Aug. 21, 1951 C. C. WANG 2,564,743

CHARGED PARTICLE BEAM FORMING APPARATUS

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Fig. 1.

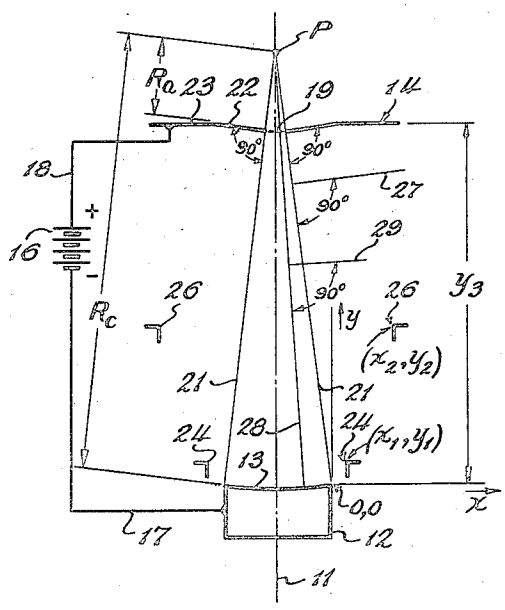
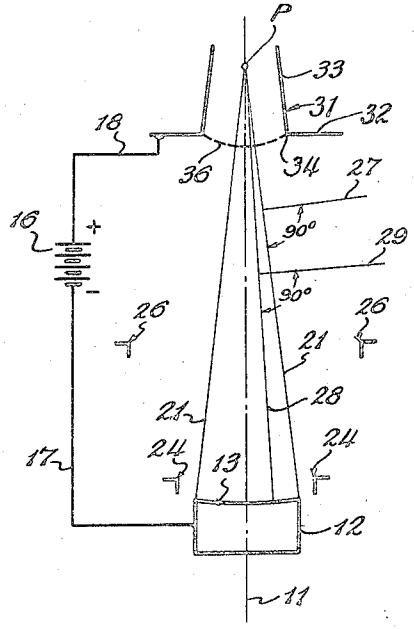


Fig. 2.



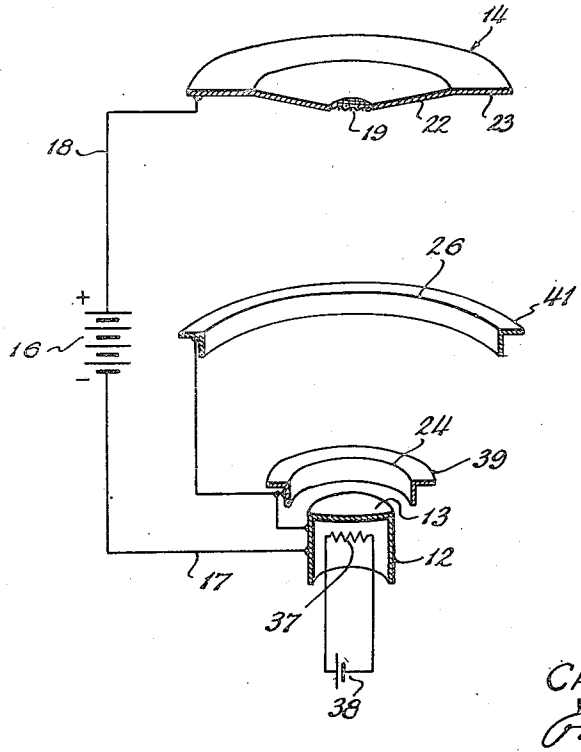


Fig. 3.

INVENTOR
CHAO C. WANG
BY
Paul B. Hunter
ATTORNEY

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Fig. 4.

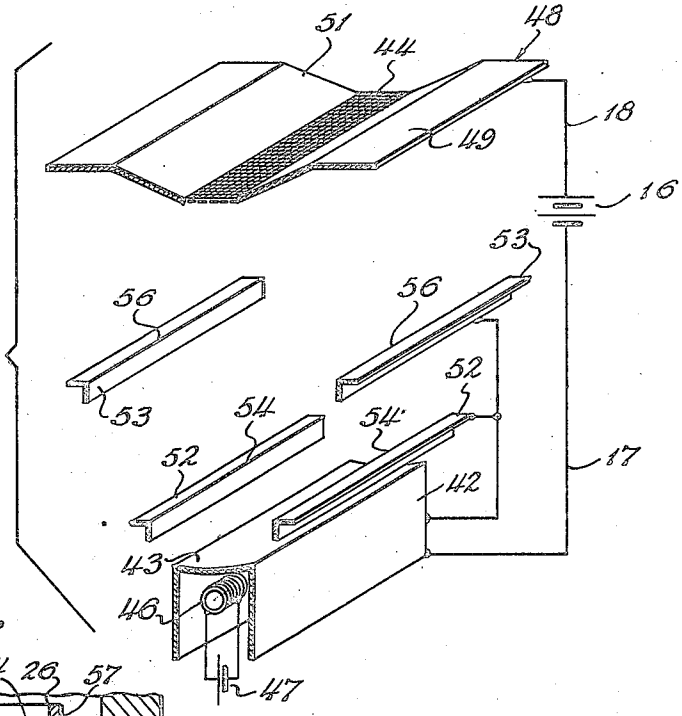


Fig. 5.

