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Kelly

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[54] **ELECTRON BEAM GENERATOR**

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[52] **U.S. Cl.** **328/228**, 313/74, 313/81, 313/231, 315/39, 315/111

[51] **Int. Cl.** **H01j 29/54**

[58] **Field of Search** 315/5.31, 39, 111; 313/74, 81, 231; 328/228

[56] **References Cited**

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[57] **ABSTRACT**

An electron beam generator in which an annular sheath of electrons is produced by an annular cathode and anode arrangement and injected in a converging manner to a focal point with a portion of the beam current returned to the center of the converging beam and through the center of the cathode annulus. Another portion of the beam current is fed back around the exterior of the converging beam.

10 Claims, 4 Drawing Figures

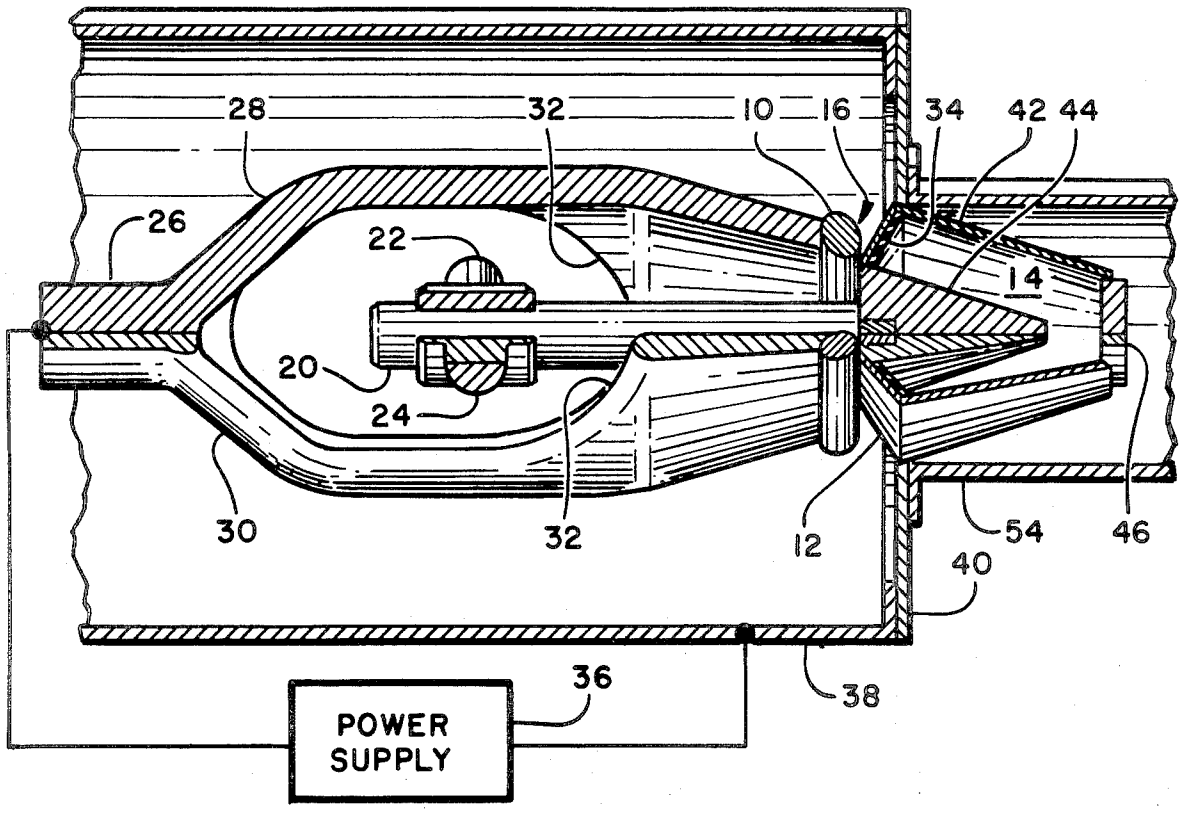


FIG. 1

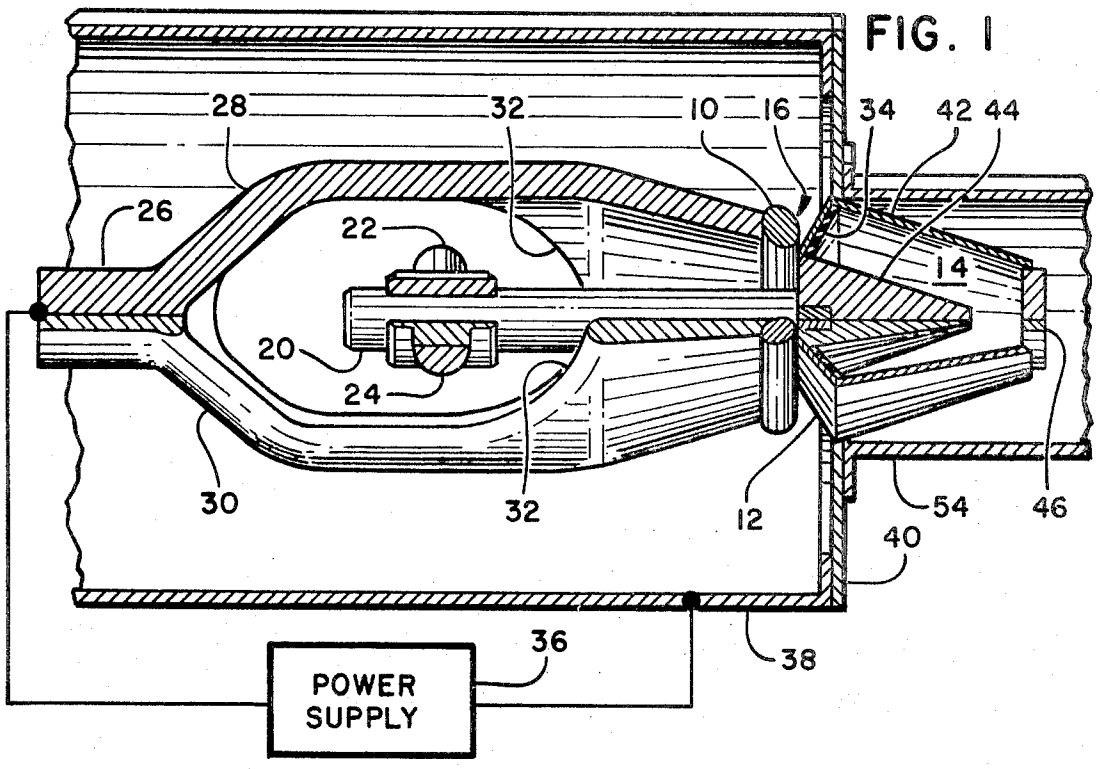


FIG. 2

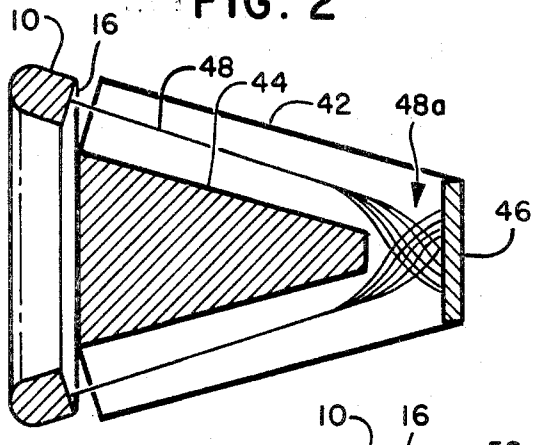


FIG. 3

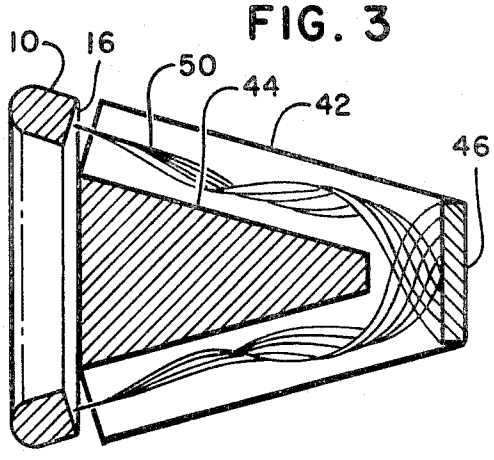
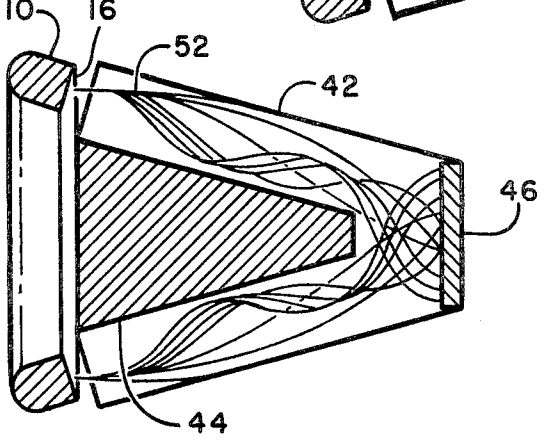


