March 12, 1940. E. BRUCE 2,193,578

ELECTRON DISCHARGE APPARATUS

Filed March 31, 1937 2 Sheets-Sheet 1

FIG. 1

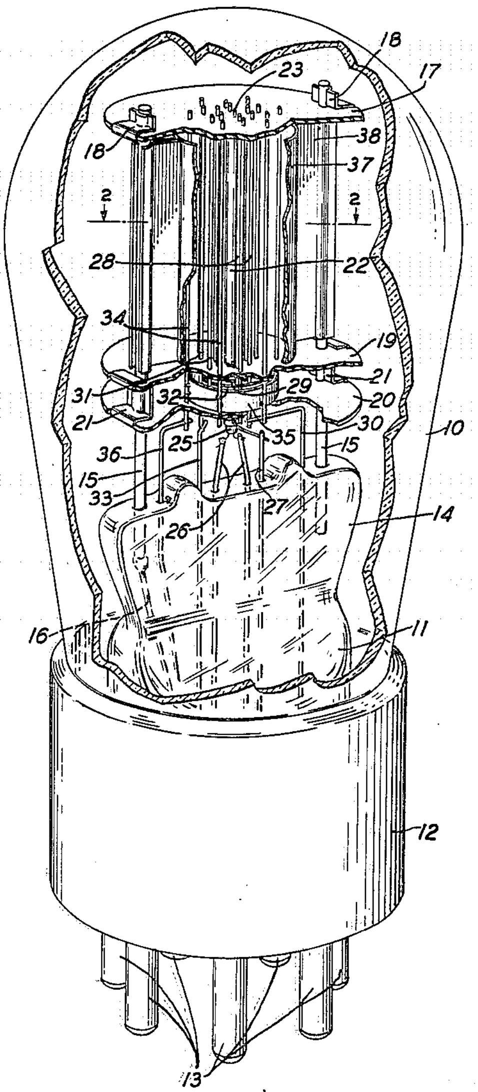

FIG. 2

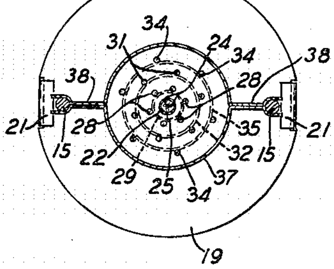

FIG. 3

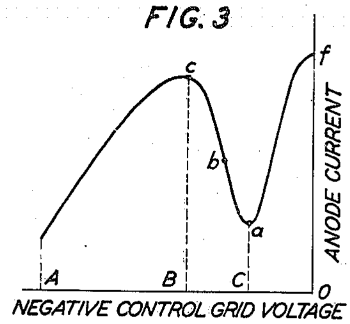

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FIG. 4

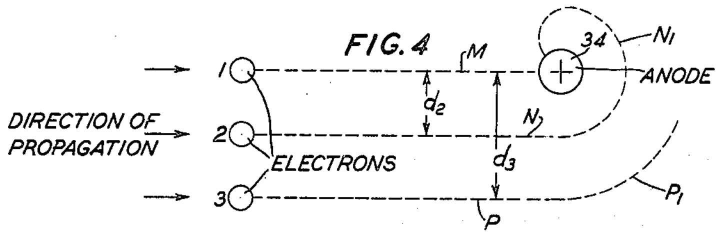


FIG. 5

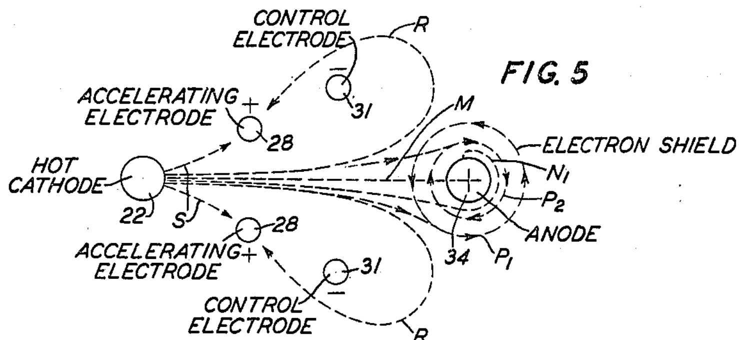
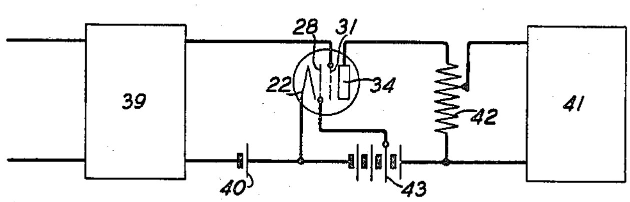