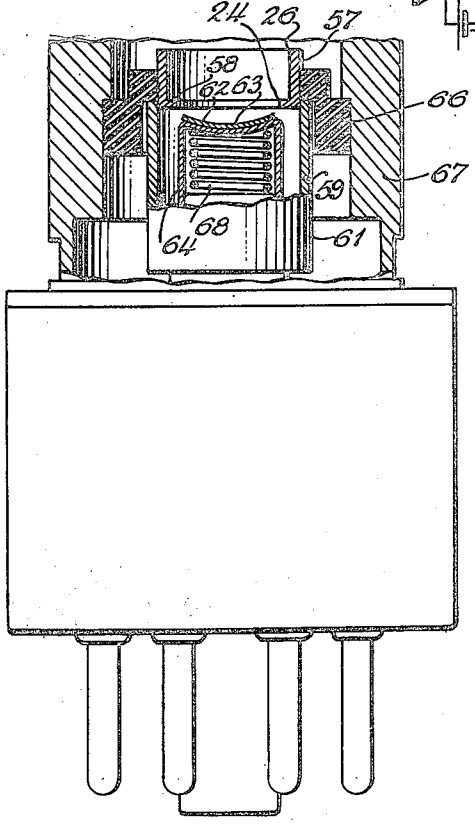
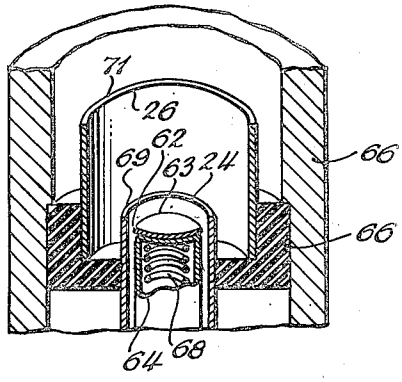


Fig. 6.



INVENTOR
CHAO C. WANG
BY
Paul B. Hunter
ATTORNEY

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UNITED STATES PATENT OFFICE

2,564,743

CHARGED PARTICLE BEAM FORMING APPARATUS

Chao C. Wang, Bayside, N. Y., assignor to The Sperry Corporation, Great Neck, N. Y., a corporation of Delaware

Application March 15, 1949, Serial No. 81,480

23 Claims. (Cl. 250—27.5)

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This invention relates to electron discharge devices and more particularly to electron guns for producing a concentrated stream of electrons for use in Klystrons, electron microscopes, cathode ray, vacuum tubes and similar electron discharge devices.

In electron guns for producing beams of finite sizes, it is frequently desirable to form a concentrated rectilinearly-moving beam of electrons. Rectilinear motion of electrons traveling between a cathode-emissive surface and an anode occurs when the potential distribution has a component of zero gradient normal to the paths of electrons of the beam. Under such conditions, the magnitudes of the fields at corresponding points inside and outside the beam are equal. Stated differently, there is no tendency for electrons in passing between the electrodes of the electron gun to deviate from paths normal to the electron-emissive surface if the fields outside the beam satisfy Laplace's equation and, over the boundary of the beam, are consistent with solutions of the space charge equations inside the beam.

The obtaining of a suitable potential distribution conducive to rectilinear electron motion has been achieved in the prior art by providing special electrodes surrounding and extending beyond the path of the electrons. These special beam-forming electrodes have opposed surfaces of complex configuration and critical location with respect to one another and the other electron gun electrodes, including the electron-emissive surface. The precise configuration and location of the beam-focusing surface electrodes have been largely determined by the electrolytic tank method, which is described in U. S. Patent 2,268,165. In addition, some attempt has been made to define the shape of part of such surfaces, as described in U. S. Patent 2,268,196.

One disadvantage of the known beam-forming electrodes is the difficulty of their fabrication and the incident cost associated therewith. Another disadvantage consists of the necessity for determining the electron gun configuration by the electrolytic tank method.

The present invention achieves the proper potential distribution to insure rectilinear motion of electrons by providing means defining two conductive edges or two line conductors located between the emissive surface and the anode. The two edges are spaced progressively outwardly from the periphery of the emissive surface and progressively toward the anode, respectively. Thus, for instance, the two edges for use in conjunction with a circular electron-emitting surface may be provided by a circularly apertured disk and a circular cylinder, the upper edge of the aperture of the disk constituting a first edge and the inner edge of the cylinder

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constituting a second edge. According to the present invention, the position of the two edges in relation to the cathode is effective for providing the desired potential distribution.

An object of the present invention is to provide an improved electron gun having predetermined electrical characteristics.

A further object of the present invention is to provide an improved electron gun wherein rectilinear motion of electrons is insured.

Another object of the present invention lies in the provision of an improved electron beam producing assembly wherein the potential gradient has a component normal to the boundary of the electron beam equal to zero.

Another object of the present invention is to provide in an electron gun a desired voltage gradient by means of two suitably positioned line conductors or edges.

A further object of the present invention is to provide an electron gun of predetermined electrical characteristics having easily fabricated beam-forming electrodes.

A still further object of the instant invention is to enable the design of an improved electron beam forming assembly without recourse to the electrolytic method.

Other objects and advantages of this invention will become apparent from the specification, taken in connection with the accompanying drawings wherein the invention is embodied in concrete form.

Fig. 1 is a diagrammatic representation, symmetrical about the electron beam axis, of one form of the improved anode-grid type electron gun of the present invention, together with a partial schematic wiring diagram;

Fig. 2 is a similar representation of the gridless-anode type improved electron gun;

Fig. 3 is a perspective view partly in cross-section of the electron gun corresponding to the diagrammatic representation of Fig. 1;

Fig. 4 is a perspective view partly in cross-section of an alternate form of the electron gun structure of Fig. 3; and

Figs. 5 and 6 are cross-section elevational views of alternate types of field-forming structures.

Similar characters of reference are used throughout the figures to indicate corresponding parts.

