March 1, 1949. C. V. LITTON 2,462,877

ELECTRON DISCHARGE DEVICE

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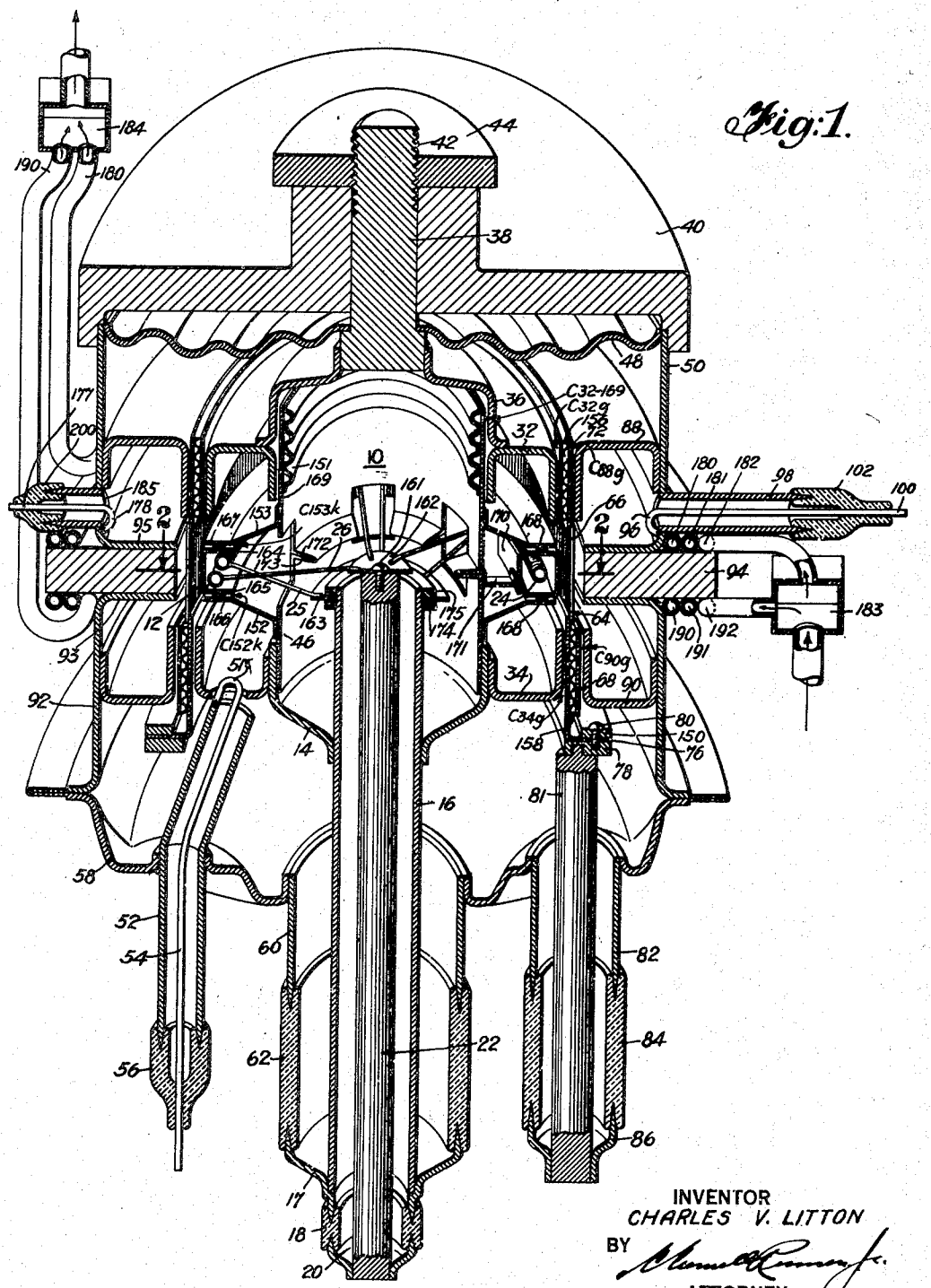


Fig. 1.

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Fig. 3.

