Feb. 6, 1951

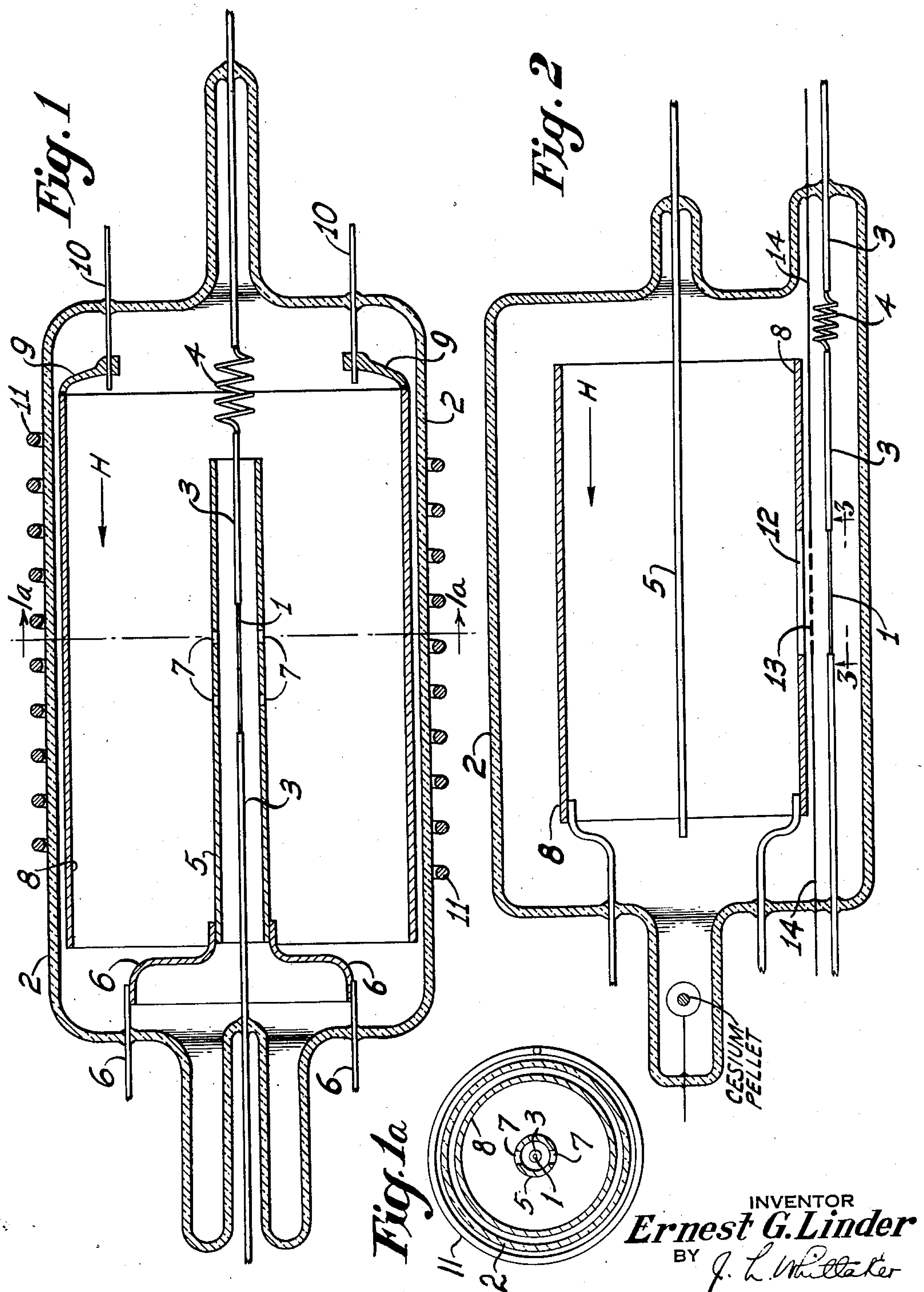
E. G. LINDER

2,540,537

VACUUM TUBE CURRENT AMPLIFIER

Filed Dec. 18, 1948

2 Sheets-Sheet 1



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Filed Dec. 18, 1948 2 Sheets-Sheet 2

