

[54] ELECTRON BEAM APPARATUS

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[22] Filed: May 23, 1973

[21] Appl. No.: 363,024

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[52] U.S. Cl. 250/398, 250/492 A

[51] Int. Cl. H01j 37/00

[58] Field of Search 250/492, 492 A, 310, 311;
219/121 EB; 313/84

[56] References Cited

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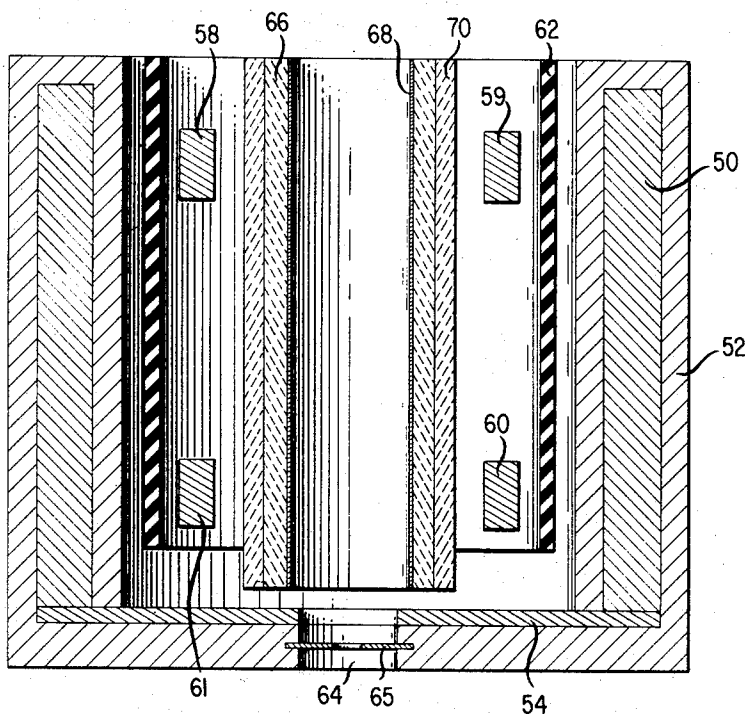
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ABSTRACT

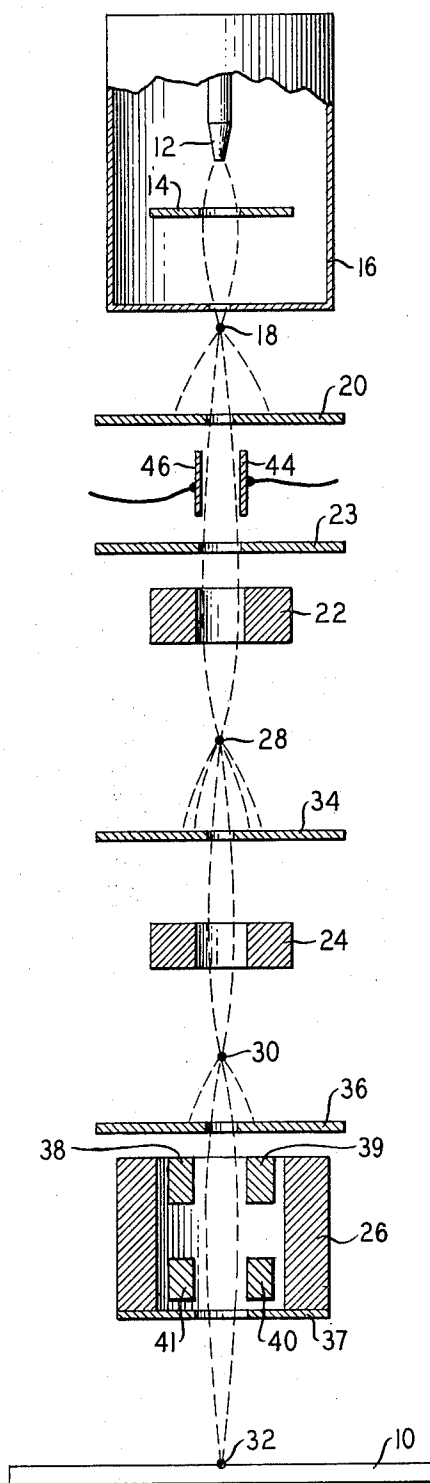
Various components of a conventional electron beam apparatus are modified to achieve precise high-speed deflection and blanking of the electron beam. The modified apparatus is designed to be included, for example in a high-resolution automated electron beam exposure system for integrated-circuit fabrication.