FIG. 6



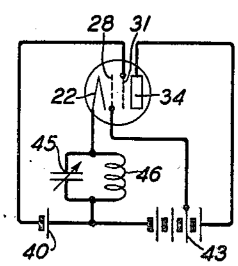
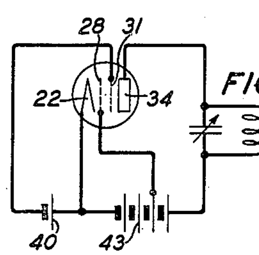


FIG. 7

FIG. 8



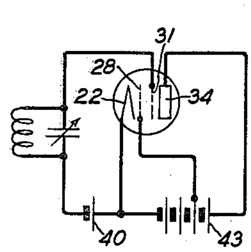


FIG. 9

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ELECTRON DISCHARGE APPARATUS

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12 Claims. (Cl. 250—27)

This invention relates to electron discharge apparatus and more particularly to such apparatus including multi-grid electron beam discharge devices and especially suitable for the detection, amplification and generation of ultra-high frequency impulses.

One object of this invention is to enable the attainment of a marked depression in the mutual conductance characteristic of an electron discharge device so that for certain values of electrode potentials the anode current of the device decreases and then increases with successive increments in the potential of the control electrode or grid.

Another object of this invention is to reduce the anode to ground and anode-control electrode capacities in electron discharge devices.

A further object of this invention is to augment the control of the anode current by the control electrode or grid in electron discharge devices.

In one illustrative embodiment of this invention, electron discharge apparatus comprises an electron beam discharge device having a cathode, a pair of spaced grid electrodes surounding the cathode and an anode outside of the outer grid electrode. The grid electrodes may comprise a plurality of spaced linear elements parallel to each other and the cathode, the corresponding elements of the two grid electrodes preferably being in radial alignment with one another and with the cathode.

The outer grid electrode may be maintained at a suitable negative bias with respect to the cathode and utilized to control the magnitude of the electron streams from the cathode to the anode. The inner grid electrode may be maintained at a positive potential lower than the anode potential, with respect to the cathode and utilized primarily as an accelerating electrode.

In acordance with one feature of this invention, the anode includes a plurality of linear elements mounted parallel to one another and to the cathode, each of the anode elements being in alignment with the cathode along a radius bisecting the space between successive corresponding elements of the grid electrodes. It has been found that in apparatus constructed in accordance with this invention, the anode current varies in a novel manner with respect to the potential upon the control electrode or grid. Specifically, it has been found that as the control electrode or grid is made less negative from a high negative value, the anode current increases somewhat gradually to a maximum. A further decrease in the negative grid potential produces a marked decrease in the anode current. This latter effect occurs throughout a limited range of grid potentials and the anode current reaches a minimum. As the grid is made still less negative, the anode current again increases. Hence, a marked depression occurs in the anode current-control grid potential characteristic of the device.

In accordance with another feature of this invention, the fixed potentials upon the several electrodes are made such that the device operates about a point in the depression occuring in the anode current-grid potential characteristic. For example, the fixed potentials upon the electrodes may be such that the anode current increases for both positive and negative increments of a varying potential impressed upon the grid, or they may be such that the anode current decreases for positive increments in the varying impressed potential and increases for negative increments of such varying potential.

The invention and the various features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawings in which:

Fig. 1 is a view in perspective of an electron discharge device constructed in accordance with this invention, a portion of the enclosing vessel and of the electrode assembly being broken away to show details of construction more clearly;

Fig. 2 is a view in cross-section along line 2—2 of Fig. 1, of the electrode assembly, illustrating the construction, configuration and arrangement of the various electrodes;

Fig. 3 is a graph showing the relation between the anode current and the negative control grid voltage in devices of the construction illustrated in Figs. 1 and 2;

Figs. 4 and 5 are diagrammatic views illustrating typical paths traversed by electrons emanating from the cathode in devices of the construction shown in Figs. 1 and 2;

Fig. 6 is a schematic of a typical circuit illustrating the utilization of apparatus constructed in accordance with this invention as a detector, amplifier, or frequency doubler;

Fig. 7 is a circuit diagram of a feedback oscillator illustrative of one embodiment of this invention; and

Figs. 8 and 9 are circuit diagrams of other oscillators illustrative of this invention.

