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MAGNETRON

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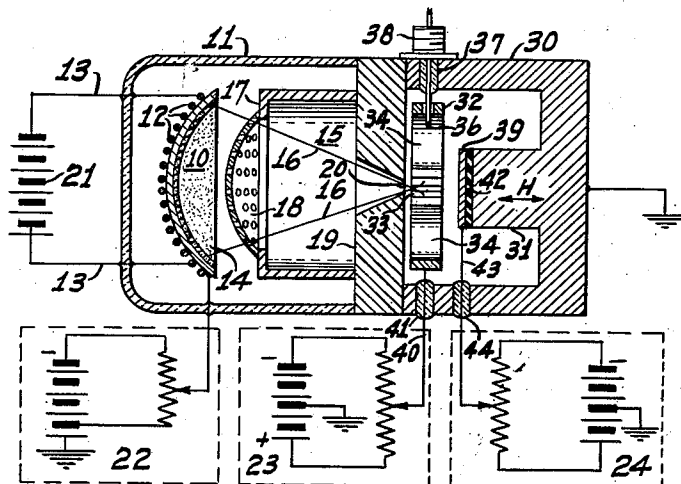


Fig. 1

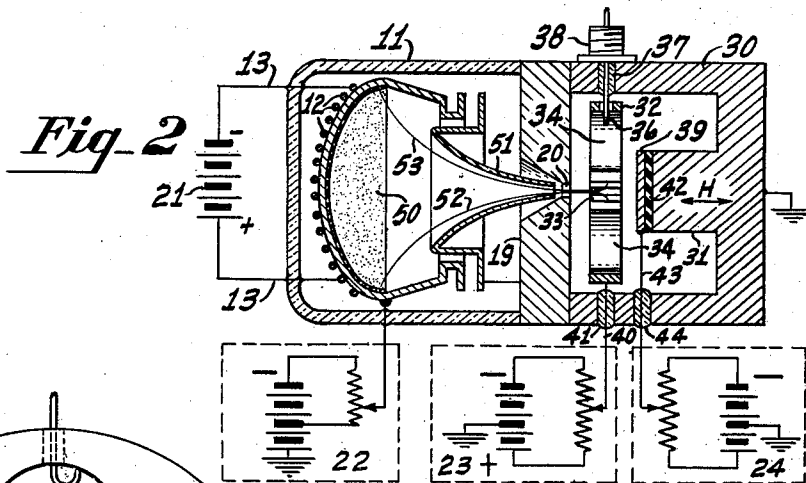


Fig. 2

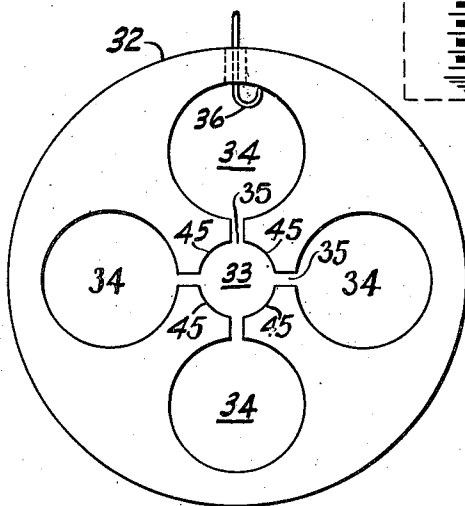


Fig. 3

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MAGNETRON

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This invention relates to improved magnetrons having external cathodes. More particularly, it relates to magnetrons of this type which in addition to producing large amounts of radio frequency power are capable of doing so with greatly increased efficiency due to a novel arrangement including an external electron gun capable of delivering a very high density electron beam.

In the magnetron art, considerable difficulty has been encountered in providing a suitable source of electrons. For example, if the source is an internal cathode, there are at least three possible difficulties; first, the cathode is subject to electron bombardment which can excessively heat it or strip away its emissive coating or both; secondly, it must be precisely mounted in the center of the interaction space since uniformity of cathode-to-anode spacings is extremely critical in its effect both on efficiency and operativeness; and thirdly, in many very small magnetrons there is no room for thick cathodes, so that recourse must be had to fine axial filaments which are capable of only very limited emission.