2 Claims, 4 Drawing Figures



SHEET 1 OF 3

FIG. 1
(PRIOR ART)



SHEET 2 OF 3

FIG. 2
(PRIOR ART)

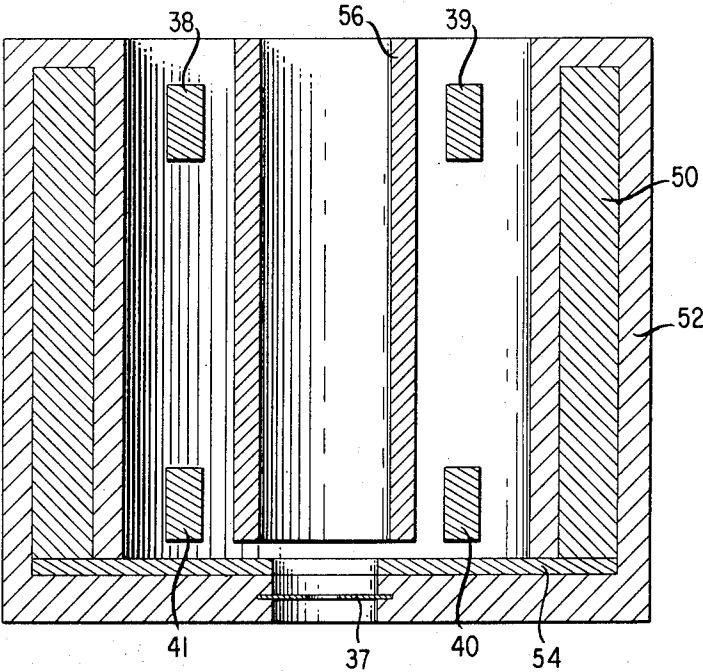
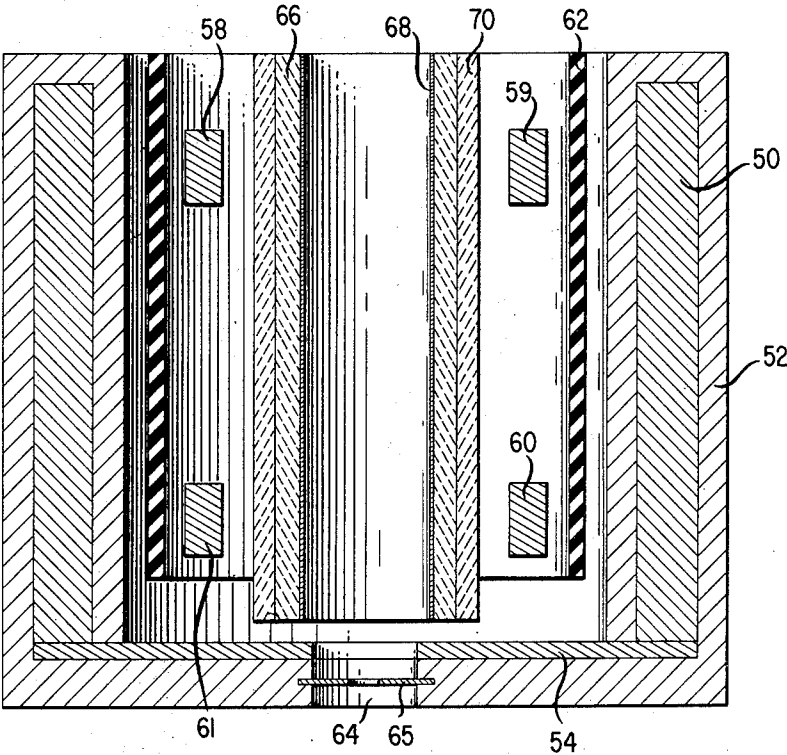
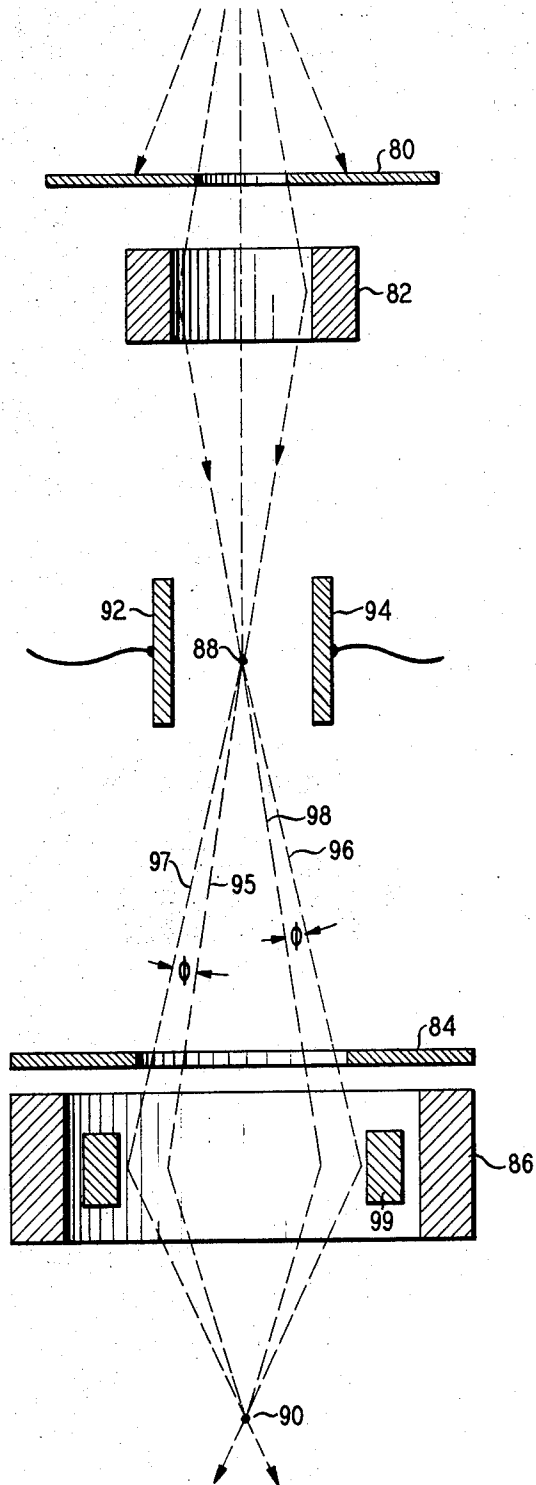


