Dec. 30, 1941. C. V. PARKER ET AL 2,268,165

ELECTRON DISCHARGE DEVICE

Filed April 4, 1940

FIG. 1

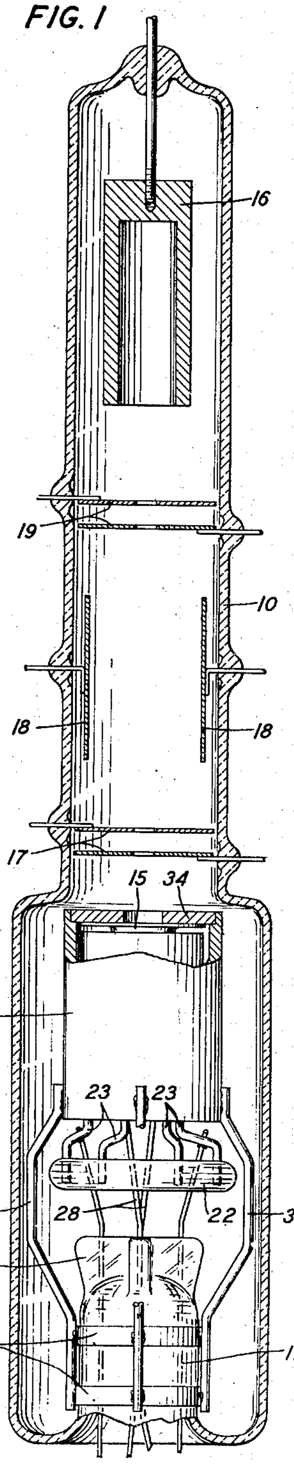


FIG. 2

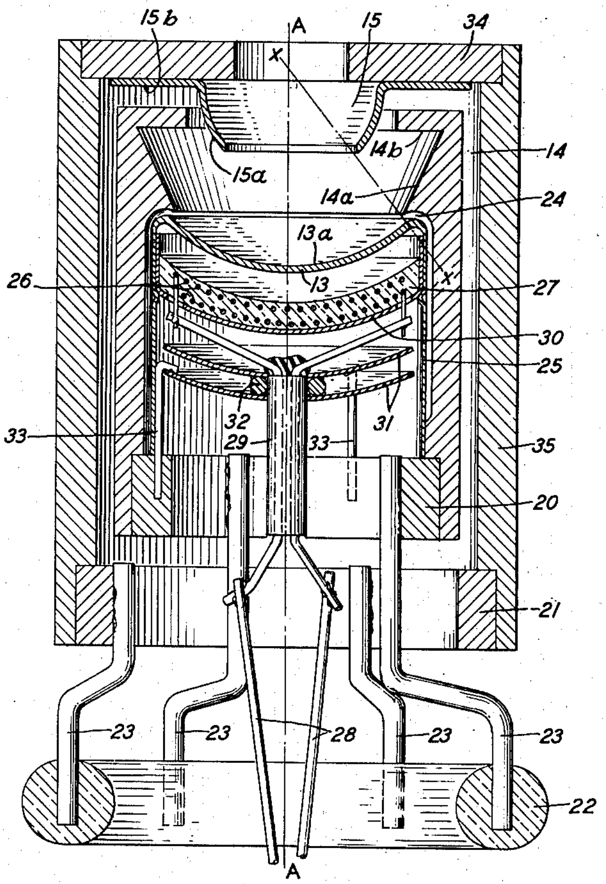
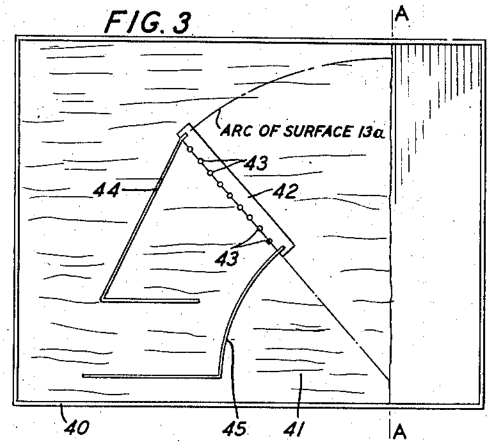


FIG. 3



INVENTORS: C. V. PARKER
A. L. SAMUEL

BY Walter C. Kiesel
ATTORNEY

Patented Dec. 30, 1941

2,268,165

UNITED STATES PATENT OFFICE

2,268,165

ELECTRON DISCHARGE DEVICE

Carlyle V. Parker, New York, N. Y., and Arthur L. Samuel, Summit, N. J., assignors to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application April 4, 1940, Serial No. 327,826

5 Claims. (Cl. 250—162)

This invention relates to electron discharge devices and more particularly to electron guns for producing a concentrated electron beam having a point focus, in cathode ray and similar electron discharge devices.