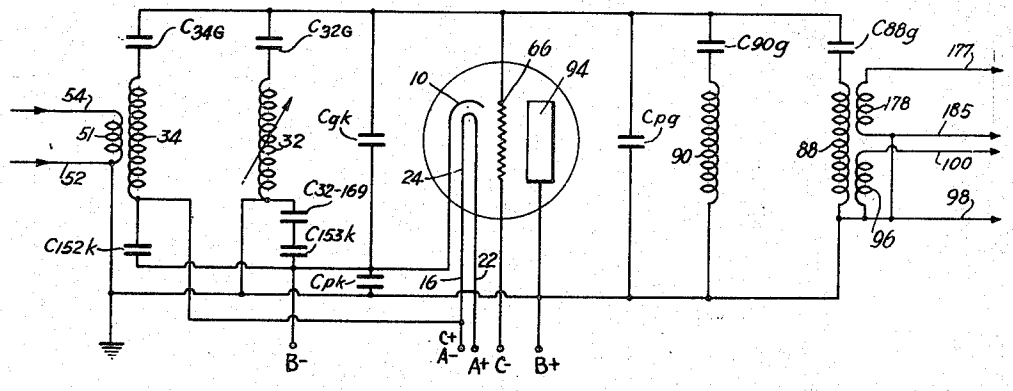


Fig. 2.

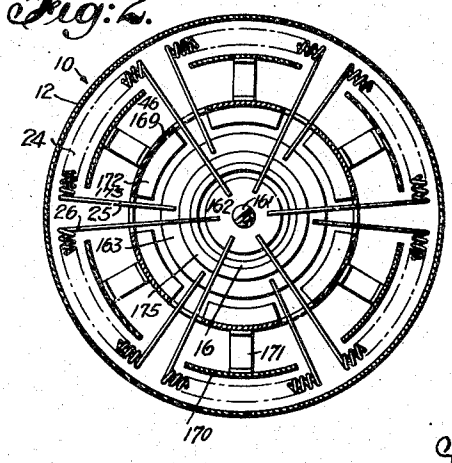


Fig. 4.

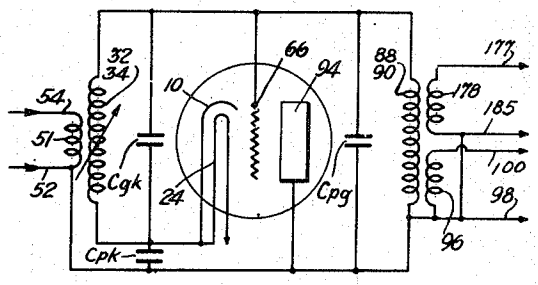
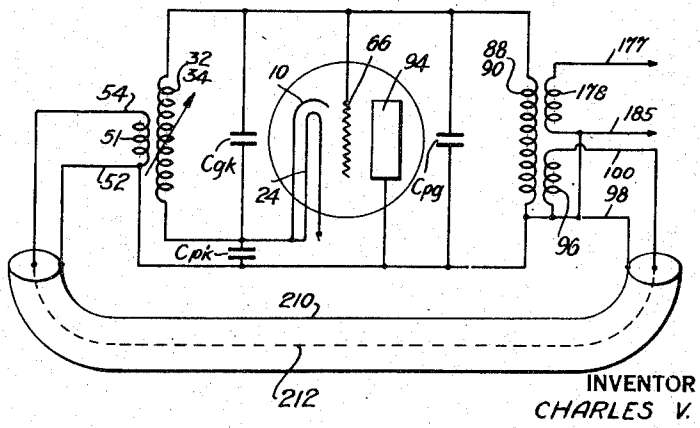


Fig. 5.



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ELECTRON DISCHARGE DEVICE

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14 Claims. (Cl. 250—27.5)

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This invention relates to improvements in electron discharge devices and more particularly to a vacuum tube resonator capable of producing large amounts of power at ultra-high-frequencies. This application is a continuation-in-part of my U. S. Patent No. 2,372,213 granted March 27, 1945.

An object of the present invention is to provide a novel high power vacuum tube resonator.

Another object of this invention is to provide a vacuum tube resonator capable of producing larger amounts of power at ultra-high frequencies than heretofore possible.

A further object of this invention is to provide a vacuum tube resonator having relatively low internal capacities for the amount of power which the tube is able to handle.

