Aug. 22, 1961 R. ADLER 2,997,615

BRILLOUIN FLOW GUN

Filed April 10, 1959

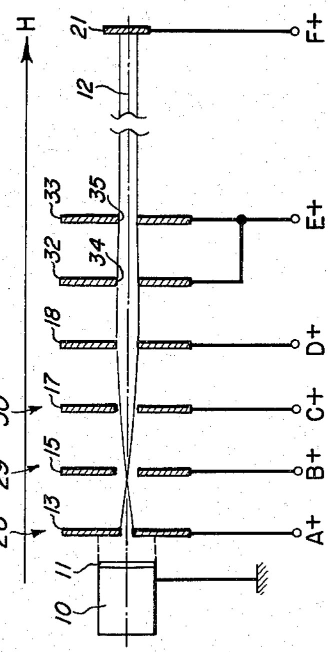

FIG. 2

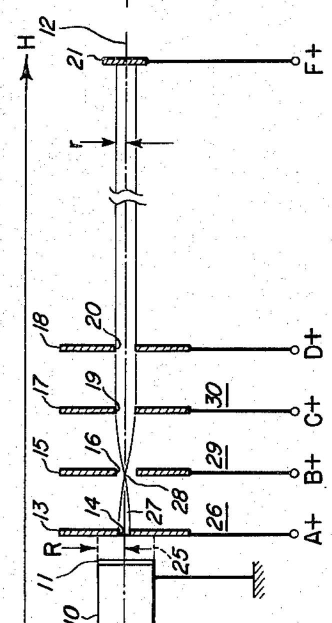

FIG. 1

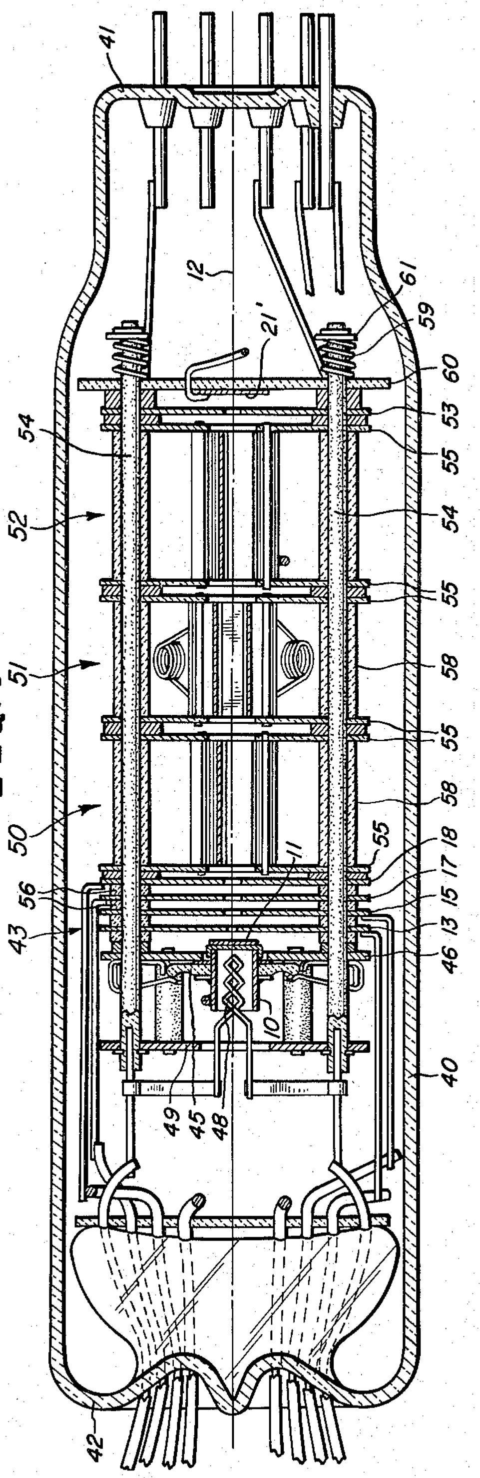

FIG. 3

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BRILLOUIN FLOW GUN

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The present invention relates to an electron gun. More particularly, it has to do with an electron gun for developing an electron beam of accurately controlled constant radius.