Referring now to the drawings, the electron discharge device shown in Figs. 1 and 2 comprises an evacuated enclosing vessel 10 having a stem 11 at one end and having suitably affixed thereto a base 12 carrying terminal prongs 13 through which the electrodes of the device may be associated with external circuits.

Embedded in the press 14 of the stem 11 and arising therefrom are parallel, rigid, metallic supports or uprights 15, one of which is connected electrically to one of the terminal prongs 13 by a leading-in conductor 16. An insulating disc 17, for example, of mica, is affixed to the supports or uprights 15 adjacent the upper end thereof, as by clips 18 which may be welded to the uprights or supports. Similar spaced insulating discs 19 and 20, which also may be of mica or the like, are affixed to the supports or uprights 15 by suitable clips 21, which also may be welded to the uprights or supports.

An elongated linear cathode, which may be either a filament or of the equipotential heater type, is supported between the insulating discs 17, 19 and 20. In the form shown in Figs. 1 and 2, the cathode comprises a cylindrical metallic sleeve 22, coated on its outer surface with a thermionic material, one end of which extends through and is fitted in central apertures in the lower insulating discs 19 and 20 and the other end of which is reduced, as indicated at 23, and fitted in a central aperture in the upper insulating disc 17. The cathode sleeve 22 encloses a heater filament 24 embedded in or threaded through a suitable ceramic or insulating body 25. Heating current may be supplied to the filament 24 through leading-in conductors 26 embedded in the press 14 and connected to corresponding ones of the terminal prongs 13. Electrical connection to the cathode 22 may be established through a leading-in conductor 27 also embedded in the press 14 and connected to one of the terminal prongs 13.

The cathode 22 is surrounded by an accelerating electrode or grid coaxial therewith and including a plurality of equally spaced linear conductors or wires 28 mounted parallel to one another and to the cathode. The conductors 28 extend through aligned apertures in the insulating discs 17, 19 and 20 and are electrically connected to one another by a metallic band or collar 29 seated upon the insulating disc 20. One of the conductors may be connected to one of the terminal prongs 13 through a leading-in conductor 30 embedded in the press 14.

The accelerating electrode or grid 28 is encompassed by a control electrode or grid, preferably coaxial therewith, which comprises a plurality of parallel, linear conductors or wires 31 each of which, as shown clearly in Fig. 2, is in radial alignment with the cathode 22 and a corresponding one of the wires 28 of the inner grid. The conductors or wires 31 extend through aligned apertures in the insulating discs 17, 19 and 20 and are connected together electrically by a metallic band or collar 32 seated upon the insulating disc 20. Suitable potentials may be applied to the control electrode through a leading-in conductor 33 connected to one of the conductors or wires 31 and to one of the terminal prongs 13.

The control electrode or grid 31 is encompassed in turn by an anode, coaxial therewith, which comprises a plurality of parallel, linear rods or wires 34 each of which, as shown clearly in Fig. 2, lies on a radius preferably bisecting the opening between successive accelerating grid wires 28 and the corresponding control grid wires 31. The anode wires or conductors 34 extend through aligned apertures in the insulating discs 17, 19 and 20 and are electrically connected by a metallic band or collar 35 seated upon the disc 20. The anode may be coupled to an external circuit through a leading-in conductor 36 connected to one of the terminal prongs 13 and to one of the conductors or wires 34.

The anode may be encompassed in turn by an auxiliary electrode having a cylindrical portion 37 and diametrically opposite flanges 38 which may be secured, as by welding, to the uprights or supports 15.

