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(54) Title: APPARATUS AND METHODS FOR HIGH-RESOLUTION ELECTRON BEAM IMAGING

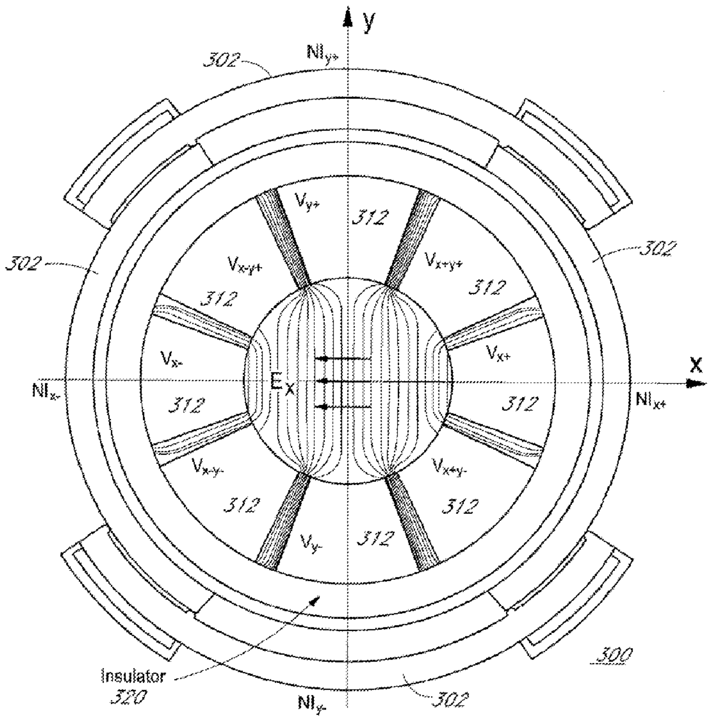

FIG. 3

(57) **Abstract**: One embodiment relates to an apparatus for high-resolution electron beam imaging. The apparatus includes an energy filter configured to limit an energy spread of the electrons in the incident electron beam. The energy filter may be formed using a stigmatic Wien filter and a filter aperture. Another embodiment relates to a method of forming an incident electron beam for a high-resolution electron beam apparatus. Another embodiment relates to a stigmatic Wien filter that includes curved conductive electrodes. Another embodiment relates to a stigmatic Wien filter that includes a pair of magnetic yokes and a multipole deflector. Other embodiments, aspects and features are also disclosed.

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APPARATUS AND METHODS FOR HIGH-RESOLUTION ELECTRON BEAM IMAGING

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to apparatus and methods for electron beam imaging.

Description of the Background Art

Electron beam imaging systems typically use an electron beam column to scan an electron beam across a region of a substrate surface to obtain image data. The present disclosure provides novel and inventive apparatus and methods for high-resolution electron beam imaging.

SUMMARY

One embodiment relates to an apparatus for high-resolution electron beam imaging. The apparatus includes an energy filter configured to limit an energy spread of the electrons in the incident electron beam. The energy filter may be formed using a stigmatic Wien filter and a filter aperture.

Another embodiment relates to a method of forming an incident electron beam for a high-resolution electron beam apparatus. The method includes limiting an energy spread of the electrons in the incident electron beam using an energy filter.

Other embodiments relate to a stigmatic Wien filter. In one embodiment, the stigmatic Wien filter includes two pairs of magnetic cores and two pairs of curved electrodes. In another embodiment, the stigmatic Wien filter may include two pairs of magnetic yokes and a multipole deflector.

Other embodiments, aspects and features are also disclosed.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view depicting an implementation of an electron beam column in accordance with an embodiment of the invention.

FIG. 2 is a top-down view of a first implementation of a stigmatic Wien filter in accordance with an embodiment of the invention.

FIG. 3 is a top-down view of a second implementation of a stigmatic Wien filter with two pairs of magnetic saddle yokes in accordance with an embodiment of the invention.

FIG. 4 shows angles of interest in relation to the two pairs of magnetic saddle yokes of the second implementation in accordance with an embodiment of the invention.

FIG. 5 is a perspective view of a pair of magnetic saddle yokes in accordance with an embodiment of the invention.

FIG. 6 is a graph of total spot size, and factors contributing thereto, as a function of convergent angle for a computer-simulated electron beam column under reference conditions.

FIG. 7 is a graph of total spot size, and factors contributing thereto, as a function of convergent angle for a computer-simulated electron beam column with incident-beam energy filtering using a stigmatic Wien filter in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

FIG. 1 is a cross-sectional view depicting an implementation of an electron beam column **100** in accordance with an embodiment of the invention. The components of the electron beam column **100** may be housed in one or more vacuum chambers.

As shown in FIG. 1, the electron beam column **100** may include, among other components, an electron gun system which includes an electron source **102**, a gun lens **106**, and a beam limiting aperture (BLA) **104**. The electron source **102** may include a cathode which emits electrons that are accelerated through an opening in an anode. The BLA **104** limits the angle of the emitted electrons to the source emission angle α, and the gun lens **106** focuses the emitted electrons that pass through the BLA **104** so as to form the incident electron beam. The gun lens **106** is generally configured below the beam-limiting aperture **104** and is typically an electrostatic lens, though it may be a magnetic lens in alternate embodiments. In one embodiment, the electron beam that is generated by the electron gun system is a telecentrically-illuminating electron beam.

In accordance with an embodiment of the invention, the electron beam column **100** may further include an incident-beam energy filter **108**. As described further below, such an incident-beam energy filter **108** may be advantageously used to substantially reduce the total spot size of the electron beam on the target substrate.

In one embodiment, as shown in FIG. 1, the incident-beam energy filter **108** may be implemented using a stigmatic Wien filter (SWF) **110** in combination with an energy filter aperture (filter aperture) **112**. The electron beam from the electron gun system is focused onto the filter aperture **112** by the SWF **110**. The electrons with energies within a small energy spread (for example, $\Delta E < 50$ meV) are influenced in a balanced manner by the electrostatic and magnetic forces of the SWF **110** such that they travel along the optical axis of the column **100**. However, the electrons with energies outside of the small energy spread (for example, greater than 50 meV from the mean energy of the beam) are deflected by the SWF **110** due to the difference of deflection capabilities between the electrostatic and magnetic forces for different beam energies. The deflected electrons with energies outside of the small energy spread are blocked by the energy filter aperture **112**. In other words, the SWF **110** may be configured to deflect electrons **114** having energies outside of a small range of energies such that they are blocked by the energy filter aperture **112** while allowing electrons **116** having energies within the small range of energies to pass through the energy filter aperture **112**.

