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ELECTRON DISCHARGE DEVICE

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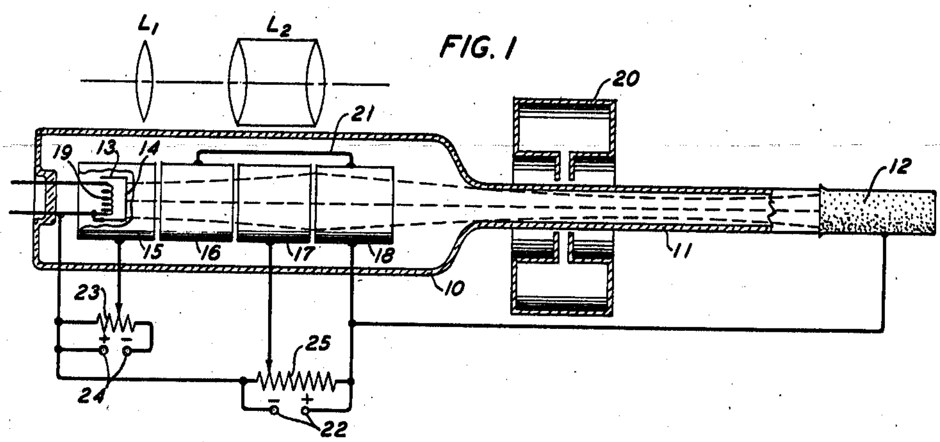

FIG. 1

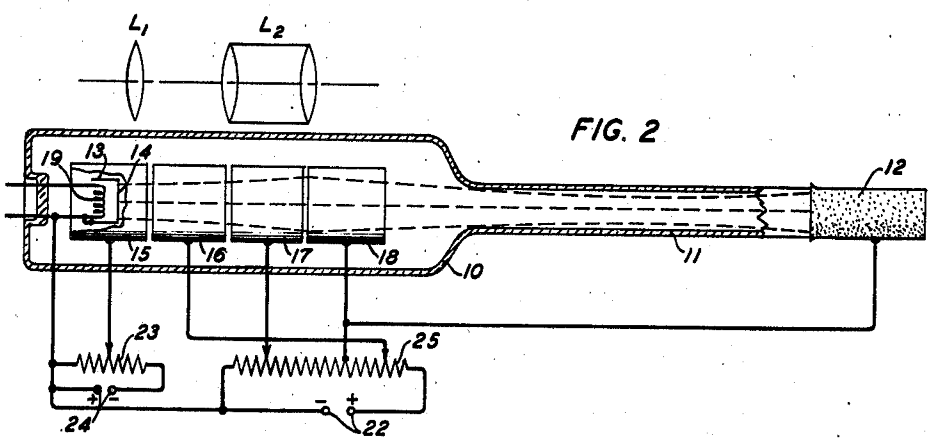

FIG. 2

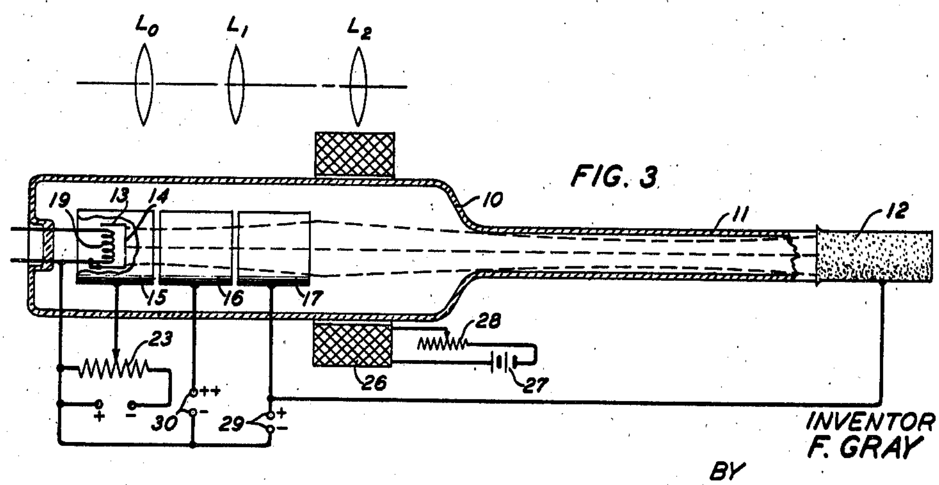

FIG. 3

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ELECTRON DISCHARGE DEVICE

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6 Claims. (Cl. 250—162)

This invention relates to electron discharge devices and more particularly to such devices of the beam type and operable at ultra-high frequencies.

