April 2, 1968 S. HARRISON 3,376,449

ELECTROSTATIC QUADRAPOLE LENS ASSEMBLY WITH TRANSVERSE INTERMEDIATE TERMINATION ELEMENTS OF RESISTIVE MATERIAL JOINING TOGETHER THE QUADRAPOLE ELECTRODES FOR PREVENTING BEAM ABERRATION

Filed Jan. 20, 1967 2 Sheets-Sheet 1

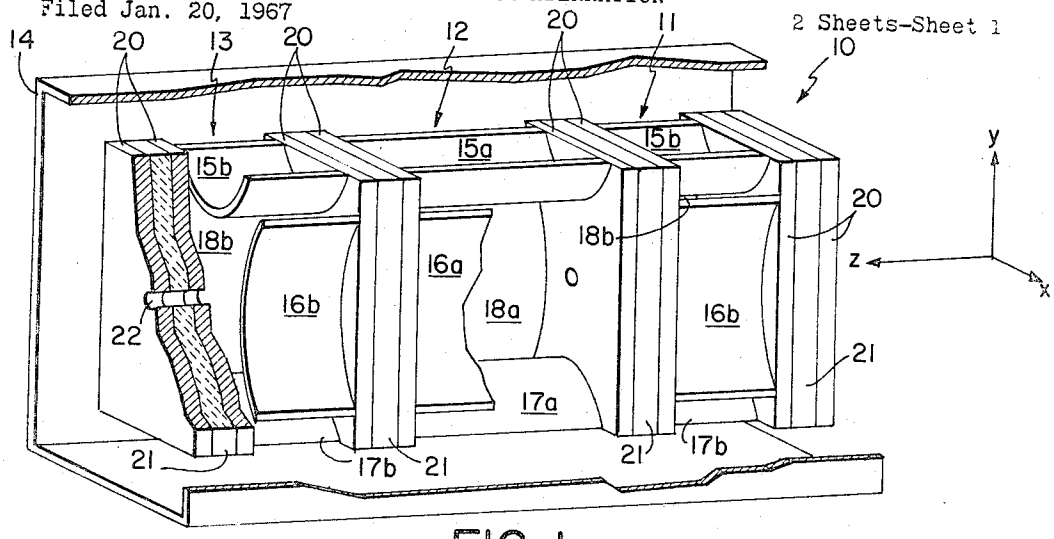


FIG. 1

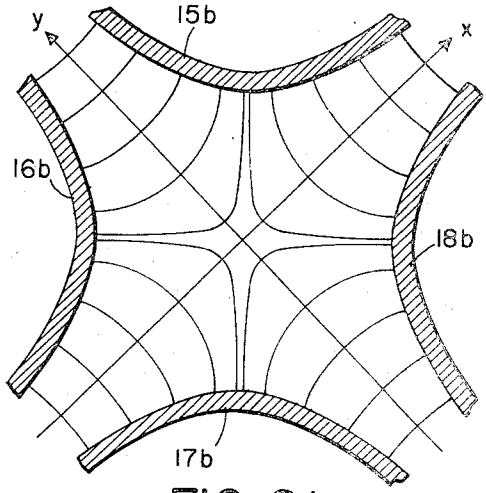


FIG. 2b

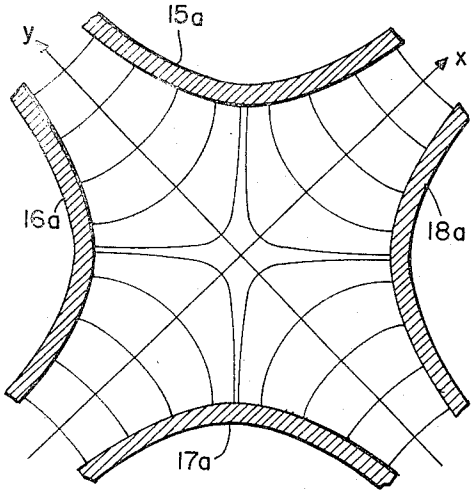


FIG. 2a

INVENTOR
STANLEY HARRISON
BY Francis J. Thornton
INVENTOR

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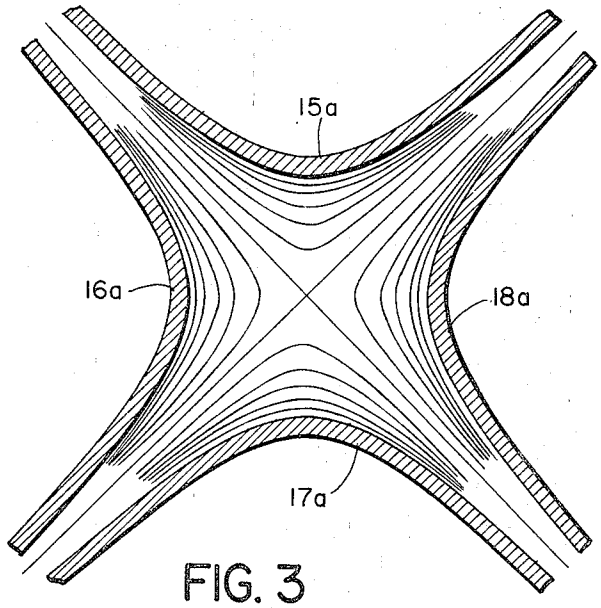


