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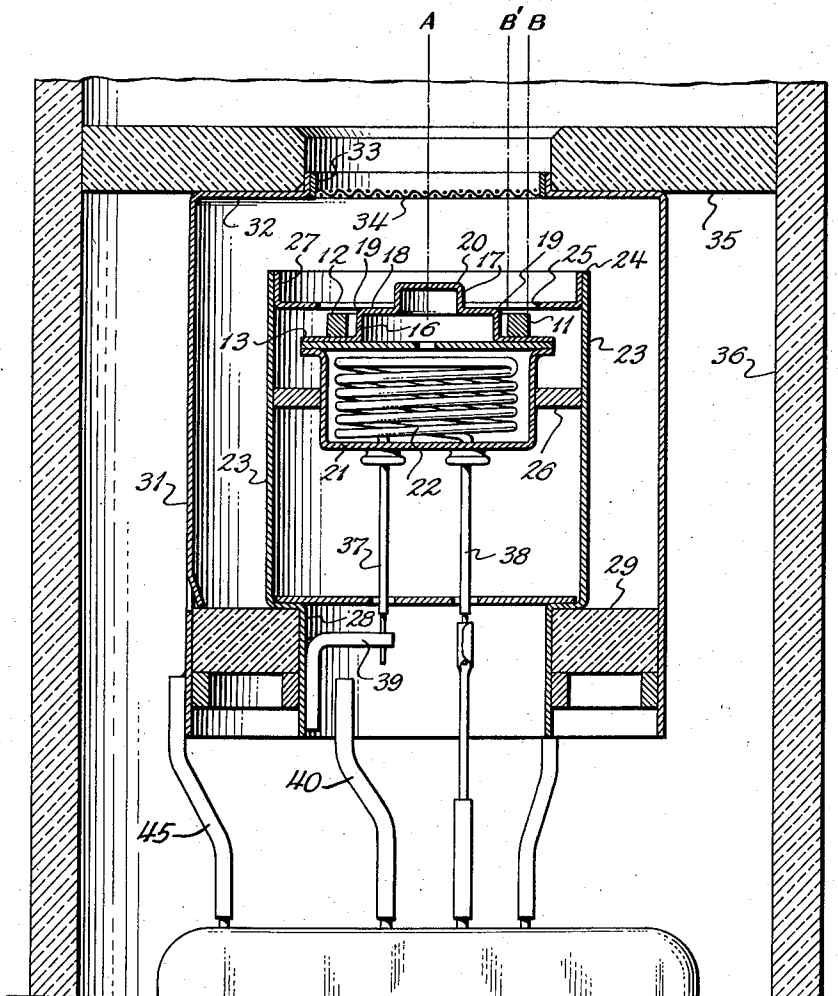


Fig. 1.