FIG. 4



ELECTRON BEAM GENERATOR

BACKGROUND OF INVENTION

High intensity electron beam generating machines are being built or developed which are capable of producing electron beams in pulses having currents of from about 100,000 to greater than 1 million amperes at voltages of from about 100,000 volts to greater than 40 million volts. Such electron beams may be used to produce high energy plasmas and other interactions with gases or other materials which may result in fusion or the like, or be used for material studies, testing of deposition of high energy in materials, production of radiation, or for similar purposes. Many of these uses require not only the production of such high power electron beams, but also that the electrons produced deposit their energy at some location in periods of 100 nanoseconds or less and that the electron beam be focused on a very small area. For example, many applications may require more than 1,000 calories of energy per square centimeter to achieve some desired results.

The production of such high energy electron beams and the focusing of them onto a small area in nanosecond time periods has been difficult to achieve due to the electromagnetic fields produced by the electron beam itself. Previous attempts to overcome these forces have only been partially successful.

SUMMARY OF INVENTION

In view of the above, it is an object of this invention to provide an electron beam generator capable of focusing a high energy beam of electrons on a relatively small area in a short period of time.

It is a further object of this invention to provide an electron beam generator which has inherent stabilizing effects on the electron beam.

Various other objects and advantages will appear from the following description of the invention, and the most novel features will be particularly pointed out hereinafter in connection with the appended claims. It will be understood that various changes in the details, materials and arrangements of the parts, which are herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art.

The invention comprises an annular cathode and conical anode for production of a beam of electrons traveling in a converging conical sheath, a converging conical channel having inner and outer conical conductive boundaries aligned with the electron beam sheath, and means for coupling current induced in the inner conical boundary through the center of the annular cathode to the anode feed line together with means for coupling the outer conical boundary also to the anode feed line, the electron beam being focused adjacent the apex of the inner boundary.

DESCRIPTION OF DRAWING

The invention is illustrated in the accompanying drawing wherein:

FIG. 1 is an elevation view, partially in cross section, of an electron beam generator incorporating the features of this invention;

FIG. 2 is a diagrammatic and somewhat simplified view of a portion of the electron beam generator of FIG. 1 showing a preferred discharge of the electron beam; and

FIGS. 3 and 4 are other simplified diagrammatic views showing typical beam discharges.

DETAILED DESCRIPTION

The electron beam generator of this invention includes an annular cathode or ring electrode 10 spaced from an annular conical anode electrode 12 to form an annular shaped diode discharge gap. Electrons may be produced by means of a diode-type discharge in this gap and injected as a hollow, conically converging sheath into an annular converging channel 14 which produces inherent stabilizing effects on the electron beam. The cathode and anode and other members of the generator may be designed and positioned to produce a high intensity, annular electron beam directed at a preferred location and angle along channel 14.

The discharge face 16 of cathode 10 may preferably be tilted or canted inwardly to insure that the desired initial electron direction of travel is in the preferred direction so as to minimize forces or momentum in directions different than the preferred direction. The face 16 of cathode 10 may be of any appropriate concave, convex or generally planar shape so long as it produces electrons having trajectories in the desired direction and of sufficient amplitude to provide the desired overall electron beam characteristics. The diameter of the cathode may be selected to insure a sufficient annular cathode discharge surface area which will provide the proper impedance match to the electron beam pulsed high voltage power supply. It has been determined that a convex cathode surface produces electrons whose trajectories are most nearly parallel to the channel 14 at the anode. Nearly parallel injection into the channel enhances its transport efficiency. The face 16 of cathode 10 may be provided with various mechanisms to increase electron emission such as by locating sharp "edges" in either an annular arrangement or in a radial arrangement. These "edges" may be formed by razor blades or other sharp ridges or the like arranged around the circumference of the cathode 10 or by separate blades arranged transversely to the discharge direction. Another convenient configuration to enhance electron emission is to provide a plurality of circumferential grooves with sharp or abrupt ridges arranged around the flat or curved surface of the face 16 of cathode 10. These grooves may provide the desired sharp electron emitting edges. In order to provide additional electron enhancement and cathode durability, the grooves may be filled with a suitable high temperature resistance insulator, such as an epoxy or other material. Other cathode surface treatments, such as by the use of electron emissive coatings, may also be used on the face 16 of cathode 10 to enhance desired electron production.

