Oct. 26, 1948. C. G. SMITH 2,452,075

VELOCITY MODULATION ELECTRON DISCHARGE TUBE

Filed Dec. 18, 1941

Fig. 1.

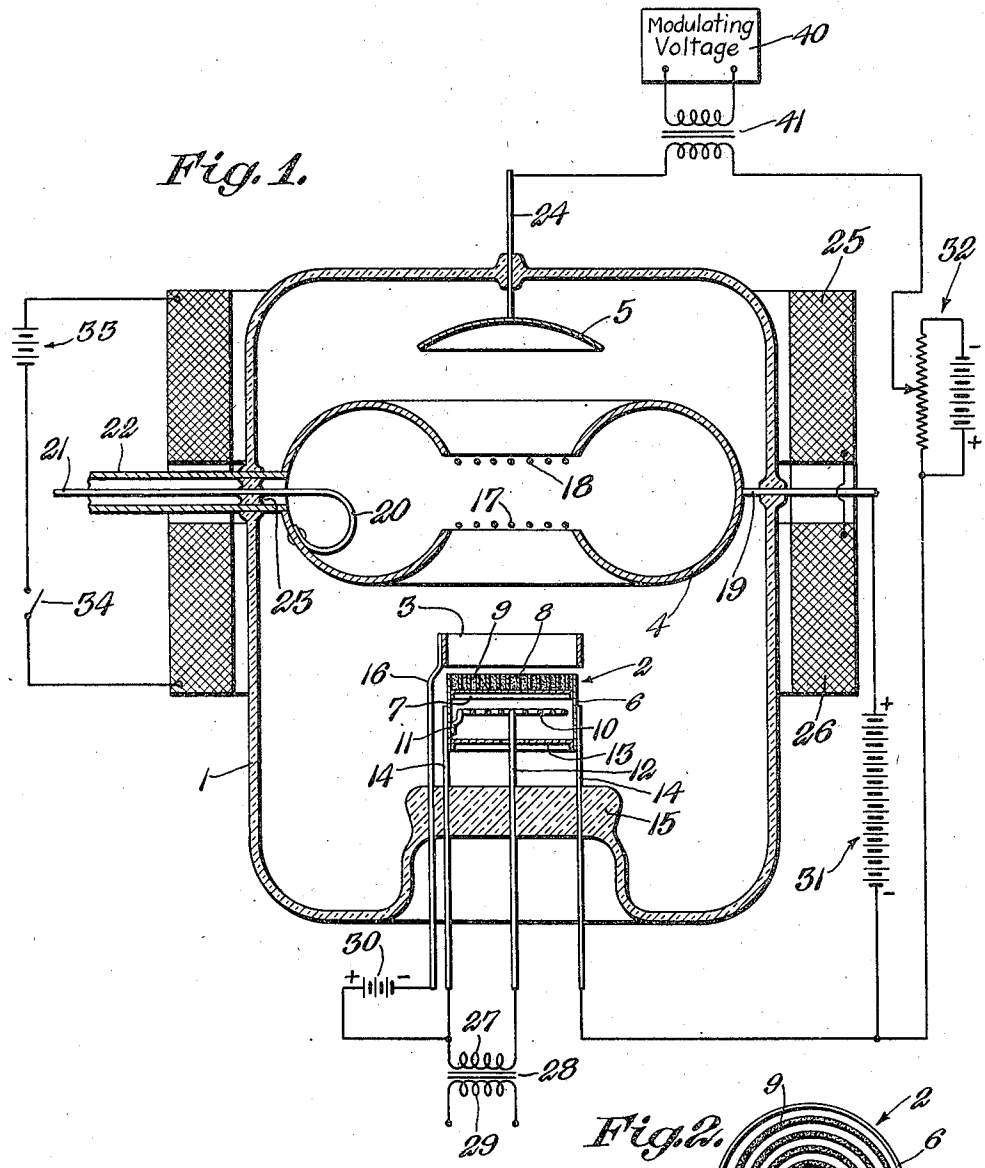


Fig. 2.

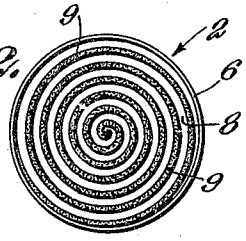


Fig. 3.

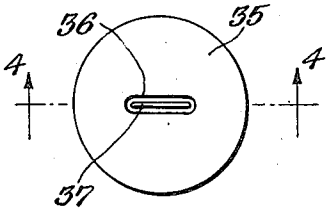
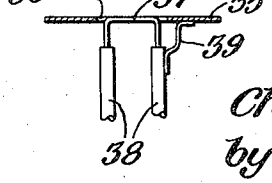


Fig. 4.