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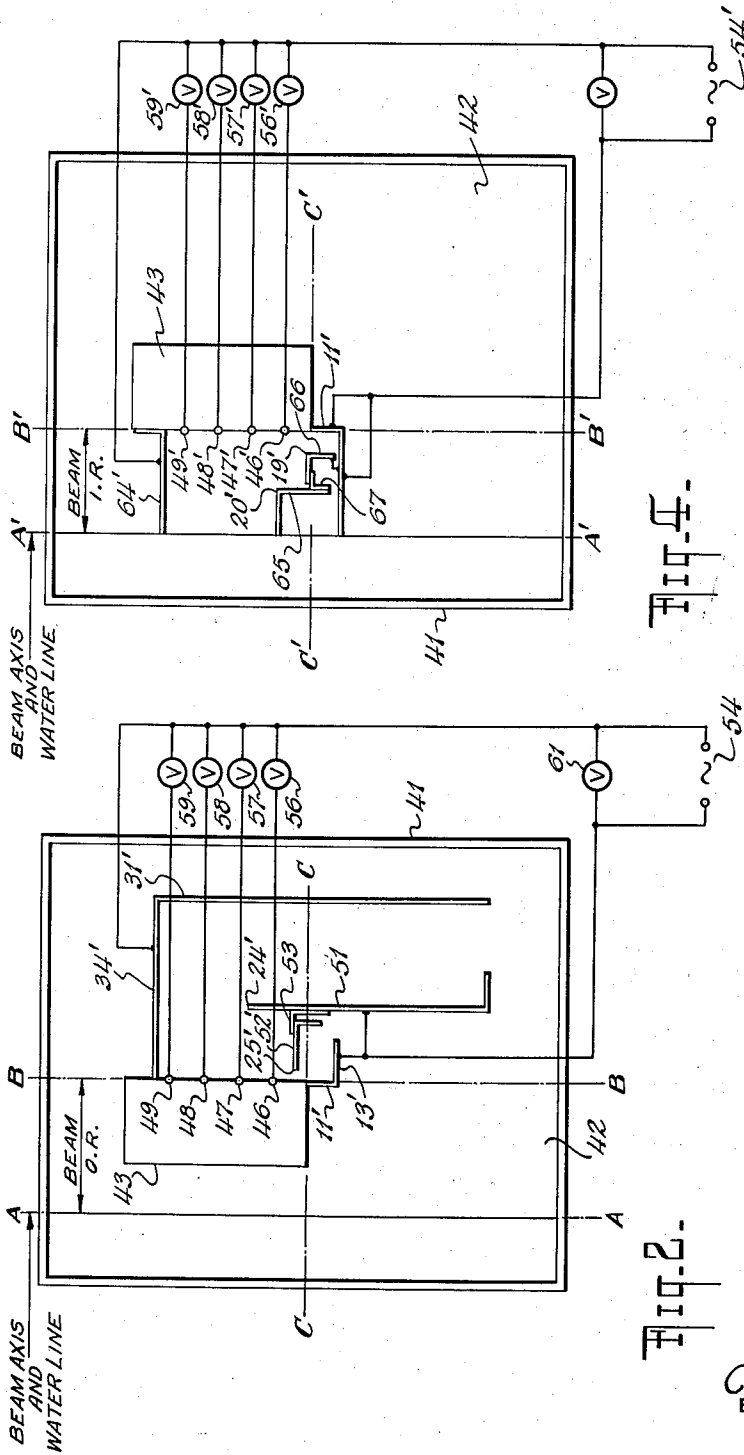
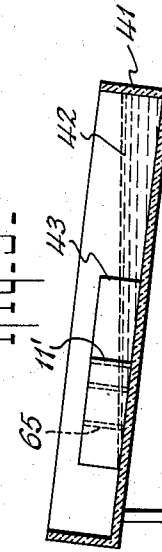
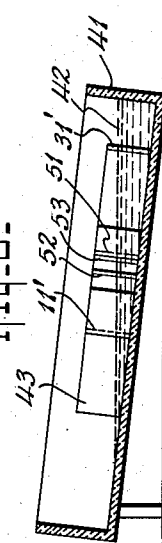


Fig. 2-

Fig. 4-

Fig. 3-

Fig. 5-



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ELECTRON GUN FOR TUBULAR BEAM

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4 Claims. (Cl. 313—82)

The present invention relates to an electron gun for providing a tubular beam of electrons.

In U. S. Patent 2,564,743, issued August 21, 1951, to the present inventor, a practical electrostatic beam forming electrode system along with certain formulae for the design thereof is disclosed for providing a solid electron beam. A modification of the electrode system shown in Fig. 1 of the patent for a solid beam is also proposed for providing a hollow cylindrical convergent beam of electrons. Although the disclosure and formulae for the location of the beam forming electrodes of a solid beam are applicable to the outer beam forming electrodes of a tubular beam, it has been found that the inner beam forming electrodes for a tubular beam must be located and designed in a different manner as the required equipotential field lines inside a tubular beam for maintaining rectilinear electron motion are not symmetrical with those required outside the beam for maintaining linear electron flow.

