HIGH FREQUENCY ELECTRIC DISCHARGE DEVICES

Filed Feb. 5, 1958 3 Sheets-Sheet 1

FIG.1.

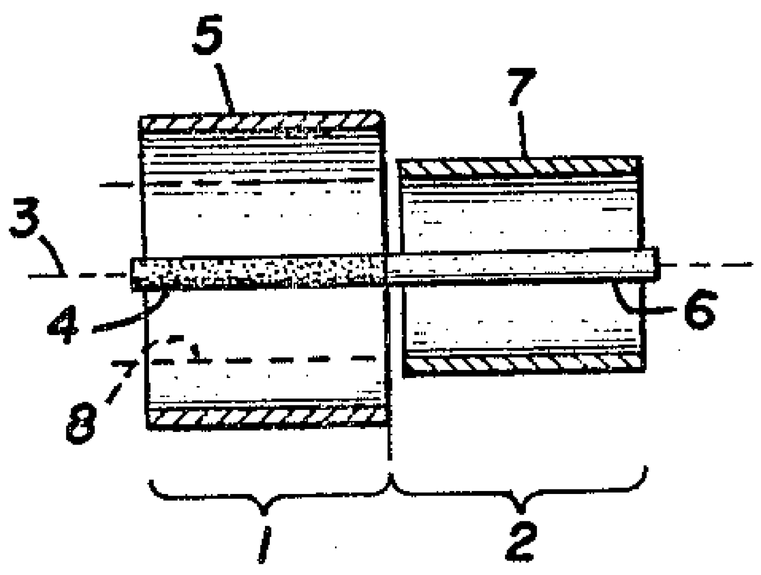


FIG.2.

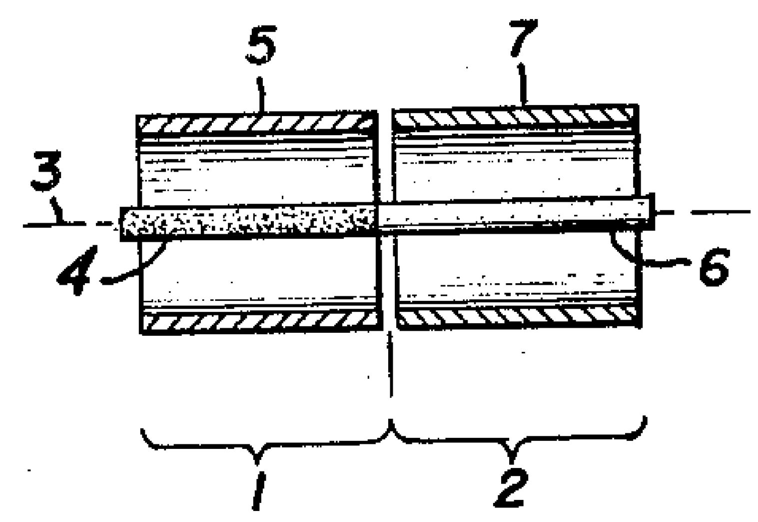


FIG.3.

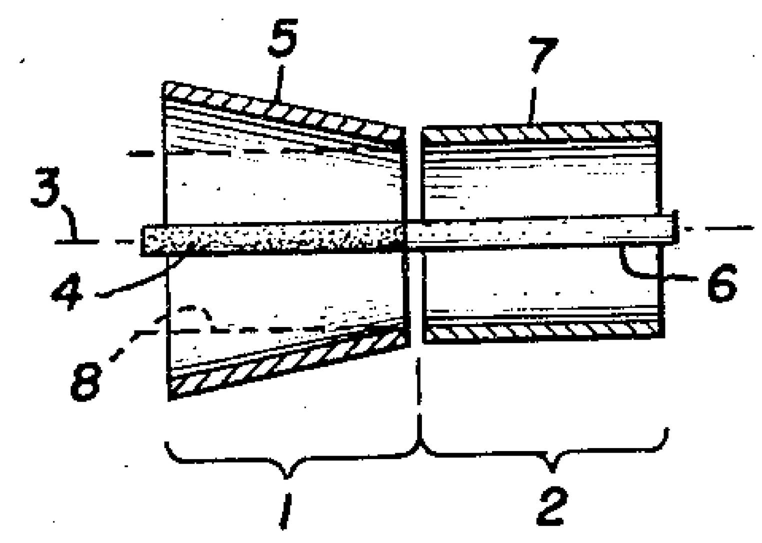


FIG.4.

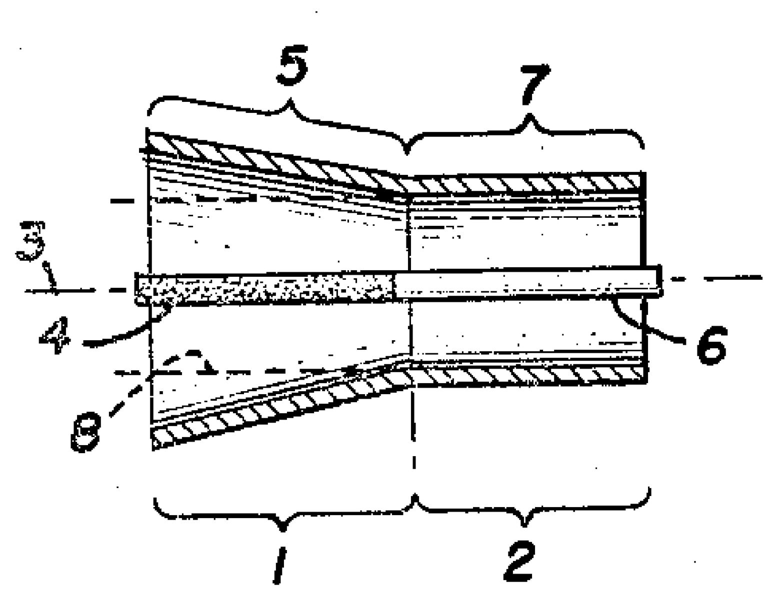


FIG.5.

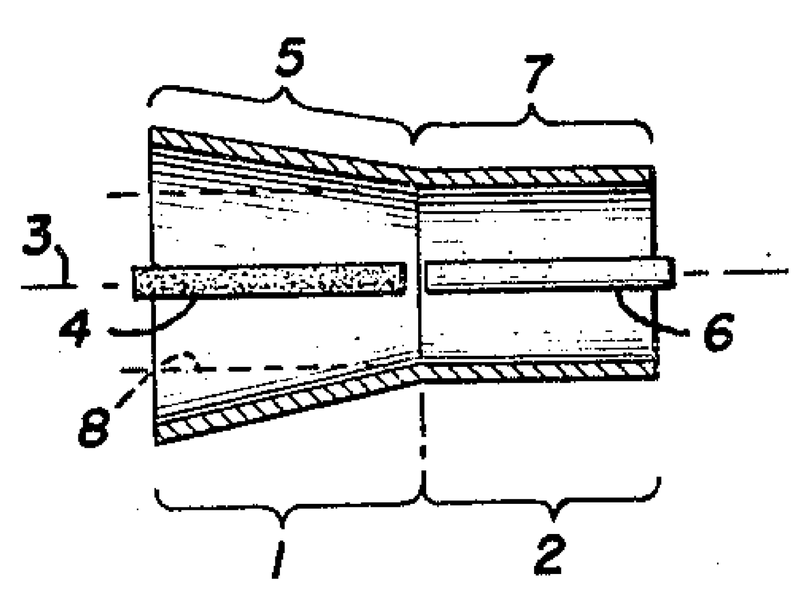


FIG.6.