Many electron-beam devices require a pencil-like electron beam for their operation. It is especially desirable in certain forms of traveling-wave tubes, electron-beam parametric amplifiers and the like to utilize a beam of small diameter and of constant radius. Such beams have in the past been obtained by the use of often impractically strong focusing fields, axially of the beam flow. By further achieving what is known as "Brillouin flow," a beam of constant radius has been produced with a lesser, more practical strength of focusing field required.

Brillouin flow is a condition in which the beam, if viewable, would resemble a solid rod moving end-wise and rotating about its principal axis, all electrons moving with the same forward velocity along the path. For this condition, the focusing field has a strength just sufficient to balance out the space charge and centrifugal forces tending to diverge the beam.

The classic approach to achieving Brillouin flow has involved critical magnetic shielding, initially producing a beam having no rotational velocity, and then introducing the beam into a magnetic field at a highly critical angle related to the field configuration. After proper introduction of the beam into the field, it is converged to the equilibrium radius (at which inward and outward forces acting on the electrons are in balance) and steps are simultaneously taken to eliminate any radial motion components existing at the point equilibrium is obtained. All this requires high precision of manufacture, complex and bulky equipment, and most careful adjustment.

In principle, Brillouin flow may be obtained with a point source of electrons located within the focusing field. With this approach, the difficult problems associated with entry of a beam into a focusing field are avoided. One suggestion in this general direction has been to provide a cathode structure productive of an electron beam of very small diameter and high density. After passing through an accelerating field, the beam is subjected to a decelerating field in which it is allowed to expand under the influence of space charge forces, while a magnetic field imparts rotational movement to the electrons. Subsequently, the beam is passed through a focusing anode where components of radial motion are reduced, theoretically resulting in a beam in which there is no radial movement. However, this technique requires critical design and adjustment. Moreover, this technique is applicable only where space charge forces are sufficiently large, and even then considerable axial distance is required to permit the space-charge forces to expand the beam to the desired equilibrium radius. In addition, no current adjustment is possible since this would upset the space charge forces; the focusing anode is highly critical as to its potential and location and any misadjustment in this respect leaves an undesired scallop on the beam throughout its travel.

It is therefore a principal object of the present invention to provide a new and improved electron beam of constant radius and which overcomes one or more of the aforenoted deficiencies and difficulties.

Another object of the present invention is to provide

a new and improved electron gun for generating a beam of constant radius while requiring a minimum of space.

A further object of the present invention is to provide a new and improved electron gun for generating a beam of constant radius and which gun is adjustable over a wide range of desired beam currents and is characterized by comparative ease of adjustment and simplicity of operation.

In carrying out the invention, an electron beam of predetermined cross-sectional area is projected along a path and subjected to a magnetic field, in which the beam originates, directed along the path and of predetermined strength. The beam is first accelerated, then strongly constricted after which it expands to a larger cross-sectional area at which the net radial forces acting on electrons in the beam approach zero. The expansion is then gradually tapered off and the electrons are directed parallel to the path with substantially zero radial motion.

An electron gun constructed in accordance with the invention includes a cathode for producing an electron stream of predetermined cross-sectional area. Following the cathode is an accelerating region terminated by a strongly convergent electrostatic lens. This lens includes a first anode, adjacent and positive with respect to the cathode, having an aperture generally centered with respect to the stream and substantially smaller than the latter. Next along the stream is a second apertured anode substantially positive with respect to the first anode. Subsequently, the gun includes a convergent electrostatic lens system including a third apertured anode with its aperture substantially larger than that of said first anode.

The features of the invention which are believed to be novel are set forth with particularity in the appended claims. The organization and manner of operation of the invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings, in which like elements are identified by like numerals in each of the figures, and in which:

FIGURE 1 is a schematic diagram of an electron beam system employing one embodiment of the present invention;

FIGURE 2 is a schematic diagram of an electron beam system employing another embodiment of the present invention; and

FIGURE 3 is a longitudinal cross-sectional view of an electron-beam amplifier tube employing an electron gun constructed in accordance with the present invention.

As illustrated in FIGURE 1, the electron gun includes a cylindrical cathode **10**, one end of which is coated with an emissive material **11**. Cathode **10** is oriented to project electrons generally in a direction along an electron beam path **12**. Spaced a very short distance in front of cathode **10** is a first anode **13** having an aperture **14** centered on axis **12**. Aperture **14** has a cross-sectional area substantially smaller than that of the electron stream emitted from cathode **10**.