During operation of the device, as shown in Fig. 6, an input circuit including a network 39 and a source, such as a battery 40, for applying a negative bias to the control electrode 31, is connected between the cathode 22 and the control electrode. An output system 41 may be connected across a suitable resistance 42 connected between the cathode 22 and anode 34 in series with a suitable source, such as a battery 43, for applying a positive potential to the anode. The accelerating electrode 28 may be connected to an intermediate terminal on the battery 41 so that it is at a positive potential, lower than the anode potential, with respect to the cathode. Preferably, the fixed potentials applied to the several electrodes are such that the electrons emanating from the cathode are concentrated in beams focussed upon the anode wires 34. The auxiliary electrode 37, not shown in Fig. 6, may be connected directly to the cathode and operated at cathode potential.

As noted heretofore, as the control electrode potential is made less negative, the anode current first increases, then decreases, and subsequently again increases. As shown in Fig. 3, for values of negative control grid voltage between A and B, as this voltage becomes less negative, the anode current increases continuously to a maximum value *c*. As the grid potential is made still less negative, between values B and C the anode current decreases to a minimum value *a*. In accordance with still further decreases in the control grid potential, as between values C and 0, the anode current increases to a value *f*.

Although this invention is not to be limited thereby, the following considerations are believed to explain the occurrence of the depression *caf* appearing in the mutual conductance characteristic shown in Fig. 3. Referring to Fig. 4, the circles designated by the numerals 1 to 3, inclusive, represent electrons having a charge q emanating from spaced portions of a cathode, not shown, and propagated with a uniform velocity v toward the anode wire 34 under the influence of the potentials upon the anode and the accelerating and control electrodes or grids.

Electron 1 will traverse a path M perpendicular to the longitudinal axis of the anode wire 34 and hence will flow directly to the anode wire 34 contributing thereby to the anode current. Electron 2, however, having the same charge and velocity as electron 1, will follow a path N and attempt to pass the anode wire 34 at a distance d_2 from the axis thereof. When this electron approaches the anode wire it comes under a powerful deviating force, due to the anode potential, normal to the path N. Consequently, the electron 2 will then traverse a curvilinear path, as indicated for example by the line N_1, and eventually reach the anode wire 34.

The electron 3 will traverse a path P and attempt to pass the anode wire 34 at a distance d_3 from the axis thereof where the deviating force due to the anode potential is less than that acting upon the electron **2**. Consequently, the path of the electron **3** will become curvilinear as indicated in part by the line P_1 and this electron may eventually reach the anode.

The velocity of certain of electrons emanating from the cathode and the deviating forces acting thereon will be such that the resulting centrifugal force is substantially equal to the deviating force. Consequently, such electrons will traverse a substantially circular path, as indicated for example by the lines P_1 and P_2 in Fig. 5, concentric with the anode wire **34**, and constitute an electron shield about the anode wires.

The force upon other electrons may be such that these electrons never reach the anode. For example, such electrons may reverse their direction of travel and flow to the accelerating electrode **28** as indicated by the lines R in Fig. 5. Still other electrons may flow directly to the accelerating electrode **28** as indicated by the lines S in Fig. 5.

The paths traversed by the electrons, of course, will be dependent upon the velocities of the electrons as they approach the anode and these velocities in turn are dependent upon the potential of the control electrode or grid. For high negative values of the control grid potential, such as indicated for example by the abscissae between A and B in Fig. 3, the electron velocities will be relatively small with the result that most of the electrons emanating from the cathode **22** will flow directly to the anode **34**. Consequently, the anode current will increase up to a point c in Fig. 3 as the grid is made less negative.

As the grid is made still less negative, the velocities of certain of the electrons will increase and these electrons will rotate about the anode wires as heretofore described with the attendant establishment of an electron shield about the anode wires. The density and effectiveness of this electron shield will increase as more electrons flow toward the anode wires and circulate thereabout, so that, as indicated by the portion ca of the curve in Fig. 3, the anode current will decrease.

As the control grid is made still less negative, the electron velocities increase with the result that a relative large radius for the circle of rotation of certain of the electrons is established and, therefore, the shielding effect decreases. The orbits of rotation may even exist beyond the confines of the denser part of the electron stream focussed upon the anode wires **34**. Consequently, the anode current increases with decreasing grid potential as indicated by the portion af of the curve in Fig. 3.