The beam crossover at the energy filter aperture **112**, which is formed by the SWF **110**, becomes the object of a first condenser lens **118**. The beam current after the energy filter aperture **112** may be further selected by a column aperture **120**. The beam passing through the column aperture **120** may then be focused by a second condenser lens **122**. The objective lens **124** may then further focus the beam so as to converge the energy-filtered electron beam at a convergent angle **β** to form a beam spot on the target substrate **126**. A substantial difference between the image formation of the column **100** in FIG. 1 and a conventional column is that the electron density is substantially reduced below the filter aperture **112** due to less beam current in a same or similar volume.

In addition, a beam stigmator **119** may be configured to compensate or correct for stigmatism which may have been introduced by the SWF **110**. The compensation preferably results in an astigmatic (i.e. round) beam spot at the target substrate **126**. In one implementation, the stigmator **119** may be configured between the first condenser lens **118** and the column aperture **120**. Furthermore, an electrostatic lens **130** may be configured between the objective lens **124** and the target substrate **126**, and a Wien filter **132** may be configured within the objective lens **124**.

The target substrate **126** may be held by a movable stage **128**. The target substrate **126** may be a semiconductor wafer being manufactured or a reticle for lithography. The movable stage **128** may be used to translate the target substrate **126** under column during an automated inspection or review process, for example.

The impingement of the incident electron beam onto the surface of the target substrate **126** causes emission of secondary and/or backscattered electrons. These secondary and/or backscattered electrons may be referred to herein as scattered electrons. The scattered electrons may be extracted by electrostatic lens **130** and pass back up through the column. The Wien filter **132** may deflect the scattered electrons so that their trajectory is at an angle with respect to the optical axis of the column. The off-axis scattered electrons may travel to the detection system **134** which may generate a detection signal based on the detected electrons.

FIG. 2 is a top-down view of a first implementation of a stigmatic Wien filter **200** in accordance with an embodiment of the invention. The stigmatic Wien filter **200** may be used in the electron beam column **100** described above in relation to FIG. 1.

The stigmatic Wien filter **200** may include two pairs of magnetic cores (magnetic pole pieces) **202**. A first pair of cores **202** may be aligned on the x-axis, and a second pair of cores **202** may be aligned on the y-axis, where the z-axis is the optical axis of the electron beam column **100**. Conductive Wien coils **204** may be wound around each magnetic core **202**. The magnetic fields along the x and y axes in the Wien filter **200** may be controllably adjusted by adjusting the electrical current flowing through the coils **204**.

In addition, the stigmatic Wien filter **200** may include two pairs of cylindrically-curved conductive plates **206**. A first pair of cylindrically-curved plates **206** may be aligned on the x-axis, and a second pair of cylindrically-curved plates **206** may be aligned on the y-axis, where the z-axis is the optical axis of the electron beam column **100**. As shown in FIG. 2, the plates **206** may be cylindrically curved and positioned so as to define an empty cylindrical space about the optical axis of the column.

As further shown in FIG. 2, insulators **208** may separate the plates **206** from the magnetic cores **202**. The insulators **208** may have a curvature corresponding to the cylindrical-curvature of the plates **206**. The surfaces of the magnetic cores **202** that abuts the insulators **208** may also have a cylindrical-curvature corresponding to the cylindrical-curvature of the plates **206**.

In one implementation, the plates **206** may be metal coatings on the insulators **208** or thin cylindrically-curved pieces fixed onto the insulators **208**. In addition, the height of the magnetic pole pieces **202** in the z-direction is preferably configured to be the same as the height of the electrostatic deflection plates **206**. As such, if the thicknesses of the insulators **208** and the deflection plates **206** are sufficiently small, then the distribution of the electrostatic field along the z-axis may be configurable to match or nearly match the distribution of the magnetic field along the z-axis. The size of the gap between the deflection plates **206** is not critical, though the gap should be sufficiently large to avoid arcing between the plates **206**.

The electrostatic fields along the x and y axes in the Wien filter **200** may be controllably adjusted by adjusting the electrical voltages applied to the plates **206**. As shown, +Vx volts may be applied to the plate **206** which is arranged to be on the positive x-axis, -Vx volts may be applied to the plate **206** which is arranged to be on the negative x-axis. Similarly, +Vy volts may be applied to the plate **206** which is arranged to be on the positive y-axis, -Vy volts may be applied to the plate **206** which is arranged to be on the negative y-axis.

In accordance with an embodiment of the invention, the electrostatic and magnetic fields around the polar angle within the Wien filter **200** is not identical such that the Wien filter **200** is stigmatic. This differs from a conventional application of a Wien filter which balances the strengths of the electrostatic and magnetic fields only in one direction in order to, for instance, split secondary electrons from primary electrons.

FIG. 3 is a top-down view of a second implementation of a stigmatic Wien filter with two pairs of magnetic saddle yokes in accordance with an embodiment of the invention. The stigmatic Wien filter **300** may be used in the electron beam column **100** described above in relation to FIG. 1.

The stigmatic Wien filter **300** may include two pairs of magnetic saddle yokes **302**. A first pair of magnetic saddle yokes **302** may be aligned on the x-axis, and a second pair of yokes **302** may be aligned on the y-axis, where the z-axis is the optical axis of the electron beam column **100**.

Conductive coils may be wound **N** times around the yokes **302** so as to implement the ampere-turns NIx+, NIx-, NIy+, and NIy-, where N is the number of turns of the coils, and the electrical current strengths are represented by Ix+, Ix-, Iy+ and Iy-. The magnetic fields along the x and y axes within the Wien filter **300** may be controllably adjusted by adjusting the electrical current flowing through the coils.

In addition, the stigmatic Wien filter **300** may include a multi-pole electrostatic deflector for creating a uniform deflection field. For example, as illustrated in FIG. 3, the multi-pole electrostatic deflector may be an octupole (8-pole) deflector, in which a uniform deflection field is created by applying specifically-defined voltages on the plates of the deflector. Alternative embodiments may use a 12-pole or 20-pole deflector, in which a uniform deflection field is created by specifically-defined angles of the deflector plates. The octupole deflector depicted in FIG. 3 includes four pairs of electodes (or plates). A first pair of electrodes **312** (with applied voltages Vx+ and Vx-) may be aligned on the x-axis, and a second pair of electrodes **312** (with applied voltages Vy+ andVy-) may be aligned on the y-axis, where the z-axis is the optical axis of the electron beam column **100**. In addition, a third pair of electrodes **312** (with applied voltages Vx+y+ and Vx-y-) may be centered on the 45 degree angle line which cuts through the first quadrant (between the positive x and the positive y axes) and the third quadrant (between the negative x and negative y axes), and a fourth pair of electrodes **312** (with applied voltages Vx-y+ and Vx+y-) may be centered on the 135 degree angle line which cuts through the second quadrant (between the negative x and positive y axes) and the fourth quadrant (between the positive x and negative y axes). Insulator material **320** may separate the electrodes **312** from the magnetic saddle yokes **302**.