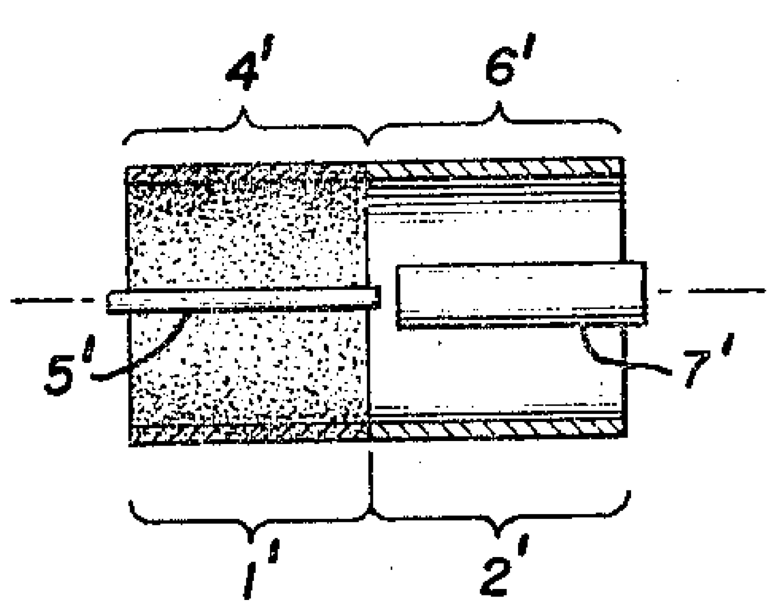


FIG.7.

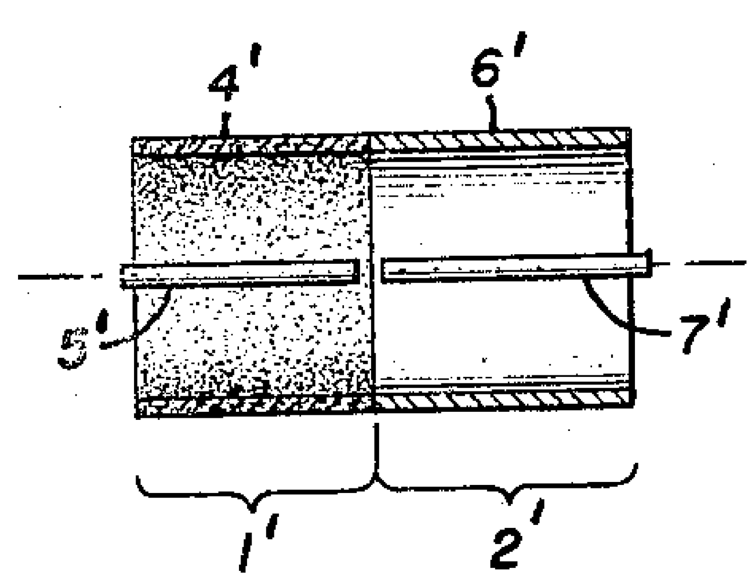


FIG.8.

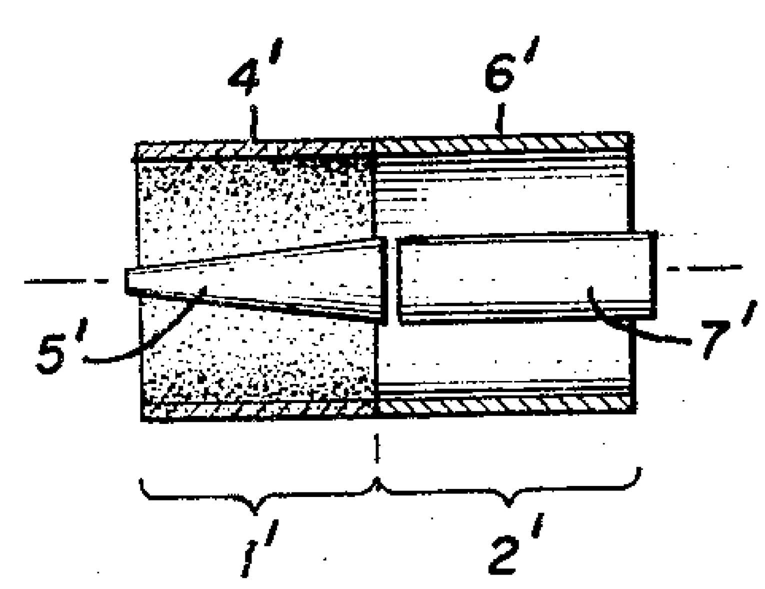


FIG.9.

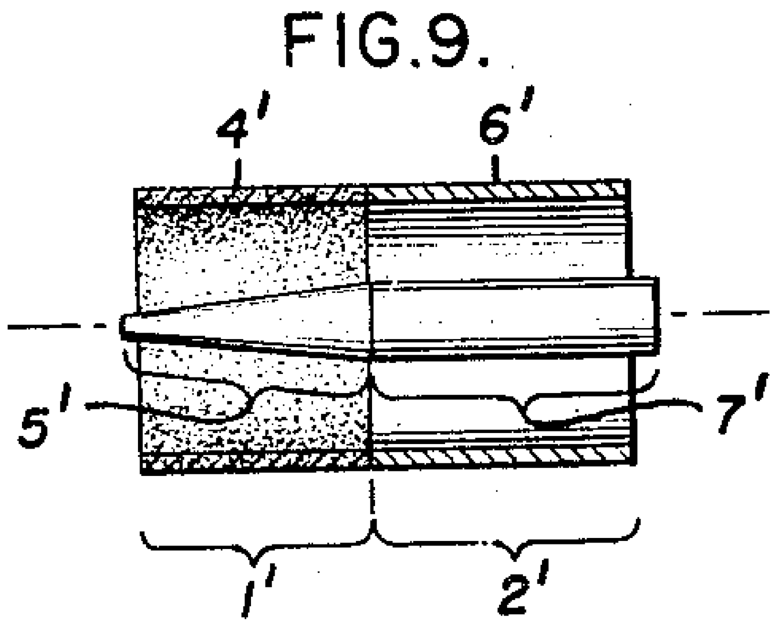
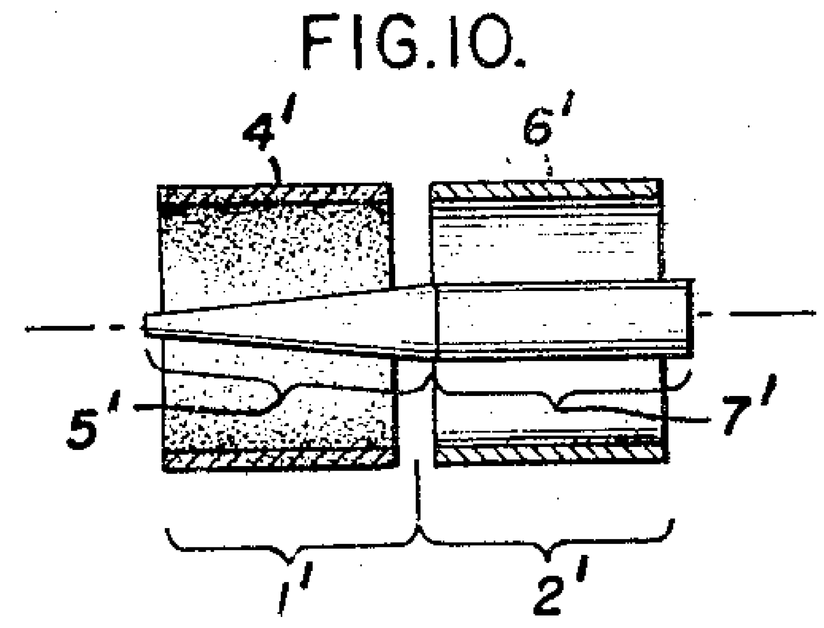


FIG.10.



INVENTOR:
ERNEST ROSTAS,

BY Philip L. Schlamp
HIS ATTORNEY.

Sept. 20, 1960 E. ROSTAS 2,953,714

HIGH FREQUENCY ELECTRIC DISCHARGE DEVICES

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FIG.11.

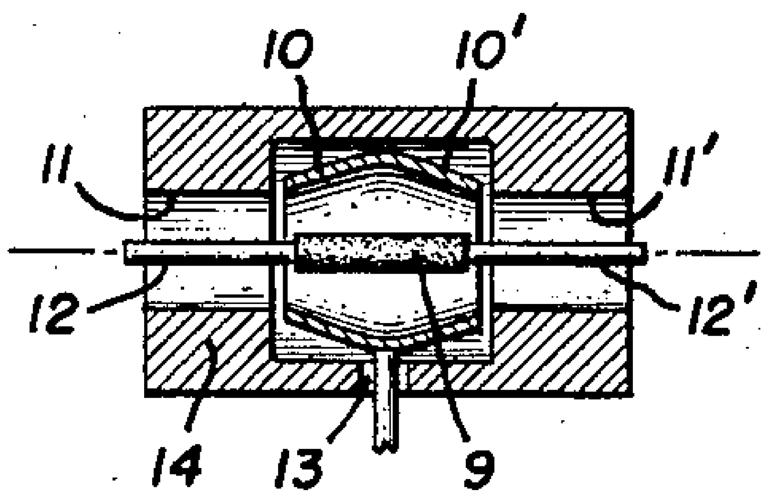


FIG.12.