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VELOCITY MODULATION ELECTRON DISCHARGE TUBE

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15 Claims. (Cl. 250—27.5)

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This invention relates to an electron velocity modulation discharge tube, and more particularly to the utilization in such a tube of a cathode which is capable of supplying large peak values of current. Heretofore such electron velocity modulation tubes have had difficulties associated with the cathode. The cathode used has been limited in its ability to supply large peak values of current. Also its life has been short, particularly when subjected to increased loads and severe ion bombardment.

An object of this invention is to produce an electron velocity modulation tube in which a limited amount of thermionic emission is produced, and in which a large part of the emission from the cathode is supplied by causing electrons to return to the cathode with sufficient energy to release secondary electrons.

Another object is to produce a cathode adapted for the foregoing use which shall have long life and relatively high efficiency.

The foregoing and other objects of this invention will be best understood from the following description of exemplifications thereof, reference being had to the accompanying drawing, wherein:

Fig. 1 is a vertical cross-section of a tube embodying my invention;

Fig. 2 is an enlarged top view of the cathode illustrated in Fig. 1;

Fig. 3 is a top view of an alternative form of cathode; and

Fig. 4 is a cross-section taken along line 4—4 of Fig. 3.

In the arrangement as shown in Fig. 1, the tube consists of an envelope 1 of some suitable material, such as glass, containing a cathode 2, a focusing electrode 3, an electron velocity modulating grid structure 4, and an electrode 5.

In accordance with my invention, I construct the cathode so as to supply a limited amount of thermionic emission, and also to supply relatively large amounts of secondary emission which may carry whatever peak current the tube is called upon to deliver. For this purpose the cathode may be constructed in a satisfactory form, as shown, for example, in Figs. 1 and 2. This cathode consists of an outer cylinder 6 of a metal, such as tantalum, nickel or the like. A short distance below the top of the cylinder 6 is supported a transverse wall member 7, leaving an upper relatively shallow cup. In this cup is inserted a ribbon 8 of some suitable refractory metal, such as tantalum, molybdenum or tungsten. The material which I prefer to use is

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tantalum. The ribbon 8 is coated with electron-emitting oxides, and then rolled up into a tight spiral and inserted snugly within the shallow cup in the top of the cylinder 6. The coating on the ribbon 8 may initially consist of a mixture of barium-strontium carbonates in a suitable binder, and baked in air at a temperature of about 400° F., so as to produce a strongly adherent coating consisting largely of the oxides of barium and strontium. The coating is scraped off the exposed surfaces of the ribbon 8, leaving coating 9 between the adjacent turns of the spiral. Thus the upper edges of the ribbon 8 are substantially bare of the coating while the coating material itself is exposed to the discharge space between the adjacent turns of the spiral. I prefer to construct the cathode so that the major portion of the surface thus exposed is substantially bare tantalum, and a minor portion of the surface thus exposed comprises electron-emitting oxides. The transverse wall member 7 forms a lower chamber within the cylinder 6 in which is inserted a heater spiral 10 of some suitable refractory wire, such as tungsten. The spiral 10 has one end 11 thereof fastened to the inner wall of the cylinder 6, and the other end connected to a central lead 12. The cylinder 6 is provided with a lower transverse shield 13 having a central opening through which the lead 12 projects. The entire cathode structure is supported by a pair of conducting standards 14 sealed in a stem 15 formed in the envelope 1. The lead 12 is likewise sealed through said stem 15.

The cathode structure, as described above, possesses the property of being an excellent secondary electron emitter, particularly from the scraped tantalum surfaces, as well as a good thermionic emitter from the exposed oxide surfaces. The tantalum has a tendency to reduce the barium oxide liberating small amounts of barium on the surface of the coating which tends to give excellent electron emission. Also the barium so liberated tends to coat the bare surfaces of the tantalum, making them excellent secondary electron emitters. Even without any barium coating, tantalum in itself is a good secondary emitter.

The electrons emitted from the upper surface of the cathode 2 are preferably concentrated into a beam by means of the focusing electrode 3. This electrode is in the form of a ring, and is supported by a conducting standard 16 likewise sealed in the stem 15.