In one embodiment, the control circuitry for applying voltages to the electrodes may be configured to implement two deflectors: a first deflector to control the amount of deflection in the x-direction; and a second deflector to control the amount of deflection in the y-direction. The relative strengths of the voltages applied on the plates of the octupole for the first (x-direction) deflector are shown in Table 1 below.

Octupole Plates	Vy+	Vx-y+	Vx+y+	Vx+	Vx-	Vx+y-	Vx-y-	Vy-
Relative voltage strength	0	$-1/\sqrt{2}$	$1/\sqrt{2}$	+1	-1	$1/\sqrt{2}$	$-1/\sqrt{2}$	0

Table 1

With the voltages on the plates in Table 1, a computer-simulated equipotential lines for the x-axis-aligned deflection field E_x are shown in FIG. 3, in which an excellent uniform field for the deflection in the central area is displayed. The relative strengths of the voltages applied on the plates of the octupole for the second (y-direction) deflector are shown in the Table 2 below.

Octupole Plates	Vx+	Vx-y+	Vx+y+	Vy+	Vy-	Vx+y-	Vx-y-	Vx-
Relative voltage strength	0	$-1/\sqrt{2}$	$1/\sqrt{2}$	+1	-1	$1/\sqrt{2}$	$-1/\sqrt{2}$	0

Table 2

Note that Tables 1 and 2 give the relative strengths of the voltages applied to achieve x and y deflections, respectively. To achieve a specific deflection in the x-direction, the relative strengths in Table 1 will be scaled (multiplied) by a first voltage level, where the magnitude of the first voltage level determines the magnitude of the deflection in the x-direction. To achieve a specific deflection in the y-direction, the relative strengths in Table 2 will be scaled (multiplied) by a second voltage level, where the magnitude of the second voltage level determines the magnitude of the deflection in the y-direction. The actual voltage applied to a particular electrode in the octupole is a linear combination of the first voltage level multiplied by the relative strength for that electrode in Table 1 plus the second voltage level multiplied by the relative strength for that electrode in Table 2. By controlling the first and second voltage level, a user may control the magnitude and direction of the electrostatic deflection.

In accordance with an embodiment of the invention, the electrostatic and magnetic fields around the polar angle within the Wien filter **300** are configured to be not identical in strength such that the Wien filter **300** is purposefully stigmatic. This differs from a conventional application of a Wien filter which balances the strengths of the electrostatic and magnetic fields only in one direction in order to, for instance, split secondary electrons from primary electrons.

FIG. 4 shows angles of interest in relation to the two pairs of magnetic saddle yokes of the second implementation in accordance with an embodiment of the invention. As shown, each yoke **302** may span an angle 2θ that is greater than 90 degrees for more uniform distribution of the magnetic deflection field, such that there may be an overlap of angle ϕ (an azimuthal overlap) between adjacent yokes.

FIG. 5 is a perspective view of a pair of magnetic saddle yokes **302** in accordance with an embodiment of the invention. In this illustration, the pair of magnetic saddle yokes **302** are arranged so as to be have coil windings which provide the magnetic deflection field in the y-direction (By) for the stigmatic Wien filter **100**. For purposes of clarity, the orientation of a winding of a coil on the top magnetic saddle yoke **302** is depicted by the dashed-line rectangle **502**.

In an exemplary embodiment, the electron beam column **100** of FIG. 1 may be configured to be used in applications with relatively low beam currents. For example, beam currents of less than 1,000 picoamperes (pA) may be used for applications such as critical dimension-scanning electron microscopy (CD-SEM), electron beam review and/or hot spot wafer inspection. In an electron beam column operating at a low beam current, the electron-electron interactions is less dominant in determining total spot blur. Rather, lens aberrations play a greater role in limiting the resolution of the column.

The resolution of the electron beam column may be commonly broken down or expressed in terms of contributing e-beam spot blurs in the plane of the target substrate. These blurs include a source image d_g, the wavelength-dependent diffraction blur d_λ, the spherical aberration d_s, and the chromatic aberration d_c. Each of these blurs may be defined in a measurement of FW50 (the full width diameter in which 50% of the electrons are included). The total spot size, d_{tot}, which may be used to characterize the resolution, may be given by a square-root of square-summation. This is stated in equation form below.

$$d_{tot} = (d_g^2 + d_\lambda^2 + d_s^2 + d_c^2)^{1/2} \qquad \text{(Eq. 1)}$$

In one implementation, the incident-beam energy filter **108** may be configured to select electrons from the source **102** within a small energy spread ΔE. The reduction in chromatic aberration is expected to be proportional to the energy filtering rate ρ. For example, the energy spread before filtering may be ΔE = 1 electron volt (eV), and the energy spread after filtering may be ΔE = 50 milli electron volts (meV) so as to achieve an energy filtering rate ρ = 1 eV / 50 meV = 20. This is expected to result in a reduction of chromatic aberration (d_c) of 20 times.

Meanwhile, the source image is expected to increase in proportion to the square-root of the energy filtering rate ρ due to the loss of source brightness. For example, if ρ = 20, then the source image d_g is expected to increase by the square root of 20. While the size of the source image d_g increase undesirably, applicants have determined that this is more than offset by the reduction in chromatic aberration. As such, the combined result is a substantial increase in resolution.

Note that, to balance blurs, the optimal convergent angle β becomes larger, while the diffraction blur d_λ is small. In addition, for a given beam current after the energy filtering, the electron-electron interactions become fairly weak because of reduced electron density and so may be neglected. Note also that the spherical aberration d_s is unchanged with and without energy-filtering and may be kept small so as to be negligible.

As described below in relation to FIGS. 6 and 7, the total spot size d_{tot} is reduced by a factor of about one-half at a beam current of sub-nano-amperes (less than one nano-ampere) compared to d_{tot} without energy filtering. In other words, the resolution may improve by a factor of about 2 times. For applications with an even lower beam current, the resolution improvement may be even larger (for example, greater than 3 times) because the source image is still less dominant after energy filtering. Furthermore, the resolution may be further improved by using a high-brightness gun in addition to the energy filtering, especially for relatively high beam currents.

FIG. 6 is a graph of total spot size, and factors contributing thereto, as a function of convergent angle for a computer-simulated electron beam column under reference conditions. The reference conditions are conventional in that there is no incident-beam energy filter being used. In other words, in FIG. 1, the incident-beam energy filter **108** (including the stigmatic Wien filter **110** and the filter aperture **112**) and the compensating stigmator **119** are absent or inactive.

As discussed above, the factors contributing to the total spot size include diffraction, chromatic aberration (chromatic aber), the source image size (source image), and spherical aberration (spherical aber). As shown in FIG. 6, under reference conditions, diffraction and chromatic aberration are the primary contributing factors to the total spot size.

FIG. 7 is a graph of total spot size, and factors contributing thereto, as a function of convergent angle for a computer-simulated electron beam column with incident-beam energy filtering using a stigmatic Wien filter in accordance with an embodiment of the invention. In this case, an incident-beam energy filter **108** is configured as shown in FIG. 1 and is being actively used.

