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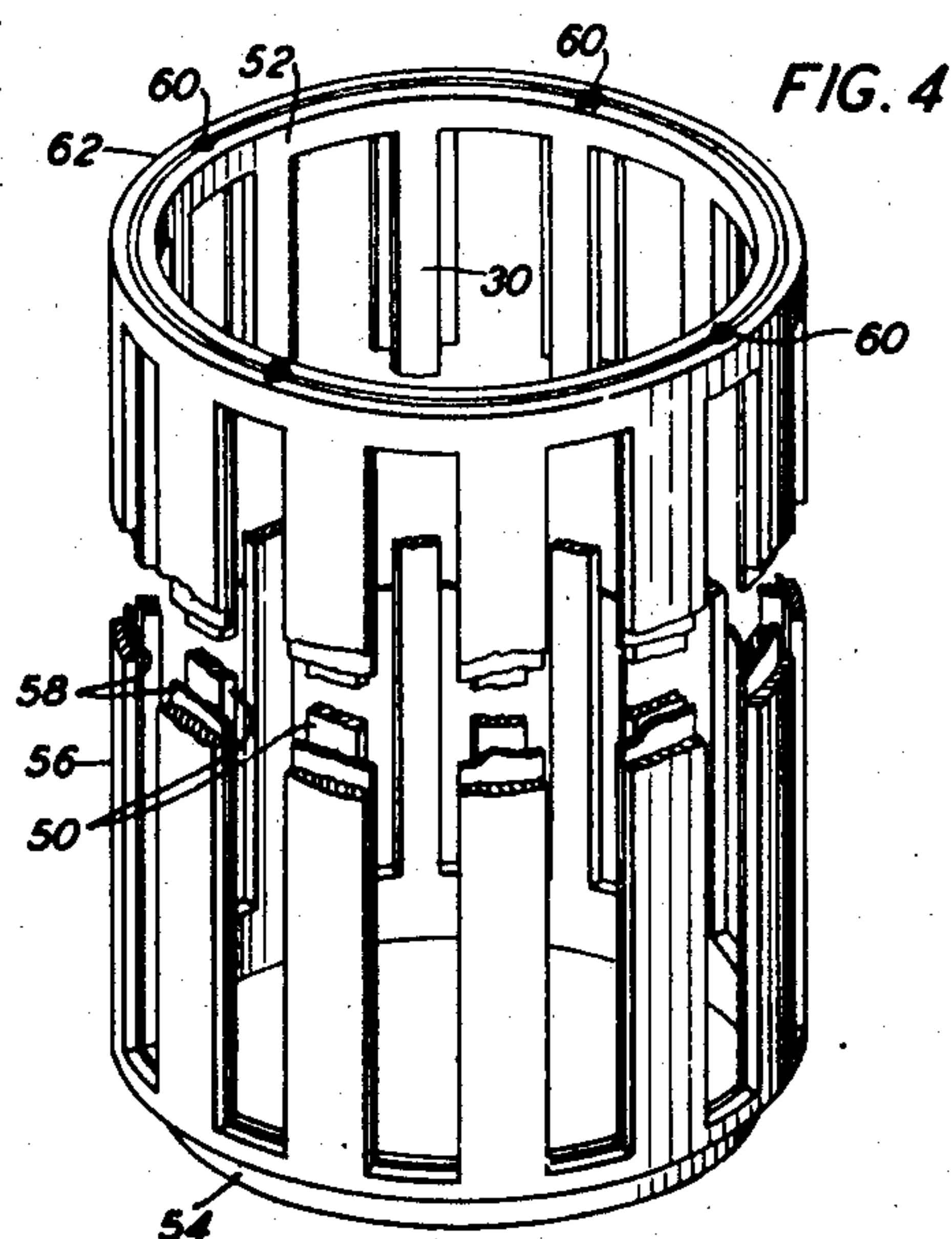
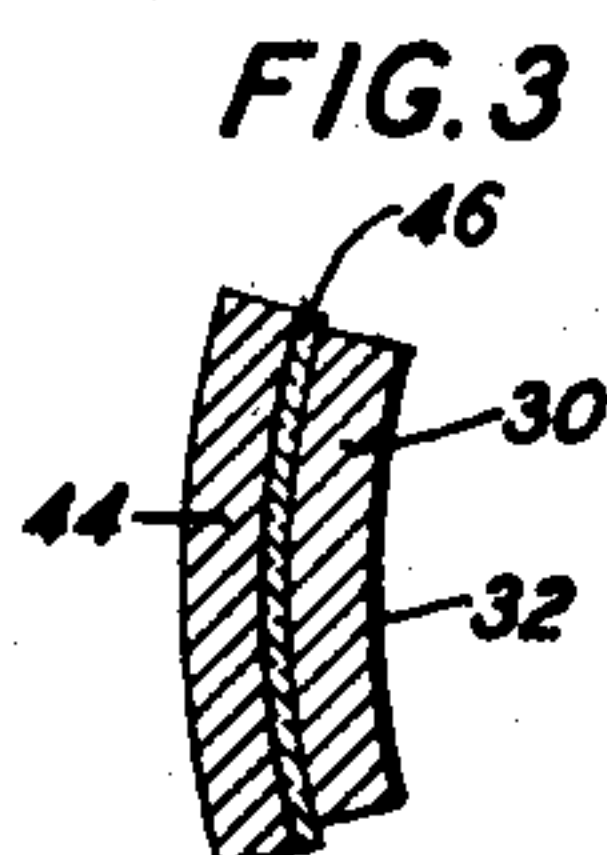