Therefore, it is an object of the present invention to provide an improved electron gun and beam forming assembly for producing a tubular beam of electrons.

It is another object of the invention to provide such an assembly for providing a parallel-flow cylindrically-tubular beam of electrons.

It is another object of this invention to provide an electron gun assembly as aforescribed which includes a circular anode aperture of substantially uniform electron permeability through any sector thereof.

It is yet a further object of the invention to provide an electron gun assembly as aforescribed which is easily fabricated and readily reproducible.

All of the foregoing and other objects and advantages of the present invention are attained by providing an annular cathode for emitting a stream of electrons, an anode having a circular aperture of substantially uniform electron permeability through any sector thereof and a diameter slightly larger than the outer diameter of the cathode for receiving the electron stream, and a plurality of inner and outer circular edge electrodes disposed within a region between the cathode and anode for forming the electron beam into a required shape. The edge electrodes comprise coaxial ring-like terminations of right cylindrical tubular supporting surfaces and/or coaxial ring-like edges of apertures through circular disc-like supporting surfaces for easy fabrication and positioning. There are two or more outer edge electrodes at the same potential disposed about the tubular beam at spaced regions therealong for establishing required equipotential fields external of the beam for parallel electron flow of the outer beam electrons with one or more edge electrodes being at the same potential being disposed inside the tubular beam for establishing required equipotential fields internal of the beam for parallel electron flow of the inner beam electrons. The proper sizes and positions of the outer edge electrodes are determined from those of similar electrodes for maintaining a solid parallel-flow

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cylindrical electron beam of the same diameter as the outer diameter of said tubular beam and similar electrical characteristics as said tubular beam. The proper sizes and positions of the inner edge electrodes are determined from those of similar electrode means for maintaining a cylindrical electron beam of similar electrical characteristics as said tubular beam and an infinite cross-section so as to have a cylindrical aperture of constant diameter therethrough of the same diameter as the inner diameter of said tubular beam.

Referring to the drawings,

Fig. 1 is a longitudinal sectional view of an electron gun assembly designed in accordance with the present invention;

Fig. 2 is a plan view of an electrolytic tank for determining the sizes and locations of the outer beam forming edge electrodes of the device shown in Fig. 1;

Fig. 3 is cross-sectional end view of the tank in Fig. 2;

Fig. 4 is a plan view of an electrolytic tank for determining the sizes and locations of the inner beam forming edge electrodes of the device shown in Fig. 1, and

Fig. 5 is a cross-sectional end view of the tank in Fig. 4.

Referring to Fig. 1, the numeral 11 represents a cathode ring having an electron emissive surface 12 in a plane perpendicular to the longitudinal axis of the illustrated structure. The ring 11 is coaxially supported upon an end flange 13 of a hollow metallic member having first and second coaxial right cylindrical surface portions 16 and 17 joined by a flange portion 18 in a plane at right angles with the axis of the structure. Ring-like edges 19 and 20 are located at respective end planes of the aforementioned cylindrical surfaces 16 and 17 at right angles with the axis of the structure and at different distances from the cathode 11 for comprising coaxial inner beam forming electrodes. The diameters and spacings of edges 19 and 20 relative to the face 12 of the cathode are determined in accordance with a procedure which will be described further below.

The aforementioned assembly comprising cathode 11 and the inner beam forming electrodes or edges 19 and 20 is coaxially supported along the axis of the illustrated structure by flange 13 affixed to a metallic heat shield or cup 21 enclosing and supporting a cathode heater coil 22. The cup 21 is coaxially supported within a right circular metallic cylinder 23 by an annular metallic member 26 whose aperture receives the heat shield 21.