Again, the factors contributing to the total spot size include diffraction, chromatic aberration (chromatic aber), the source image size (source image), and spherical aberration (spherical aber). As shown in FIG. 7, the contribution due to the source image size is substantially increased. This is a conventional reason against using incident-beam energy filtering. However, as our simulations show, the contribution due to the chromatic aberration drops a relatively larger amount so as to more than offset the increase in source image size. As a result, at least for low-beam current applications, the minimum total spot size is substantially lower with the incident-beam energy filtering in accordance with the present disclosure. The scales of FIGS. 6 and 7 are the same. Hence, it is seen that the minimum total spot size with incident-beam energy filtering per FIG. 7 is substantially reduced compared to the minimum total spot size for the reference conditions per FIG. 6.

The apparatus and methods disclosed herein provide various substantial advantages over conventional apparatus and methods. First, a breakthrough improvement in resolution of about 2 to 3 times or more is achieved for applications in CD-SEM, review and/or inspection.

Second, the innovative use of a Wien-filter based energy filter for the incident electron beam allows the beam to travel in a straight path along the optical axis of the column. In contrast, other energy filter configurations, such as a magnetic prism with an electrostatic mirror analyzer, or a sector analyzer with an electrostatic field or a magnetic field, bend or curve the path of the electron beam in order to select the electrons within a low-energy spread. With the straight-axial configuration provided by the Wien-filter based energy filter, many technical risks and issues, such as alignment, for example, are avoided.

Third, unlike a retarding energy filter, the Wien-filter based energy filter does not require the deceleration of electrons in the beam in order to select electrons in the desired energy range. This avoids the increased electron-electron interactions that are caused by such a retarding field and, as a result, avoids additional energy spread caused by Boersch effects.

Fourth, electron-electron interactions in the lower portion of the column below the energy filter aperture are advantageously reduced. This is due to the reduction in electron density after the incident-beam energy filter.

In the above description, numerous specific details are given to provide a thorough understanding of embodiments of the invention. However, the above description of illustrated embodiments of the invention is not intended to be exhaustive or to limit the invention to the precise forms disclosed. One skilled in the relevant art will recognize that the invention can be practiced without one or more of the specific details, or with other methods, components, etc. In other instances, well-known structures or operations are not shown or described in detail to avoid obscuring aspects of the invention. While specific embodiments of, and examples for, the invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize.

These modifications can be made to the invention in light of the above detailed description. The terms used in the following claims should not be construed to limit the invention to the specific embodiments disclosed in the specification and the claims. Rather, the scope of the invention is to be determined by the following claims, which are to be construed in accordance with established doctrines of claim interpretation.

CLAIMS

What is claimed is:

1. An apparatus for high-resolution electron beam imaging, the apparatus comprising:

a source configured to emit electrons;

a gun lens configured to focus the electrons from the source into an electron beam;

a beam limiting aperture configured to limit a source emission angle of electrons in the electron beam;

an energy filter configured to limit an energy spread of the electrons in the electron beam;

an objective lens configured to focus the energy-filtered electron beam onto a spot on a surface of a target substrate; and

a detector configured to detect scattered electrons from the surface of the target substrate.

2. The apparatus of claim 1, wherein the energy filter comprises an energy-dependent deflector.

3. The apparatus of claim 2, wherein the energy-dependent deflector comprises a stigmatic Wien filter.

4. The apparatus of claim 3, wherein the energy filter further comprises a filter aperture to block electrons outside of the limited energy spread.

5. The apparatus of claim 3, wherein the stigmatic Wien filter further comprises a first pair of cylindrically-curved conductive plates along a first axis and a second pair of cylindrically-conductive plates along a second axis.

6. The apparatus of claim 5, wherein the stigmatic Wien filter comprises a first pair of magnetic cores wound by conductive coils and configured along the first axis, and a second pair of magnetic cores wound by conductive coils and configured along the second axis, wherein the first and second axes are perpendicular to each other and to an optical axis of the apparatus.

7. The apparatus of claim 3, wherein the stigmatic Wien filter comprises a first pair of magnetic yokes wound by conductive coils and configured along a first axis, and a second pair of magnetic yokes wound by conductive coils and configured along a second axis, wherein the first and second axes are perpendicular to each other and to an optical axis of the apparatus.

8. The apparatus of claim 7, wherein the first and second pairs of magnetic yokes are configured with an azimuthal overlap.

9. The apparatus of claim 7, wherein the stigmatic Wien filter further comprises an multipole deflector.

10. The apparatus of claim 9, wherein the multipole deflector is one of a group consisting of an octupole deflector, a 12-pole deflector, and a 20-pole deflector.

11. The apparatus of claim 1, wherein the energy filter comprises a stigmatic Wien filter and a filter aperture, further comprising a stigmator to compensate for astigmatism introduced by the stigmatic Wien filter.

12. The apparatus of claim 11, wherein the stigmator is configured between the filter aperture and a column aperture.

13. A method of forming an incident electron beam for a high-resolution electron beam apparatus, the method comprising:

emitting electrons from a source;

focusing the electrons from the source into an electron beam;

limiting a source emission angle of electrons in the electron beam using a beam limiting aperture;

limiting an energy spread of the electrons in the electron beam using an energy filter to form an energy-filtered electron beam; and

focusing the energy-filtered electron beam onto a spot on a surface of a target substrate using an objective lens.

14. The method of claim 13, wherein the energy filter comprises a stigmatic Wien filter.

15. The method of claim 14, wherein the energy filter further comprises a filter aperture to block electrons outside of the limited energy spread.

16. The method of claim 14, wherein the stigmatic Wien filter comprises a first pair of magnetic cores wound by conductive coils along a first axis, a second pair of magnetic cores wound by conductive coils along a second axis, a first pair of cylindrically-curved conductive plates along the first axis, and a second pair of cylindrically-curved conductive plates along the second axis, wherein the first and second axes are perpendicular to each other and to an optical axis of the apparatus.

17. The method of claim 14, wherein the stigmatic Wien filter comprises a first pair of magnetic yokes wound by conductive coils and configured along a first axis, and a second pair of magnetic yokes wound by conductive coils and configured along a second axis, wherein the first and second axes are perpendicular to each other and to an optical axis of the apparatus, and wherein the first and second pairs of magnetic yokes are configured with an overlap.

18. The method of claim 17, wherein the stigmatic Wien filter further comprises an multipole deflector, wherein the multipole deflector is one of a group consisting of an octupole deflector, a 12-pole deflector, and a 20-pole deflector.

19. The method of claim 13, further comprising correct astigmatism introduced by the stigmatic Wien filter before the energy-filtered electron beam is focused onto the spot on the surface of the target substrate.