The electrode 4 is preferably in the form of

a hollow annular ring having a portion cut out of its inner central region to provide openings through the center of the electrode 4 through which the electron beam may pass. Grids 17 and 18 of relatively fine wire and wide spacing may be placed across the openings, although these grids may be omitted if desired. The proper potential may be impressed upon the electrode 4 by means of a lead-in conductor 19 sealed through a wall of the envelope 1. Oscillations which are generated in the grid electrode 4 may be supplied to a suitable external circuit through a coupling loop 20, one end of which is fastened to the inner wall of the grid electrode 4 and the other end of which is connected to a lead 21. Surrounding the lead 21 is a pipe 22 fastened to an opening in the outside of the grid electrode 4. The pipe 22 is sealed through the wall of the envelope 1, and the conductor 21 passes through a suitable seal 23 within the pipe 22. The seal 23 is preferably at a node of voltage, so as to reduce the losses at this point. The pipe 22 and lead 21 form a concentric transmission line which readily passes the ultra high frequencies generated by the tube described.

The electrode 5 functions to reflect electrons back through the electron velocity modulating grid 4. It is preferably curved so as to direct the reflected electrons toward the opening through said grid 4, and is likewise supported on a lead 24 sealed through the wall of the envelope 1.

In some instances I prefer to use coils 25 and 26 surrounding the tube for the purpose of setting up a longitudinal magnetic field which assists in focusing the electron beam issuing from the cathode 2.

The tube described above may be connected in some suitable circuit such as illustrated, for example, in Fig. 1. In this circuit the heating filament 10 is supplied with heating current from the secondary winding 27 of a heating transformer 28 having a primary winding 29 which may be connected to some suitable source of alternating current. A source of biasing potential 30 may be connected between the focusing electrode 3 and the cathode 2 with such a polarity as to make the electrode 3 slightly negative with respect to the cathode. If desired, however, the electrode 3 could be connected directly to the cathode 2. A high voltage source 31, which may be, for example, of the order of 1000 volts, is connected between the cathode 2 and the grid 4. The electrode 5 is connected through a variable biasing voltage arrangement 32 to the cathode 2. The arrangement 32 may consist of a battery across which is connected a voltage-dividing resistance provided with an adjustable tap. The tap is connected to the lead 24 and the proper terminal of the battery is connected to the cathode lead 14 so as to make the electrode 5 slightly negative with respect to the cathode. If desired, the electrode 5 could be connected directly to the cathode 2. In operation the magnitude of the voltage bias on 5 may be adjusted to give a maximum output for the device. The coils 25 and 26 are connected in series and may be supplied with current from a suitable source 33 through a control switch 34.

In starting the operation of the device, the cathode is heated to a temperature at which sufficient thermionic emission occurs to initiate the operation, such emission ordinarily being much less than that required to supply either the normal current requirements or the peak current requirements of the tube. The electrons emitted from the cathode are formed into a beam by the focusing electrode 3, and are accelerated under the action of the voltage applied to the electrode 4. The accelerated beam of electrons thereupon enters the region between the edges 17 and 18 of the grid 4. The thermal agitation of the electron atmosphere which is thus created within the grid 4 sets up variations in voltage in said grid structure which causes oscillations to be initiated therein. These oscillations impart voltage differences to the edges 17 and 18 which accelerate some of the electrons and decelerate others. The velocity differences thus imparted to the electrons cause faster electrons to catch up with slower electrons and produce bunching. The bunching usually occurs after the electrons leave the electrode 4. As the electrons approach the electrode 5, they are reflected by it since it is substantially at cathode potential or lower. The reflected electrons preferably re-enter the grid 4 in bunched condition. These electrons preferably have such a time phase relation that they enter the electrode 4 when the grid 18 is negative and the grid 17 is positive. Under these conditions the electrons are accelerated and have imparted to them an additional velocity to that which they possessed upon entering the electrode structure 4. In thus accelerating the electrons, the oscillating electrode structure 4 imparts energy thereto. The electrons thus accelerated leave the electrode 4, pass the grid 17 at relatively high speeds, and travel to the cathode with sufficient energy to impinge upon the upper surface of the cathode and liberate secondary electrons, particularly from the bare tantalum surfaces, as described above. The bunching action is substantially completed by the time the electrons reach the cathode. Therefore secondary electrons in increased numbers are liberated from the cathode surface each time a bunch of primary electrons collide with said cathode as described above. It will be seen, therefore, that the secondary electrons are likewise emitted in bunches, and will proceed toward the electrode 4 under the action of the voltage impressed on said electrode. The bunched secondary electrons will enter the structure of the electrode 4 when the grid 18 is negative and the grid 17 is positive. Under these conditions the electrons which are travelling at relatively high speeds move against the action of the electrostatic field created between the grids 17 and 18, and thus give up energy to the electrode structure 4. This energy is of proper phase and frequency to reinforce the initial oscillations and cause the device to generate sustained oscillations at considerable amplitude. The electrons which thus impart energy to the electrode structure 4 may leave said structure through the grid 18 with relatively low speeds, and fall upon the outer surfaces of the electrode 4, which in this way acts as a collector of these electrons.