Next beyond anode **13** is a second anode **15** having an aperture **16** centered on axis **12**. Following anode **15** are third and fourth anodes **17** and **18** successively spaced along the beam path and having apertures **19** and **20**, respectively.

As indicated in FIGURE 1, the electron beam is eventually intercepted by a collector **21** disposed transversely of axis **12**. In the present embodiment, the entire electron beam path is subjected to a magnetic field H having flux lines flowing parallel to axis **12** as schematically indicated.

In operation, an electron stream having an effective envelope as indicated at **25**, with a radius R, is projected toward and substantially intercepted by first anode **13** which is at a potential positive with respect to cathode 10; anode 13 is coupled to a source A+. Anode 13 is spaced but a short distance from cathode 10. Only a small portion of the beam passes through aperture 14, having an envelope 27. Second anode 15 is at a potential substantially higher than that of first anode 13 and therefore serves as an accelerator; to this end anode 15 is connected to a source B+.

The combination of cathode 11 and anodes 13 and 15 creates a convergent electrostatic lens 26 effectively located at aperture 14 and acting on the beam ahead of anode 15. Convergent lens 26 serves to highly constrict the beam as indicated at point 28, though in practice not actually to a point. Because of the high potential on anode 15, the constriction of the beam is rather violent; after having reached its smallest diameter, the beam diverges quite rapidly.

Anodes 17 and 18, the apertures of which are larger than aperture 14, are at potentials positive with respect to the cathode but substantially smaller than the potential on accelerating anode 15; for this purpose, anodes 17 and 18 are connected to sources C+ and D+, respectively. The combination of anodes 13, 15 and 17 constitutes a divergent electrostatic lens 29 effectively located at aperture 16. Because the beam passes through its smallest cross-section in the immediate vicinity of aperture 16, the lens located at that point exerts comparatively little influence on its path. After passing aperture 16, the stream continues to expand or spread apart so that the electron density is reduced below that in stream 25.

Electrodes 15, 17 and 18 constitute a gradually increasing convergent electrostatic lens system 30 effectively located at aperture 19. This lens system is of a strength and is spaced from anode 15 by a distance sufficient to permit the electrons in the beam to spread nearly to the final desired beam radius r, but no more, and to effect a gradual tapering-off of the divergent action and straighten out the beam envelope to a position parallel with axis 12.

Adjustment of the parallelizing of the envelope is preferably enhanced by the use of a further convergent electrostatic lens of which anodes 17 and 18 and the next following electrode (FIGURE 2 or 3) form a part. To this end, electrode 18 is at a potential intermediate the potentials on anode 17 and the next electrode. Thus, by adjusting the potential of electrode 18, it is possible to effectively shift some of the total refractive power of apertures 19 and 20 at will from one of these to the other, thus gaining an additional measure of control over the final diameter of the beam.

As a result of first constricting the high-density low-velocity electron beam and then spreading the beam within magnetic field H, after which the beam is shaped to its final desired dimension, Brillouin flow is achieved in but a very short distance of electron travel. Moreover, the task of gradually tapering the divergent lens action and then directing the beam parallel to the path with the correct Brillouin radius requires convergent action effectively of exactly the correct strength and precisely at the point at which that radius is achieved. By employing the dual-electrode convergent lens following accelerator anode 15, two independent variables are available for adjustment. This enables most accurate operation while at the same time greatly reducing the precision of mechanical design and manufacture required.