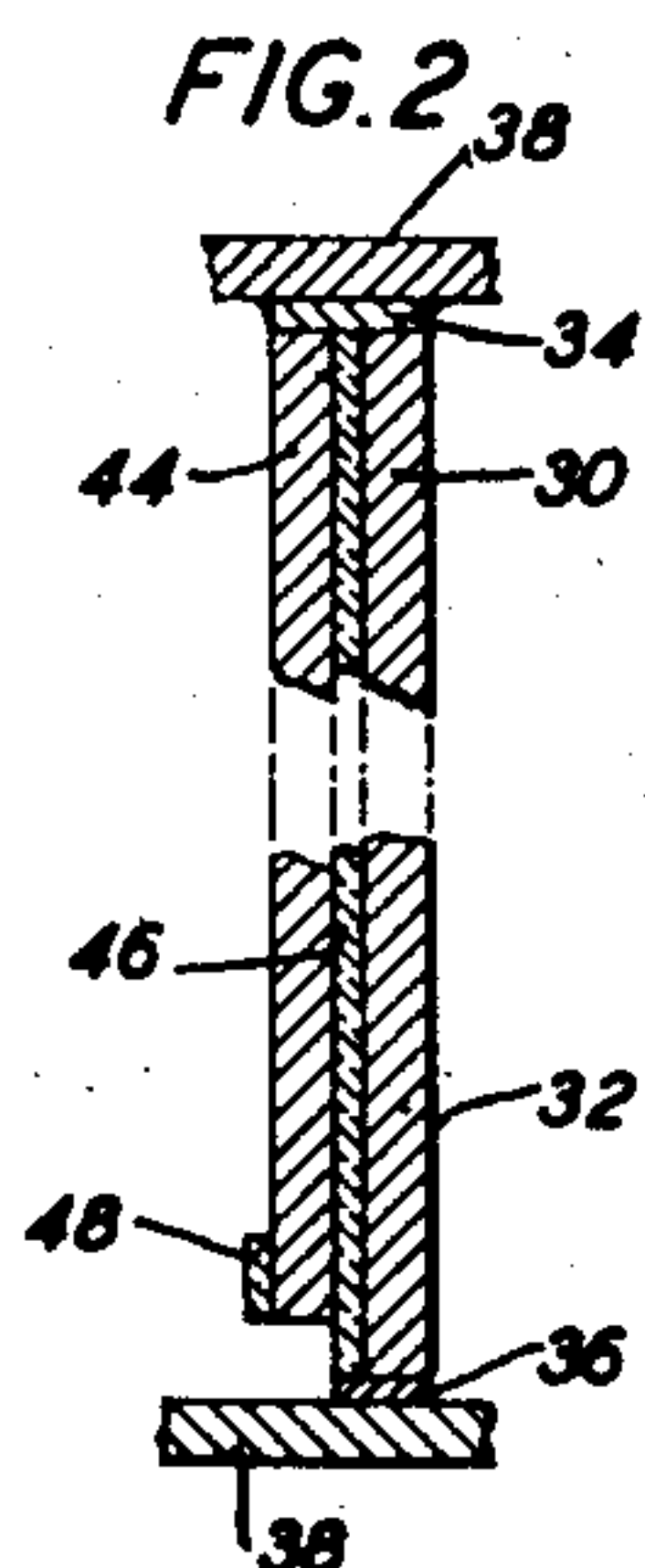
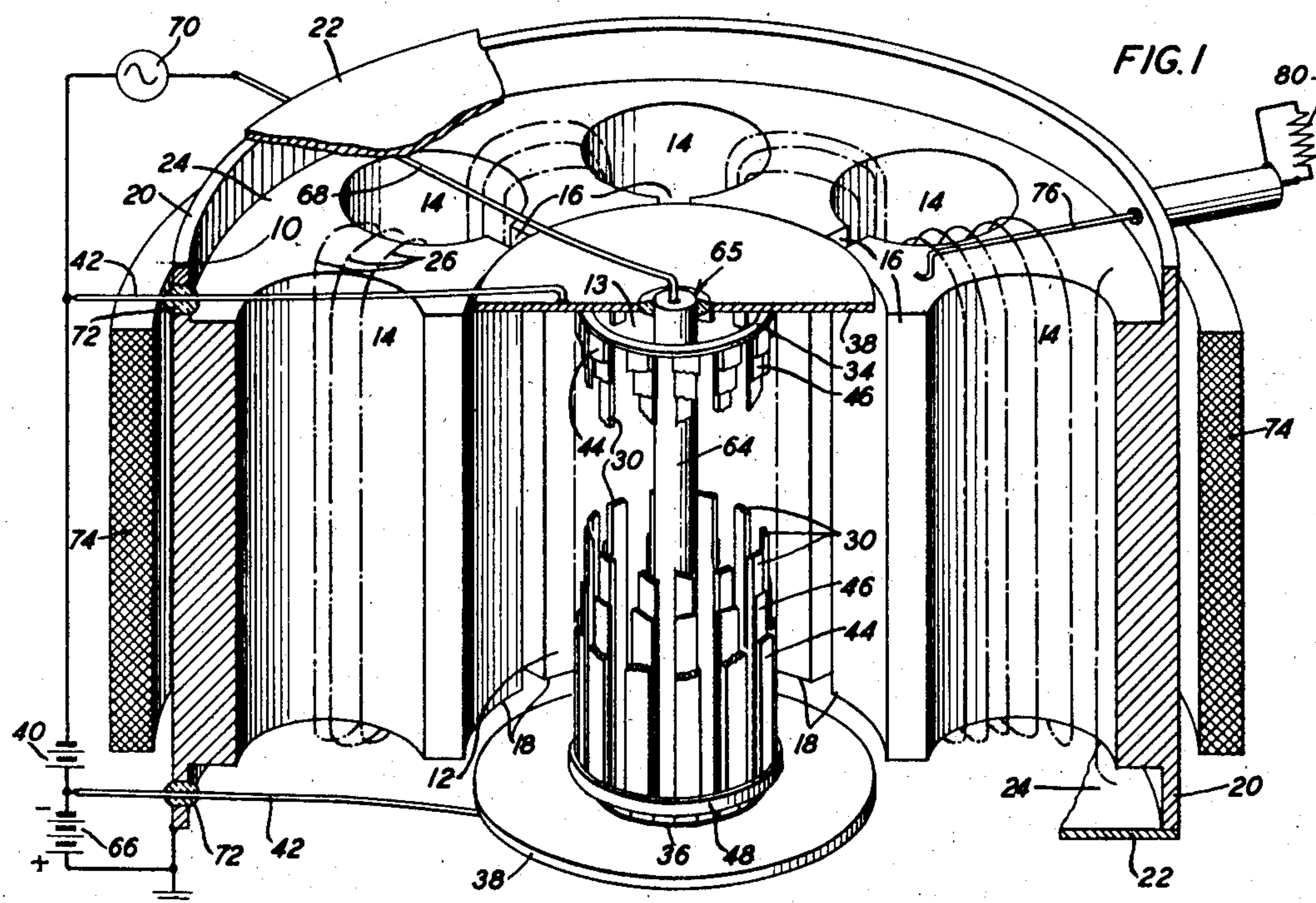
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MAGNETRON AND CONTROL