Fig. 3

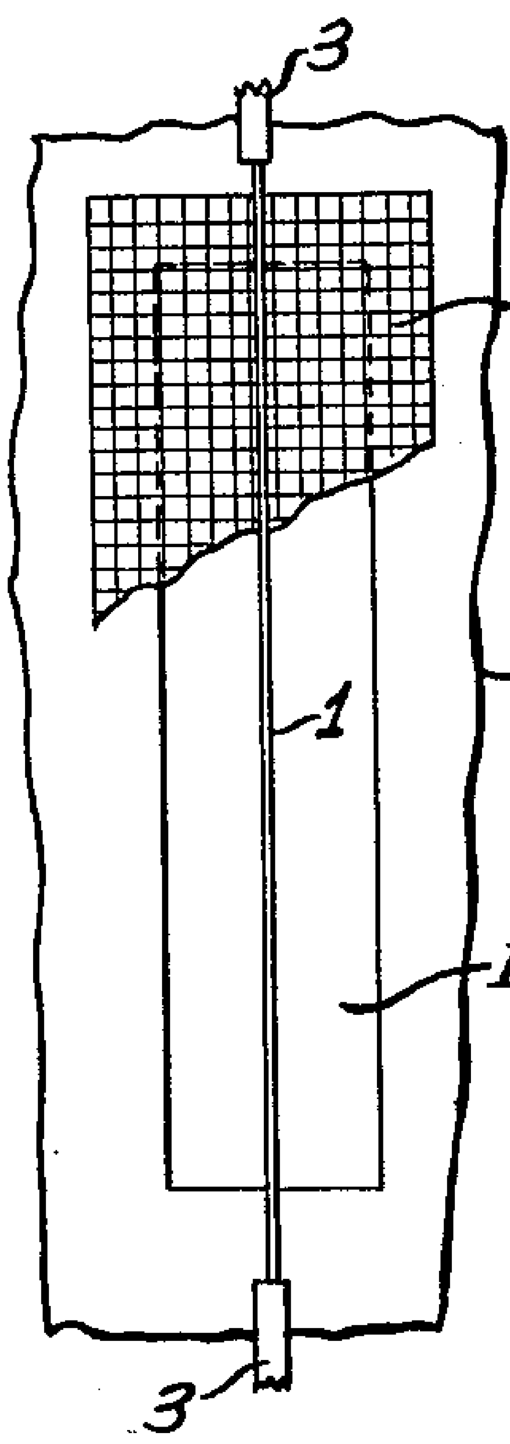


Fig. 4

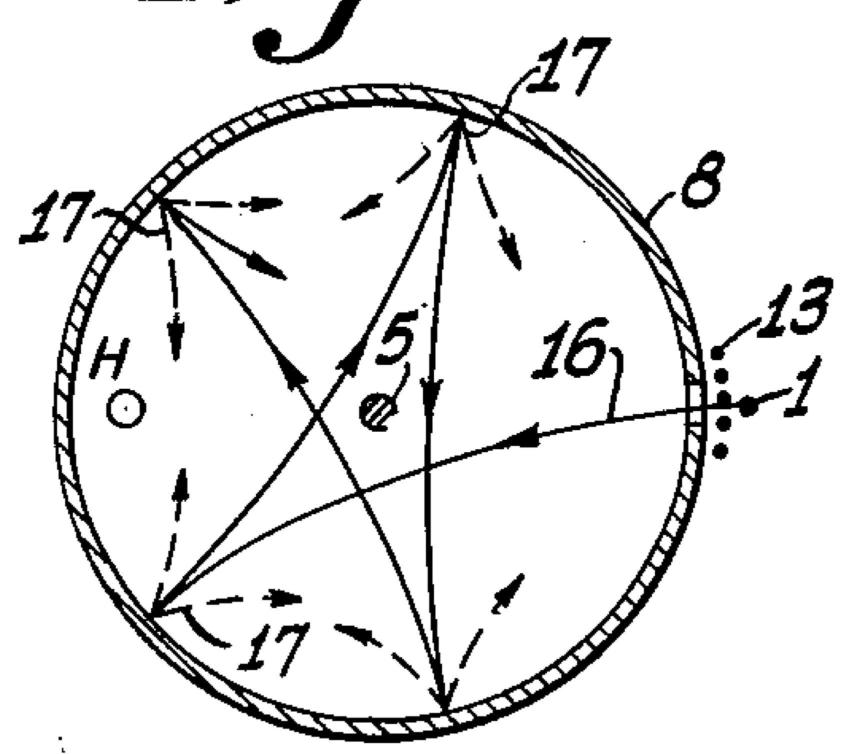


Fig. 5

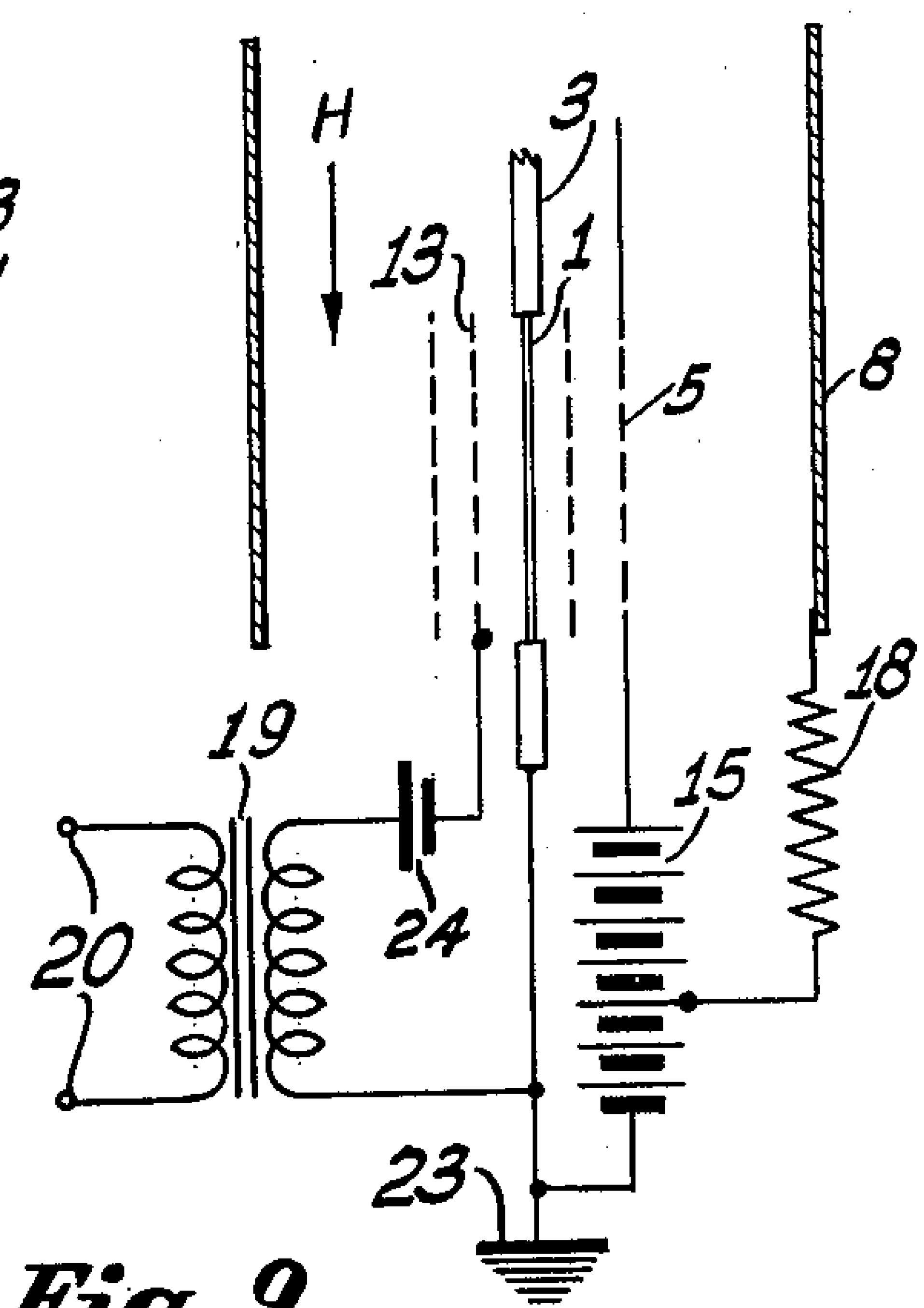


Fig. 6

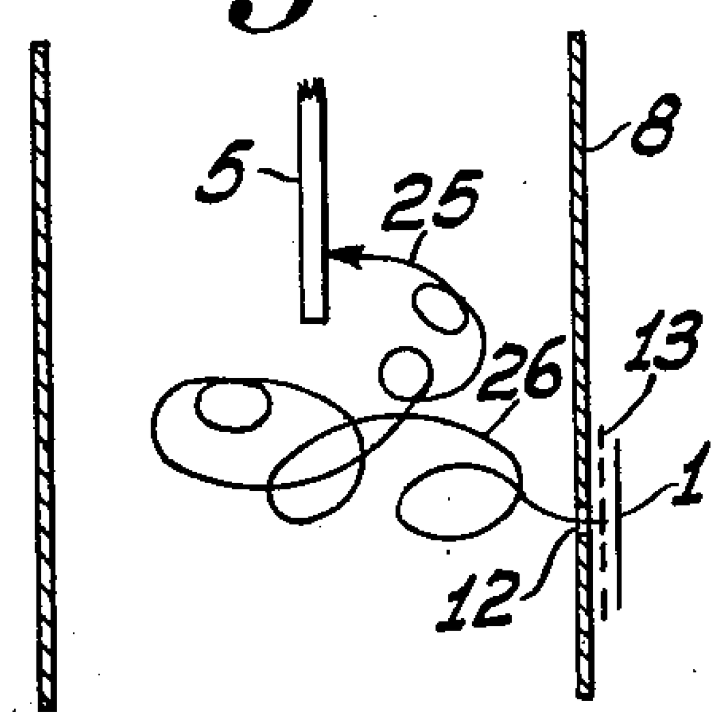


Fig. 7

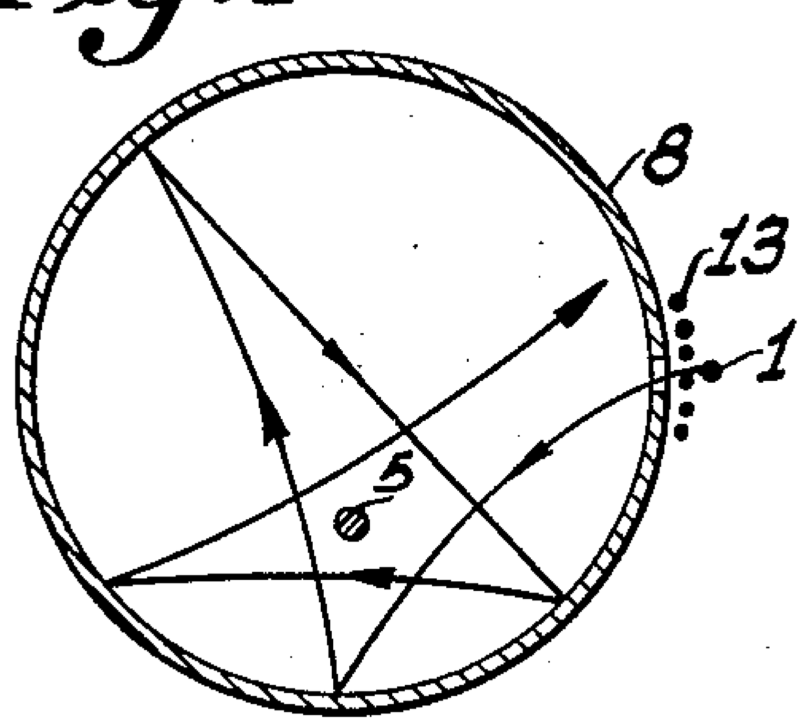


Fig. 9

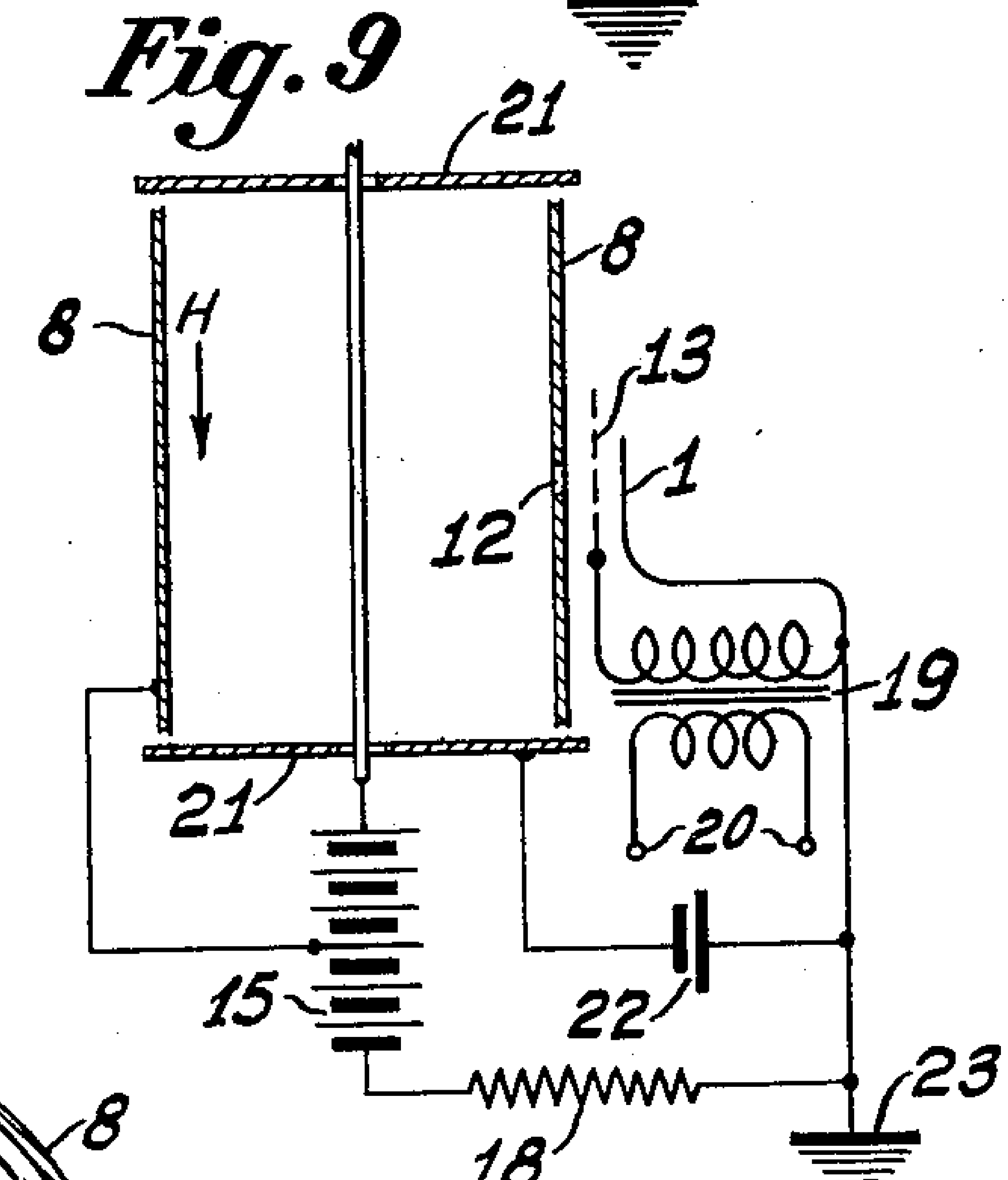


Fig. 8

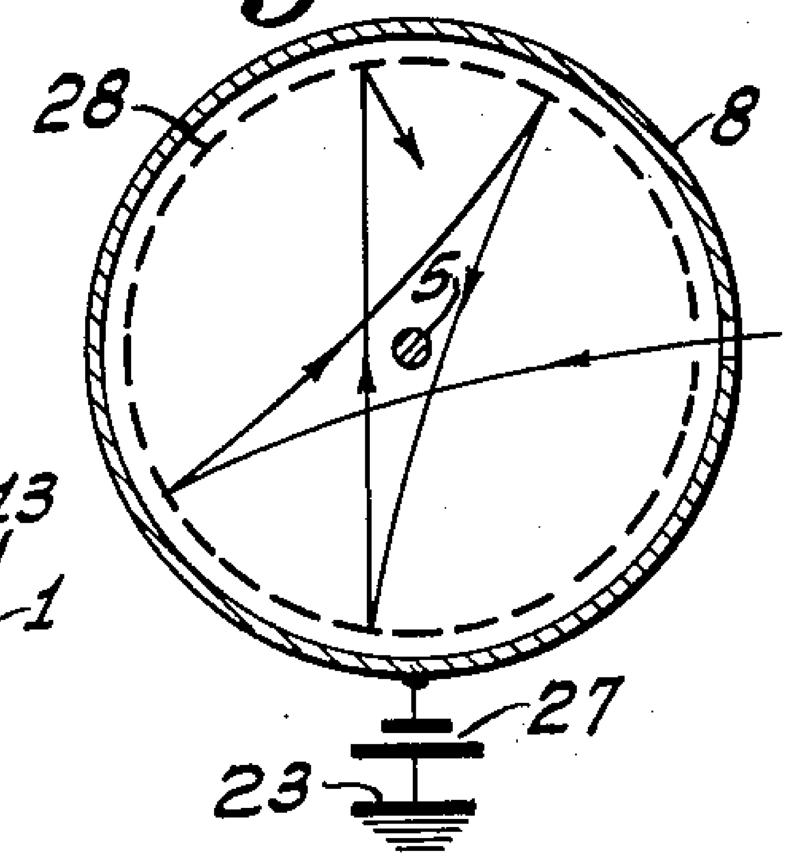
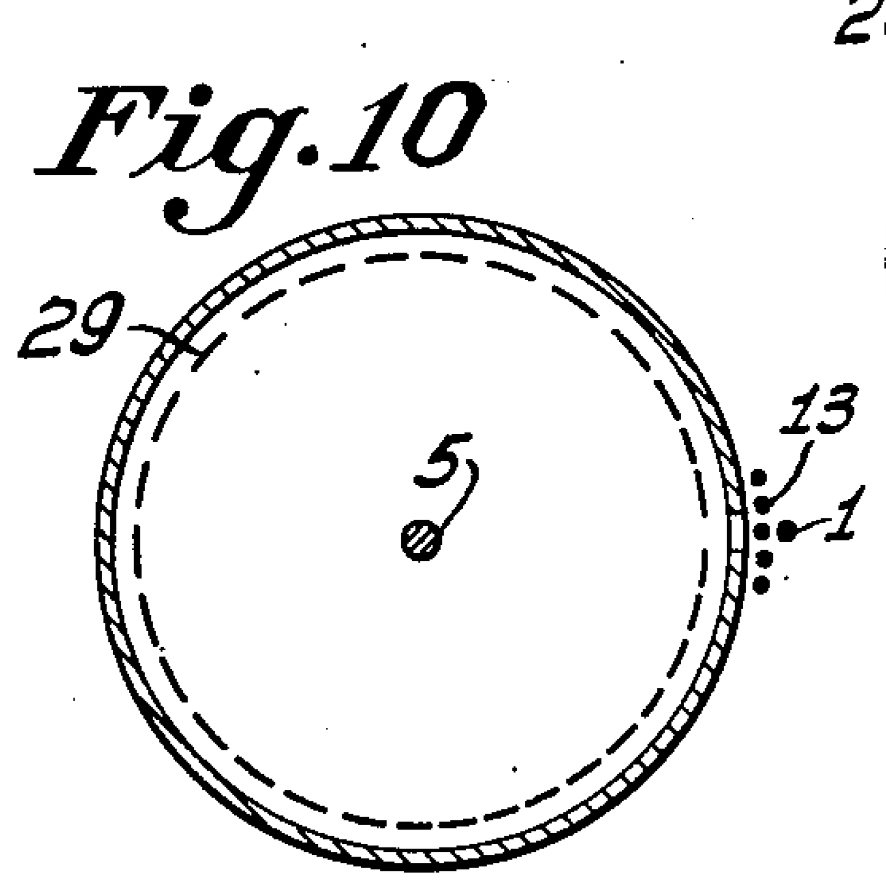


Fig. 10



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UNITED STATES PATENT OFFICE

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VACUUM TUBE CURRENT AMPLIFIER