The cylinder 23 extends beyond the plane of cathode 12 with a ring-like edge 24 being defined at its upper end in a plane at right angles with the axis of the structure for providing a further beam forming electrode outside the beam. Another outer beam forming electrode of lesser diameter is formed by the edge of a coaxial aperture 25 through an inwardly extending apertured metallic disc-like or flange portion comprising a right angle termination of a right cylindrical conductive portion 27 supported by cylinder 23. The plane of the edge electrode 25 is at right angles with the axis of the structure at a different distance from the cathode 12 than edge electrode 24. The ring-like edges 24 and 25 comprise outer beam forming electrodes having diameters and spacings relative to the cathode face 12 which are determined in a manner which will also be described further below.

An extension 28 of cylinder 23 is coaxially supported by an annular insulator 29 within an outer metallic cylinder 31 provided with an inwardly extending apertured flange portion 32 for coaxially supporting an anode ring 33 in proper spaced relationship from the cathode of the electron gun. The flange portion 32 is in a plane at right

angles with the axis of the structure with the anode ring 33 comprising a circular anode aperture and supporting means for a wire mesh grid element 34 so that an anode having a plane face opposite the cathode 11 is formed. The electron permeability of the anode through the anode ring 33 and the grid 34 is substantially uniform for any sector of the circular aperture through ring 33. An annular insulator 35 affixed to the flange 32 of cylinder 31 supports the entire electron gun assembly within a tubular vacuum envelope, a section of such an envelope being designated by numeral 36.

First and second insulated leads 37 and 38 are connected to the ends of the heater coil 22 for supplying it with a heater voltage. One end of lead 38 should be connected directly to one terminal of an external source of heater voltage, not shown, while the end of lead 37 is connected by conductor means 39 to the metallic cylindrical extension 28 of cylinder 23. A further lead 40 connected to cylinder 28 is provided for connection to a grounded terminal of the aforementioned heater voltage supply means, not shown.

The annular metallic member 26 connects the heat shield 21 and cathode 11 to the cylinder 23 for connection through cylinders 23 and 28 to the grounded lead 41. Thus, the cathode 11 and the beam forming electrode edges 19 and 20 are at ground potential or at any other potential which may be applied to lead 41. Since the electrode edges 24 and 25 are supported by cylinder 23, they are also at ground potential, all of the edges 19, 20, 24 and 25 being heat-insulated from the cathode 11 and heater coil 22. A lead 45 is connected to the anode supporting cylinder 31 for supplying the anodes 32—34 with a proper positive potential relative to cathode 12.

In operation of the electron gun assembly shown in Fig. 1, when the heater coil 22 is energized and a predetermined beam voltage is supplied between the anode 32—34 and cathode 11, a tubular beam of electrons is emitted from the cathode surface 12 for flow toward the anode. The cathode 11 should be operated space-charge limited and have a uniform current emission density of predetermined value.

The inner electrode edges 19 and 20 are of required diameters and location between the cathode 11 and anode 33 so that, with a predetermined beam voltage and spacing between the adjacent planes of the cathode and anode surfaces, the electrodes 19 and 20 establish equipotential conditions inside the tubular beam for creating a potential variation along the inner edge of the beam which follows a four-thirds power of distance between the planes of the anode and cathode. More specifically, the Child-Langmuir space charge law of $V=5680 J^{2/3} X^{4/3}$ for a parallel-flow cylindrical beam is satisfied by proper design of the edges 19 and 20. In the above equation, V is the potential in volts along the edge of the beam at any position X centimeters from the plane of the cathode 12, J designating the current density of the beam in amperes/cm.².

Similarly, the outer electrode edges 24 and 25 have proper diameters and spacings relative to the cathode for effecting conditions along the outer edge of the tubular beam so that the potential along the beam also follows the aforementioned Child-Langmuir space charge law for a parallel-flow cylindrical beam. It has been found that the external and internal equipotential field lines extending from the outer and inner beam edges of a beam as aforesaid are not of the same configuration, i. e., are not symmetrical with the beam so that inner and outer edges 20 and 24 cannot lie in the same plane and be spaced from the beam by equal increments at the same time. To a lesser extent, the same is true for the inner and outer edges 19 and 25.