Filed Nov. 2, 1942

2 Sheets-Sheet 1



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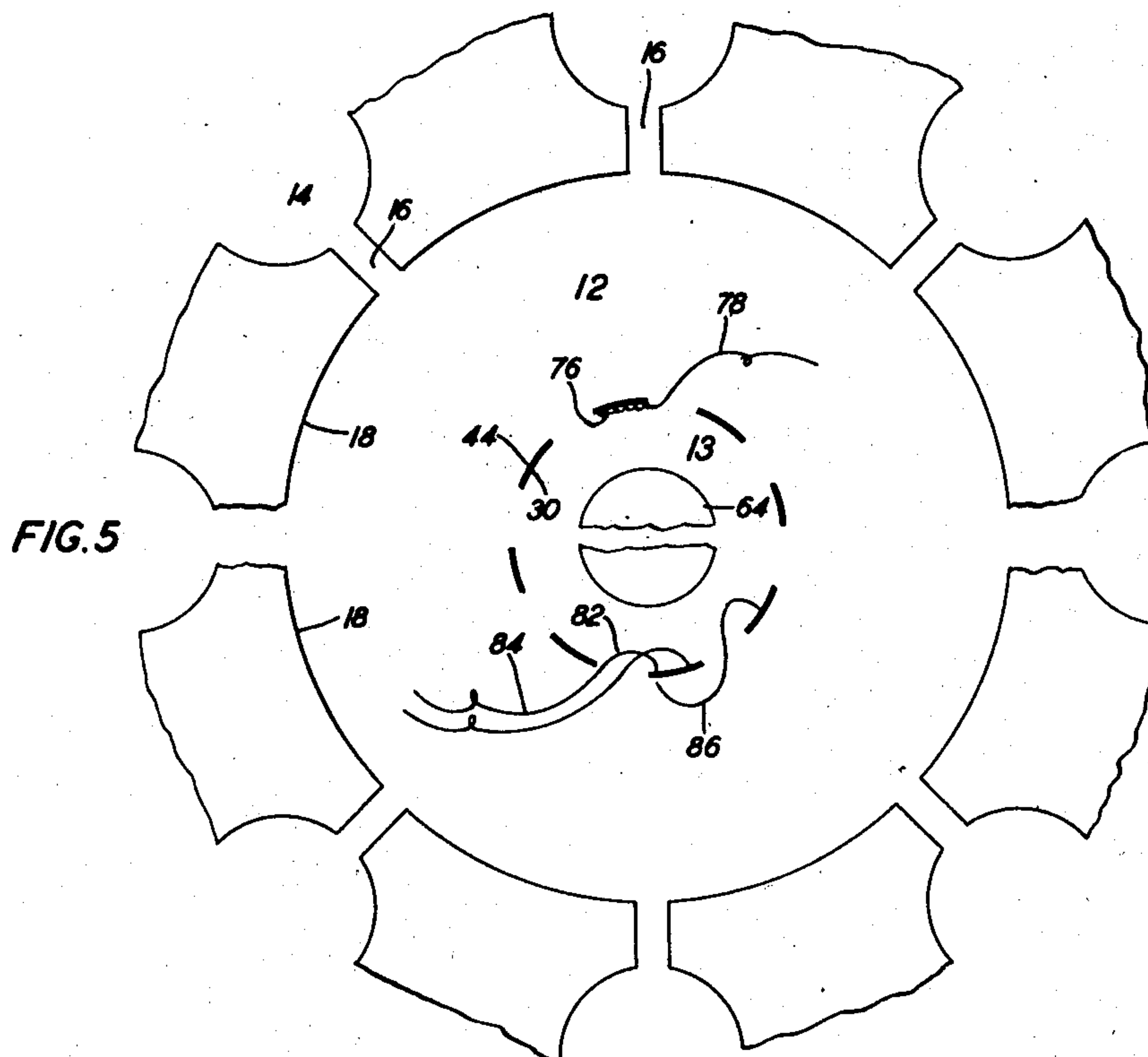
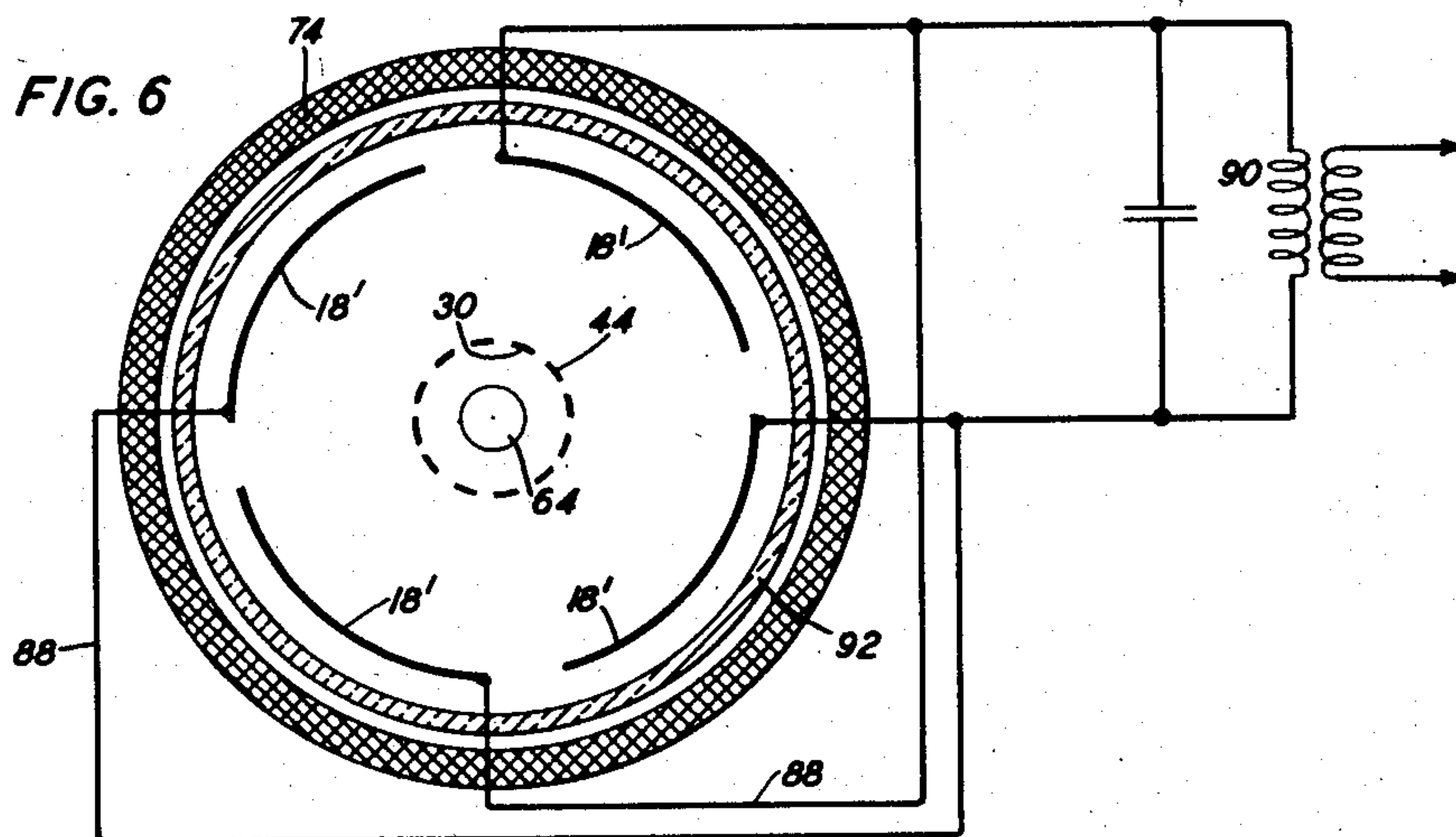
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MAGNETRON AND CONTROL

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2 Sheets-Sheet 2



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MAGNETRON AND CONTROL

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8 Claims. (Cl. 250—27.5)

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This invention relates to magnetron devices and particularly to magnetrons for the delivery of large amounts of high frequency power.

An object of the invention is to provide improved means for controlling the amount of power delivered by a magnetron.

Another object is to provide improved means for modulating the power delivered by a magnetron in accordance with a signal.

A related object is to effect such power control or modulation, as the case may be, without substantial departure from optimum efficiency conditions for oscillation.

Another related object is to effect modulation of magnetron oscillations by pure voltage control, the required power being negligible.

Still another object is to protect the active surface of a magnetron cathode from bombardment by electrons and therefore from deterioration.

Another object is to provide a magnetron which is characterized by improved geometrical inter-electrode relations.

