(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
20 January 2011 (20.01.2011)

PCT

(10) **International Publication Number**
WO 2011/009065 A2

(51) **International Patent Classification**:
H01J 37/28 (2006.01) ***H01J 37/244*** (2006.01)

(21) **International Application Number**:
PCT/US2010/042313

(22) **International Filing Date**:
16 July 2010 (16.07.2010)

(25) **Filing Language**: English

(26) **Publication Language**: English

(30) **Priority Data**:
61/226,682 17 July 2009 (17.07.2009) US

(71) **Applicant** *(for all designated States except US)*: **KLA-TENCOR CORPORATION** [US/US]; 1 Technology Drive, Milpitas, California 95035 (US).

(72) **Inventors; and**
(75) **Inventors/Applicants** *(for US only)*: **SHADMAN, Khashayar** [US/US]; 550 Ortega Ave., Unit A203, Mountain View, California 94040 (US). **HAYNES, Robert** [US/US]; 3735 Kamp Drive, Pleasanton, California 94588 (US). **TOTH, Gabor, D** [HU/US]; 1634 Tupolo Drive, San Jose, California 95124 (US). **SEARS, Christopher** [US/US]; 1958 Wave Place, San Jose, California 95133 (US). **NASSER GHODSI, Mehran** [US/US]; 42 Boardman Lane, Hamilton, Massachusetts 01982 (US).

(74) **Agents**: **OKAMOTO, James, K** et al.; Okamoto & Benedicto LLP, P.O. Box 641330, San Jose, California 95164-1330 (US).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) **Title**: CHARGED-PARTICLE ENERGY ANALYZER

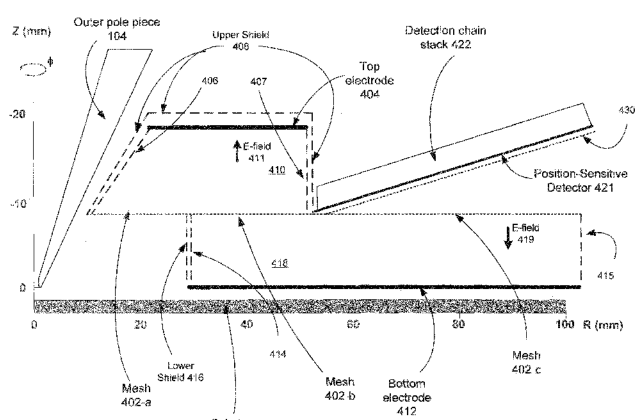


FIG. 4A

(57) **Abstract**: One embodiment relates to a charged-particle energy analyzer apparatus. A first mesh is arranged to receive the charged particles on a first side and pass the charged particles to a second side, and a first electrode is arranged such that a first cavity is formed between the second side of the first mesh and the first electrode. A second mesh is arranged to receive the charged particles on a second side and pass the charged particles to a first side, and a second electrode is arranged such that a second cavity is formed between the first side of the second mesh and the second electrode. Finally, a third mesh is arranged to receive the charged particles on a first side and pass the charged particles to a second side, and a position-sensitive charged-particle detector is arranged to receive the charged particles after the charged particles pass through the third mesh.

WO 2011/009065 A2

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

CHARGED-PARTICLE ENERGY ANALYZER

Inventors:

Khashayar Shadman; Robert Haynes; Gabor Toth; Christopher Sears; and Mehran Nasser Ghodsi

CROSS-REFERENCE TO RELATED APPLICATION

The present application claims priority to U.S. Provisional Patent Application No. 61/226,682, entitled “Energy Analyzer,” filed July 17, 2009 by inventor Khashayar Shadman, the disclosure of which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

Field of the Invention

The present disclosure relates to energy analyzers for charged-particles.

Description of the Background Art

When an electron is emitted from a core level of an atom, leaving a vacancy, an electron from a higher energy level may fall into the lower-energy-level vacancy. This results in a release of energy either in the form of an emitted photon or by ejecting another electron. Electrons ejected in this manner are called Auger electrons.

Conventional Auger electron spectrometers include the hemispherical analyzer, the cylindrical mirror analyzer, and the hyperbolic field analyzer. The hemispherical analyzer and the cylindrical mirror analyzer are serial spectrometers where the spectrometer is scanned in order to collect a complete spectrum in a serial fashion. The hyperbolic field analyzer is an example of a parallel spectrometer where a complete spectrum is acquired in parallel fashion.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional diagram depicting select components of a scanning electron microscope which includes a conventional energy analyzer.

FIG. 2 is a cross-sectional diagram showing the conventional energy analyzer in further detail and electron trajectories therein.

FIG. 3 is a cross-sectional diagram depicting select components of a scanning electron microscope which includes a multi-cavity energy analyzer in accordance with an embodiment of the invention.

FIG. 4A is a cross-sectional diagram showing the multi-cavity energy analyzer in further detail in accordance with an embodiment of the invention.