Because of these difficulties magnetrons have been constructed with external electron sources. A typical external source is a cathode mounted outside of the ring of anode segments on an extension of the tube axis in an arrangement whereby its emitted electrons are drawn into the magnetron interaction space through the axial magnetron magnetic field which serves to prevent them from following divergent paths to the anode structure and instead guides them into the interaction space. While external sources heretofore used do not entail the three above-mentioned difficulties they do entail at least two others; first, they result in very low power outputs since the electron currents which they provide are very small; and secondly, they result in very low efficiency since it is primarily axial kinetic energy that is imparted to their electrons by the direct current energization of the magnetron, i. e., a kind of kinetic energy which it cannot convert into useful radio frequency energy.

From the foregoing it is apparent that two characteristics are needed for a satisfactory external electron source: (1) that it be capable of delivering so large an electron current into the interaction space that the magnetron can operate at a high level of radio frequency power, which means, for a case where the interaction space is quite small as measured across its axis, that it should be capable of delivering this current in the form of a high density beam; and (2) that it so impart direct current energy to the elec-

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trons that in the interaction space they will move primarily in radial directions thereby promoting high-efficiency translation of this energy to radio frequency energy.

Accordingly, it is a first object of the present invention to devise an improved magnetron having an external source of electrons capable of projecting a high density electron beam into the interaction space of the tube.

It is a further object of the present invention to devise an improved magnetron having an external source of electrons and in which said source will project the electrons into the interaction space of the tube with greatly increased radially-acting components of direct current energy.

It is a further object of the present invention to devise a magnetron which has an external electron source capable of projecting into the magnetron an electron beam of such great density that the space charge thereof has much more energy than the axial kinetic energy of the electrons and which is capable of converting space charge energy into radio frequency energy.

It is a further object of the present invention to devise an improved magnetron as set forth in the preceding paragraph in which said external source is capable of focusing into said beam electrons emitted from an emissive cathode area many times as large as the cross sectional area of said beam near its point of entry into the interaction space of the magnetron.

Other features, objects and advantages of this invention will be apparent to those skilled in the art from the following description of an illustrative embodiment of the invention and from the drawing, in which:

Figure 1 is a cross section of one embodiment of the present invention;

Figure 2 is a cross section of another embodiment thereof; and

Figure 3 is an end view of the type of anode structure which, by way of example, is shown to be used in both of the embodiments shown herein.

In general, according to the present invention, the external source concentrates electrons, from a very large emissive area, to such an extent that the energy which they acquire in the form of space charge potential may even exceed their axial kinetic energy and it projects the concentration of electrons into the interaction space of the magnetron. Due to their great space charge potential the electrons will move in the interaction space with very large radial compo-

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nents which, under the influence of the magnetron magnetic field, will be converted into cycloidal movement. Contrary to common practice, the external source is carefully shielded from the lines of flux of the magnetron magnetic field so that the electrons will not be impeded from moving over convergent paths as they must in order to be concentrated.

In a preferred manner of practising this invention the external source comprises an ion-trap type of electron gun having a concave electron emissive surface in an arrangement for projecting the emitted electrons along convergent paths through a field-free ionization chamber wherein the electrons and positive ions will entrap each other to neutralize their respective space charges whereby an electron beam will be formed which will be conical in shape because of the influence of the initial directions of electron emission.

The magnetron shown in Fig. 1 comprises at its left end, as shown in the drawing, a high-current ion-trap electron gun which may be of a type described in a co-pending application of Ernest G. Linder, Serial No. 68,605, filed December 31, 1948, now Patent No. 2,622,225, dated December 8, 1952, which is assigned to the assignee hereof. This gun includes a circular cathode 10 which has the shape of a small segment of a sphere and is supported inside of one end of an evacuated envelope 11 with its concave side facing toward the other end thereof. The cathode is provided with a heater 12, which may be any one of a number of suitable types and may be supplied with heater current through a pair of leads 13 which are sealed through the envelope, and it carries an emissive coating 14 on its concave side. The coating 14 faces toward an ionization chamber 15 through which a conically shaped beam of electrons, represented at 16, is to be directed. To the end that this beam may enter the chamber 15 through one of its sides while at the same time that side may serve as an electrostatic shield, its wall 17 is formed with an electron-permeable central portion, e. g., a convex circular grid 18, which may be a woven wire mesh or similar open structure, through which a large number of the electrons may freely pass. In order that equipotential surfaces to be established between the concave coating 14 and the convex grid 18 will be spherically concentric with said coating, the grid 18 is formed in the shape of a segment of a sphere which is concentric with the coating. In the embodiment shown herein for illustrative purposes, the output end of the ionization chamber 15 consists of the outer surface of a portion of a wall 19 of a hollow cylindrical magnetron magnet 30. To permit electrons to go from the chamber 15 into the magnet 30 a small central orifice 20 is formed in the wall 19 at a point on the axis of the conical beam 16 and near to its apex. The magnet 30 serves as part of the tube envelope as described below.