The critical region of the electron shield, that is the region corresponding to conditions extent at the time the anode current is at or near the point a indicated in Fig. 3, probably obtains when the radius of the orbits of the rotating electrons just equals the radius of anode wires **34**, that is when

$$r_a=\frac{v^2}{E_r}\cdot\frac{m}{q}$$

where

r_a=the anode radius.
v=the electron velocity.
m=the electron mass.
E_r=the electromotive intensity at the anode surface due to the anode voltage.
q=the charge on an electron.

Knowing the relative distribution of the electromotive intensity along the electron's path, the critical velocity and the requisite electrode voltages may be estimated by considering that the potential energy of an electron, just outside of the cathode surfaces, is converted to kinetic energy at the surface of the anode wires.

In a specific embodiment illustrative of this invention, the minimum point a of the anode current has been obtained at a potential of −2.5 volts upon the control grid, the anode and accelerating electrode being 60 volts and 18 volts positive respectively, the accelerating and control electrodes having radii of 0.07 inch and 0.13 inch respectively, the anode wires lying in a circle having a radius of 0.19 inch and the cylindrical auxiliary electrode defining a boundary 0.25 inch in radius.

It will be appreciated, of course, that in devices constructed in accordance with this invention, because of the relatively small anode area, relatively small capacitances between the anode and ground and between the anode and the control grid will exist. Furthermore, it will be seen that in addition the usual control of the density of the electron streams by the control grid is augmented inasmuch as the focal point of the electron streams is varied in accordance with variations in the potential of the control electrode so that it may be displaced from the anode wires **34** to points nearer or more remote from the cathode **22**.

The novel characteristics of electron discharge apparatus constructed in accordance with this invention may be utilized advantageously in a variety of applications. For example, the system shown in Fig. 6 may be used as a low frequency detector in which case the control grid is biased at the point C in Fig. 3, the element **39** would be a radio frequency amplifier and the element **41** an audio amplifier. In such apparatus the anode current would increase with both positive and negative swings of the potentials impressed upon the control grid.

Similarly with the control grid biased at the point C, Fig. 3, frequency doubling accompanied by large amplification and high suppression of the fundamental frequency may be obtained. In such application, the element **39** would be an input frequency device and the element **41** would be an output doubled frequency device.

The system shown in Fig. 6 may be utilized also as an amplifier, having in addition to a high mutual conductance a negative feedback through the anode-control grid capacitance. In this system, the control grid would be biased at values corresponding for example to the point b in Fig. 3, and the elements **39** and **41** would be suitable input and output devices respectively.

Fig. 7 illustrates a feedback oscillator illustrative of one embodiment of this invention, wherein an anti-resonant element including a variable condenser **45** and inductance **46** in shunt therewith is provided common to the control grid and anode circuits. The control grid **31** is biased at a point between B and C, Fig. 3 and the potentials upon the anode and accelerating electrode are such that a positive anode resistance and a negative amplification factor exist.

The potentials upon thhe electrodes may be made such that a negative anode resistance is exhibited. Hence, feedback is not necessary to generate oscillations. In such case the grid **31** should be biased at a point between B and C, Fig. 3, and preferably at a value corresponding to point b on the characteristic. Oscillators wherein the electrode potentials are thus related are illustrated in Figs. 8 and 9. In Fig. 8 the shunt condenser-inductance element is connected between the cathode and anode; in Fig. 9, this element is connected between the control grid and the cathode.

In Figs. 6 to 9, the auxiliary electrode **37** has not been shown inasmuch as it has been found that the characteristics described hereinabove may be achieved without the use of such electrode. It may be employed, however, to prevent escape of the electrons materially beyond the confines of the anode and in such case is operated at cathode potential.

Although various embodiments of this invention have been shown and described it will be understood, of course, that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. Electron discharge apparatus comprising a cathode, an anode having a slender linear electron receiving member, a grid between said cathode and said anode, said grid and anode being separated only by space, an output circuit connected between said cathode and said anode, and an input circuit for impressing variable potentials between said grid and said cathode, said input circuit including means for impressing such a negative bias upon said grid that the anode current increases with both positive and negative increments in said variable potentials.

2. Electron discharge apparatus in accordance with claim 1 comprising an accelerating electrode between said cathode and said grid and means applying such positive potential to said accelerating electrode that electron streams emanating from said cathode are substantially focussed upon said electron receiving member.