Additional control of the electron emission from a generally central band about the cathode face is achieved by a feedback arrangement described more fully below through the center of the annulus formed by annular cathode 10 along its longitudinal axis by central and radial feedback arm and supporting members 20, 22 and 24. In order to accommodate these feedback arms, the current feeding and support members for cathode 10 may be of generally hollow configuration, at least along a portion of their length, with passageways formed to accommodate the radially extending supporting members 22 and 24. The cathode support may take the form, as shown, of a central supporting member 26 having one or more generally U or

Y shaped supporting arms 28 and 30 disposed at locations sufficiently separated from supporting arms 20, 22 and 24 to prevent electrical discharge therebetween. Each of these supporting arms 28 and 30 may be provided with flared and converging portions 32 closing around and behind cathode 10 which act to disperse and distribute the current flowing through arms 28 and 30 uniformly to all portions of cathode 10 to aid in minimizing irregularities in the electron emission around the various portions of cathode 10. Cathode 10 may be an integral part of arms 28 and 30 and flared portions 32 or be appropriately attached as a separately formed member around its periphery to the cathode support. Because of the unique feedback current features of central supporting arm 20, the spacing between feedback arms 20, 22 and 24 and adjacent portions of cathode 10 as well as the cathode supporting arms 28 and 30 in the region of compensating feedback magnetic fields (generally to the right of arms 22 and 24 in FIG. 1 may be significantly less than the space between supporting arms 20, 22 and 24 and the cathode support arms 28 and 30 outside these regions (namely to the left of arms 22 and 24 as viewed in FIG. 1). The surfaces of the cathode support and the feedback support arms may be finished to a high polish to minimize electron emission and the occurrences of extraneous arcs between the respective members.

The anode 12 functions to form an initial diode discharge with cathode 10 and may then be vaporized and essentially destroyed by this discharge when the electrons in the discharge reach the anode. Thus, anode 12 may be a thin foil or film on a supportive insulative layer 34, both of which are shown with exaggerated thickness in FIG. 1. For example, anode 12 may be made of aluminum, titanium or some other suitable electrical conductor about 10^{-4} to 10^{-3} inch thick while insulator 34 is made from polyethylene terephthalate or other suitable plastic or high strength, flexible supporting material which will not adversely scatter the electron beam and may typically be about 0.25 $\times 10^{-3}$ to 10^{-3} inch thick. The anode 12 and its supporting layer 34 may be formed in the shape of a frustum of a cone so as to be perpendicular to the direction of electron trajectories emitted from cathode 10. The anode 12 and layer 34 may be supported in any convenient manner at the desired location and cone angle, such as about their peripheries with or without additional supporting arms or vanes. The spacing between anode 12 and cathode 10 should be adjusted to best satisfy the diode impedance and electron trajectory requirements as long as a sufficient gap remains to permit generation of electron currents before the plasmas inherently produced at the cathode and anode surfaces meet and short out the diode discharge. The anode function may be performed after its vaporization, and in some devices solely, by the fields produced by the cone elements described below.

The diode discharge may be produced by connecting an appropriate power supply 36, which is capable of producing a voltage pulse of amplitude and duration to initiate and sustain the diode discharge and desired electron beam currents, between the cathode supporting member 26 and a coaxially disposed outer wall 38 and anode supporting end wall 40 of the diode, the latter being connected electrically to anode 12. Such power supplies may typically include high energy capacitive storage system with controlled discharge through a pulse forming network or the like. The transmission line impedance formed by cathode support member 26 and wall 38 should be selected so as to provide a desired impedance match with the power supply 36 to insure production of the appropriate power pulse. Feedback arms 22 and 24 may be mechanically and electrically connected to the inner surface of wall 38 in any convenient manner, such as by welding or mechanical fasteners, to provide support of the feedback arrangement and electrical coupling therewith.

