

July 17, 1962

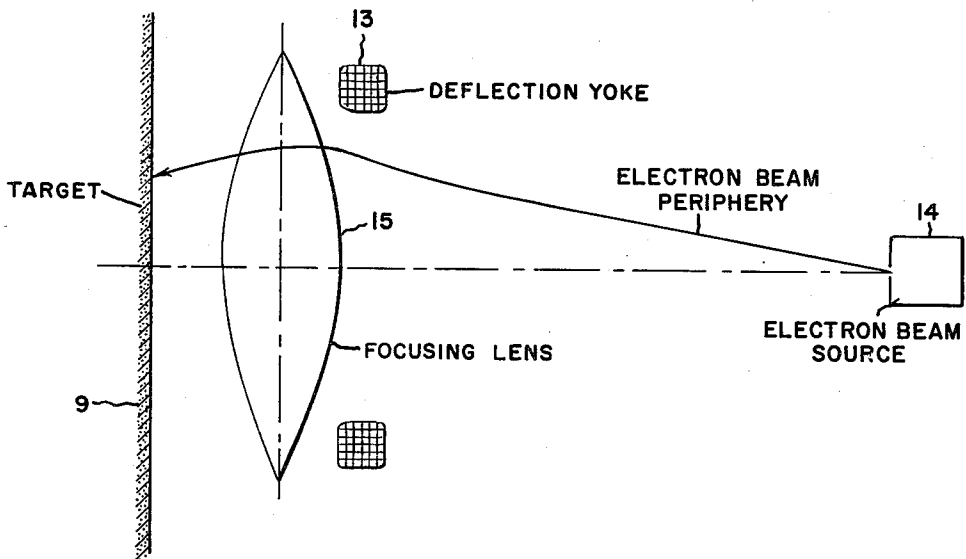
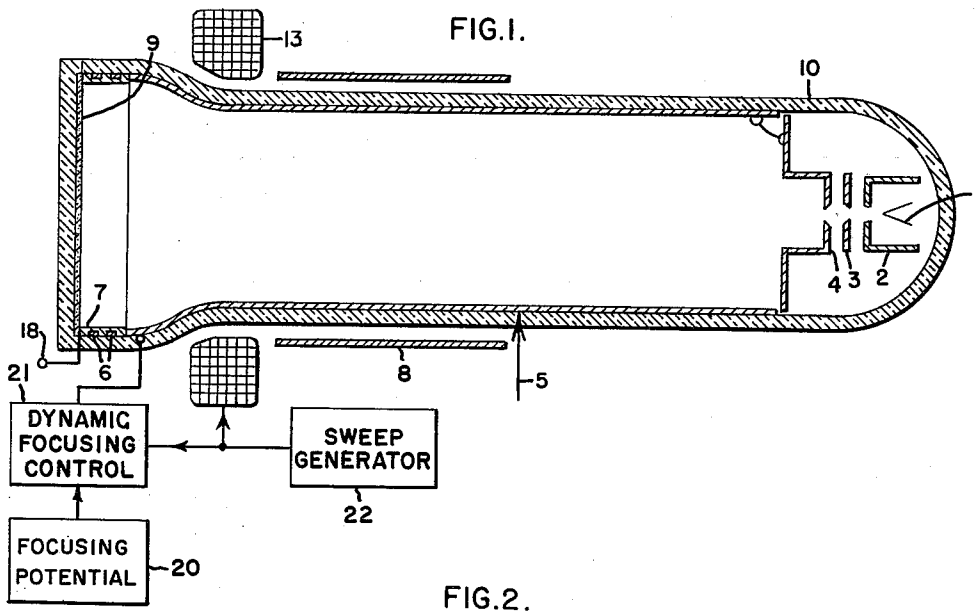
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3,045,140

HIGH RESOLUTION ELECTRON DISCHARGE DEVICE

Filed Dec. 31, 1959

3 Sheets-Sheet 1



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FIG. 3.