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24 Claims. (Cl. 250—27.5)

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This invention relates generally to vacuum tube current amplifiers and more particularly to such amplifiers using electron trapping and cumulative gas ionization.

In the copending U. S. application Serial No. 49,736, filed September 17, 1948, is disclosed and claimed the methods of and means for the generation of large conduction currents by the ionization of the medium within a vacuum tube by increasing the lengths of the paths of electrons emitted initially by a radioactive source, and secondary electrons emitted from a bombarded electrode, beyond the mean free path for collisions with the molecules of medium. This increase in lengths of the electrons is accomplished by applying a magnetic field to the medium whereby the electrons are deflected in their paths and pass by or are cut off from striking the collector electrode. This phenomenon is defined as "trapping," that is the electrons are trapped in their movements within the medium as they are reflected successively by the outer electrode. The effect of this trapping is that the paths of the electrons are lengthened beyond the mean free path for collision with molecules of the medium and ionization of the medium occurs, with attending large conduction currents.

Among the objects of the invention are to provide improved methods of and means for amplifying electrical currents.

Another objective is to provide improved methods of and means for controlling secondary radiation of electron from bombarded elements in a current amplifier tube.

Another object is to provide improved methods of and means for lengthening the paths of free electrons within a gas filled tube to effect increased ionization of the gas within the tube.