FIG. 3



SHEET 3 OF 3

FIG. 4



ELECTRON BEAM APPARATUS

BACKGROUND OF THE INVENTION

This invention relates to electron beams and more particularly to an improved apparatus in which electron beams are selectively controlled in a reliable high-speed manner.

The high-resolution and excellent depth-of-focus capabilities of an electron beam make such a beam an attractive tool for inclusion in an automated lithography system designed to make subminiature electronic devices. By controlling the beam in a highly accurate and high-speed manner it is possible, for example, to make masks or to write directly on an electron resist-coated wafer of silicon to fabricate extremely small and precise low-cost integrated circuits.

Apparatus for providing electron beams of the general type required for electron lithography is known. See, for example, Chapter 3 of *Scanning Electron Microscopy* by P. R. Thornton, Chapman and Hall Ltd., London, 1968, and *The Bell System Technical Journal*, Vol. 49, No. 9 (November, 1970), pages 2,077-2,094. The response time and accuracy of these known arrangements have, however, been found to be inadequate for inclusion in an electron beam exposure system designed to make high-precision submicrometer devices in a reliable high-speed manner.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is an improved electron beam apparatus.

More specifically, an object of this invention is an improved electron beam apparatus characterized by highly accurate high-speed deflection and blanking capabilities.