Due to the curvature of the emissive coating 14, the emitted electrons will tend to converge toward the common center of curvature of these elements, i. e., toward the central orifice 20. As is known, ordinarily the sharpness of focus of an electron beam is adversely affected by the mutual repulsion of its electrons, i. e., by space charge effects, particularly if, as is likely for the gun shown herein, it is a high-density low-velocity beam. However, as is set forth in detail in the above-mentioned co-pending application, it is

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possible to cause entrapment of positive ions within the conically shaped beam so as to neutralize space charge effects and to attain precise focusing of the beam at the center of curvature of the cathode. The requirements for positive ion entrapment are a field-free region in which cumulative entrapment can occur and gas molecules in the paths of the moving electrons to provide the ions. The relatively very small number of gas molecules comprising the "residual gas" which remains after evacuation will suffice for an adequate supply of ions because a relatively considerable number of them will be ionized by the very large electron current provided by the type of cathode shown herein.

It is possible but not necessary, to form the magnetron magnet as shown herein, i. e., to form it so that it completely surrounds some of the elements of the magnetron and constitutes a portion of its evacuated envelope. What is essential is that it establish a strong axial magnetic field extending through the interaction space so that any electrons therein which tend to move radially will be influenced to follow cycloidal paths. In addition the magnetron must include some means for shielding the external electron source from the field of the magnet. This means may be a portion of the magnet 30, as in the example herein, or a portion of its flux circuit which has such low reluctance that substantially no fringing magnetic field will extend beyond its surfaces into the region of the electron source. The magnet shown in Fig. 1 for illustrative purposes has the form of a figure of revolution of a somewhat G-shaped section. It comprises an internal pole piece 31, which is concentric with and extends toward the wall 19 and the orifice 20. Because of the sharp focusing of the electron beam 16, the orifice 20 may be so small as only negligibly to affect the density of magnetic field along the axis of the interaction space.

If desired much of the structure which is shown herein as comprised in the magnet 30 may be replaced by a similarly shaped structure of material which is not necessarily permanently magnetized itself, such as a thick-walled closed-ended hollow cylinder of soft iron, in which a dense flux is established by appropriate use of a permanent magnet or an electromagnet. For example, the flux might be made to originate in the pole piece 31 either by making it of a permanently magnetic material, such as Alnico, or by making it the core of an electromagnet.

Inasmuch as the magnet 30 constitutes a portion of the envelope of the magnetron it must be gas-tight. Accordingly, if its outer walls should be composed of a porous type of permanently magnetic material, it would be necessary to take some appropriate corrective measure, e. g., to make some or all of its surfaces impermeable by the application of vitreous or organic coatings. On the other hand the envelope 11 could be extended so as to entirely surround the magnet 30.

Mounted inside of the magnet 30 is a magnetron anode structure 32 which may be any one of a great many types which are already known or of other types which may become known in the future. The present invention does not depend on the use of any particular type of anode structure. For example, it may be of the type which comprises a plurality of anode arms in the form of radial vanes forming an annular row of wedge-shaped resonant cavities; it may be a solid block of conductive material such as

copper with cylindrical resonant cavities bored through it in an annular row around and opening into the interaction space; or it may be an annular row of anode segments which are electrically grouped and interconnected so that they may be appropriately connected to external or internal resonant means. The anode structure, whatever type it may be, will in any case include at least two anode segments which are arranged in an annular row to define a substantially cylindrical interaction space. The term "segments" as used herein is intended as the name for any anode elements which have conductive surfaces facing toward the center of the interaction space and bounding it in a certain range of angular directions therefrom, e. g., the segments of a split anode or the inner ends of the anode arms of magnetrons having internal resonant cavities. The anode structure 32 of the type used in the particular magnetrons shown herein, by way of example, comprises an interaction space 33 surrounded by four resonant cylindrical cavities 34 connected by slots 35 to space 33. The other two cavities can be seen in Fig. 3 as can the four anode segments 45. Conventionally mounted within one cavity 34 there is an inductive loop 36 for withdrawing radio frequency power from the magnetron. To permit connection of loop 36 to an output line its free end is extended through a seal 37 to serve as the inner conductor of a coaxial line terminal 38.