In a typical practical and successful construction, the following dimensions are utilized; they are set forth merely for purposes of illustration since it will be appreciated that many different structures may be employed as the requisite electron lens. Cathode 10 has a diameter of 0.132 inch and its emissive coating is spaced from anode 13 by a distance of .015 inch. Anode 13 has a thickness of 0.005 inch and its aperture has a diameter of 0.012 inch. Anodes 15, 17 and 18 are spaced successively along the beam path at intervals of 0.030 inch and have apertures of 0.030 inch. Collector 21 is spaced from anode 18 by a distance of 3.3 centimeters. This particular gun when operated has been found to produce a beam of constant radius at electrode potentials (with respect to the cathode) on anodes 13, 15, 17 and 18 of about 8, 150, 15 and 7 volts, respectively; accordingly, the accelerator electrode is biased at a potential at least an order of magnitude greater than are the other lens electrodes. Collector 21 is biased with a potential of about 6 volts. In one tube in which this gun is employed, the strength of magnetic field H is approximately 200 gauss; the beam rotates at a rate well below the cyclotron frequency at this field strength. With any particular construction the exact voltages are best determined by a small amount of experimentation to obtain maximum beam transmission with minimum interception by the electrodes of the gun and other elements in the tube, of course excluding anode 13 and collector 21.

In some instances it has been found desirable to eliminate what appear to be a few stray or marginal electrons existing around the envelope surface. To this end a collimating system is added to the electron gun system, as indicated in FIGURE 2. This system includes at least one and preferably a pair of beam-slicer anodes 32 and 33 spaced along the beam path from anode 18. Slicer anodes 32 and 33 have apertures 34 and 35, respectively, centered on axis 12 and of a diameter slightly less than that of aperture 20 in anode 18; for example, in a gun otherwise like that of FIGURE 1 apertures 34 and 35 each have a diameter of 0.016 inch. In operation, anodes 32 and 33 are biased at a potential usually intermediate that of the nearest adjacent other electrodes. Anodes 32 and 33 act to intercept any such marginal or stray electrons while accurately defining the beam envelope surface. Otherwise, the electron gun depicted in FIGURE 2 is identical with that described above with respect to FIGURE 1.

A practical form of a parametric amplifier employing an electron gun constructed in accordance with the present invention is illustrated in FIGURE 3. The amplifier itself is described and claimed in the copending application of Glen Wade, Serial No. 747,764, filed July 10, 1958, entitled "Parametric Amplifiers," and assigned to the same assignee as the present invention. The tube assembly is disposed longitudinally within an elongated envelope 40 through the opposite ends 41 and 42 of which suitable electrical connecting leads project. Disposed near end 42 is an electron gun assembly 43. The electron gun includes tubular cathode 10 supported by a ceramic wafer 45 from a metallic annulus 46 through which an end of cathode 10 freely projects and on which end a cap is disposed and exteriorly coated with electron emissive material 11 which when heated by a heater 48 emits electrons outwardly therefrom. Spaced behind cathode 10 is another metallic annulus 49 forming with annulus 46 a cage substantially confining cathode 10 except for the exposed coating 11. Spaced in front of emissive coating 11 is first anode 13 having its aperture aligned with the axis of cathode 10 and beam path 12. Next beyond the metallic wafer forming anode 13 is accelerator anode 15 in the form of a metal disc also having its aperture centered on beam path 12 to accept and pass the electron beam. Successively spaced beyond accelerator anode 15 are third and fourth anode electrodes 17 and 18 likewise having their apertures centered on beam path 12.

Just beyond the electron gun is a modulator 50 for impressing signal energy upon the electron beam. In the next portion of the beam path outwardly from the electron gun is a signal modulation expander 51 which is followed by a demodulator 52 for removing signal energy from the beam.

On beyond demodulator 52 is an electrode 53 having an aperture centered on beam path 12 and which during operation serves as a suppressor electrode. Finally, the electrode beam is collected by anode 21' which is disposed transversely of beam path 12 behind the aperture in suppressor 53. The entire assembly is supported within envelope 40 by means of four ceramic rods 54 symmetrically disposed about beam path 12 and extending through all of the various apertured electrodes and through suitable insulating discs 55 in which the modulator, expander and demodulator electrodes are secured. The different electrodes are separated by suitable ceramic washers 56 encircling ceramic rods 54 between the different electrodes; discs 55 are separated by similar ceramic sleeves 58. The entire assembly is held tightly together by means of compression springs 59 acting between a collector mounting plate 60 and a washer 61 pinned to ceramic rods 54. Of course, suitable internal leads are brought out from the various electrodes to the terminals projecting through the base presses.