The particular design and dimensions of the elements of the gun structure shown in Fig. 1 other than the diameters of the ring-like electrode edges 19, 20, 24 and 25 and their relationship with the plane of cathode emissive surface 12 are readily preselected in accordance with

mechanical requirements and the dimensions and current density of the parallel-flow cylindrically tubular beam desired to be produced with a preselected beam voltage. The spacing between the planes of cathode 11 and anode 34 is determined from the Child-Langmuir space charge law for a solid electron beam of constant circular cross-section and rectilinear parallel flow between a pair of aligned equipotential cathode and anode surfaces stating that:

$$J = \frac{2.335 \times 10^{-6} V_{a-c}^{3/2}}{X_{a-c}^2}$$

where J is the current density in amperes/cm.², V_{a-c} is the anode-cathode voltage, and X_{a-c} is the anode-cathode separation in cm. (centimeters).

The proper diameters or radii of the electrode edges 19, 20, 24 and 25 and their spacings between the cathode and anode of the electron gun are best determined by use of an electrolytic tank as shown in Figs. 2—5. The tank comprises a non-conducting tray 41 partially filled with an electrolyte 42 such as water, the tray 41 being tilted by a small angle about one of its edges.

In designing a gun as shown in Fig. 1, the electrolytic tank is first employed for simulating a solid electron beam having a radius corresponding to a selected outer radius of the desired parallel-flow cylindrically-tubular beam. This is done by placing a rectangular insulator block 43 in the tray 41 so that the length of block 43 is parallel with the water line A—A at the bottom of the tank. The line A—A represents the axis of the solid beam. A line B—B along a further water line or intersection of the water with the side of the block 43 farthest from line A—A is spaced from line A—A by a distance corresponding to the radius of the solid beam to be simulated. A line C—C represents the cathode plane for the beam. Probes 46—49 are recessed in block 43 at various positions therealong so as to protrude into the water along line B—B for reasons which will be described further below.

Two rectangular strip-like conductors 11' and 13' joined to form a right angle are inserted into the water at one end of the insulator 43 for representing the outer annular edge of the cathode 11 and the outward extension of flange support 13 therefrom, respectively, of the gun shown in Fig. 1. A further rectangular strip conductor 31' joined at right angles with another rectangular strip conductor 34' is also placed in the tank. Conductor 34' is at right angles with the line B—B and is in abutment with one side of insulator 43, and represents the anode plane of the gun in Fig. 1 defined by elements 32—34. Conductor 31' represents the cylinder 31 in the gun of Fig. 1, being parallel with line A—A and spaced therefrom by a distance corresponding to a preselected radius for cylinder 31.

The conductor 34' is spaced from the end of strip conductor 11' abutting the block 43 by a distance corresponding to the distance between the anode-cathode planes of the gun in Fig. 1. The dimensions and spacings of all the tank elements may be larger by any predetermined multiple than the dimensions and spacings of the elements of the actual gun to be constructed.

Knowing the cathode-anode spacing, the percentage of this spacing for the distance of each of probes 46—49 from the cathode 11' at the line C—C in Fig. 2 is computed, these distances being arbitrarily selected. Next, it is determined from the Child-Langmuir space charge equation $V=5680 J^{2/3} X^{4/3}$ what percentage of the total cathode to anode potential should exist at each of the probes 46—49 positioned along the insulator 43 for satisfying the aforementioned equation for a parallel-flow cylindrical beam. Then, two L-shaped strip conductors 51 and 52 are inserted into the electrolytic tank as shown in Fig. 2 with ends 24' and 25' of the aforementioned conductors 51 and 52 respectively, corresponding to the beam forming edges 24 and 25 in the device of Fig. 1.