In one type of ultra-high frequency electron beam discharge devices, an electron beam is projected through a slender tube wherein a control or other action, such as a velocity variation, of the beam is effected. For a number of reasons, such as the desirability of an efficient and close coupling between the electron beam and circuit elements exterior to the tube through which the beam is projected, the tube usually is made of relatively small diameter. As is known, space charge tends to cause a spreading or divergence of the electron beam so that the current which can be transmitted through a slender tube is limited. Any electrons in the beam which, due to space charge effects, are collected by the slender tube represent a loss and this action results in a low operating efficiency and also in unstable operating characteristics for the device.

One object of this invention is to improve the operating characteristics of electron discharge devices of the type wherein an electron beam is projected through a slender tube.

In the illustrative embodiment of this invention, an electron discharge device comprises a slender tube, a collector electrode or anode opposite or at one end of the tube, and an electron gun opposite the other end of the tube for projecting an electron beam thereinto.

In accordance with one feature of this invention, the electrode system constituting the electron gun, and the slender tube are so constructed and arranged that all of the electrons projected into the tube pass therethrough and are delivered to the anode or collector electrode.

The invention and the above-noted and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which:

Fig. 1 is in part a longitudinal view of an electron discharge device illustrative of one embodiment of this invention and in part a circuit diagram showing one manner in which the device may be operated;

Fig. 2 is a view similar to Fig. 1 illustrating another way in which the device may be operated in accordance with this invention; and

Fig. 3 is another view similar to Fig. 1 showing another illustrative embodiment of this invention.

Referring now to the drawing, the electron discharge device shown in Fig. 1 comprises an evacuated enclosing vessel **10** of vitreous material, having an elongated portion or tube **11** of relatively small diameter and at one end of which there is mounted a collector electrode or anode **12**. Opposite the other end of the slender tube **11** is an electrode system, commonly referred to as an electron gun, including a cathode **13** having an electron emissive surface **14**, and a plurality of cylindrical electrodes **15**, **16**, **17** and **18** mounted in coaxial relation with the cathode **13** and the tube **11**. The cathode may be heated by a suitable heater element, such as a filament or coil **19**. The electron gun, when the electrodes thereof are energized as described hereinafter, concentrates the electrons emanating from the cathode into a beam, circular in section, which is projected into the tube **11**.

Externally of the tube **11** there may be mounted circuit elements for coacting with the electron beam to impart energy to the beam or conversely to extract energy from the beam in ways known in the art. For example, such elements may be one or more cavity resonators for producing a velocity variation of the beam or adapted to be excited by the beam to deliver power to a load circuit. One of such cavity resonators is illustrated at **20** in Fig. 1 and is toroidal in form and coaxial with the tube.

In order that an efficient and effective coupling may be realized between the electron stream and the external circuit elements, such as cavity resonators, it is necessary that the tube **11** be of small diameter. However, inasmuch as, because of space charge, spreading or divergence of the electron stream occurs as it traverses the tube **11**, if the tube diameter is made small, a number of the electrons in the stream may be collected by the tube so that low efficiency operation and unstable operating characteristics would result.

It can be shown that the shape of a cylindrical electron beam traversing a space substantially free from external forces, for example a substantially field free space, such as the space in the tube **11** in the device shown in Fig. 1, that is the shape of the cylindrical sheath of electron paths that constitutes the boundary of the beam, is given by the equation:

$$\sqrt{I}V^{-3/4}\frac{Z}{r_0}=\pm F\frac{(r)}{(r_0)} \qquad (1)$$

where I is the total beam current, V is the voltage at which the electrons are projected into the space, Z is a coordinate taken along the axis of the beam from the plane of its minimum cross section, r is a radial coordinate measured from the axis, r_0 is the minimum radius of the beam in traversing the space, and

$$F\left(\frac{r}{r_0}\right)=\frac{1}{87}\int_0^{\sqrt{\log r/r_0}} e^{(r/r_0)^2}\delta\frac{r}{r_0} \tag{2}$$