In order that the time phase relationships described above shall occur, the electrodes should be spaced relative to each other in a predetermined relationship. The distance between the emitting surface of the cathode 2 and the grid 17 should be equal to

$$\frac{ND}{2}$$

where N is an integer and D is the distance between electron bunches. This distance D may be calculated approximately from the values of volt-

age impressed on the tube and the frequency at which the device is intended to be operated. The distance between the reflecting surface of the electrode 5 and the grid 18 should be

$$\frac{N'D}{4}$$

where N' is an odd integer. If the actual spacing in a device differs somewhat from these relationships, the effect will still be produced but to a reduced extent. However, as long as the action described occurs to a substantial degree, the operation of the device will be improved to that extent.

The relationships as described above, whereby amplified operation of the device is secured, may be affected by the voltage impressed on the electrode 5. This affords a convenient way of modulating the oscillations generated. For this purpose a modulating voltage source 40 may be connected in series with the electrode 5, preferably through a coupling transformer 41.

Under some conditions where it is difficult to set the system oscillating, the voltage of the electrode 5 may be varied through a relatively wide range, enabling a condition to be reached which may be more favorable to the initiation of such oscillations. Once oscillations have been started, the voltage of the electrode 5 may be restored to any desired value.

Instead of using a cathode structure, as illustrated in Figs. 1 and 2, a simplified cathode arrangement can be used advantageously in my invention. An example of a simplified form of cathode is illustrated in Figs. 3 and 4. This cathode consists of a disk 35 of a suitable secondary electron-emitting material. For example, this material may be a magnesium silver alloy which when placed within the tube and subjected to activating operations therein becomes an excellent secondary electron emitter. The disk 35 is provided with a central opening 36 in which is received a filament 37. This filament 37 is a good thermionic electron emitter, and may be of the thoriated tungsten or of the oxide-coated type. The ends of the filament 37 are supported on leads 38. The disk 35 may be supported from one of the leads 38 by a supporting wire 39. When the cathode illustrated in Figs. 3 and 4 is substituted for the cathode 2 in Fig. 1, the operation is substantially that as described above in connection with said Fig. 1.

In the arrangement as shown at Fig. 1, the electrode 5 may also be made of material, such as that described in connection with Figs. 3 and 4, which is a good secondary electron emitter. Under these conditions, the parameters of the device are so selected that electrons are permitted to fall upon the surface of the electrode 5 with sufficient energy to liberate increased secondary electrons. These emitted electrons proceed from the electrode 5 toward the electrode 4, substantially as described in connection with the electrons reflected from the electrode 5. Liberation of secondary electrons from the electrode 5 likewise may increase the amount of power which may be derived from an arrangement such as herein described.

Of course it is to be understood that this invention is not limited to the particular details as described above, as many equivalents will suggest themselves to those skilled in the art. For example, the electron velocity modulating grid 4 may take a wide variety of forms, including various shaped hollow chambers as well as straight

cylindrical electrodes. Also devices of this kind may be made to function as amplifiers and detectors as well as oscillators. Likewise the modulating effect exerted by the variation of voltage on the electrode 5 may be utilized where electrons are not returned to the cathode but are permitted to pass back through the grid 4 and fall upon its outer surface adjacent the grid 17. In this case the cathode need not be made a secondary electron emitter. It will be seen, therefore, that the various features of my invention as described above are capable of a wide variety of embodiments as many other equivalents will suggest themselves to those skilled in the art.

What is claimed is:

1. An electron velocity modulation discharge device comprising a cathode having a substantial thermionic emission less than that required to carry the peak current of said device, an electron velocity modulating grid interposed in the path of electrons emitted from said cathode for imparting velocity modulation to electrons passing through said grid, and electrode means interposed in the path of the electrons passing through said grid for reflecting said electrons back onto said cathode with sufficient energy and in sufficient numbers to liberate secondary electrons in sufficient numbers to produce a total electron emission capable of carrying said peak current.