20. A stigmatic Wien filter comprising:

a first pair of magnetic cores wound by conductive coils and configured along a first axis;

a first pair of curved conductive plates configured along the first axis;

a second pair of magnetic cores wound by conductive coils and configured along a second axis; and

a second pair of curved conductive plates configured along the second axis, wherein the first and second axes are perpendicular to each other.

21. The stigmatic Wien filter of claim 20, wherein the conductive plates are cylindrically-curved and positioned so as to define an empty cylindrical space.

22. A stigmatic Wien filter comprising:

a multipole deflector;

a first pair of magnetic yokes wound by conductive coils and configured along a first axis; and

a second pair of magnetic yokes wound by conductive coils and configured along a second axis,

wherein the first and second axes are perpendicular to each other, and

wherein the first and second pairs of magnetic yokes are configured with an overlap.

23. The stigmatic Wien filter of claim 22, wherein the multipole deflector is one of a group consisting of an octupole deflector, a 12-pole deflector, and a 20-pole deflector.

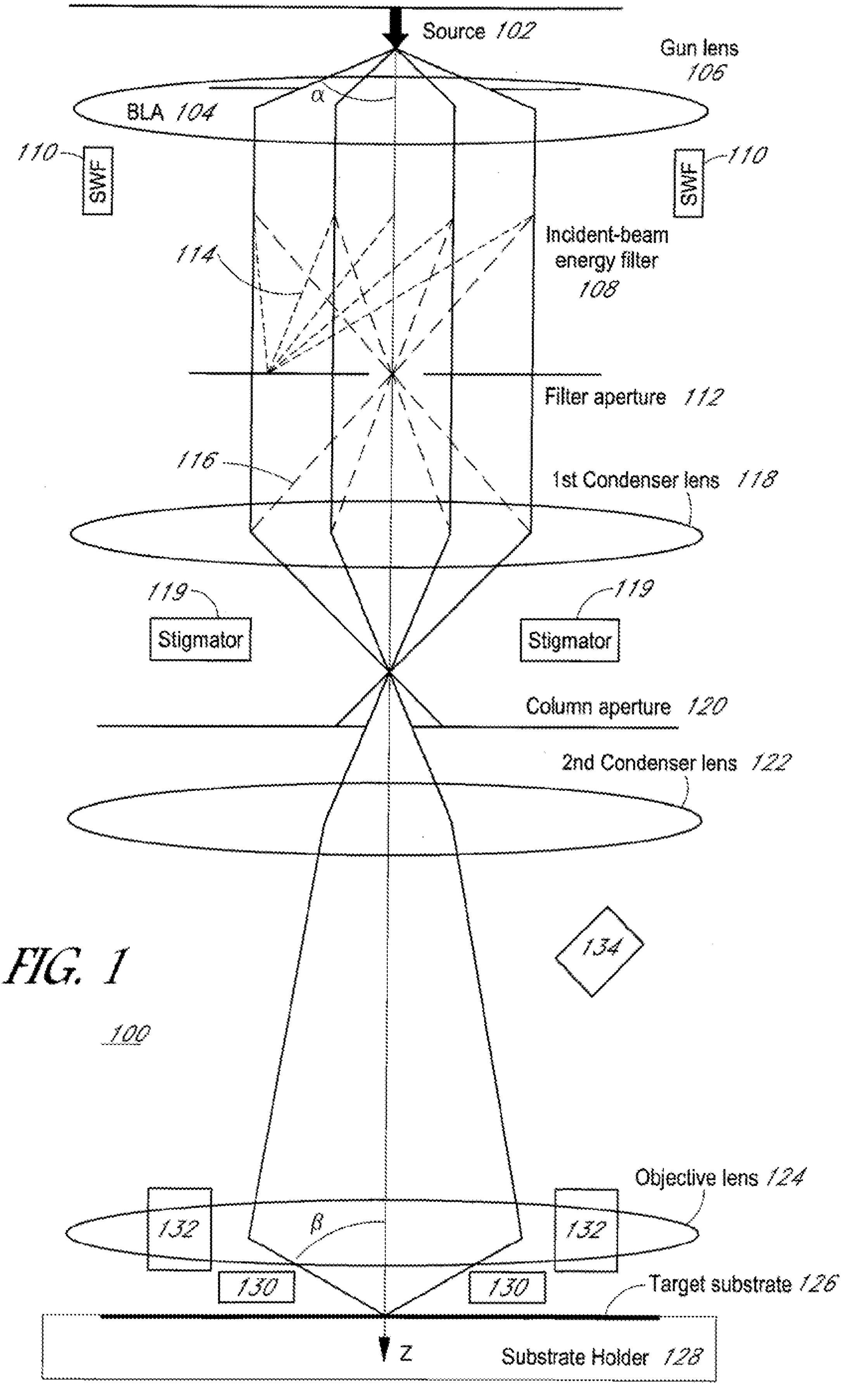
Source 102
Gun lens 106
α
BLA 104
110
SWF
SWF
110
114
Incident-beam energy filter 108
Filter aperture 112
116
1st Condenser lens 118
119
119
Stigmator
Stigmator
Column aperture 120
2nd Condenser lens 122
134
100
Objective lens 124
132
β
132
130
130
Target substrate 126
Z
Substrate Holder 128