Briefly, these and other objects of the present invention are realized in a specific illustrative embodiment thereof that comprises a modification of a standard electron beam apparatus. The electromagnetic deflection unit of the standard apparatus is modified in several ways to improve the response time thereof. These modifications are directed to reducing skin-effect and eddy-current phenomena arising from operation of the deflection unit. In addition, the electrostatic beam blanking plates of the conventional apparatus are repositioned to minimize writing-spot-position errors during the blanking operation as well as during stray electron charging and discharging of the blanking plates. Also writing-spot-position drift caused by stray electron charging of other surfaces in the apparatus is minimized by restricting the beam diameter and by centering the beam on the final aperture of the apparatus.

BRIEF DESCRIPTION OF THE DRAWING

A complete understanding of the present invention and of the above and other objects thereof may be gained from a consideration of the following detailed description of a specific illustrative embodiment thereof presented hereinbelow in connection with the accompanying drawing in which:

FIG. 1 is a schematic representation of a prior-art electron beam apparatus,

FIG. 2 shows in more detail the lower portion of the prior-art apparatus of FIG. 1,

FIG. 3 depicts a modification of FIG. 2 made in accordance with the principles of the present invention, and

FIG. 4 illustrates other modifications made in accordance with this invention.

DETAILED DESCRIPTION

A conventional apparatus for controllably moving a small-diameter electron beam to any designated position on a work surface 10 is schematically depicted in FIG. 1. The apparatus includes an electron source 12 (for example a hot filament), a grid 14 and an accelerating anode 16. Illustratively, the anode 16, which comprises a cylindrical metal cap with a circular aperture in the bottom flat end thereof, is maintained at ground potential. In that case the source 12 is maintained at a relatively high negative potential (for example 10 kilovolts below ground).

The trajectories of electrons supplied by the source 12 of FIG. 1 are represented in the drawing by dashed lines. In the vicinity of the aforementioned aperture in the anode 16 these trajectories go through a so-called crossover or source-image point 18 which, typically, is 50-100 micrometers in diameter. Thereafter the electron paths diverge from the point 18, as indicated in FIG. 1. Some electrons are blocked from further transit through the apparatus by a first apertured plate 20 that serves to protect various downstream elements in the apparatus from being contaminated by electron bombardment.

To provide at the surface 10 of FIG. 1 an electron beam or probe having a diameter of say about 0.5 micrometers, it is necessary to demagnify the crossover point 18. Typically this is done by successively projecting the beam through several demagnifying lenses. In FIG. 1, three such lenses 22, 24, and 26, each comprising an annular coil, are shown. Elements 22 and 24 constitute first and second condenser lenses, respectively, and element 26 comprises an objective lens.

Each of the lenses represented in FIG. 1 causes the electron beam trajectories passing therethrough to converge at a subsequent crossover point. Thus point 28 is shown downstream of the lens 22, crossover point 30 follows the lens 24, and spot 32 on the work surface 10 is in effect the crossover or image point formed by the objective lens 26.

The lenses 22, 24 and 26 of FIG. 1 are preceded by apertured plates 23, 32 and 36, respectively. In addition, a final apertured plate 37 is included in the apparatus. As indicated in the drawing, some electrons are intercepted by each of these additional plates.

Four additional coils 38 through 41 are schematically represented in FIG. 1. These coils, which are typically displaced 90° from each other around the path of the electron beam and connected in series in a push-pull arrangement, serve to electromagnetically deflect the electron beam to any desired position in a specified sub-area of the work surface 10. Access to other sub-areas of the surface 10 may be gained by mechanically moving the surface by means of a computer-controlled micromanipulator (not shown).

In the standard electron beam apparatus shown in FIG. 1, beam blanking is achieved by means of a pair of conventional facing plates 44 and 46 which are typically positioned adjacent to the beam in a region in which the beam has a considerable cross section. By applying an appropriate blanking potential to these

plates, the entire beam is electrostatically deflected to impinge upon a nonapertured portion of the plate 23. In this way the electron beam is blocked during prescribed intervals of time from appearing at the surface 10.

The lower part of the prior art apparatus represented in FIG. 1 is depicted in more detail in FIG. 2. In particular, FIG. 2 shows the details of the objective lens 26 and of various elements directly associated therewith.

The objective lens 26 of FIG. 1 is seen in FIG. 2 to include annular coil 50, iron pole-piece 52 surrounding the coil 50 and an apertured circular brass plate 54 that serves to maintain a prescribed gap in the pole-piece 52.