FIG. 3

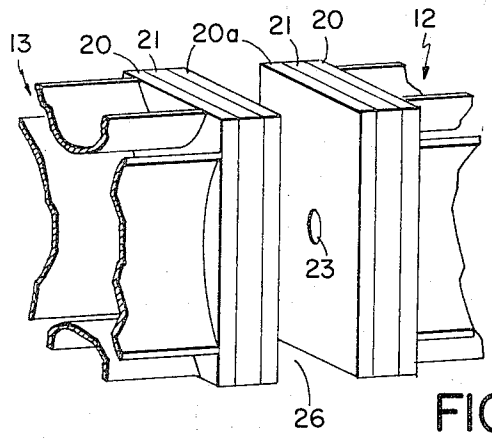


FIG. 4

INVENTOR
STANLEY HARRISON
BY Francis J. Thornton
ATTORNEY

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Stanley Harrison, Bedford, Mass., assignor to Ion Physics Corporation, Burlington, Mass., a corporation of Delaware

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ABSTRACT OF THE DISCLOSURE

This invention teaches that the end effect aberrations of strong focusing lens can be reduced by providing each lens with an apertured termination of uniform sheet resistance. Preferably the termination must be thin and have a high resistivity.

Background of the invention

This invention relates generally to means for manipulating charged particles and more particularly to a novel, strong focusing lens for charged particle beams, which has reduced end-effect aberrations.

It is well known that, in electrostatic and magnetic quadrapole lenses large end-effect aberrations occur when the active components (poles or electrodes) separation is large compared to the lens length. In an effort to reduce such aberrations the prior art attempted to set the component separation just sufficient to pass the beam. However, it was soon apparent that stray charge effects, due to surface charging of insulating films, such as oxides, found on the component surfaces, have a perturbing effect of a magnitude in inverse proportion to the component separation. This means that if such a film having a certain breakdown strength is found on the component surface then for a given lens length and separation the created surface charges become the overwhelming resolution disturbing effect. To reduce this spurious effect on the focusing field it is necessary that the component separation be enlarged. Larger component separations have the further benefit in that it requires much less precision in the component shape.

However, this increase in spacing has a serious drawback in that the end effect aberration increases monotonically with the spacing and these end-effect aberrations have a serious effect on the focusing of charged particle beams.

Thus until the advent of the present invention it was necessary to arrive at a compromise between component separation and end-effect aberrations to obtain the best beam situation for the desired application.

Summary of the invention

The present invention is thus directed towards a strong focusing lens in which the end-effect aberrations are comparable to that of a lens whose component spacing is as small as the beam size. This is realized in the present invention even though the component separation is significantly larger than the beam diameter.

A lens system built using the principles of the present invention further has the advantage that less precision is required in the component shape.

Broadly speaking these and other objects, advantages and features are obtained in such strong focusing lens by providing an apertured element, against the ends of each set of components to create a preferred field distribution between the components.

Description of the drawings

The features and advantages of the present invention can be more fully appreciated from the following description taken in conjunction with the accompanying drawing wherein

FIGURE 1 shows a partly broken away view of a quadrapole triplet utilizing the novel features of the present invention;

FIGURE 2*a* shows the field pattern between the electrodes of the central lens;

FIGURE 2*b* shows the field pattern between the electrodes of the end lenses;

FIGURE 3 shows the equipotential pattern between the electrodes;

FIGURE 4 shows a modification of the invention.

Description of the preferred embodiments

Referring now to FIGURE 1 there is shown a partly broken away perspective view of an electrostatic quadrapole triplet lens system **10** which comprises three quadrapole lenses **11**, **12** and **13** all of which are maintained inline and enclosed in a single housing **14**. For purposes of simplicity and clarity the insulating support elements which may be of porcelain, for example, between the lens sections and the housing are omitted from the drawing. Each lens consists of four shaped electrodes electrically connected by suitable leads (not shown) to a power supply (not shown). When power is applied to the electrodes they become energized such that electric fields on accompanying equipotential lines are established between them. A simplified portrayal at such fields and equipotential lines are shown in FIGURES 2*a*, 2*b* and 3.