Referring now to the drawings, the diagrammatic representation shown in Fig. 1 is useful for describing the principles and illustrating one form of the structure of the present invention. The electron gun is formed as a figure of revolution about its longitudinal axis 11 with the cathode 12 having a spherically concave electron-emissive surface 13. The center of sphericity of the electron-emissive surface 13 is point P toward which

liberated electrons converge as they travel in the direction of the anode 14. By maintaining the accelerating electrode or the anode 14 at a positive potential with respect to the cathode 12 electrons, which have been liberated from the surface 13 by means of a suitable heater element (not shown), are attracted toward the anode 14. The requisite accelerating potential is provided by means of a source of voltage, such as battery 16, connected by leads 17, 18 to the cathode 12 and the anode 14, respectively.

The anode 14, which is symmetrical about the electron gun axis 11, has a centrally-disposed grid 19 which is arranged normal to the axis 11. To enable the anode 14 to extend preferably at right angles to the boundary or edge 21 of the electron beam, the anode 14 is formed in two portions, an inner sloping portion 22 and an outer portion 23. For convenient fabrication the outer portion 23 may be planar and oriented perpendicularly to the axis 11.

To insure a suitable potential distribution between the cathode 12 and the anode 14 of the electron gun, means are provided for defining a pair of field-forming electrodes consisting of first and second conductive edges 24, 26, respectively. Thus, the part or parts providing the desired edges 24, 26, which are operated at zero bias with respect to the cathode 12, may be fabricated, gauged and accurately mounted in the electron gun with ease.

In operation, electrons emanating from the electron-emissive surface 13 of the cathode 12 are attracted toward the grid 19 in substantially rectilinear paths. As shown in Fig. 1, the electron beam in the region between the surface 13 and the grid 19 has a frusto-conical configuration, as defined by the boundary 21 of the electron beam. The apex of the cone including the frusto-conical shaped beam is the point P, toward which electrons in their flight intermediate the surface 13 and the grid 19 tend to converge.

The proper potential distribution for insuring rectilinear motion of electrons is provided by means of the zero-biased suitably positioned edges 24, 26, which may be connected electrically to the cathode 12 to prevent their disturbing the potential distribution by the accumulation of charge. Along the electron beam boundary 21 the normal gradient of the voltage field, as indicated by a field line 27, is zero. Moreover, within the frusto-conical beam along any line extending perpendicularly to the emissive surface 13, such as normal line 28, the voltage field, similarly, has a normal component equal to zero. Accordingly, along field line 29, which is oriented at right angles to the normal line 28, the voltage gradient is equal to zero. Electrons traveling in rectilinear paths between the surface 13 and the grid 19 follow such straight lines, as normal line 28 and the line defining the beam boundary 21, which latter line similarly extends normal to the surface 13. After electrons pass through the grid 19 they are no longer exposed to the specially-maintained potential distribution and, consequently, deviate from rectilinear motion.

Before discussing the manner in which the present invention achieves the desired potential distribution, there are certain general considerations pertaining to the construction and operation of electron guns which are of particular interest in connection with the instant invention. These include the following:

(*a*) The cathode should be operated fully space charge limited.

(*b*) The cathode emission current density should be maintained below a value consistent with the life expectancy of the electron-emissive surface of the particular cathode employed.

(*c*) Under space charge limited operation the cathode should preferably be operated with uniform current emission density along the electron-emitting surface. If this condition is not satisfied, the maximum operating voltage is limited by the region in the beam having the maximum current density in order to satisfy condition (*b*). Moreover, to obtain a given magnitude of total current a non-uniform emissive surface generally must be larger than a uniform surface, and, as a result, requires greater heater power.

(*d*) In many applications it is essential that the cathode-anode capacitance be maintained below a specified value.

As discussed in preceding paragraphs, structure has been provided in the prior art for insuring a zero voltage gradient normal to the edge of an electron beam. Such structure consisted of a pair of opposed surfaces of complex configuration which were costly to fabricate and difficult to position in an electron gun assembly with the required precision.

By virtue of the present invention the desired result is achieved merely by two edges which may be provided by a wide variety of structure, which include, for instance in the case of a circular cathode, concentric cylinders, apertured disks, wire rings, a bored cup, etc. Accordingly, a great degree of latitude is present in the selection of the electrode structure suitable for providing the field-forming means of the instant invention.

In the various types of electron gun configurations discussed herein each of the field-forming electrodes constitutes from an electrical standpoint a series of points or a geometric line provided by a conductive material. The term "line conductor," among others, has been employed to describe such electrodes.

Theoretically, the problem of determining the ideal electron gun structure stems from considerations of electrons passing between infinite parallel planes, concentric spheres, etc. In constructing a practical finite electrode system, an attempt has been made to approach the ideal condition by maintaining in the region laterally beyond the electron beam a potential distribution approximating that which would occur if this region were to contain electrons. In the design of practical electron guns having predetermined electrical characteristics laborious calculations were customarily prepared to determine the potential distribution along the edge of the beam in the direction of electron travel. These calculations were then employed with the electrolytic tank method to determine the configuration and orientation of opposed surfaces of complex shape which would provide a zero voltage gradient normal to the beam edge.

According to the present invention, the position of two line conductors or edges, such as edges, 24, 26 may be determined with ease for a grid-anode type electron gun of desired electrical performance. Such guns are constructed for a selected semi-angle θ, in degrees, of the electron beam and a perveance K, where

$$K=\frac{I}{V^{3/2}}\times 10^{6}$$

In the above expression I, in microamperes, is the total electron beam current and V, in volts,

is the accelerating voltage maintained between the cathode 12 and the anode 14.

Along a line extending normally to the edge of the electron-emissive surface 13, the distances from point P to the inner sloping portion 22 of the anode 14 and the surface 13 are designated Ra and Rc, respectively.