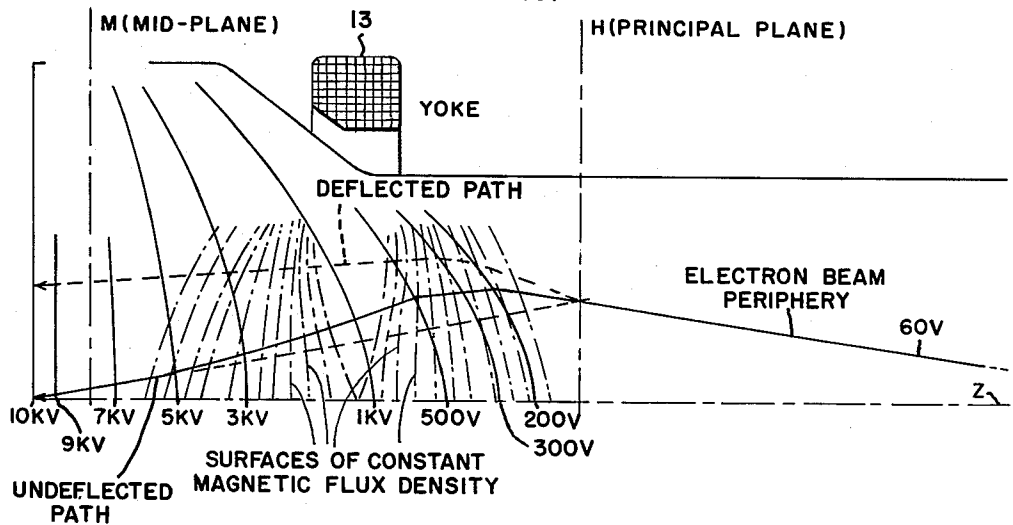
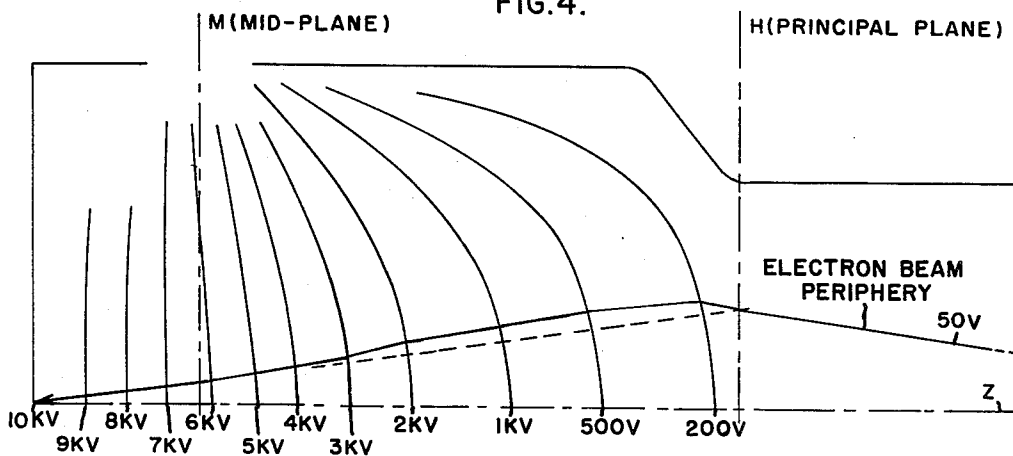


FIG. 4.



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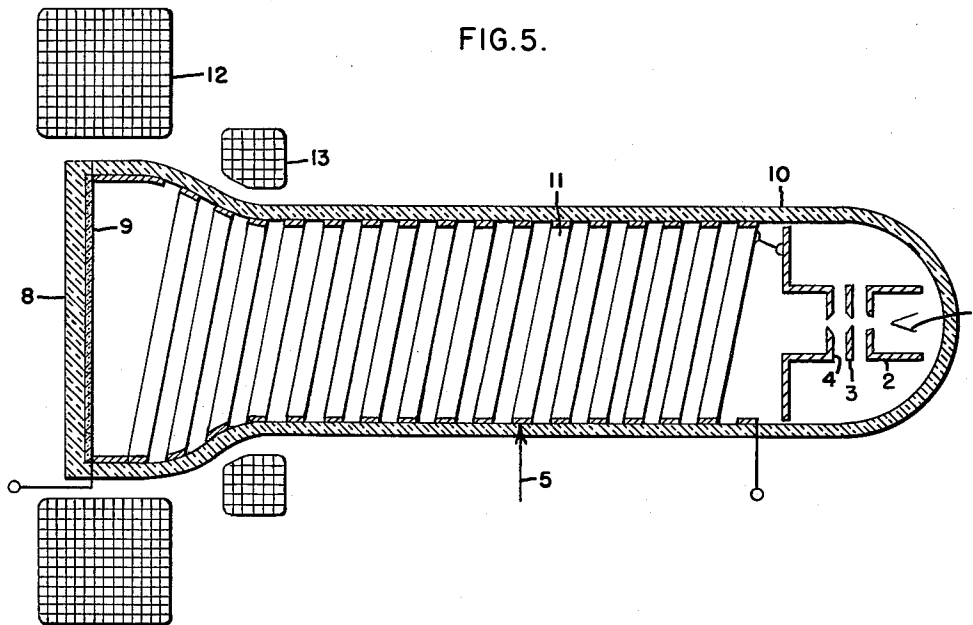
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HIGH RESOLUTION ELECTRON DISCHARGE DEVICE

