3 and 4 represent characteristic curves explanatory of the operation of gas discharge devices in accordance with the invention.

Figure 5 shows a circuit embodying a novel gas discharge device in accordance with the invention for converting alternating current into highly stable direct current.

Figure 6 illustrates another tube construction utilizing a heated cathode in place of the cold cathode arrangement according to the previous figures.

Figure 7 illustrates a discharge tube in accordance with the invention especially designed for amplifying purposes.

Figure 8 illustrates an operating characteristic curve of a tube as described by Figure 7.

Figure 9 shows another design of a gaseous amplifying tube according to the invention.

Figure 10 shows the discharge anode construction for a tube of the type shown by Figure 9.

Similar reference numerals denote similar parts throughout the different views of the drawings.

The novel features embodied in a gaseous discharge tube in accordance with the invention are based on the following considerations: Electrons emitted from a flat shaped cathode electrode in a glow discharge tube, as is well known, leave the cathode surface substantially at right angles and retain this direction until they pass the region of the space charge filling the space parallel to the cathode surface. Only after the electrons have passed the space charge region, will the shape and configuration of the anode exert an appreciable influence upon the further movement of the electrons.

This fact is made use of in our invention as illustrated by Figure 1 of the drawings showing a simple form of an electrode construction embodying the invention. We have shown in Figure 1, a discharge vessel 1, preferably of flattened shape filled with a gaseous atmosphere, such as a noble gas, at reduced pressure and including a cathode plate 2 bent to the shape of a U, and a rectangular shaped anode 3 and a further auxiliary anode 4 of similar shape, both anodes being arranged in such a manner that their edges approximately coincide with the prolongation of the cathode surface 2. In a tube of this type, the electrons emitted from the cathode 2 travel along a path, as indicated by the dotted arrows, that is, at first at right angle to the

cathode surface through the glowing layer 5 and then in a direction substantially parallel to the cathode surface towards the anodes 3 and 4. By providing means in a known manner to prevent further ionization along the path 5—3 such as by suppressing a positive column and an anode glow, a practically ion-free electron beam is obtained directed towards the anodes 3 and 4. We have discovered that this electron beam is of well defined and concentrated shape and is capable of being easily and efficiently controlled by means of extremely small potential variations applied within a controlling region (3—4) in the prolongation of the cathode surface. The edges of the electrodes 3 and 4 enclosing the control region need not necessarily coincide exactly with the prolongation of the cathode surface, but deviations therefrom are admissible, especially when taking into account the effect of wall charges and of the cathode drop within the tube. The electrodes 2, 3, and 4 may be mounted and supported within the tube in any known manner and connected to the outside, such as by leads 2', 3', and 4' as shown.

We have discovered that especially favorable effects may be secured by using a hollow cathode whereby a substantially increased cathode surface is obtained with a resultant increase of the emission current without increasing the size of the other electrodes. By choosing a cathode of cone shape or cylinder shape adapted to the shape of the discharge vessel, a uniform effect of the wall charge on the discharge is obtained and unsymmetrical fields practically avoided, thereby materially increasing the efficiency and performance of the tube.

A construction of this type is shown by Figure 2. We have shown a discharge tube 1 including a cup shaped cathode 6 and a pair of disc shaped anodes 7 and 8 substantially conforming to the cross-section of the cathode and arranged at right angles thereto in a manner similar to that described by Figure 1. The first mentioned anode 7 may be covered with an insulating coating 9, such as with a sheet of mica, covering the anode surface close to its edges. The surface of this insulator will be negatively charged during operation, thus exerting a repelling force upon the electrons and serving together with the wall charges of the tube 1 to define and concentrate the tubular shaped discharge beam emitted from the cathode.

Referring to a practical example of a discharge tube according to the invention, we have observed the following characteristics: By producing a primary discharge of about 50 milliamperes intensity between the electrodes 6 (cathode) and 7 (discharge anode), and by plotting the voltage-current characteristic for the second or operating anode 8 for potentials in the vicinity of and taken relative to the potential of the anode 7, characteristic discharge curves are obtained as shown by Figure 3, very much alike to the discharge characteristics of pure high-vacuum tubes known in the art.