The perveance may be expressed in terms of a relationship described by Langmuir and Blogett, "Currents limited by space charge between concentric spheres," Physical Review, vol. 24, pp. 49–59, 1924. This relationship may be restated to give another expression for perveance, as follows:

$$K=A \sin^2 (\theta/2)$$

where A is a Langmuir-Blogett type function of Ra/Rc.

The angle of inclination ψ is useful for determining the location of the two edges 24, 26 in terms of predetermined values of perveance and beam semi-angle, where ψ in degrees is given by the empirical relationship

$$50-8(Rc/Ra-1)-\theta$$

For convenience, it is possible to express the angle of inclination directly as a function of the perveance and semi-angle of the beam by considering the ratio Rc/Ra equal to the inverse function g of A, as follows:

$$50-8\left\{g\left[\frac{K}{\sin^2 (\theta/2)}\right]-1\right\}-\theta$$

In Fig. 1 a rectangular coordinate system is arranged in a plane including the axis 11 and any given point on the periphery of the electron-emissive surface 13. Thus, the x-axis extends radially and normal to the axis 11, with x increasing positively in a direction outwardly from the axis 11. The y-axis is oriented at right angles to the x-axis and extends parallel to the axis 11 and through the given point, with y increasing positively in the direction of the anode 14. In terms of the rectangular coordinate system the given point on the periphery of the surface 13, consequently, has 0,0 coordinates. The position of the first and second edges 24, 26 may be designated x_1, y_1, and x_2, y_2, respectively. Thus, the location of the second edge 26 is given substantially by the following expressions:

$$x_2=[(0.8+\delta) \sin \psi](Rc-Ra)$$
$$y_2=[(0.8+\delta) \cos \psi+\delta^2](Rc-Ra)$$

where δ may vary between 0.0 and 0.3

$$x_1=(0.10+\beta)x_2$$
$$y_1=(0.12+\beta)y_2$$

where β may vary between 0.0 and 0.1

It is useful at this point to refer briefly to Figs. 5 and 6, which are described more fully below, as illustrative of types of structure suitable for providing the field-forming electrodes.

In the event that the two edges 24, 26 are provided by a cylinder and apertured disk arrangement, such as shown in Fig. 5, which for convenience may be designated the apertured-cylinder or A-C type, the position of the lower edge 24 is given substantially by

$$x_1=0.10x_2$$
$$y_1=0.12y_2$$

The lower edge 24 may be located algebraically independently of the upper edge 26 substantially as follows:

$$x_1=(0.09 \sin \psi)(Rc-Ra)$$
$$y_1=(0.11 \cos \psi)(Rc-Ra)$$

Where two cylinders are employed, which may conveniently be termed the cylinder-cylinder or C-C type, such as that shown in Fig. 6, the position of the lower edge 24 is given substantially by

$$x_1=0.15x_2$$
$$y_1=0.20y_2$$

Similarly, the lower edge 24 of the C-C type may be located in an expression independent of the coordinate of the upper edge 26 substantially as follows:

$$x_1=(0.14 \sin \psi)(Rc-Ra)$$
$$y_2=(0.20 \cos \psi)(Rc-Ra)$$

In both the A-C, C-C and other structural types for providing the two edges 24, 26, the axial distance of the outer portion 23 of the anode 14 from a plane oriented normal to the axis 11 and including any of the points on the periphery of the electron-emissive surface 13 should be greater than the distance along the boundary 21 of the beam between the emissive surface 13 and the anode 14. Stated in terms of the rectangular coordinate system shown in Fig. 1, the minimum distance between the outer portion 23 and the x-axis, y_3 min., may be expressed substantially, as follows:

$$1.0<\frac{y_3 \text{ min.}}{Rc-Ra}$$

Preferably, the minimum axial distance of the outer portion 23 of the anode 14 from the edge of the emissive surface 13 should be larger, according to the following expression:

$$1.2>\frac{y_3 \text{ min.}}{Rc-Ra}$$

While the outer portion 23 of the anode 14 has been shown to be planar and oriented normal to the electron gun axis 11, this particular configuration is not essential to the successful operation of the instant invention. However, this arrangement is advantageous in many applications in that it simplifies manufacture. Moreover, while the sloping portion 22 of the anode 14 has been shown oriented at right angles to the beam boundary 21 and having a smooth surface, all that is required is that the anode 14 extend normal to the beam boundary 21 for a small distance in order to ensure the proper voltage field distribution. The region where the anode 14 approaches the beam boundary 21 may conveniently be termed the critical region. Departure from the preferable perpendicular relationship in the critical region may be tolerated within ±10° with the deviation reducing the efficiency of the electron gun.

In other words, the sloping portion 22 of the outer portion 23 of the anode 14 need not have smooth surfaces. Furthermore, in some applications of the instant invention the anode 14 has been formed without distinct portions 22, 23. In such designs the entire surface of the anode 14 smoothly extends from the grid 19 to the enclosing side wall of the electron gun.

Preferably the sloping portion 22 of the anode 14 should extend infinitely close to the beam boundary 21. In practice owing to manufacturing tolerances the diameter of the aperture of the portion 22 has been selected to be slightly greater than the diameter of the adjacent circular cross-section of the electron beam. This procedure is followed to prevent electrons impinging upon the innermost region of the sloping portion 22.

While the grid 19 is shown planar, it may be formed as a concave spherical-section member with the center of sphericity the point P. Such an arrangement, while it tends to approach more closely the condition of electrons moving between concentric spheres, is unnecessary in a practical electron gun design.

It is, of course, understood that the invention may be employed over a wide range of electron beam semi-angles, including preferably the range from 0 to 35 degrees. With beams having zero or relatively small angle the anode 14 may be formed normal to the axis 11 over its entire extent. Under such conditions the anode 14 will approach the beam boundary 21 substantially at right angles.