Owing to the transverse nature of their active fields such lenses exhibit excellent properties when the central component of the beam being handled is parallel to axis Z and where the focusing results only from a differential effect; for the same energy of incident particles and large voltage their convergence can be much stronger than other lenses. Hence they are known as strong focusing lenses. However, such quadrapoles are strongly astigmatic, being convergent in only one radial direction, and divergent in the radial direction perpendicular to that one. That is such units simultaneously converge and diverge a charged particle beam passing therethrough. This situation can be corrected however by grouping on the same axis Z a series of lenses. A series of three lenses is known as a triplet. It is however necessary that the electrodes in each lens be polarized such that the beam converges ultimately at the focus point. In particular, this is accomplished by alternation of polarity of each lens with respect to its adjacent lens. This rotation of polarity is achieved in the triplet of FIGURE 1, for example, by biasing the electrodes **15***a* and **17***a* positive and electrodes **16***a* and **18***a* negatively and simultaneously biasing the electrodes of the end lenses **11** and **13** such that electrodes **15***b* and **17***b*, of each end lens, negatively and electrodes **16***b* and **18***b* positively.

Normally such quadrapole lens systems will have objectional end effect aberrations if large component separations are used or surface charge induced aberrations if small separations are used, as discussed previously.

In the present invention, however, these end-effect aberrations are reduced to almost negligible amounts by the expediency of placing an apertured element against the electrode ends in each lens. In the electrostatic lens shown in FIGURE 1 this control is achieved by placing sheets **20** of uniform sheet resistance across the ends of each electrode set. Because for most practical electrostatic lens the sheet resistance required average about 10^9 to 10^{10} ohms per square, the sheets **20** must be extremely thin, high resistivity layers. A layer of silicon which averages

about 5000 A. thick is particularly suitable for this application. However, because such thin films are not self-supporting it is necessary that an insulating medium **21** be provided as a support for the sheets **20**. The most practical medium for this purpose is a glass sheet whose thickness is sufficient to fill the gap between the lenses when it is coated with layers of the high resistivity material **21**.

Because the silicon and glass are impervious to the charged particle beam which is to be manipulated by the lens system it is necessary to provide an axial aperture **22** in each laminate of glass and silicon. The diameter of the aperture **22** is made just large enough to admit the beam between the electrodes.

Because this aperture **22** is a discontinuity in the field terminating sheet **20** some aberration occurs around it and extends through it. However, any such aberration is minimal especially when the aperture **21** is very small when compared to the electrode separation. Such aberrations around the aperture can be further reduced if the beam diameter spaced electrodes are simulated by conforming the aperture and by providing metal hyperbolic lines with external resistances therebetween.

In any event the preferred embodiment should have the aperture **22** lined with metal which is connected to the film **21**. This liner prevents the build up of surface charge on the dielectric in the aperture and thus minimizes any effect on the beam during its passage through the aperture.

In the event long lens element separations are desired or required the apparatus would be similar to that shown in FIG. 4. In this view only are such lens element separation shown such as between lens **13** and **12**. This separation is such that each lens is coupled to a resistive plate **20** laid down on an insulator **21**. Each plate **20** is coupled via a metalized aperture **23** to plane parallel resistive plates **20***a* which are separated from one another by an air gap **26**. If the plates **20***a* are grounded the gap **26** is field free and thus preferable from a hole charging point of view.

The invention could further be used to greatly increase the usable lens aperture enabling any number of small beams to be brought through a large single lens, by using matched input and output orifice arrays in the termination sheets.

I claim:

1. An electrostatic quadrapole lens system for manipulating charged particle beams comprising a quadrapole lens arranged to produce a focusing effect on a beam of charged particles, said lens consisting of two sets of opposed, curved, conductive electrodes wherein the improvement comprises an apertured electrostatic field termination element, across the ends of said lens which couples the set of electrodes in said lens to one another thereby reducing the end effect aberrations of said lens.

2. The lens system of claim **1** wherein said termination element comprises a sheet of resistive material having uniform sheet resistance.

3. The lens system of claim **1** wherein said termination element comprises a sheet of insulating material, having a first planar side and a second opposing side, and thin films of resistive material on each of said sides.

4. The lens of claim **3** wherein said thin films have sheet resistances of between 10^9 ohms per square and 10^{10} ohms per square.

5. The lens of claim **3** wherein said thin films are interconnected by a metallic lined aperture passing through said films and said insulating sheet.

6. The lens of claim **1** wherein said aperture in said element has the approximate shape of said electrode sets.

7. The lens of claim **1** wherein each element has a multiplicity of inline apertures.

8. The lens of claim **1** wherein the termination element provided on said lens is separated from an element on adjacent lens by an air gap.

9. The lens of claim **8** wherein each element is provided with a metallic coating on the side facing said air gap.

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JAMES W, LAWRENCE, *Primary Examiner.*

V. LAFRANCHI, *Assistant Examiner.*