FIG. 1

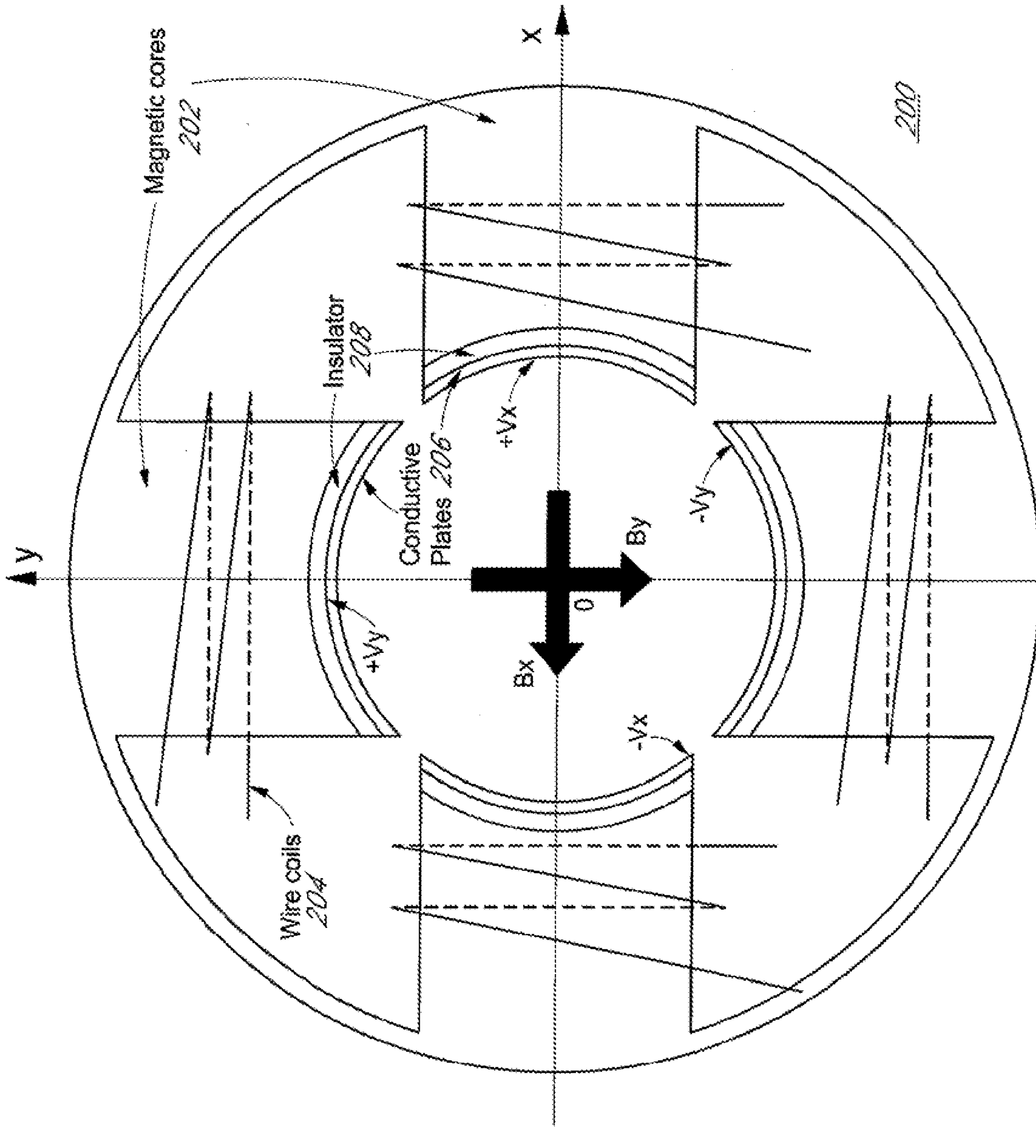
x
y
Magnetic cores
202
Insulator
208
Conductive
Plates 206
+Vx
-Vx
+Vy
-Vy
By
Bx
0
Wire coils
204
200

FIG. 2

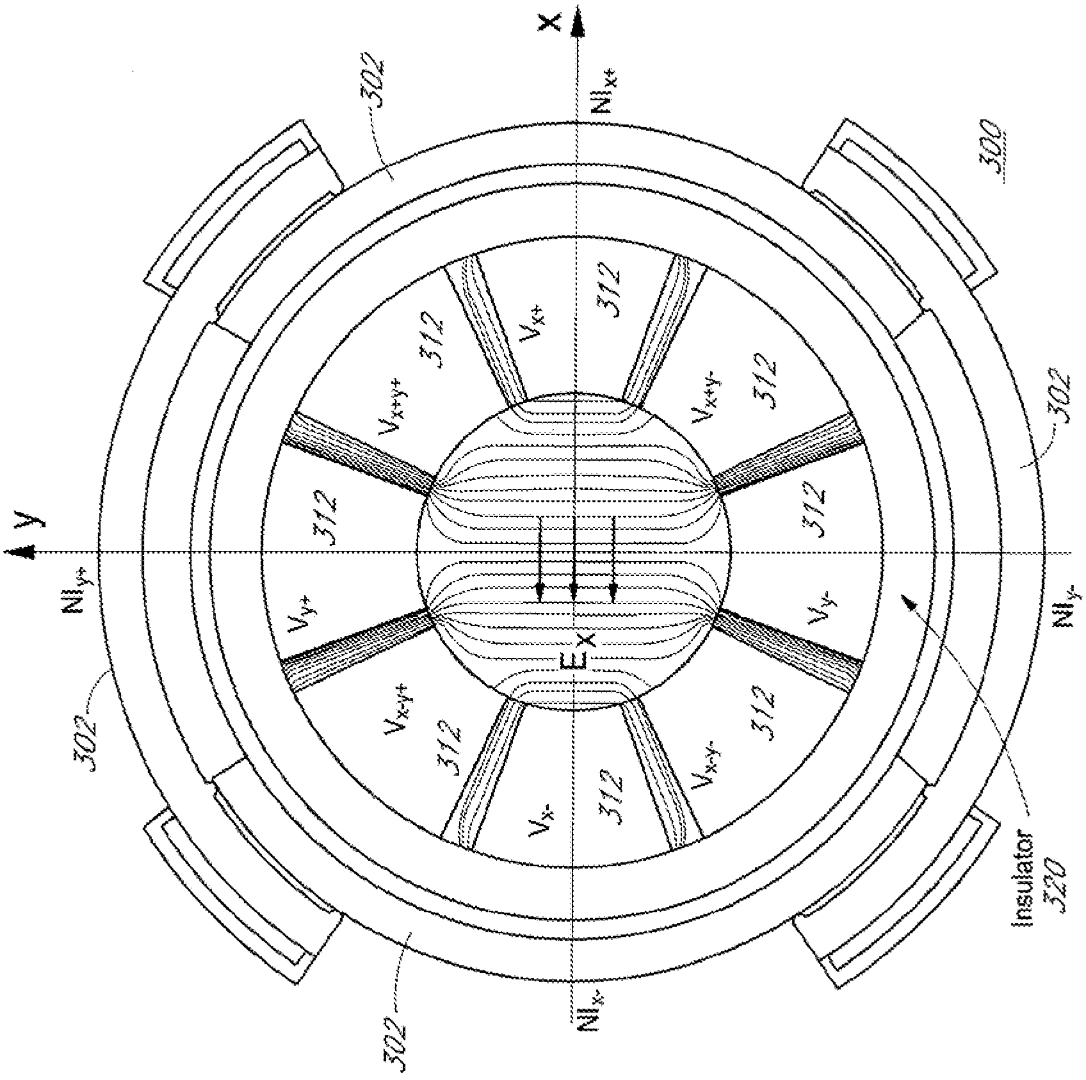
X
y
NI_{x+}
NI_{y+}
NI_{y-}
NI_{x-}
302
302
302
302
302
300
V_{x+}
V_{x+y+}
V_{x+y-}
V_{y+}
V_{y-}
V_{x-y+}
V_{x-y-}
V_{x-}
312
312
312
312
312
312
312
312
E_x
Insulator
320