The final or bottommost apertured plate 37 of FIG. 1 is seen in FIG. 2 to comprise an apertured circular plate 37 situated very closely to the pole-piece 52.

In addition, FIG. 2 diagrammatically shows the deflection coils 38 through 41 which constitute a double-deflection system employing an upper and lower pair of coils for deflection in each of two orthogonal directions. The upper coils 38 and 39 are wound in series in push-pull to encompass the electron beam path of the depicted apparatus. In turn, the upper coils are connected in series with the series-wound push-pull-connected lower coils 40 and 41 around the electron beam path. The coil connections are so arranged that current flowing through the coils causes the electron beam to be deflected in an opposite sense of each pair. The ratio of turns in the upper and lower coils is such that the central ray of the deflected beam always passes through the center of the apertured plate 37 which is also the center of the objective lens 26.

The deflection coils 38 through 41 of FIG. 2 are wound outside an electrically grounded metal screening tube 56 that serves to prevent electrons from charging the deflection coils and insulating materials in the vicinity thereof.

The frequency response of the deflection system of the prior-art electron beam apparatus shown in FIGS. 1 and 2 is limited by a number of factors. One of these is the resonant frequency of the deflection coils 38 through 41. This frequency should approximate the deflection bandwidth of interest which, in the case of the improved apparatus to be described below, is about 500 kilohertz. The resonant frequency of a typical prior art deflection system is, however, only about 100 kilohertz.

The high-frequency response of the aforescribed deflection system is also limited by the screening tube 56. The thickness of the typical prior-art tube approximates or exceeds the so-called skin depth of most metals at 500 kilohertz. Accordingly the high-frequency (500 kilohertz) electromagnetic deflection fields generated by the coils 38 through 41 are not able to effectively penetrate the tube 56 to deflect the electron beam within a prescribed range of distances.

The frequency response of the prior-art deflection system is also deleteriously affected by eddy currents induced by the deflection fields in the iron pole-piece 52 and in the brass plate 54. The effect of these eddy currents is to introduce into the process of establishing a given deflection angle a time constant of about 10 milliseconds (corresponding to the decay time of the eddy currents). Such a delay may be undesirable or intolerable when the deflection system is used in a ran-

dom-access mode for precise high-speed electron lithography.

In accordance with the principles of the present invention, the deflection system and associated components shown in FIG. 2 have been modified. The modified structure is represented in FIG. 3. Elements 50, 52 and 54 of FIG. 3 may be identical in structure and function to the correspondingly numbered elements described above in connection with FIG. 2.

The deflection coils 58 through 61 of FIG. 3 are wound with fewer turns than the aforescribed deflection coils. In this way the resonant frequency of the coils was increased to about 900 kilohertz. In addition, the lower deflection coils 60 and 61 of FIG. 3 were moved upward in the apparatus relative to their position in FIG. 2. As a result, the magnitude of the eddy currents induced in the brass plate 54 also was significantly reduced over that measured in the FIG. 2 structure.

To alleviate the aforescribed problem caused by eddy currents induced in the iron pole-piece 52, a ferrite cylinder 62 is included in FIG. 3 as a magnetic shield to isolate the deflection coils 58 through 61 from the pole-piece 52. To minimize astigmatic effects on the electron beam, the cylinder 62 is positioned as far as possible from the pole-piece gap 64.

The screening tube included in the modified arrangement of FIG. 3 comprises a dielectric cylinder 66 (for example made of glass) whose inner surface is coated with a thin metal film 68. This film comprises, for example, a layer of silver approximately one micrometer thick which is much less than the skin depth of the metallic coating at 500 kilohertz. As a result, the depicted screening tube is virtually transparent to high-frequency magnetic fields generated by the deflection coils 58 through 61.

Advantageously, the cylinder 66 is slideably positioned inside another dielectric tube 70 to which the deflection coils are attached. In this way, should the metal film 68 become contaminated after a period of use, the screening tube 66 can be easily removed and replaced with another such unit.

The response time of the modified deflection system shown in FIG. 3 was measured to be less than 1 microsecond as compared to 5 microseconds for the prior-art system represented in FIGS. 1 and 2.