For plotting these curves, a circuit may be used as shown by Figure 2 comprising a suitable source of current, such as indicated by the plus and minus signs connected to potentiometer 10 provided with tap connections for securing the potentials for the electrodes of the tube. The cathode 6 is connected to the negative terminal of source 10, the discharge anode 7 is connected to a tap point on the potentiometer 10 supplying a positive operating potential, and the operating or

suction anode 8 is connected through an ammeter 11 to a variable contact on the potentiometer to secure a varying potential in the vicinity of the potential of the discharge anode 7.

We have furthermore shown a voltmeter 12 for indicating the potential difference between the discharge anode 7 and the operating anode 8. Curve *a* of Figure 3 was taken for a tube of the type according to Figure 2 without the mica sheet applied to the discharge anode 7. It is readily seen from this curve that the portion of the cathode ray emanating from the cathode and shooting past the anode is still capable of counteracting a negative bias of about 1 volt at 1.5 milliamperes intensity. With a two volt negative bias, the current becomes zero. This curve represents an ideal detector characteristic having a very sharp bend and a mutual conductance of more than 1.5 milliamperes per volt.

The curve *b* has been plotted with the mica sheet 9 placed upon the discharge anode 7. It is readily seen from the shift of the bend towards the negative by an amount of almost 17 volts, that in this case the major part of the electrons emitted from the cathode 6 travel past the anode 7. The mutual conductance of the detector characteristic increases to about 5 milliamperes per volt, and the relative emission yield with respect to the available total emission current (50 milliamperes) is increased.

We have discovered that the available mutual conductance may be further increased by giving the electrode 8 the shape of a wire ring as shown, or of a narrow metal sheet cylinder (such as 42 in Fig. 9) in place of a solid or disc shape as shown in Figure 1; that is, in other words, by utilizing only the marginal zone for effecting control. In this latter case, a slight increase of the negative bias of the electrodes will suffice to deviate and return passing electrons towards the anode 7. By using discharge tubes of this type and maintaining the proper operating conditions, it was possible to secure mutual conductances of 14 to 20 milliamperes per volt. This makes the tube admirably suited for detecting purposes.

Tubes of this type represent practically ideal rectifiers, it being possible to shift the potential of the electrode 8 from the bend of the characteristic shown towards negative values by about 20 to 50 volts without increasing the ionic current flow over a few microamperes.

Essentially higher values of mutual conductance, however, with less ideal rectifying properties may be obtained by setting up the primary glow discharge between the electrodes 6 (cathode) and 8 (discharge anode); that is, by exchanging the connections for the electrodes 7 and 8 in the circuit as shown by Figure 2. If now a current-voltage characteristic for the electrode 7 is plotted, a curve is obtained as shown by Figure 4 with no insulating or mica sheet applied to the electrode 7. The mutual conductance will be nearly 50 milliamperes per volt. It is readily seen that a negative bias of the electrode 7 of about 1 volt relative to the anode 8 (position of the lower bend) is sufficient to swell the tubular shaped cathode beam emitted from the cathode to such an extent that practically no electron reaches the electrode 7, whereas a potential shift of only 1 volt towards positive values will result in the flow of almost the entire discharge current.

Discharge tubes according to the invention as described, may be advantageously used as voltage stabilizers. In this case, it is possible to

secure a plurality of potentials by arranging several operating or suction anodes in spaced relationship opposite the cathode 6 in place of the single operating anode 7 as shown in Figure 2. In this manner, a voltage stabilization is obtained far superior to similar arrangements known in the art.

We have furthermore discovered that tubes of the type according to the invention may be used to great advantage for supplying highly stabilized direct current potentials from alternating current networks. We have shown a circuit of this kind in Figure 5, comprising a gas discharge tube 13 including an anode 14 disposed intermediate a pair of cup shaped cathodes 15 and 16. We have furthermore shown two operating or suction anodes 17 and 18 placed in the discharge path at either side of the anode 14. The alternating current is supplied through a transformer 19, the secondary of which has a center tap connected to the anode 14. The open terminals of the secondary of the transformer 19 are connected to the cathodes 15 and 16, as shown. It is possible under circumstances, to dispense with the anode 14 since either cathode may alternately operate as an anode. The stabilized direct current potential is supplied from the terminals 21 connected between the center tap of the transformer secondary and the operating or suction electrodes 17 and 18. A single condenser 20 in parallel to the output terminals is sufficient to smooth out the alternating current ripples in view of the high stabilizing action of the tube, thus making unnecessary the use of further smoothing elements, such as choke coils, etc., and greatly simplifying thereby the circuit arrangements and decreasing costs.