As described in the applications Serial No. 307,233, filed December 2, 1939, and Serial No. 319,393, filed February 2, 1940, of John R. Pierce, rectilinear electron motion between spaced electrodes of an electrode system or electron gun may be achieved by producing, in the system or gun and in the regions traversed by and outside of the electron beam, particular potential distributions such that 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. Stated in another way, the potential distribution should be such that the field outside of the beam shall match in potential the field inside the beam and shall have zero gradient normal to the boundary of the beam.

One of the principal problems entering into the realization of the requisite potential distribution is the determination of the configuration and relation of the electrode surfaces in the system necessary for effecting the desired rectilinear motion and focussing of the electrons in the beam. Inasmuch as the potential distribution along the beam boundary is a relatively complex function of distance from the electron source in the electrode system, the electrode configurations heretofore obtained have been relatively complex.

One general object of this invention is to facilitate the fabrication and construction of an electron gun for producing an electron beam of a desired cross-section and focus.

More specifically, one object of this invention is to simplify the configuration of the electrodes in an electron gun, for establishing rectilinear motion of the electrons in the beam produced by the gun.

In one illustrative embodiment of this invention, an electron gun comprises an electron source, such as a cathode, and a pair of spaced centrally apertured beam-forming electrodes in alignment with the electron source, the source and opposed surfaces of the electrodes being of such configuration that the electrons emanating from the source are concentrated into a beam and have rectilinear motion therein. In a specific embodiment of this invention, the source and surfaces mentioned are coaxial, symmetrical about the axis and are of such configuration that the electrons emanating from the source traverse rectilinear paths converging toward a point on the axis.

In accordance with one feature of this invention, the opposed surfaces of the beam-forming electrodes are of such configuration that the generatrices thereof consist of straight lines or straight lines and arcs of circles.

The invention and the foregoing and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing in which:

Fig. 1 is an elevational view, partly in section, of an electron discharge device including an electron gun constructed in accordance with this invention, portions of the electron gun being broken away;

Fig. 2 is an enlarged sectional view of the electron gun embodied in the device illustrated in Fig. 1; and

Fig. 3 is a top view of apparatus employed in determining the configuration of the electrode surfaces in the electron gun shown in Fig. 2.

Referring now to the drawing, the electron discharge device shown in Fig. 1, which is particularly suitable for use as an amplifier at ultra-high frequencies, for example, frequencies corresponding to wave-lengths of the order of fifteen centimeters, comprises an elongated evacuated enclosing vessel 10 having at one end thereof an inwardly extending stem 11 terminating in a tri-armed press 12 and from which an electron gun is supported.

The electron gun comprises, in general, an electron source, such, for example, as a cathode having an electron emissive surface 13a and a pair of beam-forming electrodes 14 and 15 having opposed surfaces 14a, 14b and 15a, 15b, respectively, of a configuration described in detail hereinafter. The electrodes of the gun preferably are coaxial, the axis being indicated by line A—A, and the various surfaces thereof aforenoted are symmetrical about this axis.

Mounted at the other end of the enclosing vessel 10 is an electron receiving element 16 upon which the electron beam produced by the electron gun impinges. This element may be a cup-shaped metallic anode coaxially mounted with the electron gun and preferably is relatively deep to prevent the issuance of any secondary electrons produced by impingement of the electron beam upon the inner surfaces of the anode. The electron receiving element, of course, may be of other forms. For example, it may be a fluorescent screen or a secondary electron emissive target.

One or more electrodes may be provided between the electron gun and the electron receiving element for affecting, e. g., modulating the intensity of, deflecting, accelerating or retarding, the electron beam. In a specific device shown in Fig. 1, a pair of axially aligned, centrally apertured diaphragms or disc electrodes 17 are provided opposite the electron gun and have suitable potentials applied thereto to concentrate and to accelerate the beam produced by the gun.

Equally spaced from the axis of alignment of the various electrodes are a pair of electrodes **18** which may have suitable potentials applied thereto to retard the electron beam or to modulate the velocity thereof. A second pair of centrally apertured axially aligned electrodes **19** are mounted between the electrodes **18** and electron receiving element **16** and may have suitable potentials applied thereto to accelerate the beam.

The electron gun may be fabricated as a unitary assembly and, as shown clearly in Fig. 2, comprises a pair of supporting rings **20** and **21** which are mechanically connected to an insulating ring **22** by rigid wires **23** and maintained in fixed space relation thereby. The supporting ring **20** is fitted in a groove in and secured to the cylindrical portion **14** of the first beam-forming electrode, which is provided with an annular surface **24** of arcuate section overlying the edge portion of one end of the cathode.