To permit the exercise of certain controls which are helpful in optimizing the performance of this magnetron, it preferably should be possible to vary the direct current potential of the anode structure 32 or that of a final electrode 39 or both. To this end: (1) the anode structure 32 is insulatingly supported inside of the magnet 30, by means which may be of any conventional type and therefore are not shown, and is provided with a lead 40, which extends to the outside of the magnet through an insulating gas-tight seal 41, for connecting it to an external source of potential; (2) and the final electrode 39, which has a polarizing lead 43 extending to the outside of the magnetron through a seal 44, is insulatingly carried on the face of the pole piece 31 on a dielectric separator 42.

In a preferred circuit arrangement for operation of the device of Fig. 1: the chamber 15 is grounded, e. g., by grounding the magnet 30; a source of cathode heater energy 21 is connected between the leads 13; the cathode 10 is connected to an adjustable source of direct potential 22 which is negative with respect to ground potential; and the anode structure 32 and the final electrode 39 are respectively connected to sources of potential 23 and 24 each of which is adjustable to values slightly above and slightly below ground potential. In this arrangement the anode structure of the present magnetron is not polarized at a much higher potential than any portion of the external electron source, as is usually done so that the anode potential will be effective to cause a substantial part of the acceleration of the electrons. The reason why this is not necessary herein will be apparent from the following explanation of the operation of this magnetron.

In the operation of the magnetron of Fig. 1, electrons emitted from the coating 14 are accelerated in the region between this coating and the grid 12, to attain velocities which may be, for example, of the order of 300 volts. This will

carry them into the chamber 15 wherein they will drift in directions which tend to be convergent. At the very start of operation the electron space charge will prevent the beam from immediately coming to a sharp focus at the orifice 20. However, the somewhat defocused electron beam passing through the chamber 15 will cause ionization of the residual gas molecules therein and in a very few microseconds will entrap enough of the positive ions thus produced to neutralize its own space charge so that it will come to a sharp focus. The entrapped ions will be relatively static whereas the electrons, carried along by their initial kinetic energies, will converge together and shoot through the orifice 20 in a very dense stream of small cross-sectional area, space charge neutralization being maintained due to the continuous arrival of replacement electrons from the cathode.

The dense concentration of electrons entering the interaction space 33 will suddenly cease to be space charge neutralized since, as will be more fully explained below, ion entrapment cannot take place inside the magnet 32 due to the presence of "sweeping fields" therein, and since neutralization cannot be carried over from the chamber 15 inasmuch as the relatively heavy ions will not be carried along by the escaping electrons in their sudden egress through the orifice 20 and they will not be attracted out by the small amount of the unneutralized negative space charge of the escaped electrons which will be "seen" inside the chamber 15 as an ion accelerating field.

As a result, once it is inside the interaction space 33 the dense electron stream will suddenly "explode" due to space charge repulsion forces, spreading apart at a very rapid rate with its electrons moving within the interaction space with large radial components. Due to the magnetron magnetic field the radially-acting energy will be effective to move the electrons along curved paths each with a tangential component with respect to the periphery of the interaction space, i. e., with a component which the anode structure can convert into radio frequency energy in a manner which is well known.

It is possible to operate this magnetron with both the anode structure 32 and the final electrode 39 very nearly at ground potential, i. e., to so operate it that except for space charge fields and radio frequency fields, the entire interior of the magnet 30 is very nearly field-free. The reason why this magnetron may be operative under these conditions is that due to the sharp convergence of the conical beam 20 within the ionization chamber there will be at least equally sharp divergence of its electrons in the region past the cross-over point so that the beam will spread out even if some space charge neutralization occurs beyond the orifice 20 which divergence will entail radial movement of the electrons.

However, for best operation of the device it is desirable to set up some kind of an "ion sweeping field" so that there will be no space charge neutralization within the interaction space, either by ions which are carried into it from the ionization chamber or by ions produced and entrapped in it in the first instance. The requirements for an appropriate "sweeping field" are very easily met. This field should provide an electrostatic gradient in the region including the interaction space and the path of the electron beam through the orifice 20 into it. This gradient is not critical as to direction, since any gradient, irrespec-

tive of its direction, will act oppositely on electrons and ions, thus preventing entrapment, and the gradient may be very small in magnitude, since very little "sweeping" will suffice to oppose the slow build-up of ion entrapment. In being swept out of this region, ionized molecules are attracted to the lowest potential surfaces inside the magnet; there they draw enough negative current to return to equilibrium; and thereafter they leave said surfaces and move about at random under the influence of their thermal energies.