These and other objects are attained in accordance with the invention by the provision of a cathode of novel form and arrangement, the sensitized surfaces of which are shielded from the influence of the high frequency fields in the interaction space and therefore from bombardment by electrons, while a control electrode is provided whose juxtaposition with the cathode is so correlated with the electric and magnetic fields that it draws electrons from the cathode substantially in the quantities required for delivery to an external utilization circuit of a desired amount of power, and this without substantial bombardment of the control electrode by electrons or dissipation of power therein. Variation of the control electrode potential, in accordance with a modulating signal or otherwise, as desired, varies the numbers of the available electrons without in any way altering the conditions in the interaction space and therefore without affecting the electron orbits therein or the frequency of the resulting oscillations or the efficiency of the device as a generator of such oscillations.

In a preferred embodiment the cathode may comprise a plurality of spaced strips arranged in a circular row within the interaction space and defining a central discharge space, while a control electrode may be mounted centrally in the discharge space. The cathode strips may be treated to render them thermionically emissive only on their inner surfaces, being shielded on their outer surfaces from the influences of the fields in the interaction space.

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In the design of high frequency, high energy magnetrons, it is applicant's practice to select the inside diameter of the interaction space, the number of anode surfaces, the constants of the tuning means, i. e., in a magnetron of the solid anode cavity tuned type, the sizes and shapes of the tuning cavities and the channels or slots which connect the same with the interaction space, the diameter of the central cathode and the operating anode voltage and the relations between all of these quantities from considerations of efficiency and of the oscillation mode in which the device is intended to operate. When these factors have been so selected there is in devices of conventional construction no satisfactory way of controlling the cathode current and therefore the power. Cathode temperature control is inefficient at best and, on account of thermal inertia effects, it is out of the question for rapid control such as is employed in modulation. The use of a control grid surrounding the central cathode has proved unsatisfactory as a control means for a number of reasons. First, it inevitably draws a considerable current so that the cathode grid circuit presents a low impedance to the input circuit from which it is supplied and the apparatus draws substantial amounts of power at the modulation frequency. Second, to cut off the cathode current completely, such a control grid must be driven to a high negative voltage. In such case the grid-anode voltage might be so great as to cause excessive secondary emission either from the grid or from the anode or even a disruptive discharge. Furthermore, the interaction space is defined principally by the control grid and the anode surface so that variation of the control grid potential varies the electric field in this interaction space and therefore the shape of the electron orbits. This considerably alters the efficiency of oscillation of the device and also, to some extent, varies its frequency.

With the construction of the invention, on the other hand, the electric field conditions in the interaction space remain unchanged during the course of a modulation cycle, while variations of the control electrode potential affect only the number of electrons supplied from the discharge space to the interaction space, so that neither oscillation frequency nor efficiency is greatly affected during the course of the modulation cycle.

The invention will be fully understood from the following detailed description of a preferred illustrative embodiment thereof taken in conjunction with the appended drawings, in which:

Fig. 1 is a broken perspective view of a mag-

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netron device of the solid anode cavity-tuned type provided with the novel cathode and control electrode of the invention;

Fig. 2 is a vertical cross-section of a part of the cathode structure of Fig. 1;

Fig. 3 is a horizontal cross-section of the same part of the cathode structure of Fig. 1;

Fig. 4 is a broken perspective view of an alternative cathode structure;

Fig. 5 is a simplified diagrammatic cross-section of the central portion of the magnetron of Fig. 1, broken in two, to show the electron paths for two different values of control electrode potential; and

Fig. 6 is a simplified schematic view of a magnetron of the conventional split anode type, modified by the addition of the novel cathode and control electrode.

Referring now to Figs. 1, 2 and 3, the body of the magnetron may comprise a comparatively massive block 10 of conductive material, such as copper, into which are cut as by drilling a central interaction space 12 and a plurality of resonant cavities 14 surrounding the same and symmetrically arranged about it. Each of the cavities 14 opens onto the interaction space 12 through a channel or slot 16 which serves as a coupling means between the energy of movement of the electrons in the interaction space and the electromagnetic field within the cavity. The cylindrical surfaces 18 between channels 16 serve as anode surfaces.

The anode block 10 is preferably mounted centrally in a cylindrical shell or casing 20 of conductive material such as copper, and connected thereto. If preferred, anode block 10 and shell 20 may be machined from a single solid mass. In either case the shell may be closed at the ends by plates 22 which serve both to exclude air and gases and to define the end spaces 24 in which the mutual flux 26 common to adjacent cavities 14 exists.

The cathode may consist of a plurality of flattened wires or strips 30 disposed parallel with the axis of the interaction space 12 and arranged in a circular row about it. These strips 30 define a central discharge space 13, inside of the interaction space 12. Their lengths may be equal to or slightly greater than the axial length of the interaction space. The width of each strip may be substantially equal to the circumferential spacing between the strips. If desired, they may be slightly arched from side to side, as indicated in Fig. 3, to conform with the circle on which they are disposed, though flat strips serve substantially as well, especially if their number is fairly large.