The converging annular channel 14 may be formed from the inner surface of a hollow conducting cone electrode 42 and the outer surface of a conducting cone electrode 44 centrally and coaxially disposed within cone 42. Outer cone 42 may be in the form of a screen or solid member having an appropriate current conducting capacity and cone angle. Cone 44 may also be either hollow or solid and may have a cone angle, the angle between the cone axis and cone surface, the same as or similar to that of cone 42. The angles chosen may depend upon the desired beam sheat diameter, length of beam travel and beam focusing characteristics and may even approach angles of 0° and 90°. For purpose of illustration an angle of about 20° is shown which is desirable in some applications. The respective inner and outer surfaces of cones 42 and 44 provide a conductive boundary for channel 14 and effectively form two parallel inductances, one between the electron beam and the outer conductor 42 boundary and one between the electron beam and the inner conductor 44 boundary, and also form an essentially concentric, triaxial conductor configuration with the electron beam. Feedback currents may be induced in the cones 42 and 44 as a result of the electron beam and they travel in a direction opposite to that of the electron beam with amplitudes dependent upon the relative inductances and resistances of the respective conductors and beam path. With such an an arrangement, if the beam wanders near or deflects towards the inner conductor, the inner inductance will be reduced and more current induced on the surface of cone 44 increasing the magnetic field produced thereat to exert an outward force on the beam. Similarly, if the beam wanders outwardly, an inward force may be developed against the beam from magnetic fields produced by the induced currents in cone 42. It has been found that the magnetic fields may be balanced at a radius equal to the square root of the product of the radii of cones 42 and 44 at all locations along channel 14 along the loci formed therewith. At this beam radius, the feedback or return currents on both return paths are about equal to the beam current divided in half. Thus, the effective magnetic forces produced by the feedback currents tend to keep the electron beam between the conductors along this loci.

A conductive feedback path may be provided between cone 42, anode 12 and wall 38 by appropriate mounting brackets or fixtures (not shown) while a feedback path, and also its mechanical support, is provided for cone 44 by central feedback and supporting arm 20 and radial arms 22 and 24. If desired, additional current flow control and mechanical support of the respective cones may be provided by suitable vanes or other members disposed between the ends of the cones, however, with some detrimental effects on the electron beam since such supporting members will be in the path of the beam. The anode 12 is shown electrically

connected between cone electrodes 42 and 44 and as such also acts to distribute the return or feedback currents in the respective cones 42 and 44.

A suitable target or other utilization device 46 against which the electron beam may be impinged may be positioned beyond the end of cone 44 and be supported by, or mounted on cone 42. Target 46 may also form a part of the feedback path for feedback currents.

The magnetic fields produced by the respective feedback currents and beam currents may be essentially cancelled at the above referred to radius and provide stabilizing fields for minimizing oscillations of the beam toward either of the cones 42 or 44. Thus, when the electron beam is emitted by cathode 10 and directed by anode 12 along the prescribed radius the resulting beam may travel along channel 14 in a relatively stable manner following the desired radii loci converging towards target 46, such as shown by beam 48 in FIG. 2. When beam 48 reaches the end of cone 44, beam 48 may be pinched by its own inherent magnetic fields to a focal point dependent upon these fields and the trajectories and angular momentums of the respective electrons as they reach the end of cone 44. The closer the electrons in the beam 48 remain to the equilibrium radius shown in FIG. 2, the greater the concentration that may be achieved. Spreading of the electron beam near the end of channel 14, as indicated at 48*a*, may result from a changing diode voltage and current during the pulse. Additional reduction of the focal point movement may be achieved by flaring the outer cone 42 in a continuously expanding curve or bell-like shape at a position beyond the end of inner cone 44 and moving the target 46 to the end of the flare. FIG. 3 illustrates the case where the beam 50 is injected at an angle initially parallel to the converging prescribed radius but at a radius greater than the prescribed radius. The respective curves making up the entire beam 50, like that of FIG. 2, and their differing oscillating frequencies result from the different amplitudes of current of the beam at different points in time during the pulse. FIG. 4 illustrates the case where the beam 52 is injected at other than the optimum angle and radius. Portions of the beam may strike and be lost to either of the cones with the focal region being more diffuse. These figures illustrate the importance of proper selection of beam injection radius and direction to achieve maximum beam concentration.