In the present arrangement an appropriate sweeping field may be established by adjusting either the anode structure 32 or the final electrode 39 or both of them at a variety of potentials or combinations thereof. In practice, appropriate adjustments of the sources 23 and 24 for obtaining optimum performance will probably be best determined by trial and error.

Sometimes it will be advantageous to polarize the final electrode 39 at a negative potential to lengthen the time that an electron is in the interaction space, to the end that a sufficient portion of its useful energy will be usefully converted into radio frequency energy. However this will not be necessary in a case where the depth of the interaction space along the tube axis is great enough with respect to the rate of axial drift so that most of the electrons will have time to give up substantial portions of their tangential kinetic energies before leaving the interaction space.

It should be borne in mind that the potential of the final electrode 39 will also have an effect upon the space charge within the interaction space inasmuch as it will effect the crowding or dispersion of the electrons therein. The establishment of an electrostatic field or fields within the magnet 30 may be useful not only for sweeping out the positive ions but also for assisting in the elimination of slowed-down electrons. In the operation of the present magnetron these electrons, once they have slowed down to a potential slightly below that of the most positive element located inside of the magnet 30, will be attracted to it, e. g., if the anode structure and the final electrode are both polarized at potentials below ground, these electrons may be collected on the inside walls of the magnet 30 to find their return path to the cathode. On the other hand, if either the anode structure 32 or the final electrode 39 or both are polarized somewhat above ground potential one or both of them will collect the electrons.

Figure 2 shows another embodiment of the present invention using a high-current external electron gun which is not of the ion entrapment type. The gun shown in this figure is known as a Heil-gun, and is described by one Adolph Grunbaum in an article entitled, "German Wartime Research and Development in Klystrons" which is listed in the bibliography of Scientific and Industrial Reports, Vol. IV, No. 9 (February 28, 1947) as P. B. 52348. Except for the gun parts most of the elements shown in Fig. 2 are the same as the corresponding ones shown in Fig. 1 and therefore they are similarly numbered.

Like an ion-trap gun, the Heil-gun comprises a large circular concave emissive surface as shown at 50 in Fig. 2. The emission from this surface is drawn into a dense stream of small cross-sectional area through a funnel-like accelerating electrode 51 which under typical operating conditions for this gun would be above

the potential of the cathode by an amount, such as one thousand volts, which is greater than a characteristic potential difference between the cathode 10 and the grid 18 of Fig. 1. The electrons passing through the funnel-like electrode 51 do not move along straight-line convergent paths as represented at 16 in Fig. 1 but instead along convergent curved paths as at 52 and 53 in Fig. 2. For this reason there will not be as sharp a divergence of the electrons after they enter the interaction space as that which occurs past the cross-over point of an ion-trap gun. However, there will be considerable divergence due to the fact that once the electrons escape from the influence of the electrostatic field which exists between the inner surface of the cathode 50 and that of the electrode 51 their space charge will suddenly become effective to cause abrupt spreading of the beam very much as in the case of the ion-trap gun.

Due to the fact that a large axial velocity will be imparted to the electrons by a gun of this type it will often be advantageous to apply a strong negative potential to the final electrode 39. This will slow up the dense beam of electrons allowing more time for interaction and increasing the space charge by increasing the congestion of electrons within the interaction space.

In either of the embodiments shown herein, it may sometimes be advantageous to operate the anode structure at a potential which is substantially higher than the potential which corresponds to the velocity of the electron beam at the point where it enters the interaction space for the purpose of adding to the radial component of movement of the electrons. However, in magnetrons of the type shown herein this is not necessary since the space charge potential alone has sufficient energy to sustain oscillation.

If desired, the radio frequency energy produced by a magnetron of the type shown herein can be modulated by applying a modulation signal, through the use of an appropriate circuit of any known kind for combining the signal with any required direct current potential, between the cathode 10 and the grid 18; or between the anode structure 32 and ground; or between the reflector 39 and ground. The application of such a signal will usually entail both amplitude and frequency modulation either of which can be utilized or suppressed by techniques known in the magnetron art. A preferred arrangement which has the advantage of not loading the modulating source is one in which the modulating signal is applied between the reflector 39 and ground while the reflector is biased at a sufficiently negative direct current potential so that it will never be driven above the ground potential.