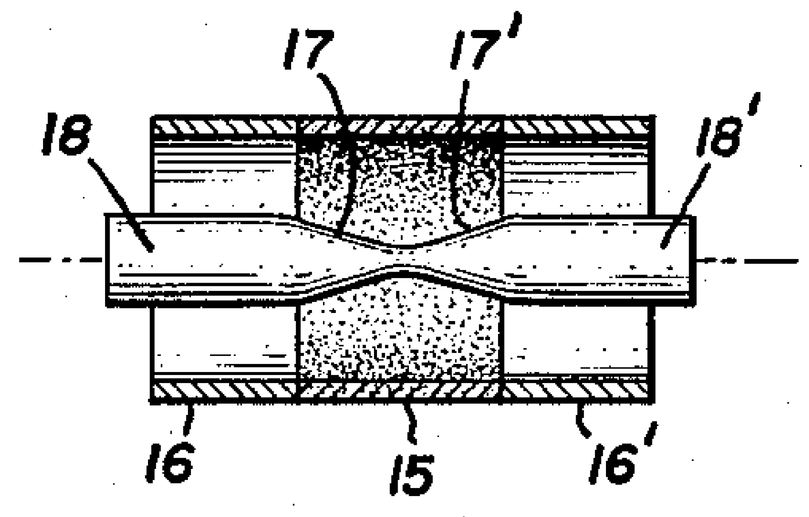
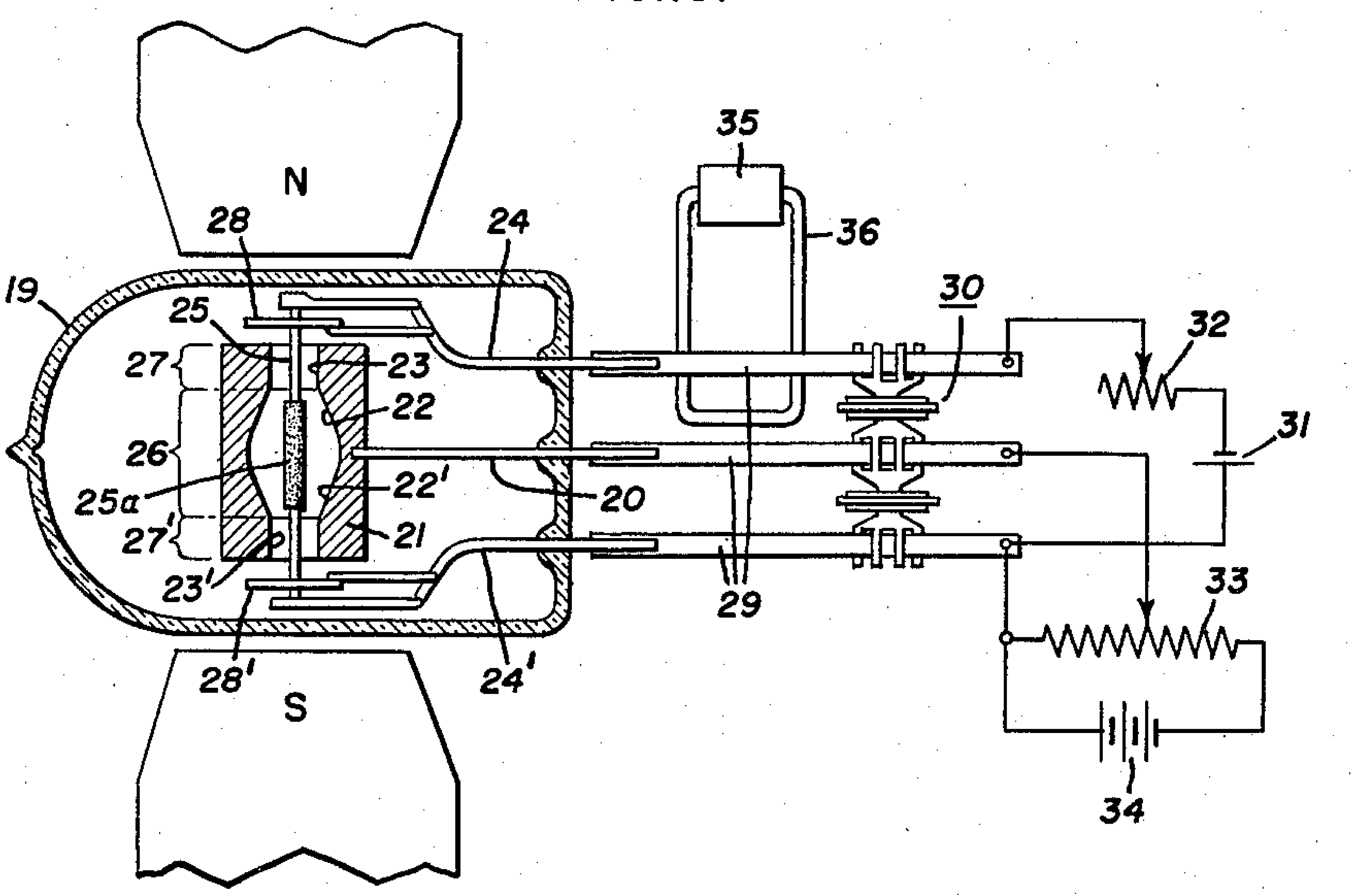


FIG.13.



INVENTOR:
ERNEST ROSTAS,

BY Philip L. Schlamp

HIS ATTORNEY.

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HIGH FREQUENCY ELECTRIC DISCHARGE DEVICES

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FIG.14.