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3 Sheets-Sheet 3



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3,045,140

HIGH RESOLUTION ELECTRON DISCHARGE DEVICE

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18 Claims. (Cl. 313-85)

The invention relates to an electron discharge device, and more particularly to a cathode ray type device in which high resolution is obtained.

In a conventional cathode ray device, such as a cathode ray tube, display device or electron microscope, the beam deflection system is placed between the target and the focusing lens of the gun. The function of the focusing lens in all such devices is to produce an image of the cathode or crossover upon the target. With such an arrangement, it is difficult to obtain any substantial geometrical demagnification of the image produced on the target i.e. small spot size. The demagnification in the cathode image, from geometrical considerations, is inversely proportional to the distance between the focusing lens system and the target and is directly proportional to the distance between the cathode or the crossover, and the lens system. Practical difficulties in electrical systems have tended to make most workers avoid the solution apparently suggested by optical considerations. One such view has been the desire to segregate the focusing lens action from the deflection action, so as to minimize the aberrations. Applicant has found that these and other such difficulties are not insurmountable, and thus has taken a distinct departure from the prior art approach.

A principal object of the present invention is to provide an electron discharge device having a highly focused electron beam.

A further object of the present invention is to provide a novel lens arrangement in a cathode ray device producing, at the target a very small spot.

In accordance with the illustrated embodiments of my invention, a high resolution cathode ray gun is obtained through a novel arrangement of gun elements. The deflection means are intermediate the target and a lower gun structure producing a slightly divergent beam. A novel focusing lens is positioned proximate to the target and between the deflection means and the target for focusing the beam upon the target. The arrangement of the elements is made in such a manner that the deflection and focusing fields substantially overlap. These measures, and others to be adverted to below, lead to a highly focused beam producing a small spot size upon the target.

The invention will be better understood from the following description taken in connection with the accompanying drawings and its scope will be pointed out in the appended claims:

FIGURE 1 is an illustration of one embodiment of the invention utilizing an electrostatic focusing lens;

FIGURE 2 is a diagrammatic illustration of the basic gun configuration of FIGURES 1 and 5;

FIGURE 3 is a plot of the equipotentials in the electrostatic field produced by the optimum arrangement of the focusing lens and the magnetic deflection field provided by the embodiment of FIGURE 1 illustrating its focusing effect on the electron beam;

FIGURE 4 is a plot of the equipotentials in the electrostatic field produced by a non-optimum arrangement of the focusing lens illustrating its focusing effect on an electron beam; and

FIGURE 5 is an illustration of one embodiment of the invention utilizing magnetic focusing.

In providing a cathode ray gun in accordance with the present invention, the following general elements sche-

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matically illustrated in FIGURE 2 are required: An electron beam source 14 including an emission system and prefocusing lens such as provided by electrodes 1-4 in FIGURE 1 producing a diverging electron beam. The resulting beam is deflected by means such as the deflection yoke 13 shown in FIGURE 2. Principal focusing is provided by a focusing lens 15 in a manner shown schematically in FIGURE 2 by placing the focusing lens near the target 9. The electrical lens is illustrated as physically placed between the deflection yoke and the target in accordance with the invention. (The illustration is not intended to show the geometrical properties of the system.)