When dealing with a semi-beam angle θ equal to zero, the expressions which have been given for determining the electron gun design are equally applicable. Under such conditions, the value of the ratio Ra/Rc becomes unity and A, which is a Langmuir-Blogett type function of this ratio, becomes infinite. Thus, the point P in Fig. 1 is infinitely removed from the surface 13 and anode 14 and the surface 13 becomes planar.

In Fig. 2 there is shown another embodiment of the instant invention for a gridless-anode type electron gun. This diagrammatic representation is similar to Fig. 1 with the following exceptions. The gridless-anode 31, which is symmetrical about the axis 11, is formed with an outer portion 32, which for convenience may be planar and normal to the axis 11 of the gun. The inner or tapered portion 33 of the anode 31 has an angle of taper which is not critical to the operation of the electron gun. The position of the junction 34 of the outer portion 32 and the tapered portion 33 has an effect upon the electrical performance of the electron gun; however, the diameter of the aperture of the outer portion 32 may vary over an appreciable range. To illustrate the similarity between the electron guns of Figs. 1 and 2, a hypothetical curved surface, represented by line 36, is shown extending to the junction 34. The curved surface is spherically concave in outline about the point P.

The operation of the gridless-anode electron gun is similar to that described in connection with Fig. 1. While the grid 19 is effective for confining the potential distribution to the region between the cathode 12 and the anode 14 in the well-known manner, the voltage field will extend beyond the curved surface 36 and within the tapered portion 33. However, the two line conductors or edges 24, 26 when properly positioned will ensure a suitable potential distribution conducive to rectilinear motion of electrons.

To prevent spreading of the electron beam after it traverses the hypothetical surface 36, it is found advisable to taper the portion 33 inwardly toward the axis 11.

In the case of the gridless-anode type of electron gun the axial spacing of the outer portion 32 of the anode 31 from the electron-emissive surface 13 markedly affects the perveance of the gun. This is in contrast to the grid type shown in Fig. 1, where the axial separation of the outer portion 23 of the anode 14 from the surface 13 may vary over a wide range without influencing the perveance.

Owing to the construction of the gridless-type electron gun, electrons emanating from the vicinity of the center of the emissive surface 13 may not experience the same accelerating potential, applied from battery 16, as in the case of the grid type. This effect may be compensated for

by providing the electron-emissive surface 13 with a somewhat flatter surface. To this end, the center of sphericity for the surface 13 may be located beyond the point P, toward which electrons between the cathode 12 and the hypothetical surface 36 tend to converge.

Thus, with regard to the gridless-anode type of electron gun the present invention dispenses with the necessity of employing opposed electrode surfaces having uneven and critical configurations. As pointed out in preceding paragraphs, such known surface electrodes were difficult and costly to manufacture and not easily mountable in an electron gun. The edges 24, 26 of the gridless-type anode gun may be fabricated with the same degree of freedom discussed in connection with Fig. 1.

The location of the line conductors or edges 24, 26 to achieve the proper potential distribution may be determined by an electron gun having adjustable electrodes or by the electrolytic tank method.

In Fig. 3 there is shown a grid-type electron gun corresponding to the diagrammatic representation of Fig. 1. A heater element 37 is surrounded by the cylindrical sleeve 38 of the cathode 12. To energize the heater element 37 suitable leads are connected to a source of electrical energy, such as cell 38. First and second conductive annular members 39, 41, respectively, constituted of an axially-extending portion and a radially-extending portion, provide the first and second line conductors or edges 24, 26, respectively, along their inner line of juncture. To ensure the zero-biased condition of the edges 24, 26 lead 35 interconnects annular members 39, 41 with the cathode 12.

Fig. 4 shows a modification of the instant invention useful in an electron gun designed to form a wedge or rectangular-shaped beam of electrons. The cathode 42 is formed with a strip-type electron-emissive surface 43, which in section is spherically concave about a point located above the grid 44. A suitable heating element 46 positioned adjacent the emissive surface 43, is energized by a cell 47. The anode 48 is formed to cooperate with the emissive surface 43 and is constituted of an outer portion 49 and an inner portion 51, the inner portion 51 extending normal to the boundary of the electron beam. Straight conductive members 52, 53 provide the edges 54, 56 in the same manner as described in connection with Fig. 3.

Thus, by considering Fig. 1 as a figure of translation rather than as a figure of revolution, Fig. 1 defines a diagrammatical elevational cross-sectional view of the electron gun of Fig. 4. Similarly, Fig. 2 is useful in the same manner for considering a modification of the device of Fig. 4, in which the grid 44 is omitted from the anode 48. Consequently, all of the constructional details, possible modifications, and operation discussed in connection with Figs. 1–3 are applicable to the device of Fig. 4.

Unless special precautions are taken in the construction of the ends of the electron gun of Fig. 4, some departure from ideal operation will occur. This condition may be minimized, however, by rounding the ends of the emissive surface 43 and forming the edges 54, 56 to cooperate therewith.

In Fig. 5 there is shown a conductive cylinder 57 open at one end and having a disk-like portion partially enclosing the other end. Such a device is illustrative of structure suitable for providing

the beam-forming edges 24, 26 and constitutes an aperture-cylinder or A-C type as discussed in connection with Fig. 1. In addition, the A-C type of beam-forming electrodes shown in Fig. 5 may be positioned in the device of Fig. 3. The cylinder 57 is supported by a supporting cylinder 59 concentric about the tube axis 11, which in turn is supported by the tube base 61. A spherically concave electron emitter 62, having an oxide coated surface 63 is mounted by positioning member 64, which is supported by the tube base 61. To further position and support the cylinder 57, a dielectric ring 66 extends to the enclosing wall 67 of the device. For energizing the electron emitter 62 a heating element 68 is provided. While the A-C type of beam-focussing electrode has been shown in Fig. 5 as formed of a single continuous part, it is of course understood that the cylinder and disk may be joined, as by welding, to constitute the beam-forming electrodes.