An explanation of the operation of the modulator, expander and demodulator is unnecessary for an understanding of the present invention which is directed solely to the electron gun. Suffice it to say for the present that input signal energy impressed upon the beam in modulator 50 develops waves representing the signal intelligence and at the same time preferably removes noise from the beam. In expander 51 the signal energy is parametrically amplified by subjecting the electrons to a time-variable inhomogeneous field. Demodulator 52 includes an electron coupler, in this case identical with the electron coupler of modulator 50, which derives the amplified signal energy from the beam.

In a successfully operated amplifier constructed as illustrated in FIGURE 3, electron gun 10 emits electrons at a current density of about 100 milliamperes per square centimeter, perhaps 99% of which is intercepted by first anode 13. With the anodes in the gun energized at potentials as described above in the discussion of FIGURE 1, a beam is obtained having characteristics resembling Brillouin flow. Interception of the beam by the deflectors and receptors and other electrodes of the tube is negligible. It may be noted in this respect that the electrodes in the modulator and demodulator define a space for beam travel approximately 0.030 inch in width while the expander electrodes, of which there are four in a quadrupole configuration, form a square 0.080 inch on a side. The lengths of the electron coupler and expander electrodes are 0.400 inch. The apertures in support washers 55 have a diameter of 0.110 inch and the entire assembly is sealed within an envelope one inch in diameter. In actual practice, about six volts is applied to suppressor 53 while collector 21' is biased at a potential of about 200 volts, all voltages discussed being positive with respect to the cathode.

While the electron gun has been described in connection with a parametric amplifier which operates within a magnetic field, it will be readily apparent that the particular electron lens combination is capable of finding specific utility in other electron beam devices. However, it has special significance in the production of a beam within a magnetic field. Since the gun generates a beam of accurately defined and constant cross-sectional area, it is most suitable for employment in a device wherein it is desired to pass the beam closely adjacent active electrodes while at the same time avoiding interception by these electrodes of any portion of the beam in order to avoid the introduction of noise into the signal channel as a result of such interception.

Devices such as certain parametric amplifiers depend for their operation upon the action of individual electrons within the beam. Most efficient operation is obtainable only if all electrons subjected to a given force move simultaneously in the same direction and with the same velocity as a result of that force. This is achieved through use of the present invention since all of the electrons initially have the same forward velocities.

The electron gun may be formed from simple, stamped parts and its tolerances are similar to those of ordinary cathode-ray-tube guns; that is, the tolerances are such as to be well within normal production techniques. Moreover, a fairly large latitude is offered in these respects in that relative adjustment of the different potentials permits compensation of production variations.

While particular embodiments of the invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspects, and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. An electron gun comprising: a cathode productive of an electron stream traveling along a predetermined axis and having a predetermined cross-sectional area; a first anode, adjacent and positive with respect to said cathode, having an aperture on said axis and substantially smaller in cross-sectional area than said stream; a second anode, beyond and substantially positive with respect to said first anode, having an aperture on said axis; and third and fourth anodes, less positive than said second anode but positive with respect to said cathode, spaced successively beyond said second anode and having apertures on said axis and of cross-sectional areas larger than that of said first anode.

2. An electron gun comprising: a cathode productive of an electron stream traveling along a predetermined axis and having predetermined cross-sectional area; a first anode, adjacent and positive with respect to said cathode, having an aperture on said axis and substantially smaller in cross-sectional area than said stream; a second anode, beyond and substantially positive with respect to said first anode, having an aperture on said axis; third and fourth anodes, less positive than said second anode but positive with respect to said cathode, spaced successively beyond said second anode and having apertures on said axis and of cross-sectional areas larger than that of said first anode; and means for subjecting said cathode and anodes to a magnetic field having flux lines parallel to said axis.

3. An electron gun comprising: a cathode productive of an electron stream traveling along a predetermined axis and having a predetermined cross-sectional area; a first anode, adjacent and positive with respect to said cathode, having an aperture on said axis and substantially smaller in cross-sectional area than said stream; a second anode, beyond and substantially positive with respect to said first anode, having an aperture on said axis; third and fourth anodes, less positive than said second anode but positive with respect to said cathode, spaced successively beyond said second anode and having apertures on said axis and of cross-sectional areas larger than that of said first anode; and at least one additional anode, positive with respect to said cathode and spaced beyond said fourth anode, having an aperture on said axis and of a cross-sectional area intermediate that of said first and fourth anodes.