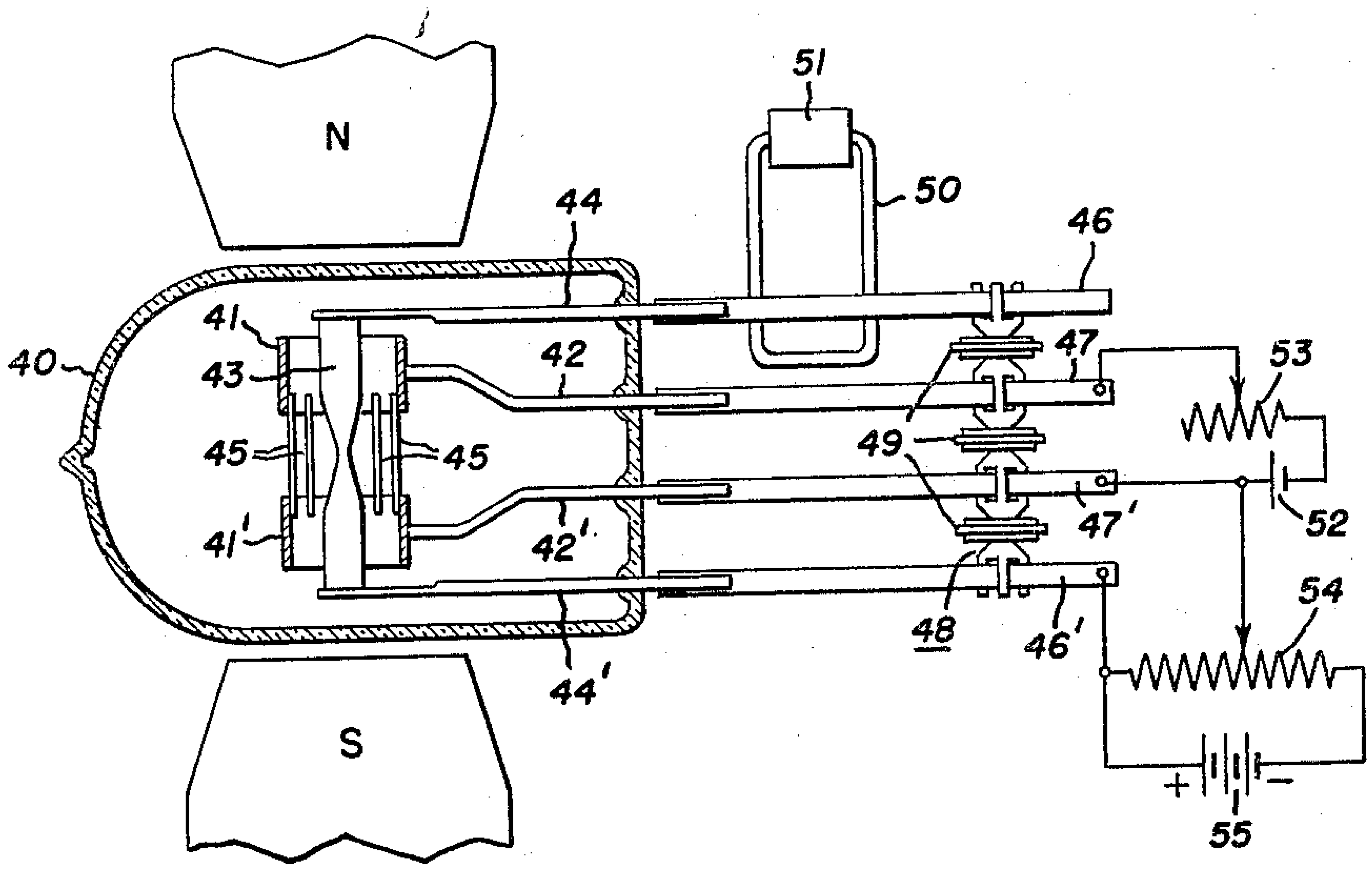
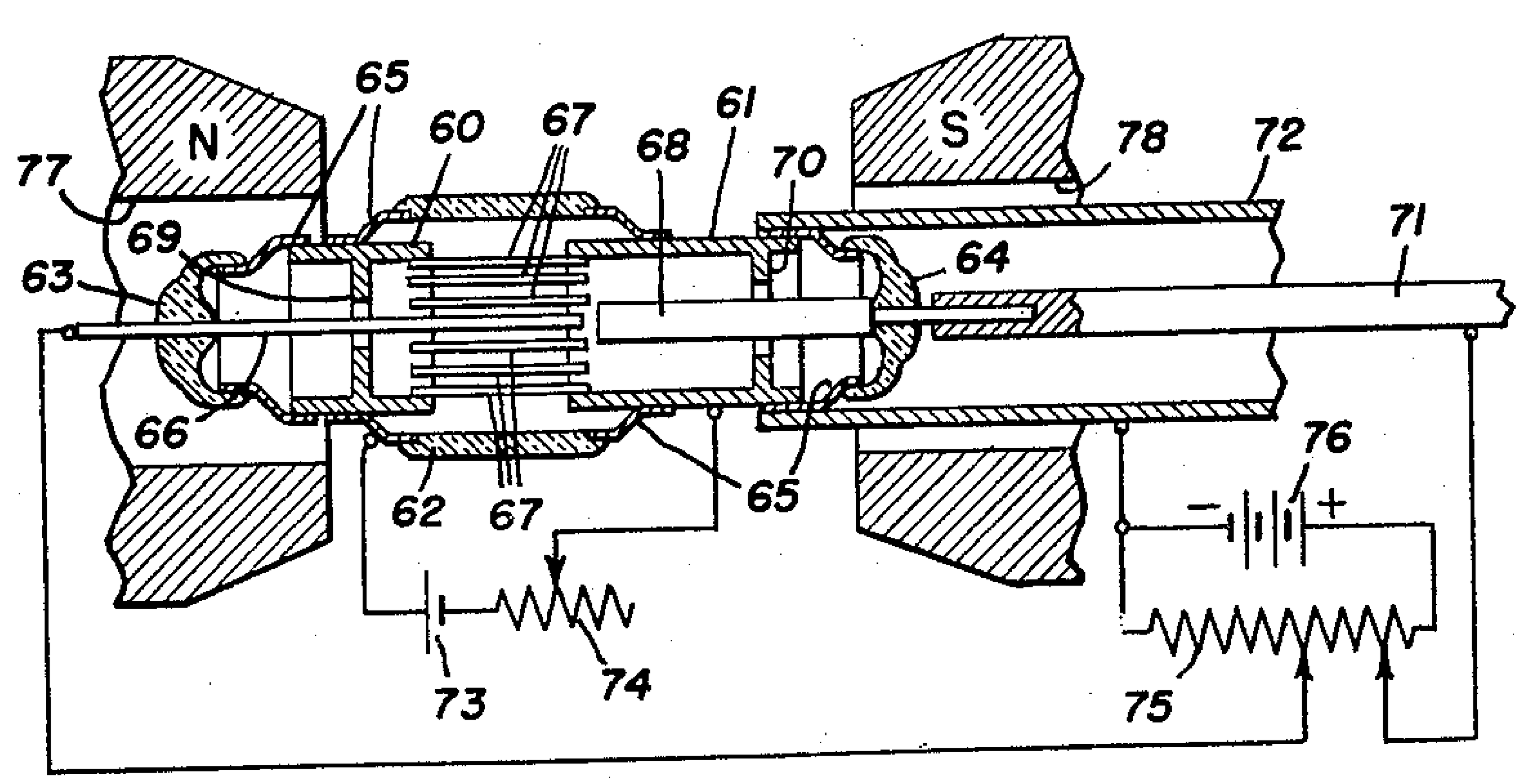


FIG.15.



INVENTOR:
ERNEST ROSTAS,
BY Philip L. Schlamp
HIS ATTORNEY.

United States Patent Office

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2,953,714

HIGH FREQUENCY ELECTRIC DISCHARGE DEVICES

Ernest Rostas, Paris, France, assignor to Compagnie Française Thomson-Houston, Paris, France

Filed Feb. 5, 1958, Ser. No. 713,434

Claims priority, application France Feb. 13, 1957

17 Claims. (Cl. 315—39.63)

My invention relates to high frequency electric discharge devices and pertains more particularly to magnetron devices adapted for being electronically tuned.

Heretofore, magnetron devices have been provided which included uninterrupted or smooth-walled cylindrical anodes. In some of these devices the anode comprised a hollow cylinder surrounding a cathode and the uninterrupted or smooth wall was defined by the inner surface of the cylinder. In others, the cathode was cylindrical and hollow and surrounded a cylindrical anode, the outer surface of which defined the uninterrupted or smooth wall of the anode. This latter type has been referred to as an "inversed magnetron." In both of these types of magnetrons the essential feature is the uninterrupted or smooth active wall of the anode, regardless of whether it constitutes the inner or outer surface of a cylindrical member. Additionally, this feature distinguishes these types from magnetrons including split or divided anodes, such as those comprising a pair of semicylindrical sections or an interdigital array of anode segments. Thus, as employed herein, the term, "smooth-walled anode" means an anode which is either internal or external of the cathode element and defines an active surface which is uninterrupted or non-divided as distinct from split-anodes or interdigital anodes employed in other forms of magnetron devices.

The operating frequency of magnetrons including smooth-walled anodes is that of the resonance motion of the rotating electrons, the oscillation period corresponding to the transit time of an electron orbit. The frequency produced, i.e., the Larmor frequency, is approximately proportional to the magnetic field, but depends also to a certain extent on the anode voltage, which latter fact permits electronic variation or the tuning of the frequency. Appreciable tuning ranges are attainable of the order of 10% to either side of the center frequency.

Various advantages are afforded by smooth-walled anode magnetron oscillators. Particularly advantageous is their mechanical simplicity, as well as the operational requirement of only a moderate magnetic field. It has been found, however, that the practical utilization of such devices is limited by the fact that, in operation, the cathode must be operated in the saturated state, which limits electron current. Prevalent theory does not provide a full explanation of this requirement, but it may be presumed that the potential distribution within the discharge space must not differ too much from the potential distribution prevailing in the absence of the electrons. This prevents the use of cathodes which are intended to function in the space-charge limited state, such as the oxide-coated cathodes. The space charge establishing itself about these cathodes would substantially adversely affect the potential distribution.