A still further object of the invention is to provide a novel annular cathode construction.

The invention specifically contemplates the construction of a vacuum tube resonator having a ring-shaped cathode surrounded by concentric annular electrodes such as an anode, or a grid and anode.

In its broadest sense, the invention is directed to a novel vacuum tube resonator in which the capacity between electrodes per active inter-electrode area is maintained extremely low.

These and other objects and advantages of the present invention will appear from the following description of a preferred form of vacuum tube resonator embodying the essential features of the invention, illustrated in the accompanying drawings, in which:

Fig. 1 is a vertical cross-sectional view, in partial perspective, illustrating a preferred embodiment of a vacuum tube oscillator in accordance with the present invention;

Fig. 2 is a horizontal cross-sectional view of the cathode structure, taken along the line 2—2 of Fig. 1;

Fig. 3 is a circuit diagram of the vacuum tube oscillator illustrated in Fig. 1;

Fig. 4 is a simplified circuit diagram showing the effective high frequency circuit of the oscillator illustrated in Fig. 1; and

Fig. 5 is a circuit diagram similar to Fig. 4 showing the tube operating as a self-excited oscillator.

For the successful operation of vacuum tubes at ultra high frequencies, it is known that the electrode spacings must be kept small in order to reduce inter-electrode transit time. On the other hand, the inter-electrode capacities must be kept small so that the resonant circuits can

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develop the required impedance. Consequently, as tubes have been developed to operate at higher and higher frequencies, the area of the elements has been reduced in order to lower the inter-electrode capacities. The reduction in cathode area means low peak emission and low peak power output under pulse operation, while small plate area means low average power capabilities.

Applicant has discovered, however, that by the use of a cathode formed as a figure of revolution of relatively large radius but with a narrow effective cathode emission surface, the periphery of this cathode being surrounded by a suitable annular anode, large amounts of power at ultra-high frequencies can be developed. This follows from the fact that whereas the total capacity between the electrodes is increased, the capacity per unit circumference of the cathode is maintained relatively small. This follows from the fact that the electrical characteristics per unit circumference are dependent upon the thickness of the adjacent electrodes and the distance between them, and are substantially independent of the radius. The resultant tube is, in effect, equivalent to an infinite number of tubes connected in parallel, each tube having a low unit inter-electrode capacity. In such event, the power developed is greatly increased but the extra capacity introduced does not add the capacity already existing in the ordinary sense, because the circular symmetry conditions existing at one point along the circumference cannot influence the conditions at any other point as contrasted, for example, to known types of tubes having concentric elements in which the radius of the centrally positioned cathode is extremely small relatively to its length. One form of such a figure of revolution tube meeting the desired conditions outlined above, is described by way of example below, while another form of such a tube is shown in my above identified copending application.

The vacuum tube resonator illustrated in Fig. 1 is provided with a cathode 10 having a configuration which meets the requirements outlined above. It will be noted that the cathode 10, shown in more detail in Fig. 2, is provided with a hollow ring having a relatively narrow periphery emitting surface 12 whose radius is substantially greater than its width in the longitudinal direction. The cathode 10 may be immediately supported on either side by a pair of partially oblique disks 152 and 153 having outwardly directed flanges 166 and 167 spaced close to but not contacting the inwardly directed integral cathode flanges 164 and 165, except through a plurality

of circumferentially spaced intermediate metal disks 168, preferably spot-welded between the opposing flanges. The disks 152 and 153, in turn, are supported by a cylindrical shell formed by the two half cylinders 46 and 169, and connected together through opposed flanges 172, 173. The half cylinder 169 may be strengthened by the cylindrical corrugated insert 151. The lower half cylinder 46 is supported by a cup-shaped member 14 at one end which, in turn, is attached to a hollow supporting tube 16. The other end of the tube 16 is attached in any suitable manner to a metal closure member 17 connected to a glass seal 18. The latter, in turn, is connected to the end member 20 to which is attached the rod 22 passing through the tubular support 16 and extending upwardly into the interior of the cylinders 46, 169 for connection with the cathode heaters 24 of which there may be six connected in parallel and spaced circumferentially within the cathode 10. One end of each heater 24 may be directly connected as by wire 26 to a disk 162 mounted on the end of the rod 22 by means such as screw 161; the rod 22 will then form one of the heater leads. The other end of the heaters 24 may be attached by lead 25 to a ring 163 fastened on the tubular support 16 between a rigid collar 174 and a threaded collar 175 threadedly mounted in the upper end of the support 16 which then serves as the other heater lead. The leads 25 and 26 will extend through suitable openings in the cylinders 46, 169. To further increase the thermal efficiency of the cathode, six heat shields 170 are placed behind the respective heater coils 24, and are attached to the cylinder 46 as by brackets 171.