FIG. 4B showing electron trajectories superimposed on the multi-cavity energy analyzer of FIG. 4A.

FIG. 5 is a diagram depicting an example implementation of a segmented detector surface.

FIG. 6 is a diagram depicting an exemplary voltage step-down array in accordance with an embodiment of the invention.

SUMMARY

One embodiment relates to a charged-particle energy analyzer apparatus. A first mesh is arranged to receive the charged particles on a first side and pass the charged particles to a second side, and a first electrode is arranged such that a first cavity is formed between the second side of the first mesh and the first electrode. A second mesh is arranged to receive the charged

particles on a second side and pass the charged particles to a first side, and a second electrode is arranged such that a second cavity is formed between the first side of the second mesh and the second electrode. Finally, a third mesh is arranged to receive the charged particles on a first side and pass the charged particles to a second side, and a position-sensitive charged-particle detector is arranged to receive the charged particles after the charged particles pass through the third mesh. The first, second and third meshes may be separate or part of a single mesh structure.

Another embodiment relates to a method of analyzing energies of charged particles. The charged particles are passed through a first electrically-conductive mesh to enter a first cavity. In the first cavity, the charged particles are deflected away from a first electrically-conductive plate. The charged particles then pass through a second electrically-conductive mesh to exit the first cavity and enter a second cavity. In the second cavity, the charged particles are deflected away from a second electrically-conductive plate. The charged particles then pass through a third electrically-conductive mesh to exit the second cavity. After exiting the second cavity, the charged particles are detected with a position-sensitive detector. The first, second and third meshes may be separate or part of a single mesh structure.

Other embodiments, aspects and features are also disclosed.

DETAILED DESCRIPTION

FIG. 1 is a cross-sectional diagram depicting select components of a scanning electron microscope which includes a conventional energy analyzer **110**. As shown, a primary electron beam **101** originates from an electron gun **111** and travels down an optical axis and through an electron-beam objective lens **102** to become focused upon the surface of a target substrate **108**.

The objective lens **102** is configured around the optical axis. The objective lens **102** may comprise an inner pole piece **103** and an outer pole piece **104**. The objective lens **102** may be configured with an electromagnetic device (such as a magnetic coil) so as to generate a magnetic field which may be used to focus the primary electron beam **101** onto a spot on a surface of the substrate **108**. Deflectors **112** may be used to deflect the primary electron beam **101** in a controllable manner so as to scan the beam spot over the surface, for example, in a raster pattern.

The energy analyzer **110** is positioned to detect secondary electrons emitted from the substrate **108** due to the impingement of the primary electron beam. The operation of the energy analyzer **110** is described further below in relation to FIG. 2.

FIG. 2 is a cross-sectional diagram showing the conventional energy analyzer **110** in further detail and electron trajectories **212** therein. In FIG. 2, the optical axis of the apparatus is defined to be the z-axis. Hence, the primary electron beam **101** travels on the z-axis and then impinges upon the target substrate **108**. The R-axis in FIG. 2 indicates the radial distance away from the z-axis.

As shown, the energy analyzer **110** may be arranged radially around the z-axis. The energy analyzer **110** includes an annular electrically-conductive mesh **202** which is electrically grounded and an annular electrically-conductive plate **204** which is biased at a negative voltage of –V.

The mesh **202** and plate **204** may be electrically-coupled by an inner sidewall **206** and an outer sidewall **208**. Together, the mesh **202**, plate **204**, and sidewalls (**206** and **208**) form a chamber or cavity in which there is a relatively uniform electrostatic field (E-field) **213** going away from the mesh **202** and towards the plate **204**.

Electron trajectories **212** are depicted for secondary electrons emitted from the target substrate **108**. As indicated, the secondary electrons whose trajectories **212** are within a certain range of polar angles θ may pass through the mesh **202** and enter the chamber of the energy analyzer **110**.

Since the electrons are negatively-charged, the E-field **213** provides a downward force so that the electron trajectories **212** are deflected away from the plate **204**. The deflected electrons pass through the mesh **202** and impinge upon a position-sensitive detector **210**.

Higher-energy electrons travel farther and impinge upon the position-sensitive detector **210** at positions farther away from the z-axis. For purposes of illustration, FIG. 2 depicts the trajectories of electrons with various initial polar angles θ but with one of three example energy levels. The electrons at the lower energy level land at a closer radial position **214** along the position-sensitive detector **210**. The electrons at the middle energy level land at a middle radial position **216** along the position-sensitive detector **210**. Finally, the electrons at the higher energy level land at a farther radial position **218** along the position-sensitive detector **210**.

One problem with the design of the energy analyzer **110** in FIG. 2 is that there is very little space for the detection chain stack **211** between the position-sensitive detector **210** and the target substrate **108**. In the context of a microchannel plate detector, the detection chain stack **211** refers to a plurality of microchannel plates used to increase the gain of the detector. In cases where such a detection chain stack **211** is necessary, then the radial extent of the detector **210** would be limited, which would reduce the range of energies that may be detected in parallel.