Fig. 6 is illustrative of an alternate construction of the device of Fig. 5 and has been designated in connection with Fig. 1 as the cylinder-cylinder or C-C type. Two conductive cylinders 69, 71 provide the edges 24, 26 to maintain the desired potential distribution.

In the instant invention two edges or line conductors are found most convenient for simplified manufacture. However, three or more suitably positioned line conductors may be employed.

While circular and strip e'ectron emitting surfaces have been shown to illustrate the present invention, it is understood that rectilinear motion of electrons emanating from cathodes having different configurations may be achieved. For instance, a hollow cylindrical beam of electrons could be produced according to the instant invention by considering Fig. 1 as symmetrical about an axis external to and parallel with axis 11.

As 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.

I claim:

1. A concentrated electron beam forming device comprising a cathode having an electron-emissive surface, an anode aligned therewith and spaced therefrom, means for maintaining a potential difference between said cathode and said anode, and field forming means for providing in the presence of complete space charge an electrical field having all components perpendicular to every line extending normal to said electron-emissive surface equal to zero, said field forming means including substantially only first and second line conductors, said first line conductor being located in a direction outwardly of said surface and toward said anode, and said second line conductor being located in a direction outwardly of said first conductor and nearer said anode than said first conductor.

2. An electron gun aligned along an axis for electron discharge devices comprising a concave spherical - section electron - emissive surface formed as a figure of revolution about said axis, an anode member symmetrical about said axis and having a centrally-disposed electron-permeable grid, field forming means providing in the presence of complete space charge a zero voltage gradient normal to the edge of the beam of said electron gun, said field forming means including means defining first and second circular interior edges; said surface, said first edge and said second edge being located in axial consecution in the direction of said anode member and having progressively larger diameters, said first and second edges being further located in axially-spaced plane perpendicular to said axis.

3. Apparatus for producing a concentrated frusto-conical stream of electrons along an axis, comprising a concave spherical-section cathode having an electron-emitting surface formed as a figure of revolution about said axis, an anode member symmetrical about said axis and having a centrally-located grid, said member in the vicinity of said grid being formed normal to the edge of said beam and further having a flat portion arranged perpendicularly to said axis, first conductive means defining a first circular interior edge of diameter greater than the circular diameter of said cathode, said first circular interior edge being concentrically situated in a plane perpendicular to said axis between said cathode and said anode surface and being nearer to said cathode than to said anode surface; second conductive means defining a second circular interior edge of diameter greater than the diameter of said first circular interior edge, said second circular interior edge being concentrically situated in a plane perpendicular to said axis between the plane of said first circular interior edge and said cathode surface.

4. Apparatus for producing a frusto-conical beam of electrons along an axis, comprising a cathode having a concave spherical-section electron-emitting surface formed as a figure of revolution about said axis, an anode member symmetrical about said axis and having a centrally disposed grid, said anode member being formed in the vicinity of said grid to extend normally to the edge of said beam and further having a planar portion disposed normally to said axis, the apex of the cone including said frusto-conical beam being displaced along said edge of said beam from said anode and said cathode surface by distances Ra and Rc, respectively, the perveance (K) and semi-angle of said beam (θ) being related according to

$$K=A\sin^2\left(\frac{\theta}{2}\right)$$

where A is a Langmuir-Blogett type function of Ra/Rc, any point on the periphery of said electron-emitting surface defining the origin of a rectangular coordinate system, first and second edges, said system being located in a plane including said axis and said first (x_1, y_1) and second (x_2, y_2) edges with y increasing axially in the direction toward said anode and x increasing in the direction normal to and away from said axis, the position of said edges being given approximately by

$$y_2=[(0.8+\delta)\ \sin\ \psi](Rc-Ra)$$
$$x_2=[(0.8+\delta)\ \cos\ \psi+\delta^2](Rc-Ra)$$

where δ varies between 0.0 and 0.3 and ψ in degrees is given by

$$50-8(Rc/Ra-1)-\theta$$

and

$$x_1=(0.10+\beta)x_2$$
$$y_1=(0.12+\beta)y_2$$

where β may vary between 0.0 and 0.1, and the axial distance between said planar portion of said anode and the x-axis of said coordinate system being greater than $Rc-Ra$.

5. Apparatus as in claim 4, where ψ may vary $\pm 2°$.

6. Electron beam producing apparatus for forming a beam of electrons having a given perveance and semi-angle, comprising a cathode with an electron-emitting surface, said surface having an edge, an anode having an electron-permeable grid spaced from said cathode substantially a distance D, means defining a first line conductor adjacent said edge, means defining a second line conductor, each point of said second conductor being spaced from a corresponding point on said edge outwardly of said surface by a distance approximately equal to

$$[(.8+\delta)\ \sin\psi]D$$

and toward said anode a distance approximately equal to

$$[(.8+\delta)\ \cos\psi+\delta^2]D$$

where δ varies between 0.0 and 0.3 and ψ is the inclination function of said given perveance and semi-angle.