The mutual conductance in the previous examples was given in relation to the total glow discharge current. By increasing the primary glow discharge current, the mutual conductance in general increases proportionately. Such increase may be effected in a large degree by coating the cathode with electron emitting material and heating it to emission temperature. In this case, the cathode is preferably made of a tubular shape whereby the discharge takes place from the inside walls of the tube, thus avoiding any possible heat losses. In order to secure a well defined cathode beam, the cathode may be covered with a covering member having an opening to allow the escape of the electrons, or the core containing the heating elements may be constructed in proper shape to secure a concentrated and well defined emission beam.

A practical embodiment of a cathode construction of this type is shown by Figure 6. The discharge vessel 22 contains the tubular shaped cathode 23 which may be heated in a known manner by means of a heating element included in a heater core 24. The open end of the cathode is covered by means of a plate 25 in such a manner as to leave a narrow open margin. The plate 25 carries a collar 26. We have furthermore shown a heat screen 27 extending beyond the opening of the cathode 23, thus leaving an annular open space between the collar 26 and the screen 27. In this manner, a directive action is exerted upon the cathode beam, insuring a well defined and highly concentrated discharge.

Anodes 28 and 29 are arranged opposite the cathode in a manner similar as described in the previous figures. The operating voltage drop of a tube of this type is about 15 to 25 volts, re-

sulting in an increased operating efficiency of tubes of this type as compared with high vacuum tubes known in the art. In order to start the glow discharge or to ignite the tube, a positive potential may be applied to the screen 27 for a short period, for which purpose the screen 27 is carefully insulated from the other electrodes and provided with a separate outside connecting lead sealed in the tube. With tubes of this construction, values of mutual conductance up to several amperes per volt may be easily secured. It is understood that all further features regarding the direction and control of the cathode beam as described in previous and subsequent figures may be utilized in a tube as described by Figure 6.

A noteworthy characteristic of the rectifying curves secured by means of discharge tubes according to the invention resides in their great similarity with thermionic discharge characteristics obtained by means of high vacuum tubes, as seen clearly from the diagrams according to Figures 3 and 4. From this it follows that the phenomenon is of purely electronic nature and that ionization has an appreciable influence only in the direct vicinity of the cathode electrode.

Starting from this recognition, we have endeavored to utilize this phenomenon for designing a new and highly efficient amplifier. For this purpose it is merely necessary, by means of suitably constructed and arranged auxiliary electrodes, to control the number of those electrons hitting the positive electrode serving as operating or suction anode. A mode of execution of a control tube of this type is shown by Figure 7. We have again shown a gas discharge vessel 30 including a cup shaped cathode 31. The inside surface of the cathode and the top outside surface are covered with mica sheets 31' to confine the glow discharge proper to the cylindrical outside surface as shown at 5. The tube furthermore contains two anode electrodes of similar shape and arranged at right angles to and spaced from the cathode, as described by the previous figures. The primary discharge takes place between the cathode 31 and the anode 33 (discharge anode) whereas the anode 32 is used as the operating or suction anode as shown by the connections to the potentiometer 10 through the load circuit connected at 37. The operating anode 32 is surrounded by a control electrode comprising two plates 34 and 35 arranged at either side of the electrode 32. The input control potential is applied to terminals 36 and the controlled or amplified current is supplied from the output terminals 37. Tubes of this type allow a control over a wide voltage swing and have a considerable mutual conductance. However, they are less suited for pure amplification on account of the appreciable currents in the control (grid) circuit. They may be used to great advantage for various other purposes, preferably as regulating devices.

By exchanging the position of the electrode 33 with the electrode system 32, 34, 35, the possible voltage swing is somewhat decreased, on the one hand, but the grid currents, on the other hand, become inappreciably small. An operating characteristic secured from a tube of this type is shown by Figure 8. The voltage difference between the glow discharge anode and the suction anode was about 4 volts in the example, corresponding to this curve, the abscissae e_g representing the input or grid potential and the ordinates i_a representing the output currents. With

a primary discharge of about 50 milliamperes, the control current swing is about 6 milliamperes. The characteristic has a typically parabolic shape so that the tube may be used advantageously for automatic amplitude regulation. The maximum mutual conductance is about 1.5 milliamperes per volt.