In the deflection and focusing system shown in FIGURE 2, the focusing member is positioned between the target and the deflection member along the axis of the tube and the deflection and focusing fields developed thereby overlap. The resulting lens system provides high demagnification of the cathode image and, therefore, a high resolution spot. From geometrical considerations it can be seen that to increase demagnification the principal plane of a focusing lens system should be brought close to the image and removed from the object, that is, close to the target and remote from the cathode or crossover. Since a properly designed focusing lens will focus both deflected and undeflected electrons back to the lens axis, certain factors are required. Instead of the normal separated relationship between the lens and deflecting means, the elements must be positioned in such a manner that the focusing field and the deflection field substantially overlap. This arrangement provides successful operation, although the required interaction is just the opposite from the customary approach.

In an embodiment utilizing an electrostatic focusing lens shown in FIGURE 1 several features must be considered. Attention is directed to the drawings wherein FIGURES 3 and 4 represent a plot of equipotentials in solid lines produced by an electrostatic lens made by the optimum arrangement shown in FIGURE 1 and a non-optimum arrangement, respectively. These plots were obtained from traces in a tilted electrolytic tank in a conventional manner using a single principal plane. By a comparison of FIGURES 3 and 4, it is seen that as the midplane, i.e., physical center of the focusing lens, is placed closer to the conductive target, the diverging portion of the accelerating lens is strongly suppressed and the focusing action is accordingly strengthened. The strong lens action is necessary because of the beam divergence caused by the mutual repulsion of the electrons which drift at low velocity from the emission system. The suppression of the lens on the target side of the midplane is evident by the flattening of the equipotentials accompanied by further penetration of the focusing lens field towards the cathode giving rise to curving of the equipotentials toward the lower gun. The lens field shape is further improved by the electrode configuration obtained by placing the flaring portion of the tube neck near the target as shown in FIGURES 3 and 1 which shifts the principal plane 20% closer to the target. Any further substantial shortening of the distance simultaneously weakens the lens. The resolution is also improved as a result of bringing the deflection field closer to the lens and providing a greater overlap with the focusing field as is made possible by the modification of the lens configuration.

The magnetic deflection fields produced by the yoke 13 are shown by dashed lines representing constant flux density. As can be seen from the field plots for the illustrated configuration, the electron beam as it is accelerated by the focusing field will be deflected, primarily in the region between the plane of the yoke and the principal plane where the electrons have relatively low ve-

locities. Since the focusing lens field is relatively short, it is desirable that the deflection field also be short, and that the deflection means be placeable in relatively close proximity to the target. These considerations dictate a physically short deflection means, usually rested close to the flaring portion of the tube.

A practical application of the invention to a short cathode ray tube operable at 10 kv. is shown in the embodiment of FIGURE 1. The resulting tube produces a beam current on the order of 10 μ a. with a resolution of over one thousand lines per inch over a maximum raster of an inch. The tube enclosure 10 is a glass envelope 6½ inches in length (parameters for a 9 inch device are given in parenthesis in the succeeding pages) with a circular cross section having a diameter varying from about 2 inches at the lower gun to 3 inches at the opposite screen.

The lower gun structure is a tetrode emission system. The cathode 1 is of the hairpin tungsten type which was chosen on the basis of atmospheric stability as required for a demountable system. For some applications, other types such as oxide coated cathodes would be more suitable. In front of the cathode is a control grid 2 with an aperture of .031 inch (or substantially smaller for a plane cathode surface). A screen 3 and a prefocusing grid 4 are mounted in front of the control grid. Further suitable dimensions are as follows: the cathode may be a .004 inch diameter wire positioned approximately .012 inch from the control grid 3. The screen grid 3 may have an aperture .036 inch in diameter and may be positioned .008 inch from the control grid 2. The prefocusing grid 4 has a .043 inch aperture .008 inch from the prefocusing grid 3.