4. An electron gun for projecting a beam of electrons of predetermined constant radius, along a predetermined axis and comprising: means including a cathode for producing and accelerating an electron stream parallel to and including said axis and of predetermined cross-sectional area; a convergent electrostatic lens effectively located at and including a first anode adjacent and positive with respect to said cathode and having an aperture on said axis and substantially smaller in cross-sectional area than said stream; a second anode having an aperture on said axis and substantially positive with respect to and spaced beyond said first anode; and a convergent electrostatic lens system effectively located at and including a third anode having an aperture on said axis of an area larger than that of said first anode aperture and substantially nega-

tive with respect to and spaced beyond said second anode, but positive with respect to said cathode.

5. An electron gun for projecting a beam of electrons of predetermined constant radius along a predetermined axis and comprising: means including a cathode for producing and accelerating an electron stream parallel to and including said axis and of predetermined cross-sectional area and current density; a convergent electrostatic lens effectively located at and including a first anode adjacent and positive with respect to said cathode and having an aperture on said axis and of a cross-sectional area substantially smaller than said predetermined cross-sectional area; means, including a second anode having an aperture on said axis and spaced beyond and substantially positive with respect to said first anode, for permitting expansion of the envelope of said beam approximately to said predetermined radius and thereby substantially reducing said current density; and means, including a convergent electrostatic lens system effectively located at and including a third anode substantially negative with respect to said second anode and having an aperture on said axis of an area larger than that of said first anode aperture and spaced beyond the second anode, for aligning said envelope parallel with said axis.

6. An electron gun for projecting a beam of electrons of predetermined constant radius along a predetermined axis and comprising: means including a cathode for producing and accelerating an electron stream parallel to and including said axis and of predetermined cross-sectional area and current density; a first convergent electrostatic lens effectively located at and including a first anode adjacent and positive with respect to said cathode and having an aperture on said axis and of a cross-sectional area substantially smaller than said predetermined cross-sectional area; means, including a second anode having an aperture on said axis with said second anode spaced beyond and substantially positive with respect to said first anode, for permitting expansion of the envelope of said beam to said predetermined radius and thereby substantially reducing said current density; means, including a convergent electrostatic lens system effectively located at and including a third anode substantially negative with respect to said second anode and spaced therebeyond with an aperture on said axis and larger in area than said first anode aperture, for aligning said envelope parallel with said axis; means for collecting said electron beam subsequent to passage through said lens system; and means for subjecting said electron stream throughout said path between said cathode and collecting means to a magnetic field having flux lines parallel to said axis.

7. An electron gun for projecting a beam of electrons of predetermined constant radius along a predetermined axis and comprising: means including a cathode for producing and accelerating an electron stream parallel to and including said axis and of predetermined cross-sectional area and current density; a first convergent electrostatic lens effectively located at and including a first anode adjacent and positive with respect to said cathode and having an aperture on said axis and of a cross-sectional area substantially smaller than said predetermined cross-sectional area; means, including a divergent electrostatic lens effectively located at and comprising a second anode having an aperture on said axis with said second anode spaced beyond and substantially positive with respect to said first anode, for permitting expansion of the envelope of said beam at least to said predetermined radius and thereby substantially reducing said current density; means, including a convergent electrostatic lens system effectively located at and including a third anode having an aperture on said axis larger in area than said first anode aperture and spaced beyond and substantially negative with respect to said second anode, for aligning said envelope parallel with said axis; and means, including at least one additional anode spaced beyond said lens system and having an aperture on said path with a radius equal to said predetermined radius, for intercepting only any outer circumferential portion of said stream of a radius greater than said predetermined radius.

8. An electron gun for projecting a beam of electrons, of predetermined constant radius, along a predetermined axis and comprising: means including a cathode for producing and accelerating an electron stream parallel to and including said axis and of predetermined cross-sectional area; a convergent electrostatic lens effectively located at and including a first anode adjacent and positive with respect to said cathode and having an aperture on said axis and substantially smaller than said stream; a second anode having an aperture on said axis and at a positive potential with respect to and at least an order of magnitude greater than that on said first anode; and a convergent electrostatic lens system beyond said second anode and effectively located at and including a third anode having an aperture on said axis larger in area than said first anode aperture.

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