Inasmuch as the radial acceleration of electrons within the interaction space of a magnetron of the type shown herein is principally due to space charge it is apparent that the inclusion of a means for controlling the cathode heater current will provide a very convenient means for making adjustments required to place the magnetron into operation or to optimize its performance. For example, the cathode heater current could be varied to control the amount of space charge in order to cause the electrons in the interaction space to have the cyclotron frequency which is appropriately related to the resonant frequency of the magnetron to result in a desired type of magnetron operation. In this connection it should be noted that changes in the cath-

ode and grid potentials as well as changes in other direct current operating potentials will influence the cyclotron frequency of the electrons.

While certain specific embodiments have been illustrated and described, it will be understood that various changes and modifications may be made therein without departing from the spirit and scope of the invention.

What I claim as new is:

1. A magnetron comprising an anode having a plurality of anode segments supported in an annular row forming an interaction space between said segments about an axis, said space being open at one end providing an axial electron entrance thereto; an electron gun external to said space and mounted opposite said entrance to project a very dense beam of electrons into said space, said electron gun including a circular cathode spaced from said entrance and having a large area relative to the cross-sectional area of said interaction space for supplying a large area electron beam of relatively low density and electrostatic means forming part of the structure of said electron gun for concentrating said large area beam into a very dense beam of small cross-sectional area relative to the cross-sectional area of said space in the region of said entrance and for projecting said dense beam through said entrance into said interaction space; and means adjacent said anode for establishing an axial magnetic field within said interaction space and including magnetic material between said electron gun and said anode for shielding said electron gun from said magnetic field.

2. A magnetron as in claim 1, wherein said cathode is concave toward said entrance, to cause the electrons therefrom to tend to converge toward a common center near said entrance.

3. A magnetron as in claim 1, wherein said last-named means comprises a hollow magnetic structure of low reluctance enclosing said anode and having an orifice adjacent to said electron entrance.

4. A magnetron as in claim 3, wherein said hollow magnetic structure constitutes part of the vacuum envelope of said magnetron.

5. A magnetron as in claim 1, which further comprises means including a repeller electrode external to said space and mounted adjacent to the opposite end thereof from said entrance for retarding the electrons axially as they move through said space away from said external electron gun.

6. A magnetron as in claim 1, which further comprises means coupled to said anode for establishing an ion-sweeping electric field in said interaction space to minimize space charge neutralization therein.

7. A magnetron as in claim 1, wherein said electron beam concentrating and projecting means includes a conductive structure defining a substantially field-free ionization chamber lo-

cated between said cathode and said interaction space and having a circular electron-permeable grid on its side toward the cathode and a small orifice on its opposite side in alignment with said interaction space and adjacent to said entrance, and a low-pressure ionizable gas within said chamber adapted to be ionized by said beam to produce positive ions for neutralizing the space charge of the beam.

8. A magnetron as in claim 7, wherein said cathode and grid are segments of spherical surfaces having a common center lying on said axis near said entrance, whereby electrons will be projected into said interaction space along divergent paths beyond said common center.

9. A magnetron as in claim 7, wherein said opposite side of said ionization chamber is formed by the exterior wall of a hollow magnetic structure of low reluctance which encloses said anode and constitutes said magnetic field means.

10. A magnetron as in claim 1, wherein said cathode is concave toward said interaction space, whereby the curvature of the cathode will cause electrons emitted thereby to tend to converge to a point on said axis intermediate said cathode and said space, and a funnel-shaped accelerating-and-focusing electrode located between said point and said entrance and positioned with its wide end facing said cathode for causing said electrons to follow curved convergent paths which are concave outwardly from said axis to form a very dense electron beam along said axis and project said beam into said interaction space.

11. A magnetron comprising an anode structure formed with an interaction space about an axis; an electron gun external to said space and in proximity to one end thereof for projecting electrons along convergent paths through a sharp apex positioned on said axis at a point near to said end of said interaction space whereby the electrons after crossing over the axis at said apex are divergent within said interaction space, and means adjacent said anode for establishing an axial magnetic field through said interaction space and including means for shielding the electron gun from said magnetic field.

12. A magnetron as in claim 1, wherein said anode is insulated for direct currents with respect to said electron gun, to permit application of a different direct-current potential thereto.

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