Each of these cathode strips 30 may be of resistive material so that its temperature may be raised to the emission point by the passage of current therethrough and their inner surfaces 32 which face the axis of the device may be treated with a suitable thermionically emissive material. They may be mounted as by welding at each end to rings 34, 36 of conductive material. End discs 38 may be connected to the cathode supporting rings 34, 36 extending outwardly therefrom in a manner partly to close the interaction space 12 and maintain space charge conditions within it at desired values and so reduce losses due to the escape of working electrons into the end spaces 24 of the device. Cathode heating current may be supplied from a suitable source such as a battery 40 to the end discs 38 by way of suitable relatively stiff conductors 42 which thus

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serve both as cathode supports and as heater leads. To minimize high frequency power losses over the heater leads 42 the latter may, if desired, be tuned as by short-circuited coaxial lines in well-known manner.

Outside of each of the cathode strips 30 and closely adjacent thereto but insulated therefrom may be placed a conductive shielding strip 44, for example of metal. Each of these shielding strips 44 may be connected each to the cathode strip 30 which it shields or to the cathode supporting ring 34 at a convenient point but they are preferably not connected to the cathode strips 30 at more than one point, else they would serve to short-circuit the cathode strips and reduce the heating of the latter. They may be slightly wider than the cathode strips 30 and they may be mounted and supported in position in any convenient manner. For example, they may be cemented throughout their lengths to the cathode strips by adhesive insulating material 46, or they may be clamped over the ends of the cathode strips, a layer of insulating material being provided at one of the clamping points. To hold the shielding strips 44 securely in position, a band 48 may surround them at their ends removed from their connections to the cathode strips 30 through the ring 34.

An alternative form and construction for the cathode assembly is shown in Fig. 4. It may consist of a tube 50 of sheet metal of a suitable material through the walls of which slots have been cut. In such case upper and lower supporting and current supply rings 52, 54 are integral with the strips 30. If this construction be preferred for both cathode strips and shielding strips, the outer shield tube 56 may be slipped over the inner cathode tube with the two sets of slots in alignment, a slotted tube 58 of suitable insulation material being placed between. The two conductive cylinders may then be interconnected at one end as by spot welds 60 between the upper cathode supporting ring 52 and the upper shield supporting ring 62. If desired, the tubes 50, 56, 58 may be fitted together prior to cutting the slots and the slots may then all be cut together. In this event since it is preferred that the shield strips be somewhat wider than the cathode strips, the slots are preferably cut from the inside outward, a tapered or shouldered tool being employed for the purpose.

Within the central discharge space 13 defined by the cathode strips 30, the auxiliary control electrode 64 of the invention may be placed. For example, it may be a cylinder of metal of diameter of the order of one-half the diameter of the cathode circle and effective length substantially equal to the axial length of the cathode strips 30. It may be supported in position by insulating bushings 65 in the end discs 38, and potential may be supplied to it by way of a suitable conductor 68.

Operating voltage may be applied between the cathode and the anode from any suitable source such as a battery 66 whose positive terminal is connected to the anode block 10 and casing 20 which, since it is external to the cathode and liable to be touched by the hands of an attendant, may be connected to ground. Thus a high negative voltage is applied to the cathode. Similarly, suitable operating potential may be supplied to the control electrode 64 by way of conductors 68 connected to a source, for example, a modulating source 70. A magnetic field whose direction is axial of the device may be supplied

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from any suitable source, such as a coil 74 carrying a steady current.

In operation both the cathode and heater leads 42 and the auxiliary electrode potential supply lead 68 will be maintained at potentials which are highly negative with respect to the anode block 10 and the end plates 22 which define the end spaces 24 through which these leads reach the electrodes. To avoid asymmetry of the electromagnetic fields within the end spaces 24 due to the presence of these low potential cathode and control electrode leads, and also to prevent high frequency induction therein and consequent power loss, these leads are preferably brought into the end spaces 24 in the plane of the axis of one of the tuning cavities 14. Thus, the mutual flux lines 26 emerging from this cavity pass to each side of the electrode supply leads in such a way that only a negligible quantity of this flux links the leads. By this expedient coupling between the leads and the electromagnetic field in the end spaces 24 may be reduced to a negligible value.

Power may be abstracted by way of a loop which links only the flux 26 which is mutual to two adjacent cavities 14. A loop of convenient and suitable form may comprise a rod 76 which extends radially inward from the outside through the casing wall 20 into the end space 24 of the magnetron and there bends over to make contact with the end face of the anode block 10. Preferably, its course lies in a plane midway between two adjacent cavities 14. Power withdrawn by way of this loop may be led over any suitable transmission path, for example, a coaxial line, to a suitable load or utilization circuit schematically indicated by the resistor 80. If desired, a plurality of such coupling loops may be employed, all feeding a common load, suitable phase shifting devices being interposed in series with the lines connected to some of them in order that current supplied by these lines to the common load may all be in cumulative phase relation at the output ends thereof.

Fig. 5 is a simplified diagrammatic end view of the magnetron of Fig. 1, in which the end discs 38, the cathode and heater supporting and supply leads 42 and the control electrode supply lead 68 have been omitted in the interests of simplicity. In the figure the body of the magnetron has been broken along a diameter to show the orbits of electrons all of which start their courses from the inner surface of one of the cathode strips 30, having been withdrawn therefrom by the accelerating potential on the control electrode 64, for different values of the potential applied thereto. This figure illustrates the geometrical relations which are preferred for optimum efficiency of operation. It has been discovered that best results are obtained when the radial width of the interaction space 12, i. e., the distance from the circle of shield strips 44 to the anode surfaces 18, is approximately four-fifths of the distance separating adjacent tuning elements. Thus, in the eight-cavity device shown, the distance separating adjacent slots 16 is approximately five-fourths the radial depth of the interaction space. With this ratio established, the dimensions of the interaction space 12 may be chosen in order to achieve, at a given wave-length, efficient operation in a convenient range of voltages. Evidently, increasing the number of tuning cavities for a given interaction space diameter dictates an increase in the diameter of the cathode circle, if this relation is to be maintained.