The conductors 51 and 52 are electrically connected

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together through a further L shaped shielding conductor 53, conductors 51—53 being connected to the cathode element 11' so as to be at the same potential. Conductors 51 and 52 are adapted to be moved about in the tank relative to each other so that the edges 24' and 25' can have different spacings relative to line C—C representing a cathode plane and the line B—B representing the beam edge. The longer side of conductor 51 and the shorter side of conductor 52 as illustrated in Fig. 2 should always remain parallel with line B—B.

A source of alternating voltage is connected between the anode simulating electrode 34' and the cathode simulating electrode 11'. The positions of the conductors 51 and 52 and edges 24' and 25' are then adjusted relative to each other and the lines B—B, C—C until the voltages at the probes 46—49 as determined by voltmeters 56—59 substantially correspond in percentage of the total voltage applied between electrodes 11' and 34' as determined by a voltmeter 61 to those percentages determined from the above-mentioned Child-Langmuir equation for a parallel-flow beam. Thus, the proper locations for the beam forming edges 24' and 25' are determined so that, if the radii of the outer beam forming edges 24 and 25 of the gun shown in Fig. 1 are designed to correspond with the spacings of edges 24' and 25' from the line A—A in the tank, and the distances of the gun edge electrodes 24 and 25 from the plane of cathode emissive surface 12 correspond to the spacings of electrode edges 24' and 25' from line C—C in the tank, the outer electrons of the beam produced thereby will not diverge to any appreciable extent from the axis thereof when travelling from the cathode to the anode.

Next the tank is used again as shown in Fig. 4 for determining the proper positions of the inner beam forming edges 19 and 20 of the gun in Fig. 1. This is done generally in the same way as mentioned before except that the edge of the insulator 43 nearest line A'—A' is spaced therefrom along a line B'—B' representing the inner edge of an aperture of a beam of infinite cross-section, the aforementioned spacing corresponding to the inner radius of the beam desired to be produced by the gun of Fig. 1. A portion of the cathode strip 11' as shown in Fig. 4 is made to correspond with this insulator edge and represents the inner annular surface of the cathode 11 in Fig. 1, a line C'—C' orthogonal with the upper end of strip 11' representing a cathode plane. A portion of an L-shaped strip conductor 64' simulates the anode plane comprising grid element 34 in the gun of Fig. 1, being spaced from the cathode plane by a distance corresponding to the anode cathode spacing in the gun of Fig. 1. Two L-shaped conductors 65 and 66 having edges 19' and 20', respectively, are inserted into the tank as shown in Fig. 4 so that the edges 19' and 20' thereof correspond to the inner beam forming edges 19 and 20 of the gun structure in Fig. 1.

An L-shaped shielding conductor 67 connects conductors 65 and 66 together, conductor 66 being connected to the cathode simulating conductor 11' so that all of these conductors are at the same potential. The positions of the edges 19' and 20' are then adjusted relative to the lines A'—A' and C'—C' until the voltages read on the volt meters 56' and 59' are required percentages of the total voltage applied between conductors 11' and 32' by source 54' as determined from the Child-Langmuir space charge voltage law mentioned above. When employing the electrolytic tank for determining the inner beam forming edges, a beam of infinite cross-section having an inner aperture of the same diameter as inner diameter of the tubular beam is assumed. When the proper potentials are attained in the set up in Fig. 4, the radii of the inner electrode edges 19 and 20 and their spacings from the plane of the cathode of the gun shown in Fig. 1 can be designed therefrom in accordance with the spacings of edges 19', 20' from the lines A'—A' and C'—C' in Fig. 4. Thus, the proper positions of the inner and outer