Up to the present, cathodes of pure metal, such, for example, as tungsten, have been used, the emission of which can be adjusted as a function of the temperature. However, and in addition to the fact that such cathodes have a low operating efficiency, the maintenance of the current at a fixed value requires rather complicated means of automatic regulation, the effectiveness of which is questionable, especially in the case of a magnetron with an external anode. In such a device, the emissive cathode becomes heated, under the influence of electron bombardment, in a manner which is difficult to control, especially since the electrons return to the cathode at a velocity greater than zero.

The present invention contemplates the provision of magnetrons with a smooth-walled or non-divided anode, which anode may be internal or external of the cathode and which magnetrons are not subject to the abovementioned limitations heretofore encountered in smooth-walled or non-divided anode magnetrons.

Thus, a primary object of my invention is to provide a new and improved electric discharge device adapted for electronic tuning over a substantial frequency range.

Another object of my invention is to provide a new and improved magnetron of the smooth-walled anode type.

Another object of my invention is to increase the practical applications of magnetron devices of a smooth-walled anode type.

Further objects and advantages of my invention will become apparent as the following description proceeds and the features of novelty which characterize my invention will be pointed out with particularity in the claims annexed to and forming part of this specification.

In carrying out the objects of my invention I provide magnetron devices each of which includes two functional and cooperative structures which shall hereinafter be referred to as the "emitter structure" and the "interaction structure," which structures are coaxial and adapted for being mounted in the same magnetic field. The emitter structure comprises a magnetron-diode including a coaxially arranged emissive cathode and control element, the purpose which structure is to produce electrons which will commence rotating in the magnetron-diode under the influence of a magnetic field and then be directed or injected into the interaction structure in a predetermined controlled manner. This interaction structure comprises a magnetron including a smooth-walled anode and which, instead of an emissive cathode, includes a non-emissive or cold electrode element to which a potential is applied approaching that of the emissive cathode in the emitter structure. The interaction from the viewpoint of energetics between the electrons and the high frequency field takes place mainly in the interaction structure. With these devices resonant circuits are provided which can be either internal or external of the evacuated containers enclosing the device.

For a better understanding of my invention reference may be had to the accompanying drawing in which:

Figure 1 is a fragmentary schematic illustration of an electrode arrangement of a magnetron device constructed in accordance with one embodiment of my invention and wherein the anode of the interaction structure is external of the cold cathode and of a smaller diameter than the positive electron element of the emitter structure;

Figure 2 is a similar illustration wherein the anode of the interaction structure and the positive electrode of the emitter structure are of substantially the same diameter;

Figure 3 is a similar illustration of a modified form wherein the positive element of the emitter structure is frusto-conical;

Figure 4 illustrates a modification which is similar to that of Figure 3 but wherein the anode of the interaction structure and the positive electrode of the emitter structure are physically connected as are the emissive and non-emissive portions of the negative electrodes of both structures;

Figure 5 illustrates an embodiment which is similar to that of Figure 4 but wherein the emissive and non-emissive negative electrodes of both structures are physically separated;

Figure 6 is a fragmentary schematic illustration of a modified embodiment of the present invention wherein the cathode of the emitter structure comprises a cylinder external of the positive element contained therein and the anode of the interaction structure is internal and of greater diameter than that of the positive element of the emitter structure;

Figure 7 illustrates a modification similar to that of Figure 6 but wherein the positive electrodes of both structures are of the same diameter;

Figure 8 is illustrative of a modification wherein the positive electrode of the emitter structure is frusto-conical in configuration and separated from the anode of the interaction structure;

Figure 9 illustrates a modification similar to that of Figure 8 but includes positive elements in both the emitter and interaction structures which are physically connected;

Figure 10 illustrates an embodiment similar to Figure 9 but includes negative elements which are physically separated;

Figure 11 is a fragmentary schematic illustration of another embodiment of the present invention including a double-ended magnetron construction;

Figure 12 illustrates schematically another embodiment including a double-ended construction;

Figure 13 illustrates somewhat schematically one embodiment of a magnetron oscillator constructed according to the present invention and incorporating a double-ended electrode arrangement;

Figure 14 illustrates somewhat schematically another magnetron oscillator constructed in accordance with the present invention; and

Figure 15 illustrates somewhat schematically still another magnetron oscillator constructed in accordance with the present invention and including an external cathode and a coaxial outlet end.

Figures 1 to 12 illustrate various electrode arrangements alternatively employable in the new device. Figures 1 to 5, 11, and 13 disclose interaction structures including external smooth-walled anodes or hollow cylindrical anodes containing a cathode or negative electrode therein. Also, in these figures the emitter structures include internal emissive cathodes and annular external positive electrodes. Figures 6 to 10, 12, 14, and 15, comprise interaction structures wherein the cathode or negative electrode element is a hollow cylinder and contains therein a cylindrical anode of smaller diameter. In these figures the emissive cathodes are annular or define a cylinder and contain a non-emissive positive electrode element. In all the figures the elements having idnentical functions are denoted by the same numerals. It is to be understood from the outset that the electrode arrangement of each of the Figures 1–12 is adapted for being contained and suitably supported in an evacuated envelope with suitable leads sealed therein for making electrical connections with the various electrode elements and suitable heating means for rendering the cathode emissive. Additionally, each of these devices is adapted for being supported between the pole pieces of a suitable magnet thereby to provide a magnetic field which is always substantially parallel to the axis of symmetry designated **3** in Figure 1 and thus substantially perpendicular to the electric fields extending between the positive and negative electrodes. As is well known, this arrangement of magnetic and electric fields is necessary to provide the rotational movement of electrons required for operation of a magnetron.

In the electrode arrangements of Figures 1–5 wherein the smooth-walled anode is external of the cathode, the emitter structure **1** comprises a cylindrical emissive cathode **4** and a coaxial positive electrode **5** of annular configuration. The interaction structure designated **2** comprises a central cylindrical conductor **6**, which might be thought of as a non-emissive extension of the cathode **4**, and a cylindrical smooth-walled anode **7**. In order to obtain resonance oscillations, a potential must be applied to the anode **7** such that it will be just attained or reached by the electrons in the case of the given magnetic induction ("critical" values of the anode voltage and of the magnetic induction). The positive electrode **5** of the emitter structure is provided with such a dimension, configuration and potential that the cylindrical potential surface **8** constituting an extension of the anode **7** will assume a potential lower than that of the anode **7**. Under these conditions electrons emitted by the cathode **4** cannot attain or be collected on the positive electrode **5**. Instead, an axial component of the electric field is established which attracts or directs the electron cloud which is rotating in the emitter structure toward the interaction section **2**. In the interaction section **2** the electrons circulate as if they had been emitted by the central conductor or nonemissive cathode **6**. Notwithstanding their axial velocity component, such electrons enter a phase of energetic exchange with the radio high-frequency electric field and finally fall on to or are collected on the inner surface of the anode **7**. The density of the current which enters the interaction structure depends upon the axial componnet of the electric field prevailing in the transition zone between the two sections; however, this current is independent of the available emission of the cathode as long as it is less than the saturation current. Thus it becomes possible to utilize cathodes of very high emissivity, such as the oxide-coated cathodes.

The schematic illustrations of Figures 1 to 4 illustrate various alternative arrangements for obtaining the desired potential on the potential surface **8**. In the case of the arrangement shown in Figure 1, the cylindrical positive electrodes **5** and **7** are both maintained at the same potential level, however, the diameter of the electrode **5** is larger than that of the electrode **7**. Additionally, these elements are physically disconnected or non-integral.

In the structure of Figure 2 the cathode **4** and non-emissive electrode **6** can be identical to that of Figure 1 and the diameters of the outer positive electrodes **5** and **7** can be the same, as shown. However, in this structure and for desired operation, the positive electrode **5** operates at a lower potential than that of **7**, in order to provide the desired axial component whereby electrons emanating from the emissive portion **4** of the cathode and rotating are caused to enter the interaction structure or, in other words, between the electrode **6** and the anode **7**. In this embodiment also, the electrodes **5** and **7** are physically disconnected as illustrated.