e being the electron charge. For a space, such as in the tube 11, having a diameter D and a length L, if $-Z_1$ and r_1 are taken as the coordinates on the periphery of the beam as it enters the space, Equation 1 may be written as

$$\sqrt{I}=V^{3/4}\frac{r_1}{Z_1}\left[\frac{r_0}{r_1}F\left(\frac{r_1}{r_0}\right)\right] \tag{3}$$

from which it will be seen that the current I is a maximum when

$$\frac{r_1}{Z_1}$$

has its largest permissible value and the quantity

$$\left[\frac{r_0}{r_1}F\left(\frac{r_1}{r_0}\right)\right]$$

is a maximum. This quantity has a maximum value, it can be shown, when

$$\frac{r_0}{r_1}=0.427$$

Inasmuch as the beam must not touch the wall of the tube 11 and is symmetrical with respect to the plane of its minimum cross section, it follows that the largest permissible value of

$$\frac{r_1}{Z_1}$$

occurs when the beam just fills the end of the tube when it is projected into it and the minimum cross section of the beam is located at the midpoint of the tube. The maximum value of

$$\frac{r_1}{Z_1}$$

is, then, equal to

$$\frac{D}{L}$$

Hence, the maximum current that can be projected through a tube, such as the tube 11, for any voltage V is given by the equation:

$$I=3.87V^{3/2}\left(\frac{D}{L}\right)^2\times10^{-5} \tag{4}$$

which equation is obtained by substituting the two maxima determined above for

$$\frac{r_1}{Z_1}$$

and the function of

$$\frac{r_0}{r_1}$$

in Equation 3.

It will be noted from the foregoing that the maximum current at a particular beam voltage which can be projected through a tube, such as the tube 11 in the device illustrated in Fig. 1, without collection of any of the electrons by the tube, is a function of this voltage and the ratio of the tube diameter to the length of the tube and that the attainment of this current without such collection of electrons by the tube necessitates a particular physical relation between the electron beam and the tube, namely that at the inlet end of the tube, the beam diameter must be substantially the same as the internal diameter of the tube, and that the minimum cross section of the beam must occur at a region midway between the ends of the tube. In any particular case, the the diameter D and length L of the tube and the voltage V at which the electrons are projected into the tube are fixed by the intended use and operating requirements for the device in which the tube is included. Attainment of the maximum beam current without collection of electrons upon the walls of the tube, then, involves realization of the requisite relation between the beam and the tube. This is accomplished in accordance with a feature of this invention as described hereinafter.

The cathode 13 is, of course, constructed in accordance with principles known in the art, so that the desired maximum current can be drawn from the emissive surface 14 thereof. As shown in Fig. 1, the cylindrical electrodes 16 and 18 are connected together electrically by a conductor 21 and are maintained at a positive potential with respect to the cathode 13 by a suitable source, not shown, connected across the terminals 22 whereby the desired potential of the projected beam is obtained. The cylindrical electrode 15 is maintained at a negative potential with respect to the cathode 13 by a potentiometer including a resistance 23 and a source, not shown, connected across the terminals 24. The cylindrical electrode 17 is connected adjustably to a resistance 25 connected across the terminals 22. In an illustrative case, the electrode 15 may be operated at a potential of the order of 300 volts negative with respect to the cathode 13 and the electrodes 16 and 18 may be maintained at a potential of the order of 2500 volts positive with respect to the cathode 13. The anode or collector electrode 12 is connected directly to the electrode 18.

The electrode 15, it will be apparent, constitutes a simple electronic lens, illustrated at L, in Fig. 1, and the electrodes 16, 17 and 18 constitute a compound electronic lens, illustrated at L_2 in Fig. 1. The focal points of these lenses will be dependent upon the potentials of the several electrodes constituting the lenses, as will the form of the electron beam projected into the tube 11. The form of the beam can be controlled by varying the potentials of the electrodes 15 and 17 to effect adjustment of the focal lengths of the lenses.

Now, the maximum current obtainable is calculable directly from Fig. 4, the voltage V, diameter D and length L being of known values. This current is then realizable in the actual device by adjusting the potentials of the electrodes 15 and 17 until the current at the collector electrode or anode 12, as measured by a suitable instrument in circuit with the anode 12, corresponds to the value determined from Equation 4.