Other objectives will be apparent from the description of the invention as hereinafter set forth in detail and from the drawings made a part hereof, in which Figure 1 is a sketch in vertical cross-section of one form of a tube of the invention; Fig. 1*a* is a cross-sectional view of the device of Fig. 1 taken along the section line 1*a*—1*a*; Figure 2 is a sketch in vertical cross-section of another tube in the invention; Figure 3 is an enlarged view of a portion of the tube of Figure 2 taken on line 3—3 of Figure 2; Figure 4 is a schematic diagram of the tube of the invention and the path of a free electron under the influence of a magnetic field, but without collision of the electron with the gas molecules within the tube; Figure 5 is a schematic diagram of the tube of the invention and associated circuits;

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Figure 6 is a schematic diagram of a modification of the tube of the invention in which the collector electrode is positioned unsymmetrical lengthwise along the axis of the tube and displaced axially the tube as to the source of electrons; Figure 7 is a schematic diagram of a modification of the tube of the invention in which the collector electrode is positioned eccentric to the axis of the tube; Figure 8 is a schematic diagram in horizontal cross-section of the tube of the invention illustrating the method of and means for establishing an electric potential reflection zone within the tube and the path of a free electron under the influence of a magnetic field, but without collision of the electron with the molecules of the gas within the tube; Figure 9 is a schematic diagram of the tube of the invention and an associated control circuit wherein tube end plates are utilized; and Figure 10 is a schematic diagram in horizontal cross-section of a tube of the invention including a suppressor grid for secondary electrons.

Similar reference characters are applied to similar elements throughout the drawings.

The invention will be first described by reference to Figure 1, which represents a tube of the invention adapted particularly to the study and observation of the phenomenon of electron trapping and cumulative gas ionization, upon which phenomenon the invention is based.

In Figure 1, numeral 1 represents the cathode filament which is supported in the axis of the envelope of the evacuated tube 2 by sections of heavy wire or light rods 3. Cathode 1 is kept taut by spring 4. Axially of the tube 2, is mounted accelerator and collector cylinder 5, suitably supported by braces 6 which act as electric terminals for collector 5. At approximately the midsection of collector 5 and opposite cathode 1 are holes 7. In practice these holes are about 0.040 inch in diameter and, in the tube shown, are four in number. Axially of the tube 2 and spaced near the side walls of the envelope 2 is mounted the cylinder electrode 8, suitably supported by brace 9 and wires 10, the latter acting as the electric terminals of electrode 8. The tube 2 is gas filled and at a pressure of 10^{-3} to 10^{-4} mm. of mercury.

In this specification and the appended claims filament 1 will be referred to as a "concentrated" filament, which is defined as a section of a conventional tube filament material the length of which is short relative to the length of the associated electrodes. As examples of such relative lengths, Figures 1 and 2 represent full scale sketches of two tubes embodying the invention. The ratios of the lengths of the filaments 1 to its associated electrodes 5 and 8 are 1:10 and 1:3, respectively.

Extending outside and lengthwise the tube 2 is solenoid 11, which is connected to a source of direct current (not shown), by which is set up the magnetic field H (arrow). Electrode 8 and collector 5 are made of some magnetic field permeable material such as aluminum or appropriate alloys of stainless steel.

In Figure 2 is disclosed a tube similar to that shown in Figure 1, in which is mounted on one side of the axis of the tube and near the side walls thereof, the cathode filament 1 which is supported by sections of heavy wire 3 and kept taut by spring 4. The collector 5 is made in a form of a rod and is mounted in the axis of tube 2. Near the mid-section of electrode 8, lengthwise along the axis of tube 2 and opposite cathode 1, is cut an opening 12, such that the electrons emitted from cathode 1 may enter the space within the electrode 8. Between cathode 1 and electrode 8 is mounted a grid 13, in any conventional way such as wires 14, which also act as electric leads and terminal for grid 13. A magnetic field H is impressed upon the space within the tube in a conventional way, such as disclosed in Figure 1. In Figure 3 is shown an enlarged view, partially broken away of the opening in electrode 8, and its associated grid 13 and cathode 1.

In operation, and with reference to Figures 2, 4 and 9, electrons emitted from cathode 1 are accelerated through the grid 13 and opening 12 toward center of the tube by a source of electric potential 15 connected to electrode 8, collector 5 and cathode 1. By adjusting the strength of the magnetic field H, the electrons may be made to be deflected and pass-by collector 5 and thereafter bombard electrode 8, as shown by the arrow 16. Upon successive reflections from electrode 8, the initial electrons from cathode 1 continue on their paths as indicated by arrow 16 and are thus trapped in the space within the tube 2. Upon bombardment of electrode 8 by the initial electrons secondary electrons are emitted, as shown by arrows 17. These secondary electrons are accelerated toward electrode 5, but, responding to the magnetic field H, they are deflected and likewise become trapped within the tube. As the paths of the initial and secondary electrons are increased and exceed the mean free path for collision with the molecules of the gas within the tube, ionization by collision occurs, causing further ionization of the gas. With the ionization of the medium, conduction currents flow between collector 5 and cathode 1. A load resistance 8 is placed in this circuit that these currents may be made available for useful purposes.

The flow of electrons from cathode 1 may be controlled by potentials applied to grid 13 by a transformer 19, the primary of which is connected to the source 20 of the currents to be amplified and the secondary of which is connected to grid 13 and cathode 1. The electrons from cathode 1 and the secondary electrons may be confined within the space opposite to collector 5 by end plates 21 which are kept at a slightly negative potential by an electric source 22 connected by the plates 21 and cathode 1. Being at negative potential, the plates repel electrons approaching them. The system may be grounded as at 23.

The principles disclosed as to Figures 2, 4 and 9 are applicable to the tubes shown in Figure 1 and are applied to tube 1, with some modification, by the circuits shown diagrammatically in Figure 5. The cathode 1, heated in any conventional manner (not shown), emits initial electrons which are accelerated by accelerator 5, which is connected to source 15. The accelerated electrons bombard electrode 8 and are trapped within the space between accelerator 5 and anode 8, causing secondary electrons to be emitted and cumulative ionization of the gas and conduction currents as hereinbefore described. The resulting conduction currents are utilized in load 18 which is connected between electrode 8 and electric source 15. The control of the conduction currents is as previously disclosed. Grid 13 and cathode 1 are connected to the secondary of transformer 19, the primary of which is supplied by the currents to be amplified, that is, from source 20. Grid 13 may be bias by electric source 24.