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electrode edges 19', 20' and 24', 25' are separately determined from the use of the electrolytic tank as shown in Figs. 2 and 4, the results being added together to obtain the beam forming structure as shown in Fig. 1.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An electron gun comprising a cathode having a planar emitting surface, electrostatic beam forming means and an anode for producing a parallel-flow cylindrically-tubular electron beam of predetermined inner and outer diameters between said cathode and said anode, said electrostatic beam forming means including outer beam forming electrode means disposed about said beam in coaxial relationship with said axis, said outer electrode means comprising first and second ring-like edges of different diameters in different planes between said anode and cathode at right angles with said axis, said first and second edges being electrically insulated from said anode, the diameters and spacings of said edges from said cathode being predetermined for location of said edges along an outer equipotential region external of said beam established for a solid parallel-flow cylindrical beam having similar electrical characteristics with said tubular beam and a diameter corresponding to the outer diameter of said tubular beam, said electrostatic beam forming means further including inner beam forming electrode means including a third ring-like edge of predetermined diameter less than the inner diameter of said beam in a plane between said anode and cathode at right angles with said axis and spaced by a predetermined distance from said cathode which is less than the spacing of said first and second ring-like edges from said cathode, the diameter and spacing of said third ring-like edge from said cathode being predetermined for location of said third edge along an inner equipotential region established for a parallel-flow cylindrical beam of similar electrical characteristics as said tubular beam and an infinite cross-section with an aperture of the same diameter as the inner diameter of said tubular beam.

2. An electron gun as set forth in claim 1, wherein said inner beam forming means further includes a fourth ring-like edge coaxial with said axis in a plane between said anode and said third ring-like edge, said fourth edge having a smaller diameter than said third edge and being located along said inner equipotential region, said fourth edge being spaced from said cathode by a distance which is less than the spacing of said second edge from said cathode, all of said ring-like edges being electrically connected together.

3. An electron gun for producing a parallel-flow cylindrically-tubular electron beam, comprising a metallic cylinder, an anode formed by a planar conductive member connected to said cylinder and extending radially inward thereof at right angles with the axis of said cylinder to form an anode plane for said electron gun, said conductive member having an anode opening there-through in coaxial relationship with the axis of said cylinder for passage of said beam through said anode plane, a cathode ring having inner and outer circular edges in a plane spaced from said anode plane, inner and outer electrostatic beam forming means coaxially supported relative to said cathode ring, means coaxially supporting said cathode ring and said beam forming means within said cylinder in insulated relationship from said anode, said outer beam forming means comprising a first metallic surface conformal with a plane at right angles with the axis of said beam, said first surface facing said anode plane and having a cylindrical aperture of diameter larger than the outer diameter of said cathode ring for passage of said beam therethrough, the edge of said first surface

conformal with said aperture defining a first ring-like edge electrode, a second metallic surface conformal with a right circular cylinder coaxial with the axis of said beam, said second surface having an end termination in a plane at right angles with the axis of said beam between said first surface and said anode plane, said end termination of said second surface defining a second ring-like edge electrode, the diameter and spacing of said second edge electrode from the outer circular edge of said cathode ring being respectively larger than the diameter and spacing of said first edge electrode from the outer circular edge of said cathode ring, said first and second ring-like edge electrodes being connected to each other for operation at the same potential for establishing an outer equipotential field externally of said beam for maintaining the outer diameter of said beam substantially constant from said cathode ring to said anode plane, said inner beam forming means comprising a further metallic surface conformal with a right circular cylinder coaxial with the axis of said beam, and of smaller diameter than the diameter of the inner circular edge of said cathode ring, said further surface having an end termination in a plane at right angles with the axis of said beam between said second ring-like edge electrode and said anode plane, said end termination of said further surface de-

fining a further ring-like edge electrode having a different spacing from the inner circular edge of said cathode ring than the spacing of said second ring-like edge electrode from the outer circular edge of said cathode ring, said further ring-like edge electrode comprising means for establishing an inner equipotential field within said beam of different configuration from said outer equipotential field for maintaining the inner diameter of said beam substantially constant from said cathode ring to said anode plane.

4. An electron gun as set forth in claim 3, further including means connecting said first, second and further edge electrodes to said cathode ring for operation at the same potential.

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