The electrostatic plates 44 and 46 shown in the prior art apparatus of FIG. 1 are capable of being operated to achieve high-speed blanking of the electron beam. Unfortunately, however, the plates typically exhibit an electron charging and discharging effect that is undesirable. Stray charges that accumulate on these plates may cause the beam to be deflected at a time when no deflection is desired. As a result, off-center positioning of the beam takes place thereby producing a so-called writing-spot-position error on the surface 10 (FIG. 1). For this reason the beam blanking arrangement shown in FIG. 1 is not satisfactory for precise high-speed electron lithography.

In accordance with the principles of the present invention, a modified electrostatic beam blanking structure is provided, as shown diagrammatically in FIG. 4. In the modified structure the effects of blanking plate charging and discharging are reduced to a tolerable level.

FIG. 4, which shows a portion of an improved electron beam apparatus made in accordance with this in-

vention, includes a first apertured plate 80, a first condenser lens 82, a second apertured plate 84 and a second condenser lens 86. The first lens 82 focuses electrons (dashed lines) to a first crossover point 88, whereas the second lens 84 focuses electrons to a second crossover point 90. Finally, the crossover point 90 is imaged by the objective lens (shown in FIG. 3) to form the writing spot on an associated writing plane.

In accordance with the present invention, a pair of opposed beam blanking plates 92 and 94 is centered or approximately centered on the crossover point 88 of FIG. 4. The first apertured plate 80 limits the size of the electron beam so that the unblanked beam passes completely unhindered between the blanking plates 92 and 94 and through the second apertured plate 84 (which comprises the blanking aperture-stop). (But in one illustrative embodiment the beam still overfills the final aperture, of the objective lens, not shown, which remains the limiting aperture of the entire optical system).

Advantageously, the positional relationship shown in FIG. 4 between the blanking plates 92 and 94 and the crossover point 88 should remain fixed or approximately fixed. As a practical matter, therefore, no adjustment or minimal adjustment of the first condenser lens 82 should occur once the depicted relationship is established. (Adjustment of the lens 82 causes the crossover point 88 to move longitudinally.) Adjustments in the apparatus may still, of course, be made by varying the properties of the downstream lenses.

Since the electron-optical properties of the first condenser lens 82 of FIG. 4 preferably remain fixed, it is feasible, for example, to make that lens from a permanent magnet.

If no crossover point is easily accessible in an electron beam apparatus for installation thereabout of a pair of beam blanking plates, additional lenses (for example, permanent magnet ones) may be added to the apparatus. In that way crossover points may be established for association with such blanking plates.

Assume that a small voltage is applied across the plates 92 and 94 of FIG. 4, the effect of such a voltage is to deflect electrons in such a way that rays 95 and 96 emerging from the crossover point 88 appear to be rotated about the point 88 through an angle Φ to rays 97 and 98, respectively. If Φ is small, all electrons pass through the plate 84 and are again focused to the crossover point 90 by the lens 86. Significantly, neither the position nor the current density of the point 90 is changed. If the beam still completely fills the final aperture (not shown), the position and current density of the writing spot on the writing surface similarly remain unaffected by any small voltage appearing across the blanking plates.

As the voltage applied to the blanking plates 92 and 94 of FIG. 4 is increased, the deflection angle Φ increases and the electron beam is partially intercepted by the plate 84. However, the remaining electrons passing through the plate 84 are still focused at the crossover point 90. Only the current density, but not the position of the writing spot, is thereby changed. If the applied blanking voltage is further increased, the beam is further intercepted by the plate 84 and finally is entirely blanked. The charging effect of the apertured plate 84 is made insignificant by deflecting the beam in its blanked condition to a region of the plate 84 that is

relatively far removed from the aperture therethrough.

From the discussion above it is clear that if electron charging and discharging of the beam blanking plates 92 and 94 of FIG. 4 result in a small additional deflecting field across the plates, the effect on the position and current density of the final writing spot is inconsequential. Another advantage of positioning the plates 92 and 94 as shown in FIG. 4 is that the voltage applied across the plates for blanking or unblanking the beam need not be well regulated. This, of course, simplifies the design of the associated drive circuitry for the blanking plates.