The diode gap between cathode 10 and anode 12 is preferably evacuated to pressures from about 10^{-3} to 10^{-5} Torr in order to insure reproducibility while the channel 14 is evacuated to an air or gas pressure of from about 10^{-1} to 20 Torr. Cones 42 and 44 may be enclosed within an appropriate drift tube 54 to maintain this pressure. The cone channel can be further divided into sections at different pressures to control the electron trajectories by changing the plasma current. The ionized gas in the channel also neutralizes the space charge field of the beam. Too high a pressure in channel 14 may cause scattering of the beam while too low a pressure may not produce enought plasma current to achieve space charge neutralization. At some point in time during the current rise of the beam during the diode discharge, the plasma will usually break down in channel 14 producing a very sudden and high plasma conductivity and essentially "freeze" the magnetic field lines at their position at the plasma breakdown. The trajectory path of the electron beam may thus be frozen along the trajectory at which the breakdown occurs. The plasma produced in channel 14 acts as a conductive path for the electron beam to provide the desired feedback currents between the respective cones and the beam described above.

As the feedback current return along central supporting arm 20 through cathode 10, the magnetic fields produced by this feedback current may also reduce the electron emission from inner edge of the cathode face 16 so as to provide a continued electron beam having initial trajectories in the desired direction along the prescribed converging radii, all effects produced by the respective elements of the generator thus coacting to increase and improve the beam size and shape. These fields also provide the compensating fields referred to above which act to prevent discharges between adjoining portions of the cathode and cathode support and the feedback arms.

The cathode and anode arrangement provides an initial converging electron injection into the channel from a relatively large cathode surface area with the thereafter resulting feedback of current through the cathode annulus providing inherent stability to the space charged neutralized beam and the cathode discharge. The usual inherent pinching toward the axis of an electron beam is also prevented by this current feedback until the beam reaches the end of the inner cone, at which point this inherent pinch may be utilized to focus the final beam against some utilization device or target. The pinched or otherwise focused beam may then be impinged directly on the target or carried to a remote position for impingement.

The ions produced at the cathode and anode by the diode discharge and the ions and other debris resulting from the destruction of the anode 12 when the beam of high intensity electrons impinges thereagainst may also travel along the tube or channel but at a lower rate of speed because of the ion's higher mass so as to permit the utilization of the electron beam before the ions can reach the target. If the target is removed from the immediate end of cones 42 and 44, the ions can be made to impinge against the walls of the outer cone 42 and not interfere with the mechanisms occurring at the target.

The respective materials utilized in the electron beam generator should be selected so as to provide necessary high strength and temperature and electron beam resistance. Generally, the cathode and wall members and other supporting members are made of steel or brass.

What is claimed is:

1. An electron beam generator comprising an annular cathode; a hollow conical electrode coaxially disposed along a longitudinal axis through the central opening of said cathode and converging away from said cathode; a coaxial electrode disposed at least partially within and having a conical outer surface spaced from said hollow conical electrode and forming therewith an annular channel adjacent to said cathode; an annular anode disposed between said cathode and said annular channel; first means for electrically coupling said anode to said hollow conical electrode; second means partially on the longitudinal axis of said annular cathode passing through said opening thereof to said coaxial electrode for electrically coupling said anode to said coaxial electrode; and third means for coupling a cath-

ode bias to said cathode spaced from said second coupling means and an anode bias to said anode.

2. The generator of claim 1 including a target disposed adjacent the apex of the conical surface of said coaxial electrode.

3. The generator of claim 1 wherein the conical surface of said coaxial electrode has a cone angle about the same as the cone angle of said hollow conical electrode.

4. The generator of claim 1 wherein said anode is in the form of a frustum of a cone.

5. The generator of claim 4 wherein said anode is a metal foil.

6. The generator of claim 4 wherein said anode is disposed perpendicular to the loci formed from the square root of the product of the radii of said hollow conical electrode and the conical surface of said coaxial electrode at each position along said converging channel.

7. The generator of claim 6 wherein the center of said cathode is disposed aligned with said formed loci.

8. The generator of claim 1 wherein said third coupling means includes a coaxial transmission line having an outer conductor coupled to said anode and a central conductor coupled to said cathode.

9. The generator of claim 8 wherein said second coupling means includes a conductive member on the longitudinal axis of said annular cathode passing through the central opening of said annular cathode to said coaxial electrode and with radially extending arms connected from said conductive member to the outer coaxial transmission line conductor coupling to said anode.

10. The generator of claim 9 wherein said third coupling means also includes a generally U-shaped yoke connected between the center conductor of said coaxial transmission line and disposed perpendicular to said radial arms with a conductive flared portion connected to said annular cathode.

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