The determination of the potentials of the electrodes 15 and 17 requisite for the attainment of the maximum current may be effected also without recourse to direct measurement of the current to the anode. In devices wherein potentials of the order mentioned hereinabove are utilized, the fact that the beam may be of a greater cross section at the inlet end of the tube 11 than the internal diameter of this tube is determined by the phenomenon that in such case the enclosing vessel of the device will fluoresce at the region adjacent the inlet end of the tube. Also the tube 11 will fluoresce at regions at which electrons impinge. In lower voltage devices or those in which the vessel is of a material which does not fluoresce at the voltages employed, the inlet end of the tube and the inner walls thereof may be coated with fluorescent material. Hence, the requirements that the beam should just fill the inlet end of the tube and should not impinge upon the tube may be met by varying the potentials of the electrodes 15 and 17 until no fluorescence of the tube and of the enclosing vessel adjacent the inlet end of the tube 11 is discernible and a small change in these values results in such fluorescence. A very small amount of inert gas may be left in the enclosing vessel of the device so that the form of the beam in traversing the tube 11 will be observable by the glow produced by the beam. The conditions for maximum current are obtained by varying the potentials of electrodes 15 and 17 until, as determined by observation of the beam glow, the beam just fills the inlet end of the tube 11 and the minimum cross section thereof appears at a region midway between the end of the tube 11.

The device disclosed in Fig. 1, it will be noted, involves two controls, namely of the potential of the electrode 15 and that of the electrode 17. The invention may be embodied also in devices involving three controls, one of which devices is illustrated in Fig. 2 and is of generally the same construction as the device illustrated in Fig. 1. In the device shown in Fig. 2, however, the electrode 16 is provided with a separate leading-in conductor adjustably connected to the resistance 25 so that the potential of the electrode 16 may be varied. As in the device shown in Fig. 1, the potential of the electrode 18 is made such that the beam projected into the tube 11 is of the desired potential. The potential of the electrode 15 is made such that the required current is drawn from the emissive surface 14 of the cathode. The requisite form of the beam to give the maximum current to the anodes or collector electrode 12 as determined by Equation 4 is obtained by adjustment of the focal lengths of the electrostatic electron lenses L_1 and L_2 in the manner described heretofore in connection with Fig. 1.

The invention may be embodied also in devices utilizing a magnetic electron lens. One illustrative device is shown in Fig. 3 and is of generally the same construction as the devices shown in Figs. 1 and 2 except that it comprises three cylindrical electrodes 15, 16 and 17 and a magnetic coil 26 encompassing the vessel 10 for producing a field coaxial with the longitudinal axis of the enclosing vessel 10 of the device. The coil 26 may be energized by a suitable source, such as a battery 27 connected thereto through a variable resistance 28. The electrode 15 is maintained negative with respect to the cathode as in the devices illustrated in Figs. 1 and 2 and the electrodes 16 and 17 are maintained positive with respect to the cathode by suitable sources, not shown, connected across the terminals 29 and 30.

In the device illustrated in Fig. 3, the electrode 17 is maintained at a fixed potential to provide the desired voltage on the electron beam projected into the tube 11. The electrode 15 functions primarily to control the beam current and the potential thereof is made such that the requisite beam current is drawn from the cathode 13. Incidentally, this electrode acts as a weak electrostatic electron lens L_0 to cause convergence to a small extent only of the electron stream. The electrode 16, the potential of which is adjustable, defines a strong electrostatic lens L_1, and, as noted above, the coil 26 acts as a second lens L_2. As in the devices illustrated in Figs. 1 and 2, the two lenses L_1 and L_2 in the device shown in Fig. 3 have an appreciable separation and the focal lengths thereof are adjustable by varying the potential of the electrode 16 and the current through the coil 26. By proper adjustment of these focal lengths, as in the manner described heretofore in connection with Fig. 1, the requisite form of the projected beam and its relation to the tube 11 for the transmission of the maximum current through the tube 11 are obtained.

It will be appreciated that this invention enables the construction of electron beam discharge devices which will transmit a desired current at a desired voltage and wherein the tube 11 will be of the minimum diameter permissible with transmission of the maximum current therethrough so that not only is a close and efficient coupling obtained between the beam and external circuit elements, such as the cavity resonator 20, but also maximum efficiency and stable operating characteristics are realized.