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The number and angular disposition of the cathode strips 30 and the shielding strips 44 is not critical, nor is the diameter of the control electrode. It is preferred, however, that the width of the apertures separating adjacent strips be substantially equal to the widths of the strips themselves, and that the control electrode 64 be of such diameter that the radial width of the discharge space 13, measured from the surface of the control electrode to the inner sensitized surface 32 of the nearest cathode strip 30, be somewhat in excess of the strip width.

To obtain the best results it is of course necessary to select correctly the cathode-to-anode voltage and the strength of the axial magnetic field in a manner to cooperate with the preferred geometrical relations stated above to give operation at maximum efficiency at a given wave-length.

The geometrical relations hereinabove described, while preferred, are still not critical, and are in no sense essential to the practice of the invention in its other aspects. For this reason no attempt has been made to bring Figs. 1 and 6 into conformity with these preferred relations.

Coming now to the mode of operation of the apparatus, and referring to Fig. 5, if the control electrode potential is negative with respect to the cathode, the electric field at the surface of the cathode strips is negative and substantially no electrons are withdrawn therefrom. This condition represents the current cut-off condition for the magnetron. As the control electrode potential is raised to a small positive value, a few electrons are drawn from the inner surfaces 32 of the cathode strips 30 and into the discharge space 13 as shown in the upper half of the figure. Their movements are at low velocity and under the combined influence of this comparatively weak electric field and the axial magnetic field, these electrons turn through circular orbits 76 of short radius, most of them returning to the inner surface of the cathode strips at or near their points of origin. Inasmuch as the discharge space 13 is substantially shielded from the high frequency fields which exist in the interaction space 12, these electrons return to the cathode surfaces 32 at substantially zero velocity and therefore do not injure it by bombardment. A few of them, especially those which originate near one side of a cathode strip 30 and close to the neighboring aperture, emerge through the latter and into the interaction space 12 defined by the cathode circle and the anode surface 18 as indicated at 78, there to undergo their orbital movements under the combined influence of the anode voltage and the axial magnetic field. Some of these electrons emerge through the interstices between adjacent cathode strips 30 when the phases of the high frequency electro-magnetic field existing within the interaction space 12, and particularly in the neighborhood of the anode surfaces 18, are such that the electrons travel through their predestined orbits 78 to strike one of the anode surfaces 18. These electrons contribute energy to the high frequency electromagnetic field. Others of these electrons will emerge between the cathode strips 30 into the interaction space 12 at instants when the high frequency fields are in such phase relation that they will not reach the anode surfaces 18 but will return toward the cathode at high velocity. These electrons are those which have withdrawn energy from the high frequency electromagnetic field. Their paths are roughly indicated in the figure by the path 86. The return

of these electrons toward the cathode and, in the apparatus of the invention, their return to the shielding strips 44 constitutes a source of unavoidable power losses. In conventional devices, the bombardment of the cathode surface by the high energy returning electrons may constitute, in addition, a source of deterioration of the cathode surface. With the construction of the invention, however, the returning electrons strike the shielding surfaces 44 instead of the cathode surfaces 32 and therefore, while they are responsible for a part of the losses inherent in magnetron operation, they do not injure the cathode.

As the potential on the control electrode 64 is progressively increased, more and more electrons are drawn from the inner surfaces 32 of the cathode strips 30 into the discharge space 13 wherein they travel through curved paths of progressively greater radii of curvature, so that the proportion of the emitted electrons which emerge through the apertures between adjacent cathode strips 30 is increased while the proportion which return to the inner cathode surface is reduced. The lower half of Fig. 5 illustrates the conditions for a control electrode potential of roughly the maximum value. The conditions for a control electrode potential of intermediate value are intermediate those shown in the upper and lower halves of the figure. It will be observed that with the maximum value of control electrode potential, substantially all of the emitted electrons travel through paths 82 of larger radius and escape capture by the cathode surface and emerge from the discharge space 13 through the apertures between cathode strips 30 into the interaction space 12, there to undergo their orbital movements 84, 86. With proper selection of the spacing of the cathode strips 30, the potential and diameter of the control electrode 64, and the diameter of the ring of cathode strips 30, it can be arranged that none of the electrons, even when emission is maximum as shown in the lower half of Fig. 5, strike the control electrode 64, but rather pass by the latter and out through the apertures in the cathode structure into the interaction space 12.

As the control electrode potential is progressively raised from zero to the highest positive value, more and more electrons emerge through the cathode apertures for two reasons: first, because the supply of electrons from the cathode surfaces 32 to the discharge space 13 is increased as the accelerating field at the cathode surfaces is increased; and second, because a progressively greater proportion of the electrons withdrawn from the inner cathode surfaces 32 emerges through the apertures into the interaction space 12 to undergo their predestined orbits. When the supply of electrons is a maximum, as shown in the lower half of Fig. 5, a virtual cathode may be formed in a circle coincident with or near to the cathode circle. By reason of the preferred equality between the arc lengths of the cathode strips 30 and the spaces between them, at the maximum value of the control electrode potential, substantially all of the electrons emitted from any one of the cathode surfaces 32 emerge through the aperture immediately to one side of it. This condition represents current saturation for the magnetron.