The cathode comprises a dished end portion **13**, a cylindrical portion **25** seated upon the supporting ring **20** and affixed thereto and to the cylindrical portion of the electrode **14**, and a heater filament **26** encased in insulating material **27** and disposed adjacent the end wall **13** of the cathode, the surface **13***a* of this wall being coated with an electron emissive material. Leading-in conductors **28** for the heater filament **26** are encased, in part, by an insulating sleeve **29** and sealed in the press **12**. The filament **26** and insulation **27** therefore may be supported upon a cup-shaped closure member **30** affixed to the cylindrical wall **25**.

Mounted between the supporting ring **20** and the closure member **30** are a pair of dished metallic baffles **31** which serve to conserve the heat produced by the filament **26** and thereby insure a high cathode efficiency. The baffles may be fitted on the insulating sleeve **29** and are spaced by a metallic annulus **32** and affixed thereto. Rigid supports, such as wires **33**, extend from the support ring **20** and are secured to one of the baffle members **31**, as shown.

The beam-forming electrode **14** comprises a cylindrical portion seated on and affixed to the support ring **20** and is provided with axially symmetrical surfaces **14***a* and **14***b* of a configuration described hereinafter.

The beam-forming electrode **15** is mounted in coaxial relation with the cathode **13** and electrode **14** by an annular metallic plate member **34** which is carried by a metallic cylinder **35** seated upon and affixed to the supporting ring **21**.

The electrode gun assembly described above is supported as a unit by a plurality of rigid metallic uprights **36** affixed, as by welding, to the cylinder **35** and extending from collars **37** clamped about the stem **11**.

The paths traversed by the electrons in the electron beam and, hence, the configuration of the beam emanating from the electron gun will be dependent upon the fields extant within the beam and the region about the beam, and these fields, in turn, are determined by the configuration and relation of the emissive surface **13***a* and the surfaces **14***a*, **14***b* and **15***a*, **15***b* of the electrodes **14** and **15**.

In an electron gun, such as shown in Fig. 2, for producing a converging electron beam, the emissive surface **13***a* of the cathode conforms to a segment of a sphere and the surfaces **14***a*, **14***b* and **15***a*, **15***b* are of such configuration and relation that all electrons emanating from the surface **13***a* traverse rectilinear paths which converge toward a point on the axis A—A of alignment of the electrodes of the electron gun.

In order that the desired electron motion will be realized, it is necessary that the field outside of the beam boundary correspond to an axially symmetrical solution of Laplace's equation and be such that the potential gradient normal to the beam boundary is zero, and the potential along the beam boundary varies in accordance with the solutions of the space charge equations for rectilinear motion of electrons between concentric spheres. The requisite potential variation along the beam boundary may be expressed by the relation

$$\phi = K(\alpha^2)^{2/3} \tag{1}$$

where ϕ is the potential, K is a constant and α^2 is a function of

$$\frac{r_o}{r}$$

r being distance from the center of curvature of the emissive surface **13***a* of the cathode and r_0 being the radius of curvature of this emissive surface. The constant K may be expressed by the relation

$$K = \left(\frac{i}{29.34 \times 10^{-6}}\right)^{2/3}$$

where i is the current which would flow between two concentric spheres. The values of α^2 for particular ratios of

$$\frac{r_o}{r}$$

may be determined in ways known in the art.

The configurations for the surfaces **14***a*, **14***b* and **15***a*, **15***b* can be determined through the use of an electrolytic tank apparatus as described in the application Serial No. 319,393, of John R. Pierce noted hereinabove. In brief, and as illustrated in Fig. 3, such apparatus comprises a tank **40** having an inclined bottom wall of insulating material and containing an electrolyte **41**, such as water. The water line on the inclined bottom wall is indicated at A—A in Fig. 3 and represents or corresponds to the axis of the electron gun. A strip **42** of insulating material is mounted in the tank normal to the base and has mounted on one face thereof a plurality of conductors or probes **43**. The insulating strip represents the boundary of the electron beam and is mounted so that it makes, with the axis A—A, an angle equal to the angle the elements of the conical beam boundary make with the axis of the gun. Extending from opposite ends of the insulating strip are a pair of pliant metallic strips **44** and **45**.

The insulating and metallic strips and the electrolyte represent a wedge-shaped sector of the electron gun. Inasmuch as, as noted heretofore, in the gun axially symmetrical fields obtain between the electrodes, the fields in any sector of the region between the electrodes will be illustrative of the fields in all other sectors.

In the electrolytic tank, it will be seen that the fields produced by potentials between the metallic strips **44** and **45** are in accordance with the Laplacian equation. Inasmuch as the strip **42** and the base wall of the tank are of insulating material, the potential gradient normal to the insulating strip and normal to the base is zero. Hence, two of the conditions requisite for the production of a converging electron beam wherein the electrons traverse rectilinear paths are established. There remains, then, only the determination of the electrode configurations to produce the necessary variation of potential along the beam boundary, i. e., as given by Equation 1, supra. These configurations may be established by altering the form of the metallic strips **44** and **45** until the potential along the insulating strip **42**, as measured at the probes or conductors **43**, varies in the prescribed manner. The electrodes **14** and **15** are then constructed so that the generatrices of the opposed surfaces thereof are of the configuration and in the relation of the strips **44** and **45** formed as described.