2. An electron velocity modulation discharge device comprising a plurality of electrodes including a cathode having an active surface which liberates secondary electrons readily, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, the electrons emitted from said cathode forming an electron stream along said path, said electrode elements being connected to each other by a cavity resonator having a sufficiently high resonant frequency to impart bunching to the electron stream in said path, and electrode means for directing electrons onto said cathode with sufficient energy and in sufficient numbers to liberate secondary electrons which form part of said electron stream.

3. An electron velocity modulation discharge device comprising a plurality of electrodes including a cathode having an active surface which liberates secondary electrons readily, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, the electrons emitted from said cathode forming an electron stream along said path, said electrode elements being connected to each other by a cavity resonator having a sufficiently high resonant frequency to impart bunching to the electron stream in said path, and electrode means for reflecting said electron stream after it has passed through said electrode structure back onto said cathode with sufficient energy to liberate secondary electrons which then form part of said electron stream.

4. An electron velocity modulation discharge device comprising a cathode having an active surface which liberates secondary electrons readily, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, the electrons emitted from said cathode forming an electron stream along said path, said electrode elements being connected to each other by a cavity resonator having a sufficiently high resonant frequency to impart bunching to

the electron stream in said path, and an additional electrode on the opposite side of said electrode structure from said cathode and adapted to reflect said electron stream back through said electrode structure onto said cathode with sufficient energy to liberate secondary electrons which then form part of said electron stream.

5. An electron velocity modulation discharge device comprising a cathode, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, said electrode elements being connected to each other by a cavity resonator having a sufficiently high resonant frequency to impart bunching to the electron stream in said path, whereby the electrons of said stream are concentrated into bunches travelling through said device a predetermined distance apart, and electrode means for reflecting said electron stream after it has passed through said electrode structure back onto said cathode, said cathode being spaced from said electrode structure a distance which is substantially

$$\frac{ND}{2}$$

where N is an integer and D is the distance between electron bunches.

6. An electron velocity modulation discharge device comprising a cathode, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, said electrode elements being connected to each other by a cavity resonator having a sufficiently high resonant frequency to impart bunching to the electron stream in said path, whereby the electrons of said stream are concentrated into bunches travelling through said device a predetermined distance apart, and an additional electrode on the opposite side of said electrode structure from said cathode and adapted to reflect said electron stream back through said electrode structure, said cathode being spaced from said electrode structure a distance which is substantially

$$\frac{ND}{2}$$

where N is an integer and D is the distance between electron bunches, said additional electrode being spaced from said electrode structure substantially

$$\frac{N'D}{4}$$

where N' is an odd integer.

7. An electron velocity modulation discharge device comprising a cathode having an active surface which liberates secondary electrons readily, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, said electrode elements being connected to each other by a cavity resonator having a sufficiently high resonant frequency to impart bunching to the electron stream in said path, whereby the electrons of said stream are concentrated into bunches travelling through said device a predetermined distance apart, and electrode means for reflecting said electron stream after it has passed through said electrode structure back onto said cathode with sufficient energy to liberate secondary electrons which then form part of said electron stream, said cathode being spaced from said electrode structure a distance which is substantially

$$\frac{ND}{2}$$

where N is an integer and D is the distance between electron bunches.

8. An electron velocity modulation discharge device comprising a cathode having an active surface which liberates secondary electrons readily, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, said electrode elements being connected to each other by a cavity resonator having a sufficiently high resonant frequency to impart bunching to the electron stream in said path, whereby the electrons of said stream are concentrated into bunches travelling through said device a predetermined distance apart, and an additional electrode on the opposite side of said electrode structure from said cathode and adapted to reflect said electron stream back through said electrode structure with sufficient energy to liberate secondary electrons which then form part of said electron stream, said cathode being spaced from said electrode structure a distance which is substantially

$$\frac{ND}{2}$$

where N is an integer and D is the distance between electron bunches, said additional electrode being spaced from said electrode structure substantially

$$\frac{N'D}{4}$$

where N' is an odd integer.

9. In an electrical system, an electron velocity modulation discharge device comprising a plurality of electrodes including a cathode, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, said electrode elements being connected to each other by a cavity resonator having a sufficiently high resonant frequency to impart bunching to the electron stream in said path, and an additional electrode on the opposite side of said electrode structure from said cathode and adapted to reflect said electron stream back through said electrode structure, whereby said device is adapted to operate with high frequency currents in said electrode structure, and means connected to said additional electrode for varying the voltage on said additional electrode with respect to said cathode for varying said high frequency currents.