The cathode construction, described above is advantageous in many respects. The spacing between the emitting surface 12 and its supporting disks 152 and 153 acts as a thermal insulation preventing excessive heating of the disks and permitting the dissipation of such heat. The emitting surface 12 is electrically connected to the disks 152, 153 by the capacity between the opposed flanges 164, 167 and 165, 166 and directly connected by the metal disk 168.

Coaxial cavity resonators 32 and 34 in the form of split toroids are positioned coaxial with and upon opposite sides of the annular cathode emitting surface 12. In the preferred embodiment of the invention illustrated, the resonator 32 is spaced from the cylindrical member 169 and supported by an inverted cup-shaped member 36 mounted upon the end of a longitudinally adjustable bar 38. The bar 38 is slidably mounted in a centrally positioned opening within the tube cap 40 and at its outer end is provided with suitable threads 42 which are engaged by a nut 44. It will be clear to those skilled in this art that rotation of the nut 44 will result in an upward or downward movement of the bar 38, and a resulting adjustment in the position of the resonator 32. The end of the tube is sealed despite the presence of the longitudinally movable bar 38 by suitable means such as a flexible metal membrane 48 tightly conencted about the bar 38 at its center, and connected about its circumference to a metallic wall 50 of the tube.

The coaxial resonators 32, 34 preferably form the high-frequency input circuit for the vacuum tube oscillator and coupling thereto may be made by a suitable loop 51 projecting through an opening into the resonator 34. The loop is supported by a coaxial line in the form of an outer tubular member 52 surrounding an internal lead 54. A

suitable seal 56 closes off the outer end of the tube 52 and holds the lead 54 in position. The tube 52 is held in place relatively to the resonator 34 by firmly connecting it to the lower outer shell 58 of the tube. In accordance with the preferred form of invention, and in contrast to the mounting of the resonator 32, the lower coupled resonator 34 is rigidly attached to the cup-shaped cathode support 14. Depending from the center of the lower outer shell 58 is a metal cylinder 60, connected by glass cylinder 62 to the metal closure member 17, thus completing the sealing of the lower end of the electron discharge device.

The grid is positioned concentric to the cathode 10, being spaced relatively closely to the active cathode surface 12 and also relatively closely to the outer annular surfaces of the resonators 32, 34. The grid 64 may consist of a plurality of circumferentially spaced wires 66 supported at their ends by rigid annular members 68 and 72. These annular members may be strengthened, if desired, by respective corrugated cylinder 156, inside the grid and corrugated cylinder 158, outside the grid. The lower end of the grid support 68 may be turned over as a flange 76 connected to a supporting ring 78 by suitable means such as a clamping ring 150 and screws 80. The ring 78, in turn, is mounted on one or more rods 81 extending outside of the tube through means such as the cylinder 82, the cylindrical tube 84 and the closure cap 86. The rod 81 may thus serve as a grid terminal for the grid tube.

Radially spaced from the grid 64 and in juxtaposition with the coaxial resonators 32 and 34 are positioned a second pair of generally open toroidal coaxial resonators 88 and 90. There are, thus, four cavity resonators about the electrodes, the first and second cavity resonators 88 and 90 being supported rigidly by the metallic wall 50 of the tube, the third cavity resonator 34 being supported rigidly by the cathode 10 and the fourth cavity resonator being adjustably supported by the cup-shaped member 36. The resonator 90 is rigidly connected to and supported by the lower outer shell 92 of the tube, and at its upper end is provided with an inwardly turned flange 93 supporting the annular anode disk 94. The upper resonator 88 is rigidly attached to and supported by the upper outer shell 50 of the tube and is provided with a similar inwardly directed annular flange 95 at its lower end. It will be thus seen that the anode disk 94 is, in effect, mounted between the resonator flanges 93 and 95 and is directly electrically connected to one side of these resonators. The flanges 93 and 95 are so positioned that the inner periphery of the anode 94 extends about the grid 64 and is concentric with the active cathode surface 12. The spacing between the internal anode surface and the grid 64 is made as small as desired, noting, however, that the internal annular surfaces of the resonator 88 and 90 are also spaced from the surrounded grid supports 68 and 72.