7. Apparatus for producing a tapered electron beam having a given semi-angle (θ) and aligned along an axis comprising an electron-emitting surface, an anode having a grid, and spaced axially from said surface by a distance Rc—Ra, the apex of the continuation of said tapered beam being spaced axially from said anode a distance Ra, the axial distance from said apex to said surface being designated Rc, means providing a first circular conductive interior edge positioned above and outwardly of said surface, means providing a second conductive interior edge located axially toward said anode and from a plane oriented perpendicularly to said axis and including a given point on the periphery of said surface a distance approximately equal to

$$[(.8+\delta)\ \sin\psi](Rc-Ra)$$

and located normally from said axis and from a plane oriented parallel to said axis and including said point a distance approximately equal to

$$[(.8+\delta)\ \cos\psi+\delta^2](Rc-Ra)$$

where δ varies between 0.0 and 0.3 and ψ in degrees is given by

$$50-8(Rc/Ra-1)-\theta$$

8. Apparatus for producing a concentrated electron beam, in which the individual electron paths of said beam are parallel comprising an emitter having a substantially planar electron-emissive surface, an anode spaced from and registering with said surface, said anode having an electron-permeable grid and a planar portion which is parallel to said electron-emissive surface in the vicinity of said grid, means defining a first line conductor electrode which is adjacent the periphery of said surface and positioned outwardly of said periphery and toward said anode, and means defining a second line conductor electrode which is spaced from said first electrode and positioned outwardly of said first electrode and closer to said anode than said first electrode, whereby rectilinear motion of electrons travelling between said surface and anode is provided.

9. An electron gun aligned along an axis for producing a concentrated electron stream, comprising a cathode symmetrical about said axis and having a substantially flat circular electron emitter portion extending normal to said axis, an anode member having a centrally-located electron-permeable grid, said grid being symmetrical about said axis, said member having a planar portion arranged normal to said axis and surrounding said grid, and conductive means defining first and second circular interior edges which are concentrically situated about said axis and spaced from said emitter portion in successive respective planes perpendicular to said axis and intermediate said emitter portion and said anode member; said emitter portion, said first and second edges having progressively larger diameters, whereby in the presence of complete space change substantially rectilinear motion in parallel paths of electrons of said stream is provided.

10. Apparatus for producing a tapered beam of electrons along an axis, comprising a cathode having a circular electron-emissive surface which is spherically concave in section and formed as a figure of revolution about said axis, a gridless anode member symmetrical about said axis and having outer planar and inner tapered portions, said outer portion being located in a plane normal to said axis, said inner portion extending away from said surface and tapering toward said axis in the direction of electron flight; conductive means providing first and second circular line conductors located in succession from said electron-emissive surface, respectively, in planes which are intermediate said electron-emissive surface and said anode member and normal to said axis; said electron-emissive surface, said first conductor and said second conductor having progressively larger diameters; whereby rectilinear motion of electrons of said beam is provided.

11. Apparatus for producing a concentrated stream of electrons along an axis, comprising an electron-emissive surface spherically concave in section and formed as a figure of revolution about said axis, a gridless anode member symmetrical about said axis and spaced from said surface, and electric field-forming means providing in the presence of complete space charge electric field lines substantially having only components of value greater than zero extending normal to said surface, said field-forming means including first and second circular line conductors concentrically positioned in planes which are normal to said axis and intermediate said surface and said anode member, said first conductor having a diameter greater than that of said surface, and said first and second line conductors having progressively larger diameters.

12. Apparatus having a longitudinal axis for producing a concentrated stream of electrons, comprising a cathode having a strip-type electron-emissive surface, an anode spaced from and registering with said surface, and first and second line conductor means, said surface being spherically concave in a plane extending normal to said axis, said first line conductor means being located in said plane outwardly from the periphery of said surface and toward said anode, said second line conductor means being located in said plane outwardly of said first line conductor means and nearer said anode than said first line conductor means.

13. Apparatus having a longitudinal axis for forming a wedge-shaped beam of electrons, comprising a cathode having an electron-emitting surface with elongated edges extending parallel to said axis, an elongated anode cooperating with said surface, said anode having outer portions situated in a plane parallel to a plane including points located on the periphery of said surface, said anode further having inner portions which

extend normal to the longitudinal beam boundary, said anode further having an elongated electron-permeable grid joining said inner portions, said surface being spherically concave in vertical section about a point located beyond said grid, and conductive means defining first and second pairs of rectilinear interior edges extending parallel to said longitudinal axis, said first pair of interior edges being located outwardly of said elongated edges of said surface and toward said anode, said second pair of interior edges being located outwardly of said first pair of interior edges and nearer to said anode than said first pair of interior edges.

14. An electron gun having a longitudinal axis for producing a concentrated stream of electrons, comprising an elongated electron-emissive surface, an elongated anode cooperating therewith, and means defining first and second elongated interior edges; said electron-emissive surface being spherically concave in elevational section taken normal to said longitudinal axis, said anode member in said section having a centrally-disposed electron-permeable grid, said anode member in said section in the vicinity of said grid being formed normal to the edges of said beam and further having outer flat portions arranged perpendicularly to the vertical axis of said section, said first and second edges being located in said section intermediate said surface and said anode, said first edge being located in said section outwardly and toward said anode, and said second edge being located in said section outwardly of said first edge and nearer said anode than said first edge, whereby said section defines a figure of translation for said electron gun.

15. An elongated electron gun for forming a wedge-shaped beam of electrons, comprising an elongated electron-emissive surface, an elongated anode spaced therefrom and registering therewith, means for maintaining a potential difference between said surface and said anode, and field-forming means for providing in the presence of complete space charge and electric field having all components perpendicular to substantially every line extending normal to said electron emissive surface equal to zero, said field-forming means including pairs of first and second line conductors, said first line conductor pair being located in a direction outwardly of said surface and toward said anode, and said second line conductor pair being located in a direction outwardly of said first conductor and nearer said anode than said first conductor.

16. An electron gun for producing a tapered beam of electrons along an axis, comprising a circular electron-emissive surface spherically concave in section and formed as a figure of revolution about said axis, an apertured disk-like member forming an anode and having planar surfaces arranged normal to said axis; and conductive means providing first and second circular interior edges located in succession respectively in the direction of said anode, and further being located in axially-spaced planes perpendicular to said axis and intermediate said surface and said anode; said surface, said first edge and said second edge having progressively larger diameters.