FIG. 3

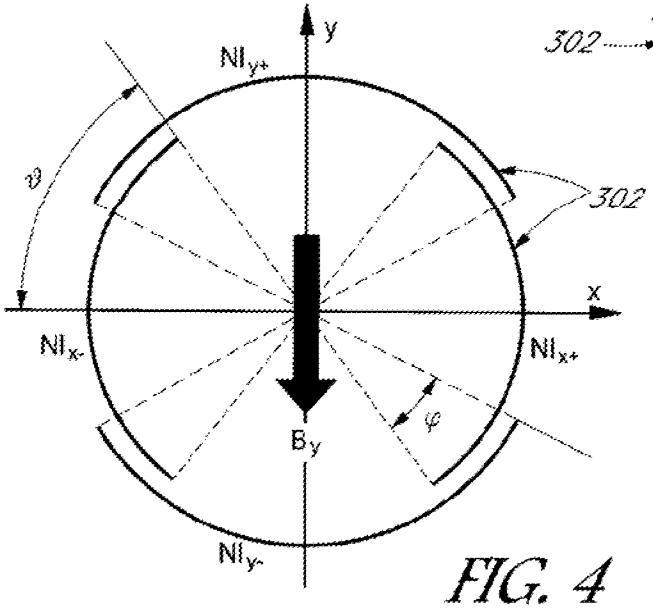

FIG. 4

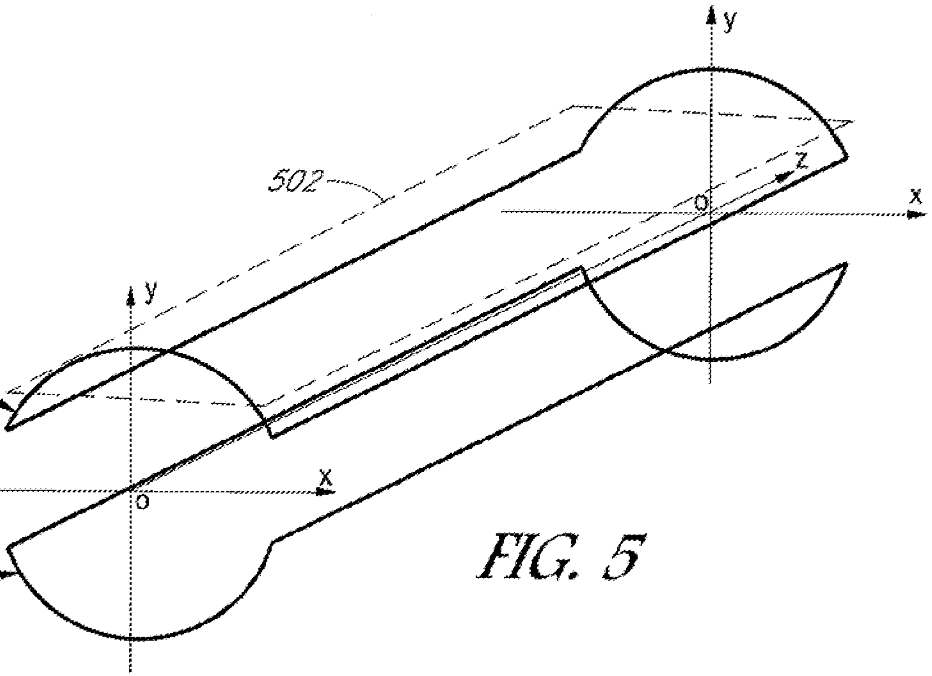

FIG. 5

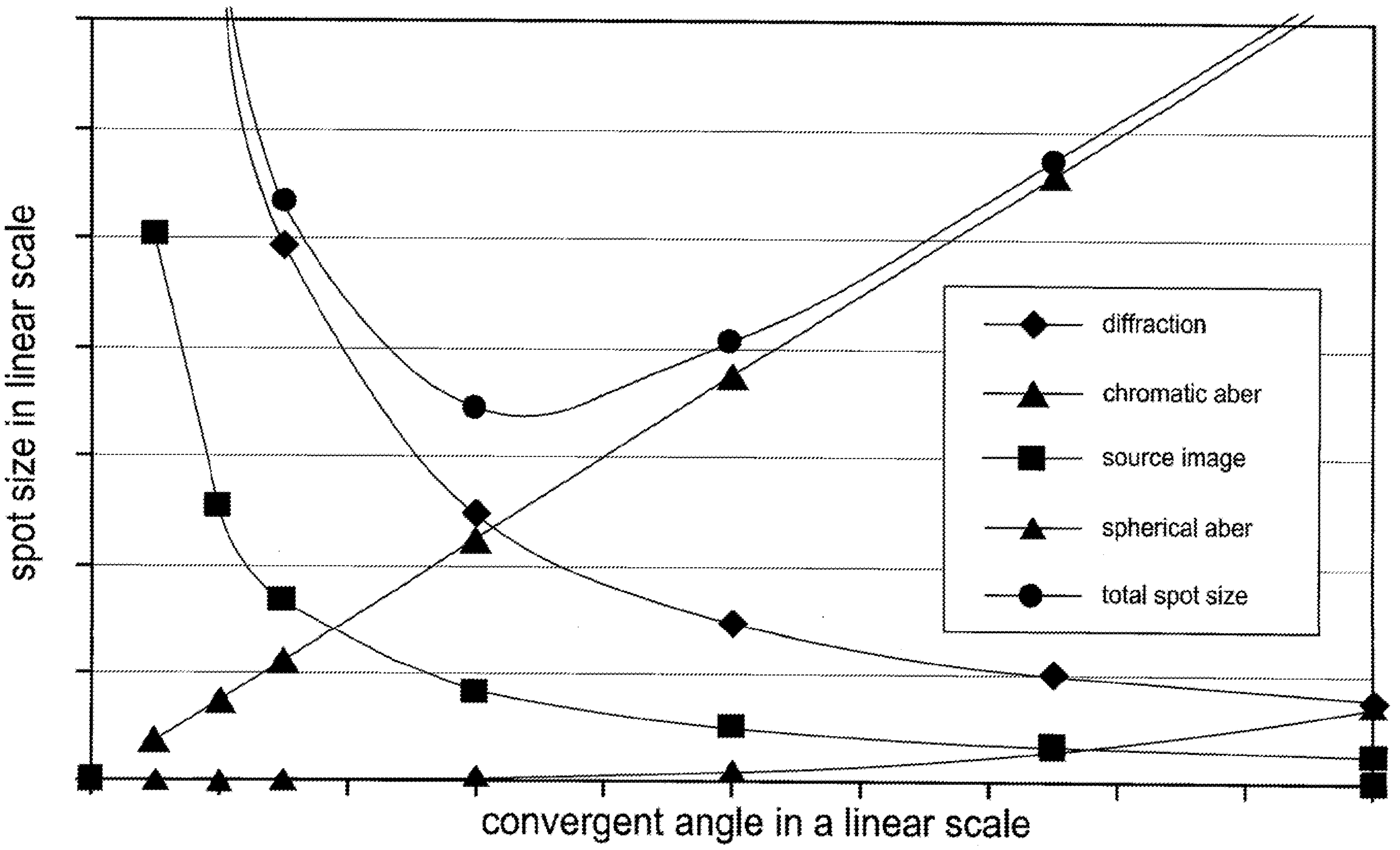

FIG. 6
(Reference conditions)