It is desirable in current amplifier systems that the devices operate with as large a multiplication factor as possible. The multiplication factor may be increased by lengthening the paths of the initial electrons as shown in Figures 6, 7 and 8 or electrically as disclosed in Figures 8 and 10.

As shown in Figure 6, collector 5 is so shortened that it does not extend to a position opposite the opening 12. The average path from cathode 1 to collector 5 is thereby lengthened, as illustrated by arrow 26. The tight spirals in arrow 26 represent deflections of the electrons upon striking gas molecules.

The average length of the paths of the initial electrons are increased as shown in Figure 7, by positioning collector 5 eccentric the axis of the tube. The initial electrons have less chance of reaching collector 5 when collector 5 is placed in the indicated position. A further method of increasing the multiplication factor is that shown in Figure 9, previously described, that is, by confining the electrons within a limited volume of the tube by end plates kept at a slightly negative potential.

The discharge in the tubes disclosed herein is of the Townsend type and may be defined by the equation:

$$\frac{i}{i_0}=\frac{(\alpha-\beta)\epsilon^{(\alpha-\beta)x}}{\alpha-\beta\epsilon^{(\alpha-\beta)x}}$$

where

i_0=output current
i=input current
α=first Townsend coefficient
β=second Townsend coefficient
x=separation of electrodes
ϵ=Napierian logarithm base.

Here, α may be considered the number of electrons formed per centimeter per electron and β is the number of electrons formed per positive ion. By use of the magnetic field, which produces electron trapping, α is greatly increased, whereas β is particularly unaffected by the magnetic field since the heavy positive ions continue in substantially straight paths. It is desirable to make α large and β small since this reduces the likelihood of instability which occurs when the denominator of the equation is zero or

$$\alpha=\beta\epsilon^{(\alpha-\beta)x}.$$

If β equals zero, the current equation reduced to $i=i_0\epsilon^{\alpha x}$ and the gain is an exponential function of ax. Furthermore, the gain is linear since i varies directly as i_0.

The coefficient β may be decreased by suppressing secondaries emitted from cylinder electrode 8. This may be done, as shown in Figure 8, by placing a small negative bias on the electrode 8 by the biasing electric source 27, which is connected to electrode 8 and ground 23. There is thus created a zero potential zone 28 so that the initial electrons from cathode 1 will not reach electrode 8, but will be reflected by this potential zone 28.

It has been found that secondary electron emission from electrode 8 may be suppressed by carbonizing the inner surface of electrode 8 or by painting that surface with aquadag or other similar materials. This suppression increases the efficiency of the tube for reasons heretofore disclosed.

Another means of suppressing secondary electrons is by the use of a suppressor grid electrode 29 as shown in Figure 10.

I claim as my invention:

1. A vacuum tube comprising an evacuated envelope and inside said envelope: a filament, a cylindrical apertured first electrode concentrically juxtaposed said filament, a second electrode in concentrically spaced relation to said first electrode, the said first electrode having said aperture immediately opposite said filament to form a restricted opening therethrough and a control grid positioned between said filament and said first electrode opposite said aperture.

2. A vacuum tube comprising an evacuated envelope and inside said envelope: a filament disposed midway the length of said tube and juxtaposed said envelope, a cylindrical apertured first electrode juxtaposed said filament, a second electrode disposed adjacent to said first electrode, the said first electrode having said aperture immediately opposite said filament to form a restricted opening therethrough, and a control grid positioned between said filament and said first electrode opposite said aperture.

3. A vacuum tube comprising an evacuated envelope and inside said envelope: a filament structure extending lengthwise the tube that includes a mid-portion of filament wire and a plurality of conducting and supporting heavy wire end sections, a cylindrical apertured first electrode concentrically juxtaposed said filament, a second electrode in concentrically spaced relation to said first electrode, the first electrode having said aperture immediately opposite said filament wire to form a restricted opening therethrough, and a control grid positioned between said filament and said first electrode opposite said aperture.

4. A vacuum tube comprising an evacuated envelope and inside said envelope: a filament structure extending lengthwise the tube that includes a mid-portion of filament wire, a plurality of conducting and supporting heavy wire end sections and a resilient section, whereby the said structure is kept taut, a cylindrical apertured first electrode concentrically juxtaposed said filament, a second electrode in concentrically spaced relation to said first electrode, the said first electrode having said aperture immediately opposite said filament to form a restricted opening therethrough, and a control grid positioned between said filament and said first electrode opposite said aperture.

5. A vacuum tube comprising an evacuated envelope and inside said envelope: a filament, a cylindrical apertured first electrode concentrically juxtaposed said filament, a second electrode disposed adjacent to said first electrode, the said aperture in said first electrode comprising a restricted opening therethrough and the second electrode being positioned in the axis of the tube, and a control grid positioned between said filament and said first electrode opposite said aperture.

6. A vacuum tube comprising an evacuated envelope and inside said envelope: a filament, an apertured cylindrical first electrode juxtaposed said filament, a second electrode disposed adjacent to said first electrode, the said aperture in said electrode being disposed immediately opposite said filament to form a restricted opening therethrough and the second electrode being positioned eccentric the axis of the tube, and a control grid positioned between said filament and said first electrode opposite said aperture.