Although the invention has been described with reference to particular embodiments wherein the tube constitutes a portion of the enclosing vessel, it is obvious that it may be embodied in other constructions, for example, constructions wherein the tube is mounted within the enclosing vessel of an electron discharge device. It will be understood also that various modifications may be made in the devices shown and described without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. An electron discharge device comprising an elongated tube, an electron receiving electrode opposite one end of said tube, and means opposite the other end of said tube for projecting an electron stream thereinto and coaxial therewith, said means including a cathode and a pair of electron lenses in cooperative relation with said cathode and having such focal lengths that at said other end of said tube the electron stream has substantially the same cross section as said tube and the current transmitted through said tube is substantially equal to

$$3.87V^{3/2}\left(\frac{D}{L}\right)^2\times10^{-5}$$

where D and L are the diameter and length, respectively of said tube and V is the voltage at which said stream is projected into said tube.

2. An electron discharge device comprising an elongated tube, an electron receiving electrode opposite one end of said tube, a cathode opposite the other end of said tube, and means for concentrating electrons emanating from said cathode into a stream coaxial with said tube and having a minimum cross section substantially midway between the ends of said tube and a cross section at said other end of said tube substantially equal to the cross section of said tube, said concentrating means including means defining a pair of coaxial, axially spaced electron lenses between said cathode and said other end of said tube and coaxial with said tube.

3. An electron discharge device comprising an elongated tube, an electron receiving electrode opposite one end of said tube, and means for projecting through said tube to said one end thereof an electron beam current having a value of substantially

$$3.87V^{3/2}\left(\frac{D}{L}\right)^2\times10^{-5}$$

where D and L are the diameter and length, respectively, of said tube and V is the potential at which the beam is projected into said tube, said means comprising a cathode, means including a cylindrical electrode adjacent said cathode defining a first electron lens coaxial with said tube and means defining a second electron lens between said first lens and said tube, said lenses being coaxial with said tube and axially spaced.

4. An electron discharge device comprising an elongated tube, an electron receiving electrode opposite one end of said tube, a cathode opposite the other end of said tube and coaxial therewith, and an electrode system for concentrating electrons emanating from said cathode into a stream projected into said tube and having, at said other end of said tube, a cross section substantially equal to the cross section of said tube and having a minimum cross section substantially midway between the ends of said tube, said system comprising means including a plurality of cylindrical electrodes mounted in end to end relation between and coaxial with said cathode and said other end of said tube, defining an electrostatic electron lens adjacent said cathode and a compound electrostatic electron lens between said first lens and said other end of said tube.

5. An electron discharge device comprising an elongated tube, an electron receiving electrode opposite one end of said tube, and means for projecting an electron stream into the other end of said tube and coaxial with said tube, said means comprising an electrode system coaxial with said tube and opposite the other end thereof and including a cathode and a cylindrical electrode defining a first electron lens adjacent said cathode, said means comprising also a magnetic coil between said cylindrical electrode and said other end of said tube and defining a second electron lens, and said first and second electron lenses having such focal lengths that said electron stream is concentrated within a boundary having, at said other end of said tube, a cross section substantially equal to that of said tube and the current transmitted through said tube is substantially equal to

$$3.87V^{3/2}\left(\frac{D}{L}\right)^2\times 10^{-5}$$

where D and L are the diameter and length respectively of said tube and V is the voltage at which said stream is projected into said tube.

6. An electron discharge device comprising an enclosing vessel having an elongated, vitreous cylindrical portion, a collector electrode opposite one end of said cylindrical portion, and an electrode system opposite the other end of said portion and coaxial therewith for projecting an electron stream into said portion, said system comprising a cathode, a positive electrode for drawing from said cathode a current of substantially

$$3.87V^{3/2}\left(\frac{D}{L}\right)^2\times 10^{-5}$$

where D and L are the diameter and length respectively of said portion and V is the potential at which said stream is projected into said portion and means including a plurality of electrodes coaxial with said portion defining a pair of axially spaced electron lenses having such focal lengths that at its plane of injection into said portion said stream is of substantially the same cross section as said portion and all of said current is transmitted through said portion.

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