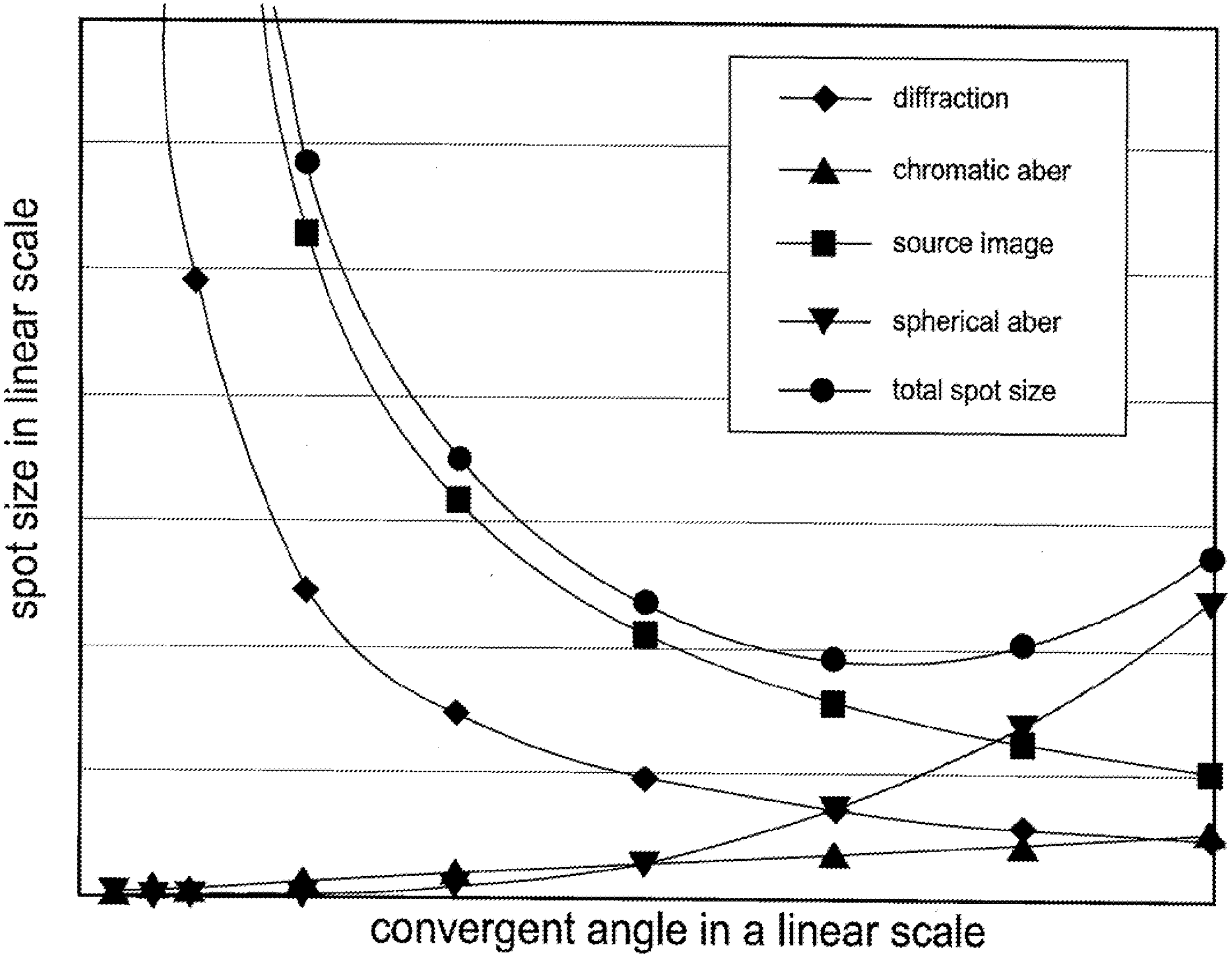

FIG. 7

(energy filter applied to incident electron beam)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/034999

A. CLASSIFICATION OF SUBJECT MATTER

H01J 37/22(2006.01)i, H01J 37/10(2006.01)i, H01J 37/147(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01J 37/22; H01J 37/153; H01J 37/05; H01J 49/48; H01J 29/76; H01J 37/10; H01J 37/147

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: electron beam imaging, stigmatic Wien filter

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0989584 A1 (ADVANTEST CORP.) 29 March 2000 See paragraphs [0010]-[0032]; and figures 3, 8.	1-4,11-15,19
Y		5-10,16-18
X	JP 06-103946 A (INTERNATL BUSINESS MASCHINES CORP.) 15 April 1994 See paragraph [0030]; and figures 2, 4.	20,21
Y		5,6,16
X	JP 05-275057 A (JEOL LTD.) 22 October 1993 See paragraphs [0007], [0021]-[0026]; and figures 1, 2.	22,23
Y		7-10,17,18
A	EP 1610358 A1 (ICT INTEGRATED CIRCUIT TESTING GESELLSCHAFT FUER HALBLEITERPRUEFTECHNIK MBH) 28 December 2005 See paragraphs [0042]-[0056]; and figure 3.	1-23
A	JP 05-054853 A (JEOL LTD.) 5 March 1993 See paragraphs [0013]-[0021]; and figures 3-6.	1-23

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"P" document published prior to the international filing date but later than the priority date claimed
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"&" document member of the same patent family

Date of the actual completion of the international search 26 June 2013 (26.06.2013)	Date of mailing of the international search report **28 June 2013 (28.06.2013)**
Name and mailing address of the ISA/KR Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea Facsimile No. 82-42-472-7140	Authorized officer KIM, Do Weon Telephone No. 82-42-481-5560

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2013/034999

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0989584 A1	29.03.2000	DE 69827791 D1	30.12.2004
		DE 69827791 T2	21.04.2005
		EP 0989584 B1	24.11.2004
		JP 04106162 B2	25.06.2008
		JP 2000-100361 A	07.04.2000
		US 6489621 B1	03.12.2002
JP 06-103946 A	15.04.1994	DE 69327429 D1	03.02.2000
		DE 69327429 T2	08.06.2000
		EP 0580212 A1	26.01.1994
		EP 0580212 B1	29.12.1999
		US 05389858 A	14.02.1995
		US 05481164 A	02.01.1996
JP 05-275057 A	22.10.1993	None	
EP 1610358 A1	28.12.2005	DE 602004016131 D1	09.10.2008
		EP 1610358 B1	27.08.2008
		JP 04896877 B2	14.03.2012
		JP 2008-503853 A	07.02.2008
		US 2007-0164228 A1	19.07.2007
		US 7465939 B2	16.12.2008
		WO 2005-124816 A1	29.12.2005
JP 05-054853A	05.03.1993	None	