In place of screening the suction anode by the control electrode—which may also have the shape of a grid in place of a solid electrode as shown—we have found it advantageous to arrange the grid in such a manner that the electron beam is controlled by deviation by the grid towards the operating or suction anode. In this manner, the grid currents decrease with increasing anode current, a condition of great importance for the design of amplifying apparatus.

A tube of this type is shown by Figure 9 of the drawings. The discharge vessel 38 includes a tubular cathode 39 of similar construction as described by Figure 7, a discharge anode 40 covered with a mica sheet 41, a cylindrical suction anode 42 and a control electrode 43 consisting of a plurality of wire rings. The discharge anode 40 is provided with cut-out openings 44, as shown by Figure 10, separated merely by narrow stiffening portions. The tubular shaped electron beam emitted from the cathode 39 passes through the holes 44 into the space enclosed between the suction anode 42 and the control electrode 43. The suction anode 42 and the control electrode (grid) 43 are preferably biased negatively by a few volts relative to the discharge anode 40. The number of electrons attracted by the suction anode will be the higher, the higher the negative bias of the control electrode 43.

The amplifying tubes above described may obviously be provided with a heated cathode in place of the cold glow discharge as shown and since it is well known that considerably increased emission currents are obtained when using an attenuated atmosphere due to the influence on the space charge as compared with a high vacuum, amplifying tubes are obtained in this manner of appreciable performance and efficiency as compared to similar devices known in the prior art.

The filling to be used for discharge tubes according to the invention preferably consists of gases being free from metastable conditions, such as argon and krypton. A special advantage of the noble gases resides in their high ionization potential and it is therefore preferable to use gases in as pure a state as possible. The gaseous pressure should be low to avoid a disturbing dispersion of the cathode beam, and we have found it advantageous to use pressures below 5 millimeters Hg. When using cold cathodes the most favorable operating region, depending on the gas used and on the cathode material used is about 5 to .2 millimeters Hg. When using hot cathodes, the pressure may be considerably decreased, in some cases below one-thousandth of a millimeter. In this case, it has been found favorable to use mercury vapor or the heavy noble gases, such as xenon and krypton, on account of their high compensating effect on the space charge in the tube.

The constructions shown in the drawings are specially characterized by the feature that the anodes are formed geometrically similar to the cross-section of the cathode and arranged concentrically in the tube in such a manner, that their edge-zones approximately coincide with the prolongation of the cathode surface. By these means between the—preferably metallized e. g.

silvered—inner walls of said tube and the cathode surface a tubular shaped stream of electrons is formed which is directed to the edge-zone of the discharge anode and which by very low controlling potentials may be swelled or choked thus passing or reaching the operating anode.

Although we have described our invention specifically with reference to the constructions and embodiments shown by the drawings, it is understood that the broad ideas and underlying principles of the invention are subject to numerous variations and modifications coming within the broad scope and spirit of the invention as expressed by the ensuing claims.

We claim:

1. A glow discharge device comprising a tubular shaped vessel filled with a gaseous atmosphere at reduced pressure, a hollow cylindrical cathode arranged coaxially to and within said vessel and having its inner surface lined with insulating material, a first disc shaped anode substantially equal to the cross-section of said cathode and disposed coaxially and in spaced relationship thereto for producing a concentrated annular electron discharge stream from the outer surface of said cathode to said anode and a second electrode of similar shape to said anode arranged in spaced relationship and coaxial with said anode.

2. A glow discharge device as claimed in claim 1 in which said discharge anode is closest to the cathode and is covered with an insulating coating close to its edges.

3. A glow discharge device as claimed in claim 1 including a control element for influencing the discharge current to said operating anode.

4. A negative glow discharge device comprising a tubular shaped vessel filled with a gaseous atmosphere at reduced pressure, a hollow cylindrical cathode arranged coaxially with and within said vessel having its inner surface lined with insulating material, a first disc shaped anode arranged coaxially with and in spaced relationship to said cathode, means for setting up an electric glow discharge between said cathode and said anode, and a second annular shaped operating anode spaced from and disposed coaxially to said first anode.

5. A glow discharge device as claimed in claim 4 including a control electrode for influencing the discharge current to said second anode.