17. A concentrated electron beam forming device comprising a cathode having an electron-emissive surface, an accelerating electrode aligned therewith and spaced therefrom, and field-forming means for providing in the presence of space charge an electrical field having all components perpendicular to every line extending normal to said electron-emissive surface equal substantially to zero, said field forming means including substantially first and second conductors, said first conductor being located in a direction radially outwardly of said surface and toward said accelerating electrode, and said second conductor being located in a direction radially outwardly of said first conductor and nearer said accelerating electrode than said first conductor.

18. Apparatus as in claim 17 wherein said electron-emissive surface is substantially planar, and a grid is substantially-centrally disposed in said accelerating electrode.

19. An electron gun aligned along an axis for producing a frusto-conical beam of electrons having a semi-angle (θ), comprising an electron-emissive surface spherically concave and formed as a figure of revolution about said axis, an anode member having a centrally-located grid and symmetrical about said axis, the apex of the cone including said frusto-conical beam being spaced from said anode and said cathode surface by distances Ra and Rc respectively, and means defining first and second interior edges, any point on the periphery on said surface defining the origin of a rectangular coordinate system said system being located in a plane including said axis and said first edge (x_1, y_1) and said second edge (x_2, y_2) with y increasing in the direction toward said anode member and x increasing in the direction normal to and away from said axis, the position of said edges being given approximately by

$$x_2=[(.8+\delta)\ \sin\ \psi](Rc-Ra)$$
$$y_2=[(.8+\delta)\ \cos\ \psi+\delta^2](Rc-Ra)$$

where δ varies between 0.0 and 0.3 and

$$x_1=[(0.09+\beta)\ \sin\ \psi](Rc-Ra)$$
$$y_1=[(0.11+\beta)\ \cos\ \psi](Rc-Ra)$$

where β may vary between 0.0 and 0.1 and ψ in degrees is given by $50-8\ (Rc/Ra-1)-\theta$.

20. An electron gun aligned along an axis for forming a concentrated beam of electrons in which the individual electrons travel in substantially parallel paths, comprising a planar electron-emissive surface arranged normal to said axis, an anode member aligned therewith and spaced therefrom an axial distance D and having a centrally-disposed grid, and means defining first and second circular interior edges formed concentrically about said axis and in planes situated perpendicularly to said axis, each point of said second edge being spaced outwardly from a corresponding point on the periphery of said surface by a distance substantially equal to

$$[(0.8+\delta)\ \sin\ 50]D$$

and toward said anode member a distance substantially equal to

$$[(0.8+\delta)\ \cos\ 50+\delta^2]D$$

where δ varies between 0.0 and 0.3.

21. Electron beam producing apparatus aligned along an axis for forming a beam of electrons having a given perveance and semi-angle equal to zero, comprising a cathode formed as a figure of revolution about said axis and having a planar electron-emitting surface arranged perpendicularly to said axis, an anode having a centrally-disposed electron-permeable grid spaced from said surface substantially a distance D, means providing first and second circular conductive interior edges positioned intermediate said surface and said grid and concentrically situated about said axis, any point on the periphery of said

electron-emitting surface defining the origin of a rectangular coordinate system, said system being located in a plane including said axis and said first edge (x_1, y_1) and said second edge (x_2, y_2) with y increasing axially toward said anode and x increasing normal to and away from said axis, the position of said edges being given approximately by

$$x_2=[(0.8+\delta)\ \sin 50]D$$
$$y_2=[(0.8+\delta)\ \cos 50+\delta^2]D$$

where δ varies between 0.0 and 0.3 and by

$$x_1=[(0.10+\beta)]x_2$$
$$y_1=[(0.12+\beta)]y_2$$

where β may vary between 0.0 and 0.1.

22. An electron gun aligned along an axis for forming a tapered electron beam, comprising a cathode having an electron-emitting surface spherically concave and formed as a figure of revolution about said axis, an anode member spaced therefrom and symmetrical about said axis, and field-forming means providing in the presence of complete space charge a zero voltage gradient normal to the edge of said beam of said electron gun, said field-forming means including first and second circular interior edges concentric with said axis and positioned in axial spaced planes normal to said axis and between said surface and said anode member, said first edge defining a boundary of an area which is larger than that of said surface, and said second edge defining a boundary of an area which is larger than that of said first edge.

23. Apparatus for producing a concentrated electron stream with the paths of the individual electrons thereof substantially parallel, comprising a substantially planar electron-emissive surface, an anode spaced from said surface and having an electron-permeable grid registering with said surface, said anode further having a substantially planar portion disposed parallel to said electron-emissive surface in the vicinity of said grid, means defining a first line conductor positioned relative to a geometric plane perpendicularly located with respect to said electron-emissive surface radially outward from the periphery of said surface and axially toward said anode, and means defining a second line conductor positioned relative to said geometric plane radially outward from said first conductor defining means and closer to said anode than said first conductor defining means.

CHAO C. WANG.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,979,392	Lubcke	Nov. 6, 1934
2,064,981	Knoll	Dec. 22, 1936
2,176,974	McGee et al.	Oct. 24, 1939
2,194,547	Haines	Mar. 26, 1940
2,268,165	Parker et al.	Dec. 30, 1941
2,268,196	Pierce	Dec. 30, 1941
2,303,166	Laico	Nov. 24, 1942
2,318,423	Samuel	May 4, 1943
2,443,916	Kelar	June 22, 1948

FOREIGN PATENTS

Number	Country	Date
22,106/35	Australia	Apr. 4, 1935