3. Electron discharge apparatus comprising a substantially linear cathode, an anode having a linear electron receiving member parallel to said cathode, a grid between said cathode and said anode including a pair of spaced linear members parallel to said cathode and mounted at opposite sides of a line passing through said cathode and said anode, said spaced members being electrically integral, a circuit connected to said cathode and said anode, a second circuit connected to said cathode and said grid, means for biasing said grid negatively with respect to said cathode so that the current in said first circuit increases with negative increments in the potentials impressed upon said grid by said second circuit, an accelerating electrode between said cathode and said grid having a pair of spaced linear elements each in alignment with said cathode and a corresponding one of said spaced linear members, said elements being spaced from one another a distance smaller than the spacing between said linear members, and means for maintaining said accelerating electrode at a positive potential with respect to said cathode.

4. Electron discharge apparatus in accordance with claim 3 wherein said first means applies such biasing potential to said grid that the anode current increases with both positive and negative swings in the potentials in said second circuit.

5. Electron discharge apparatus comprising a cathode, a grid electrode having spaced electrically integral members in alignment with said cathode and substantially equally spaced therefrom, and an anode having a linear rod electron receiving member of cross-sectional dimensions less than the cross-sectional dimensions of said cathode, in alignment with said cathode and the opening between two of said spaced members, said grid electrode being between said cathode and said anode, and said grid electrode and anode being separated only by space.

6. Electron discharge apparatus comprising a cathode, a pair of cylindrical grids coaxial with said cathode, each of said grids having a plurality of spaced rod elements parallel to each other and the corresponding elements of said grids being arranged in alignment with one another and said cathode, and an anode surrounding said grids and including a plurality of slender spaced conductors parallel to said cathode, said conductors being in radial alignment only with said cathode and with the openings between successive elements of said grids, and the cross-sectional dimensions of said conductors being small in comparison with the spacing between successive rod elements of the outer of said grids.

7. Electron discharge apparatus comprising a cathode, a control electrode including a plurality of spaced members parallel to one another and said cathode and arranged in a cylindrical boundary coaxial with said cathode, a cylindrical accelerating electrode between said cathode and said control electrode and coaxial therewith, said accelerating electrode including a plurality of linear elements each of which is radially aligned with a corresponding one of said spaced members, said members being electrically connected together, and an anode surrounding said control electrode including a plurality of spaced slender linear conductors mounted parallel to one another and the cathode, each of said conductors being in alignment with said cathode and an opening between two of said spaced members, and the portions of said control electrode between said cathode and anode consisting of said spaced members.

8. Electron discharge apparatus in accordance with claim 7 comprising a circuit coupled to said cathode and said anode, and a second circuit coupled to said cathode and said control electrode and including means for biasing said control electrode negatively with respect to said cathode such that the anode current varies directly with variations in the negative potential of said grid.

9. Electron discharge apparatus in accordance with claim 7 a circuit coupled to said cathode and said anode, a second circuit coupled to said cathode and said control electrode and including means for applying a negative bias to said control electrode, and means for maintaining said accelerating electrode at a positive potential with respect to said cathode, said negative bias and positive potential being such that electrons emanating from said cathode form streams substantially focussed upon said conductors of said anode.

10. Electron discharge apparatus comprising a linear slender wire anode, means for producing a stream of electrons directed toward said anode comprising an electrode system including a cathode and a control electrode, said control electrode being between said cathode and said anode, the outermost electrode of said system and separated from said anode only by space, a circuit coupled to said cathode and said anode, and a circuit connected to said cathode and said control electrode and including means for biasing said control electrode at such a negative potential that the anode current varies directly with variations in the potential of said control electrode throughout a range of negative values of control electrode potential.

11. Electron discharge apparatus in accordance with the preceding claim wherein said first means includes an auxiliary electrode between said cathode and said control electrode and means for maintaining said auxiliary electrode at such potential that said auxiliary electrode together with said control electrode defines an electronic lens focussing the electron stream upon said anode.

12. Electron discharge apparatus comprising a cathode, a linear cylindrical rod anode, an output circuit coupled to said cathode and anode, means for accelerating the electrons emanating from said cathode, and means for controlling the velocity of the accelerated electrons including a control electrode biased negatively with respect to said cathode at such potential that the current in said circuit varies directly with increments in the potential of said control electrode.

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