6. A glow discharge device as claimed in claim 4 in which said first anode is arranged closest to said cathode and provided with openings to allow the passage of the discharge stream to said second anode.

7. A glow discharge device comprising a tubular shaped vessel filled with a gaseous atmosphere at reduced pressure, a cup-shaped cylindrical cathode electrode mounted coaxially with and within said vessel, a disc shaped discharge anode electrode arranged in spaced relationship to the open end of and coaxially with said cathode, a second operating anode disposed in spaced relationship to said discharge anode and away from said cathode, means including a coating of insulating material covering the inner walls and the outer bottom wall of said cathode cup for setting up a negative glow discharge between the outer cylindrical surface of said cathode and said discharge anode to produce a tubular shaped stream of negative discharge carriers substantially parallel to the cylindrical surface of said cathode and in a direction towards said operating anode, said first anode being provided with open-

ings for passing said negative discharge stream.

8. A glow discharge device as claimed in claim 7 in which the surface of said discharge anode facing said cathode is covered with a coating of insulating material.

9. A glow discharge device as claimed in claim 7 including a control electrode arranged to control the discharge stream to said operating anode.

10. In a glow discharge device as claimed in claim 7 in which said operating anode is of cylindrical ring-shape and disposed coaxially to said discharge anode and a cylindrical control grid electrode arranged coaxially with and surrounding said operating anode.

11. An electrical discharge device comprising an envelope, a gaseous atmosphere therein, a cylindrical cathode, a disc-shaped anode of substantially equal contour to the cross-section of said cathode and arranged coaxially with said cathode and spaced therefrom, means including a member disposed adjacent to the inner surface of the cathode to produce an annular electron discharge stream from the outer surface of said cathode to said anode, and a further anode electrode spaced in relation and coaxial to said first anode and adapted to variably concentrate and diffuse said electron stream.

12. An electrical discharge device comprising an envelope, a gaseous atmosphere therein, a cylindrical cathode, a disc-shaped anode having a diameter substantially equal to the diameter of said cathode and arranged coaxially with said cathode and spaced therefrom, means including a member disposed adjacent to the inner surface of the cathode for producing an annular discharge stream between the outer surface of said cathode and said anode, and further electrode means for varying the degree of concentration of said stream in accordance with input potential fluctuation.

13. An electrical discharge device comprising an envelope, a gaseous atmosphere therein, a cylindrical cathode therein having an outer electron emitting surface, a disc-shaped anode of substantially equal contour to the cross section of said cathode and arranged in spaced relation to and coaxially with said cathode for producing a concentrated annular electron discharge stream between said emitting surface and said anode, and an additional electrode of substantially equal contours to and arranged coaxially with said

anode and adapted to vary the degree of concentration of said electron stream in accordance with applied controlling potential variations.

14. A gas discharge tube for the amplification, rectification, or generation of electric current fluctuations comprising a vessel, a gaseous atmosphere therein, a cylindrical cathode therein having an outer emitting surface, a layer of insulating material disposed adjacent to the inner cathode surface, a first anode being disposed at right angle to the axis of said cathode and having its contour substantially equal to and in line with the prolongation of the cathode cylinder surface, means for setting up a substantial annular shaped gas discharge stream from the outer surface of said cathode to said anode, and at least one further electrode spaced from said anode for attracting electrons from said discharge stream around the edge of said first anode.

15. An electrical discharge device comprising an envelope containing a gaseous medium, a cylindrical cathode having an electron emitting surface, a similarly shaped member spaced from and enveloping said cathode and adapted to have a suitable potential impressed thereon, a disc-shaped anode of substantially equal contour to the cross section of said cathode and arranged in spaced relation to and coaxially with said cathode for producing a concentrated annular electron discharge stream between said emitting surface and said anode, and an additional electrode of substantially equal contour to and arranged coaxially with said anode and adapted to vary the degree of concentration of said electron stream in accordance with applied controlling potential variations.

16. An electrical discharge device comprising an envelope containing a gaseous medium, a cathode having an extended emitting surface, means for concentrating the electron emission from said cathode into an annular discharge beam, an anode of substantially equal contour to the inner cross-section of said discharge beam and arranged in spaced relation to said cathode and coaxially within said beam, and an additional electrode of substantially equal contour to and arranged coaxially with said anode and adapted to vary the degree of concentration of said electron beam in accordance with applied controlling potential variations.

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