The illustrative beam blanking unit described above and shown in FIG. 4 operated with a 10 nanosecond response time and was observed to exhibit minimal problems arising from electron charging.

A symmetrical electron charging of the various apertured plates included in a conventional electron beam apparatus is a persistent problem which manifests itself as position drift of the writing spot and as beam astigmatism.

In accordance with the principles of the present invention, the problems stemming from electron charging are minimized. Illustratively, this is accomplished by initially restricting the beam diameter by means of a first apertured plate 80 (FIG. 4) so that the beam will just fill the final aperture in the plate 65 (FIG. 3). In one specific illustrative embodiment, the first aperture has a diameter of 0.1 millimeters, the final aperture has a diameter of 0.4 millimeters and the writing spot has a diameter of 0.5 micrometers. Under these conditions the unblanked beam passes unintercepted (except during blanking) through all intermediate apertures. Consequently, one need be concerned only with the charging effects of the first plate 80 and the final plate 65. Since the beam blanking plates 92 and 94 (FIG. 4) are located after the first plate, the beam strikes the first plate continuously as long as the apparatus is energized. The effect of the first plate on the beam reaches a stabilized condition soon after the electron source starts emitting, and can be appropriately compensated. The charging effect of the final plate 65 shown in FIG. 3 may, however, depend on the duty cycle of the beam on-time. The beam drift due to this effect can be reduced to a tolerable level if the beam is aligned to be always centered on the final aperture during unblanked intervals. As a result of such centering, any charge accumulation that does occur on the final plate will be symmetrical in nature and therefore cause minimal deflections on the writing surface.

Centering of the beam with respect to the final aperture may be accomplished, for example, by adding to the apparatus an additional deflection coil located in any position downstream of the topmost apertured plate 80 (FIG. 4) and before the final aperture. Advantageously, a centering coil 99 is added to the apparatus at the position shown in FIG. 4. Alignment of the beam is effected by passing an appropriate direct current through the coil 99. In actual operation, with a properly centered beam achieved by means of the coil 99, spot position drift in the writing plane was measured to be less than 0.1 micrometers as the duty cycle of the beam on-time was varied from 1 percent to 100 percent.

Finally, it is to be understood that the above-described arrangements are only illustrative of the application of the principles of the present invention. In

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accordance with these principles numerous other structures may be devised by those skilled in the art without departing from the spirit and scope of the invention. For example, although emphasis herein has been placed on locating the beam blanking plates at the first crossover point **88** (FIG. 4), it is to be understood that these plates may be centered or approximately centered with respect to any other crossover point in an apparatus of the type described herein. Moreover, in an apparatus in which the beam traversing the objective lens is well centered, the final aperture plate may be eliminated. In this way electron charging of the final plate is alleviated altogether.

What is claimed is:

1. In combination in an electron beam apparatus, a source of a beam of electrons, means including a plurality of successive lenses for successively demagnifying said source, each of said lenses having a crossover point respectively associated therewith, means for deflecting said beam to any specified point on a work surface that includes the crossover point associated with the last one of said successive lenses, aperture means interposed between said source and said work surface, electrostatic beam blanking means interposed between said source and said aperture means and centered with respect to a crossover point for caus-

8

ing said beam to be directed through an aperture in said aperture means and at said work surface when no blanking potential is applied to said blanking means and to be deflected to be blocked by said aperture means when a blanking potential is applied to said blanking means,

said deflecting means comprising deflection coils positioned between one of said successive lenses and an adjacent portion of the path traversed by said electron beam,

a cylindrical ferrite shield interposed between said coils and said one lens,

and a cylindrical screening tube interposed between said deflection coils and an adjacent portion of the path traversed by said electron beam, said tube comprising a dielectric cylinder having coated on the inner surface thereof a conductive layer whose thickness is substantially less than the skin depth of the metal at the desired bandwidth of the deflecting means.

2. A combination as in claim 1 wherein the last one of said successive lenses includes a circular opening through which the electron beam is directed at said work surface,

and further including an additional coil positioned adjacent to a portion of the path traversed by said electron beam for centering said beam with respect to said opening in said last lens.

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