The high frequency output may be taken from the resonator 88 by means of a suitable loop 96 extending through an opening therein and mounted within an output 98 rigidly electrically connected to the resonator. The loop 96 is directly connected at one end to the tube 98 and its other end is in the form of a lead 100 extending concentrically within the tube 98 and out through a suitable glass seal 102, closing the outer end of the tube.

A second high frequency output may be taken from the resonator 88 through an oppositely posi-

tioned loop 178 extending through an opening therein and mounted within a tube 185. The loop 178 in this case is directly connected at one end to the tube 185 and its other end is in the form of a lead 177 extending concentrically within the tube 185 and out through a suitable glass seal 200.

If it is desired to provide water cooling of the anode, an arrangement such as shown in Fig. 1 may be used. A continuous piece of tubing starting from the inlet junction box 183 is wound inwardly on the upper outer surface of the anode 94 in a flat spiral to form tubes 180, 181 and 182, ending in the outlet junction box 184. A second piece of tubing runs from the inlet junction box 183, forming tubes 190, 191 and 192, also ending at the outlet junction box 184.

The high frequency electrical circuit resulting from the construction illustrated in Fig. 1 can best be understood from the circuit diagram of Fig. 3. Beginning with the high frequency input lead 54 connected to the loop 51, it will be seen that this is coupled to the resonator 34. The other end of the loop 51 will be electrically connected to the anode 94 via the cylindrical support 52, and the tube shell sections 58 and 92. This same end of the loop will also be electrically connected to the resonator 32 through the upper tube shell 50, the flexible metallic membrane 48, the movable bar 38 and the inverted cup-shaped support 36.

The resonator 32 will be variably coupled at one end to the cathode 10 by reason of the serial capacitances existing between the adjacent parts, represented in Fig. 3 as C_{32-169} and C_{153k}. The other end of the resonator 32 will be capacitatively coupled to the grid by reason of the capacitance existing between the outer surface of the resonator 32 and the surrounding grid support; this capacitance is represented in Fig. 3 by C_{32g}. The input resonator 34 will be connected on the one hand to the cathode 10 through the cup-shaped support 14 and the capacitance C_{152k}, as previously described, and at the other end capacitatively coupled to the grid by reason of the capacitance existing between the outer surface of the resonator 34 and the immediately adjacent surrounding grid support; this capacitance is represented in Fig. 3 as C_{34g}.

The output loops 96 and 178 are, as previously described, each directly connected at one end to the anode 94 which, at the same time, forms a center tap between the resonators 88 and 90. The other ends of the loops are, of course, connected to the respective output leads 100 and 177. The inner, opposite ends of the resonators 88 and 90 are capacitatively coupled to the grid by reason of the capacitance existing between their respective inner surfaces and the adjacent grid supports. These capacitances are represented in Fig. 3 as C_{88g} and C_{90g}, respectively. The high-frequency oscillator circuit is completed by the internal inter-electrode capacities indicated in Fig. 3 as C_{pg}, between grid and anode, C_{pk} between anode and cathode, and C_{gk} between grid and cathode.

The simplified high frequency circuit of the tube operating as a high frequency tuned amplifier is illustrated in Fig. 4, in which the capacitances C_{34g}, C_{152k}, C_{32g}, C_{32-169}, C_{153k}, C_{90g} and C_{88g} have been neglected, since they will all be effectively short circuited at ultra high frequencies. Under these conditions, the resonators 32, 34 and 88, 90 may be shown as lumped inductors forming tank circuits with the grid cathode capacitance C_{gk} and the anode-grid capacitance C_{pg}, respectively. The resonators 32, 34, 88 and 90 are so proportioned as to act as inductive reactors at the generating frequency. The tank circuit represented by the resonators 32, 34 and the shunt capacitance C_{gk} may be tuned by varying the dimensions of the resonator 32, as previously described. While this also varies the capacitance C_{32-169} slightly, this variation is unimportant and can be neglected at high frequencies when this capacitance is an effective short circuit.