In Figure 3 is shown a structure including an emissive cathode **4** in the emitter structure **1** and a cold or non-emissive negative electrode **6** in the interaction structure **2**. In this arrangement the positive electrode **5** is frusto-conical in configuration and the smooth-walled anode **7** is cylindrical and equal to or smaller than the smallest diameter of the frusto-conical electrode **5**. The electrode **5** operates at a potential less than or equal to that of the anode **7**. Thus, the potential surface indicated by the dash lines and designated **8** is less than the potential of the electrode **7**, whereby an axial component is effected for directing the rotating electrons axially into the interaction structure. In this embodiment the inter-electrode region between the elements **4** and **5** is constricted at the end adjacent the anode **7** which is also effective for directing electrons toward the interaction structure.

Also, the electrodes 5 and 7 are physically disconnected while the electrodes 4 and 6 can be integral.

In those arrangements wherein the two positive elements, namely, the positive element 5 and the smooth-walled anode 7, are maintained at the same D.C. potential level, they can be electrically connected and thus converted into a single dual-purpose electrode structure, as shown in Figure 4. In this arrangement the electrons emanating from the cathode 4 find themselves, upon emanation, in a high frequency field. However, in this case it is still possible advantageously to utilize the concepts of the emitter structure and interaction structure, since the high frequency field begins to exert a noticeable influence on the electrons only in the narrow or constricted part of the outer electrode arrangement which constitutes the smooth-walled anode portion 7 of the device wherein the space field is negligible and the electrons approach closer the inner surface of the anode.

In the arrangements of Figures 1 to 4, the central conductor 6 or non-emissive negative element of the interaction structure is physically and electrically connected to the cathode 4. However, as seen in Figure 5, the cathode 4 and element 6 can be separated both physically and electrically, either to enable application of different potentials which may improve, under certain circumstances, the potential distribution in the device, or to enable separation of the two elements with respect to the high frequency voltages. The last-mentioned reason may be decisive in the case where the anodes or positive elements of both structures are interconnected. Thus it will be seen that in this manner the schematic arrangement of Figure 5 can simply be derived by modifying that of Figure 4.

For those devices in which the emissive cathode lies outside or surrounds the positive element in the emitter structure, the physical considerations are quite similar. The purpose is still the creation of such a potential distribution in the emitter structure and interaction structure that the electrons produced in the emitter structure will not attain or be collected on the positive electrode thereof but instead will, under the influence of an axial component of the electric field, be drawn toward or injected into the interaction structure. The structures illustrated schematically in Figures 6 through 10 are adapted for providing the desired potential distribution, in which figures elements corresponding generally to those of Figures 1–5, respectively, have been given primed numeral designations.

In all of the Figures 6–10 the emitter structure 1′ comprises a positive electrode 5′ which has the configuration of a solid revolution and a cathode or emitter 4′ which has the configuration of a hollow cylinder surrounding the positive electrode 5′. The interaction structure 2′ consists of a cylindrical electrode 6′ which surrounds an anode 7′ and which, since it serves as a negative electrode, can be integral with the cathode 4′.

In the arrangement of Figure 6 both of the positive electrodes 5′ and 7′ are cylindrical. However, the interaction anode 7′ which constitutes in this case the smooth-walled anode of the device has a larger diameter. Thus the potentials of the two positive electrodes 5′ and 7′ can be almost the same and yet there is provided a suitable axial component for directing electrons emitted from the cathode 4′ and rotating in the emitter structure into the interaction structure. Thus, the electrons are rotating in the desired manner before they enter the interaction space. This affords better operation than where the electrons commence rotating in the interaction structure.

In Figure 7 both of the positive electrodes 5′ and 7′ are cylindrical and the latter provides the required smooth-walled anode surface. As shown, these elements have the same diameter. However, they are separated and, thus, adapted for application of a potential to the positive electrode 5′ of the emitter structure which is lower than that of the interaction anode 7′, thus to provide the desired potential distribution for affording injection or axial direction of electrons into the interaction structure.

In the arrangement of Figure 8 the positive electrode 5′ of the emitter section 1 comprises a tapered or conical element, the major diameter of which is not larger than the diameter of the interaction anode 7′. In this case also the elements 5′ and 7′ can be physically disconnected but the potentials thereof can be almost the same, whereby suitable potential distribution is provided for directing electrons from the emitter into the interaction structure. Additionally, in this arrangement the interelectrode region between the cathode 4′ and electrode 5′ is constricted adjacent the interaction structure for enhancing electron injection thereinto.

In Figures 9 and 10 the positive electrodes of the structures can be the same as those shown in Figure 8 except that they have been physically connected to provide an integral structure. In the schematic illustration of Figure 10 the external conductor 6′ of the interaction structure is separated from the cathode 4′, which separation has the purpose of uncoupling the two structures as regards high-frequency.

From all of the foregoing it will be seen that my invention contemplates and I have provided various smooth-walled anode magnetron electrode arrangements including an interaction structure comprising a coaxial smooth-walled cylindrical anode and a non-emissive negative electrode and means for injecting electrons rotating in an emitter structure from the emitter structure longitudinally spaced from the interaction structure into the interaction structure in a controllable manner.

As seen in Figures 11 and 12, the entire electrode structure of the device can be symmetrical with respect to one plane, and this preferably in such a manner that an emitter structure which is located centrally will feed or inject electrons axially into two interaction structures that will oscillate either in parallel or in push-pull fashion. The devices of Figures 11 and 12 constitute such symmetrical arrangements, that of Figure 11 having external smooth-walled anodes, and that of Figure 12 having internal smooth-walled anodes.

In the arrangement of Figure 11, the emitter structure comprises an emissive cathode 9 and a positive electrode consisting mainly of two frusto-conical sections 10 and 10′. Two interaction structures comprising a pair of smooth-walled cylindrical anode surfaces 11 and 11′ and central non-emissive conductors or leads 12 and 12′, are symmetrically arranged with respect to the emissive cathode 9. The two central non-emissive conductors or electrodes 12 and 12′ are physically electrically connected to the emissive cathode 9 and the two anode surfaces 11 and 11′ can be part of a single element 13 that surrounds the emitter structure. An aperture 14 provided centrally in one side of the element 13 allows for extension therethrough of a lead-in conductor conected to the positive element including the sections 10 and 10′. In this arrangement, as in those of Figures 3–5 and 8–10, the interelectrode region between the elements comprising the emitter structure is constricted adjacent the interaction structure.

In the structure of Figure 12, a hollow cylindrical emissive cathode 15 is provided on both sides thereof with external cylindrical negative elements 16 and 16′ in interaction structures. Conical or tapered positive electrodes 17 and 17′ of the emitter structure and cylindrical smooth-walled anodes 18 and 18′ of the interaction structure can, as seen, comprise a single conductive element. Due to the cylindrical arrangement of elements it is possible to shorten the electrode arrangement and thus to effect considerable savings as regards the means of producing the magnetic field, since in both cases, namely, that of the internal cathode, as well as the external cathode, the extremities of the cathode, which are not sufficiently heated for the production of electrons, may act as cathode leads of the interaction structures.

As will be understood from the foregoing, the interaction structure of any of the disclosed arrangements can comprise part of a coaxial line which, by means of coaxial seals, can pass through the vacuum-tight envelope of the device or which, in other cases, can form a resonating circuit that is entirely located in the envelope.

Additionally, the cathode, in the case where it is located externally of the anode, need not form an entire or continuous wall cylinder. It can be made of individual emissive elements arranged circumferentially about the surface of a cylindrical support.

Illustrated in Figure 13 is a magnetron oscillator including a symmetrical electrode arrangement and an internal cathode. This device includes a vacuum-tight envelope **19**. Supported in the envelope **19** from a conductive support lead **20**, which is suitably sealed in a side wall of the envelope **19**, is a non-magnetic conductive element **21**. The conductive element **21** contains a central opening shaped to provide a pair of frusto-conical centrally located surfaces **22** and **22'** and a smooth-walled cylindrical surface **23** and **23'** at either end thereof. Extending centrally through the element **21** is a tungsten filament **25**, only the central portion **25*a*** of which is provided with a thin coating of barium oxide to serve as a source of electrons. Thus the emissive portion **25*a*** of the filament and the portion of the element **21** including the frusto-conical surfaces **22** and **22'** serve to constitute an emitter structure designated **26**, and the outer ends of the element **21**, including the smooth cylindrical walls **23** and **23'** in cooperation with the outer non-emissive portions of the filament **25**, constitute a pair of interaction structures **27** and **27'**.