Grids 2 and 3 together form a strong "immersion" type lens. The strength of the immersion lens is indicated by a cutoff voltage of about -110 volts on the control grid 2 which is normally operated, for example, at 20 v. above cutoff. Grids 3 and 4 are operated at 550 (1200) and 100 (200) volts, respectively, and together form a prefocusing lens. The prefocusing lens is kept weak in order that the principal plane of the focusing lens system will not be substantially shifted toward the object thus reducing demagnification. The function of the prefocusing lens is mostly to prevent the electron beam from striking the sides of the tube. The tube neck is provided with a conductive coating 5 which is connected to the grid 4. The conductive coating 5 is a colloidal graphitic dispersion designated Aquadag, a trademark of the Acheson Colloids Corporation. The target is formed by a conductive aluminized transparent phosphor screen 9 coated on the envelope 10 and connected to terminal 18. The face plate of the tube is preferably flat with a circular perimeter. The conductive coating forming a portion of the target is thus planar and of a precise circular outline. Proximate the screen 9, a lens gap is formed by a band of chromic oxide 7. Intermediate the ends of the band 7, a plurality of rings of Aquadag are provided as shown at 6.

When the electrode coating 5 is maintained at 100 volts and the screen end of the coating 7 is maintained at 10 kv. a short focusing lens is formed in the vicinity of the screen. The chromic oxide coating 7 provides a high resistance gap across which there will be a potential gradient. The voltage distribution is made more symmetrical by the Aquadag rings 6 since these conductive rings provide a plurality of "floating" conductors which form equipotential circles. The arrangement is particularly advantageous for a short lens, but it is applicable to a lens of any length where good symmetry is desired.

Magnetic deflection is employed in the illustrated embodiments. A toroidal ring yoke two inches in diameter and one-half inch thick is arranged as shown schematically in FIGURE 2. The yoke is of the type developed by R. B. Gethmann as described in the IRE, BTR Transactions, February 1958, No. 1, volume BTR-4, "Deflec-

tion Distortions Contributed by the Principal Field of a Ring Deflection Yoke." In the present embodiment, the full deflection angle as measured from the midplane of the yoke may be approximately 40° with a field strength as low as a fraction of a gauss. The useful deflection is primarily obtained in the first portion of the focusing lens field where the velocities of the electrons are low. The apparent deflection plane is thus shifted more toward the emission means than in a system wherein the electrons are not accelerated during deflection. The localization of the magnetic field is improved by a cylindrical isolating shield 8 placed around the tube neck and extending from the yoke toward the emission means for shielding the beam from the deflection lens until it enters the principal deflection field. An electrostatic deflection system such as the deflection developed by K. Schlesinger as described in Proceedings of the IRE, May 1956, volume 44, No. 5 ("Progress in the Development of Post-Acceleration and Electrostatic Deflection") may also be used.

For proper focusing, the focusing voltage during deflection is dynamically varied by about 20% in accordance with deflection displacement. A dynamic focusing control element 21 varies the focusing anode potential supplied by element 20 in accordance with the sweep generator current from element 22. Since the focusing voltage determines the velocity of the electrons entering the deflection yoke, the deflection nonlinearly may be corrected, if substantial, by a further dynamic deflection correction.

Typical performance data are compiled in the following table. Measurements were made on a transparent phosphor target using the shrinking raster method. The total demagnification calculated from the current density in the spot and the peak cathode current density in the center of the emitting area is between 4½ and 6 times. The geometrical demagnification calculated from the field plot is in excess of 2 times. The average current density in the spot at the target is about 5 amp./cm.² as compared with standard spot current densities of 50-100 ma./cm.² in conventional cathode ray tubes.

Typical Performance of Electrostatically Focused Device at 10 Kilovolts

Gun Length in Inches	Beam Current in Microamperes	Spot Size in Microns	Maximum Raster in mm.	Resolution in Lines
6½	1	14	25	1,700
6½	5	18	25	1,400
6½	10	25	25	1,000
9	1	5	20	4,000
9	5	<10 (7.5)	20	2,600
9	10	14	20	1,400

One may observe that the definition falls at higher beam currents and that it is improved in the longer tube, which permits higher demagnification.

An embodiment utilizing magnetically focused guns is shown in FIGURE 5. Magnetic focusing has the theoretical advantage that the position of the principal plane of the lens is not effected by the potential of the target. As shown in the drawings, the gun can be constructed with the emission system producing a diverging beam identical with that shown in FIGURE 1 but with the anode in this case electrically coupled to a helical high resistance coating 11. The coating 11 may be of Aquadag. It provides a gradual potential gradient from 2 kv. at the anode 4 to 10 kv. at the target 9. The resulting electrostatic field is substantially axial and produces minimum focusing action. The primary focusing is produced by coil 12 producing an axially directed field of a few hundred oersteds and deflection is produced by yoke 13 resulting in a system basically equivalent to the diagrammatic system of FIGURE 2.