It will be appreciated that these opposed surfaces may be of a number of configurations most of which are of relatively complex form. In accordance with a feature of this invention, however, these surfaces are made of such configurations that the generatrices thereof consist of straight lines or of straight lines and arcs of circles.

Thus, in the case of a converging electron beam, such as illustrated in Fig. 2, it has been found that the fields requisite for rectilinear electron motion may be realized if the surface **13***a* is a segment of a sphere, the electrode **14** is operated at cathode potential, the electrode **15** is operated at a positive potential with respect to the cathode and the generatrices of the surfaces **14***a*, **14***b* and **15***b* are straight lines and the generatrix of the surface **15***a* is an arc of a circle. In a specific embodiment, for which the included angle of the beam boundary is 84 degrees and the potential along the beam boundary varies in accordance with Equation 1 for a value

$$\frac{r_0}{r}=1.88$$

the surfaces **13***a* and **15***a* are segments of concentric spheres, the elements of the frusto-conical surface **14***a* extend at an angle of 67.5 degrees to the normal $x—x$ to the emissive surface **13***a* at the periphery thereof and the surfaces **14***b* and **15***b* are annular, with the planes thereof normal to the axis of symmetry A—A.

Although a specific device has been shown and described, it will be understood, of course, that it is but illustrative and that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. An electron gun for electron discharge devices comprising an electron emissive surface, and means for establishing such fields adjacent said surface that substantially all electrons emanating from said surface traverse rectilinear paths within a predetermined boundary extending from adjacent said surface, said means comprising a pair of spaced electrodes opposite and in alignment with said surface and having opposed axially symmetrical surfaces of revolution, the generatrix of one of said opposed surfaces including a straight line extending from adjacent the periphery of said emissive surface and away from said surface and including also a second straight line extending toward and substantially normal to the axis of alignment of said electrodes from the end of said first straight line remote from said emissive surface, and the generatrix of the other of said opposed surfaces including a straight line opposite and parallel to said second straight line and including also a second line extending toward said emissive surface from the inner end of said third straight line.

2. An electron gun for electron discharge devices comprising a concave emissive surface, and means for establishing such fields adjacent said surface that substantially all electrons emanating from said surface traverse converging rectilinear paths within a conical boundary along which the potential varies substantially in accordance with the relation

$$\phi=K(\alpha^2)^{2/3}$$

where ϕ is potential, K is a constant and α^2 is a known function of

$$\frac{r_0}{r}$$

r_0 being the radius of curvature of said emissive surface and r being distance from the center of curvature of said emissive surface, said means comprising a pair of spaced electrodes opposite and in alignment with said surface and having opposed axially symmetrical surfaces of revolution, the generatrix of one of said opposed surfaces consisting of straight lines and the generatrix of the other of said opposed surfaces consisting of a straight line and an arc of a circle.

3. An electron gun for electron discharge devices comprising an electron emissive surface corresponding to a portion of a sphere, and a pair of spaced centrally apertured electrodes opposite and coaxial with said emissive surface and having opposed axially symmetrical surfaces of revolution, one of said opposed surfaces comprising a frusto-conical portion extending from immediately adjacent the periphery of said emissive surface and flaring outwardly therefrom and an annular portion at the end of said frusto-conical portion remote from said emissive surface, and the other of said opposed surfaces including an annular outer portion and an inner portion conforming to a segment of a sphere.

4. An electron gun as defined in claim 3 wherein said annular portions are substantially parallel and extend substantially normal to the axis of alignment of said emissive surface and said electrodes.

5. An electron gun for electron discharge devices comprising an electron emissive surface conforming to a segment of a sphere, a centrally apertured electrode opposite said surface and coaxial therewith and having an axially symmetrical surface opposed to said emissive surface, which includes an inner portion conforming to a segment of a sphere and concentric with said emissive surface and an outer annular portion extending normal to the axis of coaxiality of said surface and electrode, and a second electrode between said surfaces, coaxial therewith and having an axially symmetrical inner surface which includes a frusto-conical portion extending from immediately adjacent the periphery of said emissive surface and an annular portion extending inwardly from the end of said frusto-conical portion remote from said emissive surface, and substantially normal to said axis, the elements of said frusto-conical portion being inclined outwardly with respect to said axis and at an angle of substantially 67.5 degrees to the normal to said emissive surface at the periphery thereof.

CARLYLE V. PARKER.
ARTHUR L. SAMUEL.