In the arrangement just described, the internal diameter of the positive electrode of the emitter structure becomes smaller starting from the center and moving in the direction of the interaction structures, and as a result thereof the electrons emitted by the emissive portion **25*a*** of the cathode and which commence rotating in the emitter structure are attracted into the interaction structures wherein they set up the oscillations and then fall onto or are collected by the surfaces **23** and **23'** of the anode. The electrons which have not been captured or collected by the anode and which escape by way of the open ends of the latter element are repelled by a pair of reflecting disks **28** and **28'** mounted on the cathode supports **24** and **24'**, respectively.

A magnet, the pole pieces N and S of which are illustrated, produce a magnetic field which is substantially parallel to the longitudinal axis of the cathode. The two interaction structures **27** and **27'** are adapted for oscillating without phase displacement; thus the two lead-in conductors **20** and **24'** of the filament carry the same high-frequency potential with respect to the anode lead-in conductor **20**. Thus, the resonating circuit is disposed outside of the device and is constituted of a trifilar line **29** that can be tuned by means of the double-short circuiting, movable capacitive device **30**. Behind the short-circuiting device **30** the conductors, which no longer carry any high-frequency potential, are connected to voltage sources, the filament conductors being connected to a source **31** through a variable resistor **32** and the anode conductor and one of the filament leads connecting the filament to a potentiometer **33** which is energized by a source **34**. The high-frequency power is transmitted to a useful load **35** by means of a coupling loop **36**.

Illustrated in Figure 14 is a symmetrical device with an external cathode contained in a vacuum-tight envelope **40**. In this arrangement the interaction structures comprise hollow smooth-walled cylinders **41** and **41'** which are supported by support leads **42** and **42'** sealed in the side wall of the envelope **40**. In this structure the positive electrode or conductor **43** can be identical to the anode arrangement of Figure 12 and is axially supported in the cylinders **41** and **41'** by support leads **44** and **44'** which extend through and are suitably sealed in the side wall of the envelope **40**. The emissive portion of the cathode structure comprises a plurality of wire-like or emissive filamentary elements **45** which, for example, can constitute thoriated tungsten wire. The elements **45** are stretched between the adjacent edges of the cylinders **41** and **41'** and correspond in position to the central portion of the anode conductor which constitutes a pair of tapered or conical portions with the smaller ends joined. A magnet, the pole pieces N and S of which are illustrated in Figure 14, produces a magnetic field which is substantially parallel to the longitudinal axis of the anode conductor **43**. The leads and the support leads are connected to four conductors **46** and **46'** and **47** and **47'**. The pairs of conductors **46** and **47** on the one side and **46'** and **47'** on the other side form each a Lecher system and inasmuch as the two interaction sections can oscillate in parallel, the two external conductors **46** and **46'** carry the same alternating potential with respect to the internal conductors **47** and **47'**. The two Lecher lines are tuned by means of a movable short-circuiting device **48** common to both. Due to the different direct or continuous potentials of the conductors, the short-circuiting is effected by three capacitors **49**. A loop **50** couples a useful load **51** to the oscillator. Behind the short-circuiting device where the four conductors are free of any high-frequency voltages, a heating-voltage source **52** is connected to the conductors **47** and **47'** through a variable resistor **53** which enables adjustment of the temperature of the cathode filaments, and thus controls the emissivity thereof. The anode voltage which is applied to the conductors **46'** and **47'** is tapped from a potentiometer **54** which is energized by a source **55**.

Illustrated in Figure 15 is a non-symmetrical device with an external cathode and a coaxial outlet end. In this arrangement the envelope of the device consists of two cylindrical parts **60** and **61** formed of a non-ferromagnetic material, such for example, as copper, with a cylindrical part **62** made of glass and two spherical caps **63** and **64** likewise made of glass enclosing the extremities of the arrangement. A plurality of thin metallic annular sealing elements **65** seal, without any substantial mechanical strain, the glass elements to the metal elements, thus to complete the envelope structure.

In this device the emitter structure consists of a central positive electrode element **66** and a surrounding series of emissive wire-like or filamentary elements **67** formed, for example, of thoriated tungsten wire and stretched between and circumferentially spaced about and secured to, the edges of the cylindrical parts of elements **60** and **61**. The mentioned positive electrode element of the emitter structure is a cylindrical stem of small diameter which is supported by and suitably sealed through the cap **63**. The interaction structure of this device consists of the cylinder **61**, which carries cathode potential, and a smooth-walled cylindrical anode **68**, the diameter of which is larger than the positive element **66** of the emitter structure. The anode **68** is held and supported by the glass entrance seal **64**. Two annular elements **69** and **70**, which coact with cylinders **60** and **61**, and which thus carry the cathode potential, prevent any escape of electrons from the discharge spaces.

Externally of the tube, coaxial conductors **71** and **72** are connected to the outlet end of the anode **68** and to the cylindrical part **61** of the envelope so that they, thus, form with the interaction structure a single coaxial line. The latter structure goes to the load circuit and can have more or less high Q, depending upon the more or less reactive character of its closing impedance. A heating voltage source **73** is connected through a variable intermediate resistor **74** to the parts **60** and **61** of the envelope. The two anodes or positive elements **66** and **68** can, as a matter of principle, carry the same potential since the difference of their diameters already insures the desired potential distribution whereby electrons emanating from the emissive cathode in the emitter structure and caused to rotate therein are directed axially or injected into the interaction structure. However, in order better to regulate the electron current entering the interaction structure, I tap the two voltages separately from a potentiometer **75** which is energized by a source **76**. The magnet producing the required magnetic field includes pole pieces N and S, which pole pieces are centrally bored at **77** and **78**, respectively, through which the outgoing leads of the device extend.

While I have shown and described specific embodiments of my invention, I do not desire my invention to be limited to the particular forms shown and described, and I intend by the appended claims to cover all modifications within the spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A magnetron comprising an interaction structure including a smooth-walled cylindrical anode and a coaxial cylindrical non-emissive negative electrode cooperating to define a straight cylindrical interaction space, an emissive cathode coaxial with and longitudinally displaced relative to said interaction space, and an elongated positive electrode coaxial with said other electrodes and defining with said emissive cathode an inter-electrode space longitudinally displaced from said interaction space and of varying dimensions along the length thereof adapted for having magnetically rotated therein electrons emanating from said emissive cathode and for directing rotating electrons from said inter-electrode space into said interaction space for rotational movement therein.

2. A magnetron comprising an interaction structure including a smooth-walled cylindrical anode and a coaxial cylindrical non-emissive negative electrode defining a straight cylindrical interaction space, an emissive cathode coaxial with and longitudinally displaced relative to said interaction space, and an elongated annular coaxial positive electrode surrounding said emissive cathode and defining with said emissive cathode an inter-electrode space longitudinally displaced from said interaction space and of progressively decreasing width in the direction toward said interaction space adapted for having magnetically rotated therein electrons emanating from said emissive cathode and for directing rotating electrons from said inter-electrode space into said interaction space for rotational movement therein.

3. A magnetron comprising an interaction structure including a smooth-walled cylindrical anode and a coaxial cylindrical non-emisisve negative electrode cooperating to define a straight cylindrical interaction space, an annular emissive cathode coaxial with and longitudinally displaced relative to said interaction space, and an elongated positive electrode contained in said emissive cathode and defining with said emissive cathode an inter-electrode space longitudinally displaced relative to said interaction space and of varying dimensions along the length thereof and adapted for having magnetically rotated therein electrons emanating from said emissive cathode and for directing rotating electrons from said inter-electrode space into said interaction structure for rotational movement therein.

4. A magnetron comprising an interaction structure including a smooth-walled cylindrical anode and a coaxial cylindrical non-emissive negative electrode defining a straight cylindrical interaction space, an emissive cathode coaxial with and longitudinally displaced relative to said interaction space, and an elongated coaxial positive electrode defining in cooperation with said emissive cathode an inter-electrode region longitudinally displaced from said interaction space and adapted for having magnetically rotated therein electrons emanating from said emissive cathode, only said inter-electrode region being constricted at the end adjacent said interaction structure to provide an electrostatic field having substantial axial components for directing rotating electrons from said inter-electrode region into said interaction space for rotational movement therein.