As in the other embodiment, the deflection yoke 13 is

placed so as to provide a field overlapping with the field of the focusing coil 12. Since the focusing yoke should be of high power, and close to the target for optimum demagnification, the yoke must also be placed close to the target. If one removes the deflection yoke from the target so that it exhibits a substantial deflection effect upon the beam prior to entry into the focusing field, resolution is reduced.

In general, the goal of increased demagnification may best be achieved by use of a physically short focusing element, providing a rather short, strong focusing field in combination with a similarly physically short deflection member, providing a short deflection field. When these two factors are optimized, the final elements may be placed close to the target allowing the emission elements to be placed at a relatively greater distance, thus giving the spacial relationship productive of high demagnification.

The principal plane of electrostatic lens arrangements, such as that shown in FIGURE 3, in most practical arrangements, lies to the emission side of the deflection means. In every case, whether electromagnetic or electrostatic focusing is employed, the principal plane of the focusing lens will be close to the deflection means. The primary consideration is that the deflection means must not be separated from the focusing lens to such an extent that substantial overlap of their field is not attained.

While the invention has been shown applied to a cathode ray tube having a phosphor coated target, the invention may also be applied in applications where a highly defined beam is desired at the plane normally occupied by the target but wherein the target is no longer of a phosphor coated design. In applications where the target is desired to be nonconductive, the focusing may be achieved by means of the magnetic focusing lens and the desired terminal beam velocity achieved as by suitable accelerating means applied to the lateral walls of the tube as, for instance, the helical conductive element illustrated in FIGURE 5. In applications where the target may be conductive, either the electrostatic or magnetic focusing means may be employed. In this sense, the invention may be treated as disclosing a high resolution electron gun.

While the fundamental novel features of the invention have been shown and described as applied to illustrative embodiments, it is to be understood that the invention is broad in scope. All modifications, substitutions and omissions obvious to one skilled in the art are intended to be within the spirit and scope of the invention as defined by the following claims.

What is claimed is:

1. An electron discharge device comprising: an evacuated tube; emission means for providing a divergent beam of electrons at one end of said tube; a target surface upon which said beam impinges at the other end thereof and spaced from said emission means; deflection means close to said target providing a deflection field for causing said beam to regularly scan over said target; and lens means interposed between said deflection means and said target for creating a substantially uniform, demagnifying field in the deflection region adjacent the surface of the target for focusing said beam thereon.

2. An electron discharge device comprising: an evacuated tube; emission means for providing a divergent beam of electrons at one end of said tube; a target surface upon which said beam impinges at the other end thereof and spaced from said emission means; deflection means close to said target providing a deflection field for causing said beam to regularly scan over said target; means interposed between said target and the extremity of said deflection field remote from said target for accelerating said electron beam as it passes through said deflection field and for focusing said divergent beam upon the surface of said target.

3. An electron discharge device comprising: an evacuated tube; emission means for providing a divergent beam of electrons at one end of said tube; a target surface upon

which said beam impinges at the other end thereof and spaced from said emission means; deflection means close to said target providing a deflection field in the vicinity thereof for causing said divergent beam to regularly scan over said target, and focusing means positioned beyond said deflection means, on the side thereof toward said target providing a focusing field in the region of said target and extending through said deflection field.

4. An electron discharge device according to claim 3, wherein the deflection means is positioned in the vicinity of the principal plane of said focusing means.

5. An electron gun discharge device comprising: an evacuated tube of circular cross section; emission means for providing a low velocity divergent beam of electrons at one end of said tube; a circular substantially plane conductive target upon which said beam impinges spaced from said emission means at the other end of said tube; a conductive coating on said tube extending in proximity to said conductive target and having the near edge thereof lying in a plane parallel to said target and forming in cooperation therewith an electrostatic focusing lens for focusing said beam upon said target; and deflection means close to said target for producing a substantial deflection field in the converging portion of the focusing lens field.