10. In an electrical system, an electron velocity modulation discharge device comprising a plurality of electrodes including a cathode having an active surface which liberates secondary electrons readily, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, said electrode elements being connected to each other by a cavity resonator having a sufficiently high resonant frequency to impart bunching to the electron stream in said path, and an additional electrode on the opposite side of said electrode structure from said cathode and adapted to reflect said electron stream back through said electrode structure onto said cathode with sufficient energy to liberate secondary electrons which then form part of said elec-

tron stream, whereby said device is adapted to operate with high frequency currents in said electrode structure, and means connected to said additional electrode for varying the voltage on said additional electrode with respect to said cathode for varying said high frequency currents.

11. In an electrical system, an electron velocity modulation discharge device comprising a cathode, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, said electrode elements being connected to each other by a cavity resonator having a sufficiently high resonant frequency to impart bunching to the electron stream in said path, whereby the electrons of said stream are concentrated into bunches travelling through said device a predetermined distance apart, and an additional electrode on the opposite side of said electrode structure from said cathode and adapted to reflect said electron stream back through said electrode structure, whereby said device is adapted to operate with high frequency currents in said electrode structure, said cathode being spaced from said electrode structure a distance which is substantially

$$\frac{ND}{2}$$

where N is an integer and D is the distance between electron bunches, said additional electrode being spaced from said electrode structure substantially

$$\frac{N'D}{4}$$

where N' is an odd integer, and means connected to said additional electrode for varying the voltage on said additional electrode with respect to said cathode for varying said high frequency currents.

12. In an electrical system, an electron velocity modulation discharge device comprising a cathode, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, said electrode elements being connected to each other by a cavity resonator having a sufficiently high resonant frequency to impart bunching to the electron stream in said path, whereby the electrons of said stream are concentrated into bunches travelling through said device a predetermined distance apart, and an additional electrode on the opposite side of said electrode structure from said cathode and adapted to reflect said electron stream back through said electrode structure, whereby said device is adapted to operate with high frequency currents in said electrode structure, said cathode being spaced from said electrode structure a distance which is substantially

$$\frac{ND}{2}$$

where N is an integer and D is the distance between electron bunches, said additional electrode being spaced from said electrode structure substantially

$$\frac{N'D}{4}$$

where N' is an odd integer, and means connected to said electrodes for varying the relative potentials on said electrodes with respect to said cathode for altering said relationships and thereby varying said high frequency currents.

13. An electron velocity modulation discharge device comprising a cathode, said cathode having a surface portion of a good thermionic emissive material and another surface portion of a good secondary electron-emissive material, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, said electrode elements being connected to each other by cavity resonator having a sufficiently high resonant frequency to impart bunching to the electron stream in said path, and electrode means facing said cathode for reflecting electrons emitted from said cathode back onto said cathode with sufficient energy and in sufficient numbers to liberate secondary electrons from the secondary electron-emissive portion of the cathode, which electrons form part of said electron stream.

14. An electron velocity modulation discharge device comprising a cathode having an active surface which liberates secondary electrons readily, and having a substantial thermionic emission less than that required to carry the peak current of said device, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, said electrode elements being connected to each other by a cavity resonator having a sufficiently high resonant frequency to impart bunching to the electron stream in said path, and electrode means on the opposite side of said electrode structure from said cathode for reflecting said electron stream after it has passed through said electrode structure back onto said cathode with sufficient energy to liberate secondary electrons in sufficient numbers to produce a total electron emission capable of carrying said peak current.

15. An electron velocity modulation discharge device comprising a cathode, said cathode having a surface portion of a good thermionic emissive material and another surface portion of a good secondary electron-emissive material, an electron velocity modulating electrode structure comprising a pair of electrode elements through which an electron path from said cathode passes, said electrode elements being connected to each other by a cavity resonator having a sufficiently high resonant frequency to impart bunching to the electron stream in said path, and electrode means on the opposite side of said electrode structure from said cathode for reflecting said electron stream after it has passed through said electrode structure back onto said cathode with sufficient energy to liberate secondary electrons from said latter portion, which electrons form part of said electron stream.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,650,232	Pickard	Nov. 22, 1927
2,117,636	Tjoflat	May 17, 1938
2,173,208	Lecorguillier	Sept. 19, 1939
2,244,318	Skellett	June 3, 1941
2,259,690	Hansen et al.	Oct. 21, 1941
2,263,032	Farnsworth	Nov. 18, 1941
2,278,210	Morton	Mar. 31, 1942
2,295,396	George	Sept. 8, 1942