5. A magnetron comprising an interaction structure including an elongated annular cylindrical non-emissive negative electrode, an elongated cylindrical anode coaxially contained in said cylindrical negative electrode and cooperating therewith to define a straight cylindrical interaction space, an annular emissive cathode coaxial with and longitudinally displaced relative to said interaction space, and an elongated positive electrode contained in said emissive cathode and defining with said emissive cathode an inter-electrode space longitudinally displaced relative to said interaction space and of progressively decreasing width in the direction toward said interaction space adapted for having magnetically rotated therein electrons emanating from said emissive cathode and for directing rotating electrons from said inter-electrode space into said interaction space for rotational movement therein.

6. A magnetron comprising a coaxial pair of longitudinally spaced non-emissive annular cylindrical negative electrodes, a smooth-walled anode comprising a straight cylindrical portion of a positive electrode extending coaxially in one of said negative electrodes and cooperating therewith to define oppositely disposed straight cylindrical interaction spaces, a plurality of emissive filaments mounted between and circumferentially spaced about the opposed ends of said cylindrical negative electrodes, and another portion of said positive electrode extending coaxially in the cylinder defined by said filaments and shaped to define therewith to an inter-electrode region of decreasing width in the opposite directions toward said interaction spaces for directing electrons into said interaction spaces for rotational movement therein.

7. A double-ended magnetron comprising a pair of longitudinally spaced interaction structures each including a smooth-walled cylindrical active anode section of an elongated positive electrode and a non-emissive end section of an elongated coaxial negative electrode, and a coaxial emitter structure interposed between said interaction structures and including an intermediate emissive section of said negative electrode and an intermediate section of said positive electrode together defining an inter-electrode region adapted for having magnetically rotated therein electrons emanating from said emissive section, said inter-electrode region being constricted at the ends thereof adjacent said interaction structures to provide an electrostatic field having substantially oppositely directed axial components for directing rotating electrons from said inter-electrode region into said interaction structures for rotational movement therein.

8. A magnetron comprising an interaction structure including a smooth-walled cylindrical anode and a coaxial non-emissive negative electrode, an emissive cathode coaxial with and longitudinally disposed relative to said interaction structure, and a frusto-conical, positive electrode surrounding said emissive cathode for defining therewith an inter-electrode space adapted for having magnetically rotated therein electrons emanating from said emissive cathode and cooperating with said anode and emissive cathode for directing rotating electrons from said inter-electrode space into said interaction structure for rotational movement therein.

9. A magnetron comprising an interaction structure including a smooth-walled cylindrical anode and an annular coaxial non-emissive negative electrode surrounding said anode, an annular emissive cathode coaxial with and longitudinally displaced relative to said interaction structure, and a tapered positive electrode coaxially contained in said emissive cathode for defining therewith an inter-electrode space of varying dimensions along the length thereof adapted for having magnetically rotated therein electrons emanating from said emissive cathode and anode for directing rotating electrons from said inter-elec-

trode space into said interaction structure for rotational movement therein.

10. A magnetron comprising an annular anode including a pair of longitudinally spaced smooth-walled cylindrical bores each at an end thereof, a coaxial negative electrode extending through said anode and including an emissive central portion and non-emissive end portions, said non-emissive end portions corresponding to the smooth-walled cylindrical bores of said anode and defining therewith interaction structures, and a positive electrode comprising a pair of hollow frusto-conical sections connected at the larger ends thereof, said last-mentioned electrode being positioned in said anode about said emissive portion of said negative electrode for defining therewith an inter-electrode space adapted for having magnetically rotated therein electrons emanating from said emissive portion of said negative electrode and cooperating therewith for directing rotating electrons from said inter-electrode space into said interaction structures for rotational movement therein.

11. A magnetron comprising an elongated annular negative electrode including an emissive central portion and non-emissive end portions, a positive coaxial electrode extending through said annular electrode and including smooth-walled cylindrical end portions positioned in said non-emissive end portions of said annular electrode, and a pair of tapered portions connected at the smaller ends thereof and positioned in said emissive portion of said electrode, for defining therewith an inter-electrode space of varying dimensions along the length thereof adapted for having magnetically rotated therein electrons emanating from said emissive portion of said negative electrode for directing electrons longitudinally outwardly from said interelectrode space into interaction structures defined by the end portions of said coaxial negative and positive electrodes.

12. A magnetron comprising an envelope, an annular anode contained in said envelope, said anode including a longitudinally spaced pair of smooth-walled cylindrical bores each at one end thereof and a pair of frusto-conical surfaces meeting at the larger ends thereof and centrally disposed in said anode, a conductive support lead for said anode sealed through said envelope, a filamentary heater coaxially supported in said anode by a pair of conductive support leads sealed through said envelope, and extending over the opposite ends of said anode, and an emissive coating on said filamentary heater in the central region of said anode corresponding to said frusto-conical surfaces.

13. A magnetron comprising an envelope, a coaxial pair of longitudinally spaced non-emissive annular conductors contained in said envelope, a plurality of emissive filaments mounted between and circumferentially spaced about the opposed ends of said annular conductors, a pair of support leads connected each to one of said annular conductors and sealed through said envelope, a coaxial conductor extending through said annular conductors, said annular conductors including smooth-walled cylindrical end portions positioned in said non-emissive annular conductors and a pair of tapered portions connected at the smaller ends thereof and positioned in the cylinder defined by said emissive filaments, said tapered portions and said cylinder defining an interelectrode space of varying dimensions along the length of said space for directing electrons axially in the direction of said smooth-walled end portions, and a pair of conductive support leads sealed through said envelope and each connected to one end of said coaxial conductor.

14. A magnetron comprising an elongated annular positive electrode, an elongated negative electrode contained in said positive electrode, one end of said annular positive electrode constituting a cylindrical smooth-walled anode and cooperating with a corresponding cylindrical non-emissive end of said negative electrode to define therewith a straight cylindrical interaction space, the other end of said negative electrode being emissive and cooperating with the other end of said positive electrode and defining therewith an inter-electrode space of progressively decreasing width in the direction toward said interaction space adapted for having magnetically rotated therein electrons emanating from said emissive end of said negative electrode and for directing rotating electrons into said interaction space for rotational movement therein.

15. A magnetron comprising an elongated annular positive electrode assembly including a cylindrical section and a frusto-conical section, an elongated negative electrode assembly contained in said positive electrode, said cylindrical section of said positive electrode constituting a smooth-walled anode and cooperating with a corresponding non-emissive section of said negative electrode assembly to define an interaction space, the other section of said negative electrode being emissive and cooperating with said frusto-conical section of said positive electrode assembly to define an inter-electrode space adapted for having magnetically rotated therein electrons emanating from said emissive section of said negative electrode assembly, whereby rotating electrons are directed from said inter-electrode space into said interaction space for rotational movement therein.

16. A magnetron comprising an elongated cylindrical negative electrode, an elongated positive electrode contained in said negative electrode, one end of said positive electrode constituting a cylindrical smooth-walled anode and cooperating with a corresponding non-emissive end of said cylindrical negative electrode to define a straight cylindrical interaction space, the other end of said annular negative electrode being emissive internally and the other end of said positive electrode being conical to define an inter-electrode space of varying dimensions along the length thereof adapted for having magnetically rotated therein electrons emanating from said emissive end of said negative electrode and whereby said electrons are directed from said inter-electrode space into said interaction space for rotational movement therein.

17. A magnetron comprising an elongated cylindrical negative electrode assembly including non-emissive and emissive sections, an elongated positive electrode assembly contained in said negative electrode assembly, one section of said positive electrode having a cylindrical surface constituting a smooth-walled anode cooperating with said non-emissive section of said negative electrode assembly to define an interaction space, the other end of said positive electrode assembly being tapered and positioned in said emissive section of said annular negative electrode assembly and cooperating therewith to define an inter-electrode space of varying dimensions along the length thereof adapted for having magnetically rotated therein electrons emanating from said emissive section of said negative electrode assembly and whereby said electrons are directed from said inter-electrode space into said interaction space for rotational movement therein.

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