Additional means such as can be readily designed by those skilled in this art may be used to tune resonators 88 or 90, by making one of them slidable similarly to resonator 32.

If the tube is to be used as a self-excited oscillator, a circuit such as illustrated in Fig. 5 may be used. In this case the input 52, 54 is connected to one of the outputs 98, 100 through means such as a coaxial line 210, 212. The output of the self-excited oscillator may then be taken from 177, 185.

It will be seen that the construction described above is admirably adapted to provide a vacuum tube oscillator with high power for ultra-high frequencies. While there is a large amount of active inter-electrode surface for producing high power, the thickness of the effective cathode surface and of the effective anode surface in the longitudinal direction has been kept extremely narrow and, as a result, undesired capacities between these elements have been avoided and the resulting capacity per unit of circumference is extremely small. At the same time, the arrangement of the resonators to form the oscillating circuit is relatively neat and compact and provision is made for adjustment of a resonator, if desired.

While the invention has been described in connection with a certain specific constructional embodiment, it will be apparent that the novel features of the invention may be applied to tubes having other structural relationships. For example, the principle of obtaining high power at ultra-high frequencies is applicable to tubes constructed as diodes, as well as triodes. The resonators themselves may be of other configurations known to the art and the manner in which the individual parts of the tube are constructed is without any particular importance. While a special improved form of cathode has been shown it is only essential, however, for the optimum operation of a vacuum tube oscillator in accordance with the present invention, that the cathode be shaped with an outer effective peripheral surface whose thickness is smaller than its radius. This form of cathode may be variously described as "annular, ring-shaped" or by any other similar connotation. Furthermore, it is important that the anode, of preferably substantially the same thickness as the cathode, surrounds the cathode concentrically in order to provide a minimum of inter-electrode capacitance with a maximum of active inter-electrode energy transferred.

Accordingly, while I have described above the principles of my invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation on the scope of my invention as set forth in the objects and the accompanying claims.

What is claimed is:

1. A high frequency electron discharge device including a pair of electrodes comprising a substantially ring-shaped cathode whose outer radius is substantially greater than its longitudinal

dimension, and a ring-shaped grid surrounding the periphery of the concentric with said cathode, means forming a cavity resonator capacitatively coupled to and coaxial with both of said electrodes, and sealed envelope-forming means enclosing said electrodes.

2. A high frequency electron discharge device including a pair of the electrodes comprising a substantially ring-shaped cathode whose outer radius is substantially greater than its longitudinal dimension, and a ring-shaped anode surrounding the periphery of and concentric with said cathode, means forming a cavity resonator capacitatively coupled to said cathode, directly connected to said anode and coaxial with both of said electrodes, and sealed envelope-forming means enclosing said electrodes.

3. A high frequency electron discharge device including a pair of electrodes comprising a substantially ring-shaped cathode whose outer radius is substantially greater than its longitudinal dimension, and a ring-shaped grid surrounding the peripherey of and concentric with said cathode, means forming a cavity resonator capacitatively coupled to said grid and to said cathode and coaxial with both of said electrodes, and sealed envelope-forming means enclosing said electrodes.

4. A high frequency electron discharge device comprising a substantially ring-shaped cathode whose outer radius is substantially greater than its longitudinal dimension, a ring-shaped grid surrounding the periphery of and concentric with said cathode, a ring-shaped anode surrounding the periphery of and concentric with said grid, means forming a cavity resonator capacitatively coupled to said cathode, directly connected to said anode and mounted coaxial with all of said electrodes, and sealed envelope-forming means enclosing said electrodes.

5. A high frequency electron discharge device comprising a substantially ring-shaped cathode whose outer radius is substantially greater than its longitudinal dimension, a ring-shaped grid surrounding the periphery of and concentric with said cathode, a ring-shaped anode surrounding and concentric with said grid, means forming a cavity resonator capacitatively coupled to said grid and to said cathode and mounted coaxial with all of said electrodes, and sealed envelope-forming means enclosing said electrodes.