6. The electron discharge device of claim 5 including: a coating of high resistance material on said tube making continuous electrical connection between said target and said conductive coating.

7. The electron discharge device of claim 6 including: at least one conductive ring making continuous electrical contact with said high resistance coating lying in an intermediate plane parallel to the planes of said target and of said electrode edge.

8. The electron discharge device of claim 5 wherein said tube is provided with a neck extending into proximity to the target and flaring therefrom to said target, the conductive coating thereon tending to confine said focusing field.

9. The electron discharge device of claim 5, wherein said deflection means includes a magnetic yoke; said discharge device further comprising means for shielding said divergent beam from the deflection field of said yoke to the point where the beam enters the focusing lens field.

10. The electron discharge device of claim 5, wherein said deflection means includes a magnetic yoke, said discharge device further comprising means for shielding said divergent beam from the deflection field of said yoke to approximately the point where said beam passes the principal plane of said focusing lens.

11. The electron discharge device of claim 5, wherein said deflection means are positioned in the vicinity of the principal plane of the focusing lens.

12. An electron discharge device comprising: an evacuated tube; emission means for providing a divergent beam of electrons at one end of said tube; a conductive target surface at the other end thereof and spaced from said beam forming means; a narrow band of high resistance material coated around said tube and contacting said target; a conductive coating in contact with said band of high resistance material around said tube, said target, band and coating arranged in such a manner as to produce, when energized, an electrostatic focusing lens proximate to said target having a suppressed diverging portion and deflection means arranged intermediate said target and the principal plane of the focusing lens.

13. An electron discharge device comprising: an evacuated tube; emission means at one end of said tube providing a divergent beam of electrons; a conductive target surface at the other end thereof and forming one electrode of a two electrode electrostatic focusing lens; a second electrode member cylindrical in shape coaxial with said tube and spaced from said target surface to form a short constant width lens gap therebetween; and deflection means arranged intermediate said focusing lens and

said emission means in such a manner as to deflect electrons in the first part of said focusing lens.

14. An electron discharge device comprising: an evacuated tube; emission means for providing a low velocity divergent beam of electrons at one end of said tube, a conductive target upon which said beam impinges spaced from said emission means at the other end of said tube, a conductive coating on said tube extending into proximity with the outer perimeter of said conductive portion of said target, and forming in cooperation therewith an electrostatic focusing lens in proximity to said target for focusing said beam upon said target, and deflection means producing a deflection field in the converging portion of the field produced by said focusing lens.

15. An electron discharge device comprising: an evacuated tube; emission means at one end of said tube for providing a divergent beam of electrons; a target surface at the other end of said tube; deflection means intermediate said emission means and said target surface, an electrostatic focusing lens defined by spaced conductive members applied to the surfaces of said tube, and electrically connected by a coating of high resistance material on said tube; and at least one conductive ring making continuous electrical contact with said coating for providing an equipotential circle to improve the focusing lens symmetry.

16. An electron discharge device comprising: an evacuated tube; emission means for providing a divergent beam of electrons at one end of said tube; a substantially plane conductive target upon which said beam impinges spaced from said emission means at the other end of said tube; a magnetic focusing coil positioned with the plane of said coil parallel and proximate to said target and forming an axially directed lens field in the region of said target for focusing said beam upon said target; and deflection means close to said target for producing a substantial deflection field in the converging portion of said focusing lens field.

17. The electron discharge device of claim 16 including means for producing an electrostatic field between the target and emission means directed axially of the tube and providing essentially planar equipotential surfaces for accelerating the electron beam.

18. An electron discharge device comprising: an evacuated tube; emission means for providing a divergent beam of electrons at one end of said tube; a substantially plane conductive target upon which said beam impinges spaced from said emission means at the other end of said tube; a magnetic focusing coil positioned with the plane of said coil parallel and proximate to said target and forming an axially directed lens field in the region of said target for focusing said beam upon said target; deflection means close to said target for producing a substantial deflection field in the converging portion of said focusing lens field, and means for producing an electrostatic field between the target and emission means directed axially of the tube and providing essentially planar equipotential surfaces for accelerating the electron beam comprised of a helical coating of conductive material on said tube and coaxial therewith.

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