The invention is not limited in its application to magnetrons of the solid anode cavity-tuned type, but may be applied to magnetrons of other types as well. Fig. 6 is a simplified schematic plan view of the novel cathode strips 30 and the control electrode 64 of the invention as applied

to an otherwise conventional magnetron of the split-anode type, of which alternate anode segments 18' are directly connected together as by conductors 88 while the two groups of plates so formed are coupled by way of a tuned circuit, for example, an antiresonant circuit 90 consisting of an inductance element and a capacitance element connected in parallel. The electrodes may be mounted in any suitable manner within an evacuated envelope 92, for example, of glass, while the tuning elements 90 may be mounted within the same envelope or externally thereto as desired. An array of cathode strips 30 and shielding strips 44, which may be constructed as described in connection with Figs. 1 to 4, a control electrode 64 and a magnetizing coil 74 are indicated. Cathode and heater leads as well as anode and control electrode potential supply leads may be brought into the envelope as through air-tight seals in well-known manner. Such structural details have been omitted from the figure in the interests of simplicity.

The novel cathode and control electrode arrangement may be employed separately or together as desired. They are by no means limited to magnetrons in which the anode surfaces are circularly arranged, but may be applied as well to magnetrons in which the anode surfaces are linearly extended, while the novel geometrical relations apply equally to a circularly arranged magnetron having a central cylindrical cathode and no internal control electrode.

Still other variations and modifications of the illustrations shown and described herein, which may be made without departing from the spirit of the invention, will suggest themselves to those skilled in the art.

What is claimed is:

1. A magnetron device comprising a hollow apertured cathode member thermionically emissive on its inner surface but not on its outer surface, an anode mounted opposite the outer surface of said cathode member, a control electrode disposed within said hollow cathode member, and magnetic means adjacent said cathode for establishing a magnetic field axially of said device, whereby electrons which are drawn from said inner cathode surface move in curved paths past said control electrode and pass out through the apertures of said cathode element into the space between said cathode element and said anode.

2. A magnetron device comprising an array of cathode members spaced apart in a closed configuration defining a discharge space, an anode mounted outside said closed configuration of cathode elements and opposite thereto, magnetic means adjacent said array of cathode members for establishing a magnetic field axially of said device for causing electrons originating at a cathode member to travel over curved paths to said anode, and a control electrode axially disposed within said closed configuration of cathode elements to control the amount of electron current flowing from said cathode members.

3. A magnetron device which comprises a plurality of anode surfaces surrounding an interaction space, a hollow apertured cathode member mounted axially of said interaction space, which cathode member is thermionically emissive on its inner surface but not on its outer surface, a control electrode disposed within said hollow cathode member, and means for establishing a magnetic field axially of said device, whereby electrons which are drawn from said inner cathode surfaces move in curved paths past said control

electrode and pass out through said cathode apertures into said interaction space.

4. A magnetron device which comprises a plurality of anode surfaces defining an interaction space, an array of cathode members spaced apart in a closed configuration and defining a discharge space, means for establishing a magnetic field axially of said device for causing electrons originating at said cathode to travel over curved paths to said anode, and a control electrode axially disposed within said closed configuration of cathode members, to control the amount of electron current flowing from said cathode members.

5. A discharge device which comprises a plurality of anode surfaces defining an interaction space, an array of elongated cathode strips spaced apart in a closed configuration within said interaction space and defining a discharge space, the inner surfaces of said strips being thermionically emissive, and a shielding strip disposed radially outward of each of said cathode strips and closely adjacent thereto, the width of each of said shielding strips being slightly in excess of the width of the cathode strip to which it is adjacent.

6. A cathode structure for a magnetron device which comprises a first hollow cylindrical member provided with a number of spaced slots piercing the wall thereof, the inner surfaces of the unpierced portions of the wall of said cylinder being thermionically emissive, a second hollow cylindrical member provided with a like number of spaced slots piercing the wall thereof, said second cylinder surrounding said first cylinder with the slots of the two in alignment, the slots of said second cylinder being slightly narrower than the slots of said first cylinder.

7. A discharge device which comprises a plurality of anode surfaces circularly mounted about an axis of symmetry and defining an interaction space, an array of conductive shielding members circularly mounted within said interaction space, and a source of electrons within the circle of said shielding members, the radial distance from said shielding members to said anode surfaces being of the order of four-fifths of the circumferential distance separating corresponding points of said anode surfaces.

8. A magnetron device comprising an anode structure defining a substantially cylindrical interaction space, a cathode comprising a plurality of strips disposed within said interaction space on the circumference of a circle coaxial with said interaction space and spaced apart by distances substantially equal to their widths, said strips defining a discharge space within said circle and said strips being thermionically emissive on their inner surfaces but not on their outer surfaces, a control electrode disposed on the axis of said discharge space, said control electrode adapted to have a positive potential with respect to said cathode to accelerate electrons in the direction away from the inner surfaces of said cathode strips and towards said control electrode, means adjacent said cathode for establishing a magnetic field axially of said device to constrain electrons to follow curved orbits some of which return to the same strip from which the electron is emitted and others of which pass between strips into said interaction space and means connected to said control electrode for varying the potential of the control electrode to control the amount of electron current passing between strips.

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