6. A high frequency electron discharge device comprising a substantially ring-shaped cathode whose outer radius is substantially greater than its longitudinal dimension, a ring-shaped grid surrounding the periphery of and concentric with said cathode, a ring-shaped anode surrounding and concentric with said grid, means forming a cavity resonator capacitatively coupled to both said grid and cathode and mounted coaxial with all of said electrodes, and sealed envelope-forming means enclosing said electrodes.

7. The combination according to claim 6, in which said cavity resonator-forming means is directly connected to said anode.

8. A high frequency electron discharge device comprising a cathode in the form of a hollow ring, open at its center, whose outer radius is substantially greater than its longitudinal dimension, a pair of disks on each side of said ring, circumferentially spaced metallic spacing members connecting said disks to the lateral faces of said ring, and a hollow cylinder supporting said disks, an annular grid surrounding the periphery of and concentric with said cathode, an annular anode surrounding and concentric with said annular grid, means forming a cavity resonator coupled to said cathode and one of said other electrodes, and mounted coaxial with all of said electrodes, and sealed envelope-forming means enclosing said electrodes.

9. An annular cathode comprising a hollow ring, open on its inner side, whose outer periphery constitutes an electron emitting surface, a pair of disks, one positioned on each side of said ring, circumferentially spaced metallic spacing members connecting said disks to the respective adjacent faces of said ring, and a hollow cylinder extending through and supporting said disks, the diameter of said cylinder being substantially less than the outer diameter of said ring.

10. An annular cathode according to claim 9, further comprising cathode heating means positioned inside said ring between said ring and cylinder, heater terminals mounted within said cylinder, and leads extending through said cylinder from said terminals to said heating means for supporting the latter.

11. An annular cathode according to claim 9, further comprising cathode heating means positioned inside said ring between said ring and cylinder heater terminals mounted within said cylinder, leads extending through said cylinder from said terminals to said heating means for supporting the latter, and a heat shield connected to said cylinder and mounted close to said heating means between the same and said cylinder.

12. A high frequency electron discharge device comprising, a hollow cylinder having circumferentially spaced openings near its center, arcuately shaped heating means surrounding the center of the cylinder, leads extending from said heating means through said openings into said cylinder, heater lead terminals within said cylinder, said terminals including a hollow tube extending downwardly from and coaxial with said cylinder, means connecting said heater leads to said heater terminals for supplying current to and simultaneously supporting said heating means, means supporting one end of said cylinder from said tube, a hollow ring-shaped cathode surrounding and partially enclosing said heating coils, means supporting said cathode from said cylinder, an annular grid spaced from and surrounding said cathode, an annular anode spaced from and surrounding said cathode grid, a generally cylindrical metal member forming an outer wall of said electron discharge device, coaxial with said electrodes and supporting said anode, said anode having a radial extension projecting through the outside of said wall, a pair of cavity resonators in the form of hollow toroids open at one side, supported by and within said cylindrical member with their open sides respectively on opposite sides of the said annular anode and their inner peripheries spaced from but adjacent the outer periphery of said grid, a third cavity resonator in the form of a hollow toroid having an open side, supported by said hollow cylinder with its open side facing one lateral face of said cathode and its outer periphery spaced from but adjacent the inner periphery of said grid, a fourth cavity resonator in the form of a hollow toroid having an open side, mounted with its open side facing the other lateral face of said cathode, its outer periphery spaced from but adjacent the inner periphery of said grid, and its inner periphery spaced from but adjacent the outer surface of said hollow cylinder, means adjustably supporting said fourth resonator from said generally cylin-

drical metal member, said means including means sealing the tube of said cylindrical member, means sealing the bottom of said cylindrical member and forming therewith an evacuated vessel enclosing said electrodes, means supporting said grid from said bottom sealing means, input coupling means extending through the bottom sealing means into said third resonator, and output means extending through said cylindrical member into one of said pair of resonators.

13. A high frequency electron discharge device according to claim 12, further comprising arcuately shaped heat shielding means supported by said hollow cylinder intermediate the latter and said heating means.

14. A high frequency electron discharge device according to claim 12, in which both said coupling means are formed as loops, one end of each of which is galvanically connected to said anode

through said outer cylindrical member, and the other ends of which are formed as leads projecting outside of the electron discharge device.

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