7. A vacuum tube comprising an evacuated envelope and inside said envelope: a filament, an apertured cylindrical first electrode juxtaposed said filament, and a second electrode disposed adjacent to said first electrode, the aperture in said first electrode being disposed to form a restricted opening therethrough, a control grid positioned between said filament and said first electrode opposite said aperture, and a second grid juxtaposed said first electrode.

8. Discharge tube apparatus for amplifying electric currents comprising: an envelope enclosing a source of initial electrons, electrode means for accelerating said electrons through a restricted area within the tube, further electrode means for accelerating said electrons through the medium of the tube, means for reflecting said further accelerated electrons successively within said medium, means for applying a magnetic field to said medium whereby said electrons are trapped within said medium and conduction currents are generated, electrode means for collecting said conduction currents, and control electrode means for controlling the flow of said initial electrons in accordance with the characteristics of the currents to be amplified.

9. Discharge tube apparatus for amplifying electric currents comprising: an envelope enclosing a source of electrons, electrode means for accelerating said electrons through a restricted area within the tube for generating further electrons by cumulative gas ionization, further electrode means for accelerating all of said electrons through the medium of the tube, means for reflecting said further accelerated electrons, means for accelerating said further accelerated electrons and secondary electrons within said medium, means for applying a magnetic field to said medium whereby said further accelerated electrons and said secondary electrons are trapped within said medium and conduction currents are generated, means for collecting said conduction currents, means for and controlling the flow of said electrons in accordance with the characteristics of the currents to be amplified.

10. Discharge tube apparatus for amplifying electric currents comprising: an envelope enclosing a source of initial electrons, electrode means for accelerating said electrons through a restricted area within the tube, further electrode means for accelerating said electrons through the medium of the tube, means providing an equipotential zone in said envelope for reflecting said further accelerated electrons, means for applying a magnetic field to said medium whereby said elec-

trons are trapped within said medium and conduction currents are generated, means for collecting said conduction currents, and means for controlling the flow of said initial electrons in accordance with the characteristics of the currents to be amplified.

11. Discharge tube apparatus for amplifying electric currents comprising: an envelope enclosing a source of initial electrons, electrode means for accelerating said electrons through a restricted area within the tube, further electrode means for accelerating said electrons through the medium of the tube, means for providing a negatively charged potential zone in said tube for reflecting said further accelerated electrons, means for applying a magnetic field to said medium whereby said electrons are trapped within said medium and conduction currents are generated, means for collecting said conduction currents, and means for controlling the flow of said initial electrons in accordance with the characteristics of the currents to be amplified.

12. Discharge tube apparatus for amplifying electric currents comprising: an envelope enclosing a source of initial electrons, electrode means for accelerating said electrons through a restricted area within the tube, further electrode means for accelerating said electrons through the medium of the tube, a negatively charged reflector for said electrons of such potential that the electrons are reflected without contacting the reflector and whereby secondary electron emission is suppressed, means for applying a magnetic field to said medium whereby said electrons are trapped within said medium and conduction currents are generated, means for collecting said conduction currents, and means for controlling the flow of said initial electrons in accordance with the characteristics of the currents to be amplified.

13. A discharge tube current amplifier comprising: cathode means for producing initial electrons within the said tube, electrode means for accelerating said electrons through a restricted area within said tube, further electrode means for further accelerating said electrons within the medium of the tube, reflecting electrode means for reflecting said further accelerated electrons, means for trapping said further accelerated electrons, whereby conduction currents are generated, electrode means for collecting said currents and control electrode means for controlling the flow of said initial electrons in accordance with the characteristics of the currents to be amplified.

14. An amplifier as defined in claim 13, the electron producing means being concentrated in a space immediately adjacent said restriced area.

15. An amplifier as defined in claim 13, the said electron producing means being in the axis of said tube and concentrated at the mid-section thereof, the said accelerating means being a cylindrical electrode surrounding said electron producing means, and said restricted area being passageways in said electrode.

16. An amplifier as defined in claim 13, the said electron producing means are positioned adjacent the envelope of said tube and concentrated at the mid-section lengthwise of said tube and the said further accelerating means being an electrode positioned in the axis of said tube and charged to a positive potential.

17. An amplifier as defined in claim 13, the said further accelerating means being an electrode in the axis of said tube and charged to a positive potential, the said electrode being so positioned axially the tube that no portion thereof is laterally opposite said electron producing means.

18. An amplifier as defined in claim 13, the said electron producing means being positioned adjacent the envelope of said tube and the said further accelerating means being an electrode positioned eccentric to the axis of the tube.

19. An amplifier as defined in claim 13, the said reflecting means being a secondary electron responsive surface.

20. An amplifier as defined in claim 13, the said reflecting means being a surface charged at a negative potential whereby the said further accelerated electrons are repelled by the electric field at said surface.

21. An amplifier as defined in claim 13, the reflecting means being a cylindrical electrode and a negatively charged grid juxtaposed thereto, whereby the said further accelerated electrons are repelled by the electric field of said grid.

22. An amplifier according to claim 13, including means for confining the said further accelerated electrons within a restricted portion of said tube.

23. An amplifier as defined in claim 13, the said reflecting surface being carbonized, whereby secondary electron emission at said surface is suppressed.

24. An amplifier as defined in claim 13, the said reflecting surface being coated with aquadag, whereby secondary electron emission at said surface is suppressed.

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