FIG. 3 is a cross-sectional diagram depicting select components of a scanning electron microscope which includes a multi-cavity energy analyzer **310** in accordance with an embodiment of the invention. As shown, a primary electron beam **101** originates from an electron gun **111** and travels down an optical axis and through an electron-beam objective lens **102** to become focused upon the surface of a target substrate **108**.

The objective lens **102** is configured around the optical axis. The objective lens **102** may comprise an inner pole piece **103** and an outer pole piece **104**. The objective lens **102** may be configured with an electromagnetic device (such as a magnetic coil) so as to generate a magnetic field which may be used to focus the primary electron beam **101** onto a spot on a surface of the substrate **108**. Deflectors **112** may be used to deflect the primary electron beam **101** in a controllable manner so as to scan the beam spot over the surface, for example, in a raster pattern.

In accordance with an embodiment of the invention, the multi-cavity energy analyzer **310** is positioned to detect and analyze the secondary (or scattered) electrons emitted from the substrate **108** due to the impingement of the primary electron beam **101**. The operation of the multi-cavity energy analyzer **310** is described further below in relation to FIGS. 4A and 4B.

FIG. 4A is a cross-sectional diagram showing the multi-cavity energy analyzer **310** in further detail in accordance with an embodiment of the invention. FIG. 4B shows electron trajectories **420** superimposed on the multi-cavity energy analyzer **310** of FIG. 4A. In FIGS. 4A and 4B, the optical axis of the apparatus is defined to be the z-axis. Hence, the primary electron beam **101** travels on the z-axis and then impinges upon the target substrate **108**. The R-axis indicates the radial distance away from the z-axis.

The multi-cavity energy analyzer **310** may be arranged in a radially-symmetric around the z-axis. In that case, the multi-cavity energy analyzer **310** includes an annular electrically-conductive central mesh **402** (comprising an inner portion **402-a**, a middle portion **402-b**, and an outer portion **402-c**) which is electrically grounded, a first annular electrically-conductive electrode ("top electrode") **404** which is biased at a negative voltage of –V, and a second top annular electrically-conductive electrode ("bottom electrode") **412** which is biased at a negative voltage of –V. In one embodiment, the top and bottom electrodes (**404** and **412**) may comprise annular metal plates. In other embodiments, one or both of these electrodes may comprise wire meshes. Implementing the top and bottom electrodes (**404** and **412**) as wire meshes is advantageous in that the surface area which produces tertiary electrons is reduced.

A top inner resistor-like sidewall **406** may be configured to electrically-couple an inner end of the inner portion of the central mesh **402-a** and an inner end of the top electrode **404**. A top outer resistor-like sidewall **407** may be configured to electrically-couple an outer end of the middle portion of the central mesh **402-b** and an outer end of the top electrode **404**. Together, the inner and middle portions of the central mesh (**402-a** and **402-b**), the top electrode **404**, and the top inner and outer resistor-like sidewalls (**406** and **407**) form a first (top) cavity (or chamber) **410** in which there is a relatively uniform electrostatic field (E-field) **411** going away from the inner and middle portions of the central mesh (**402-a** and **402-b**) and towards the top electrode **404**. An electrically-grounded upper shield **408** may be arranged to house the upper chamber **410** and shield the E-field **411** from stray fields from the detector chain stack **421** or other components.

A bottom inner resistor-like sidewall **414** may be configured to electrically-couple an inner end of the middle portion of the central mesh **402-b** and an inner end of the bottom electrode **412**. A bottom outer resistor-like sidewall **415** may be configured to electrically-couple an outer end of the outer portion of the central mesh **402-c** and an outer end of the bottom electrode **412**. Together, the middle and outer portions of the central mesh (**402-b** and **402-c**), the bottom electrode **412**, and the bottom inner and outer resistor-like sidewalls (**414** and **415**) form a second (bottom) cavity (or chamber) **418** in which there is a relatively uniform electrostatic field (E-field) **419** going away from the middle and outer portions of the central mesh (**402-b** and **402-c**) and towards the bottom electrode **412**. An electrically-grounded lower shield **416** may be on the inner side of the bottom inner resistor-like sidewall **414** so as to shield the E-field **419** from stray fields and the secondary electrons.

Electron trajectories **420** are depicted in FIG. 4B for secondary electrons (SEs) emitted from the target substrate **108** due to impingement of the primary electron beam **101**. As indicated, the secondary electrons whose trajectories **420** are within an acceptable range of polar angles θ may pass through an aperture and through the inner portion of the central mesh **402-a** so as to enter the upper chamber **410** of the multi-cavity energy analyzer **310**. The aperture may be in the form of an annular slit which is configured to limit the acceptable range of SE polar angles. For example, the acceptable range of SE polar angles θ may be centered around 30 degrees with respect to the surface of the substrate **108**.

Since the electrons are negatively-charged, the E-field **411** in the upper chamber **410** provides a downward force so that the electron trajectories **420** are deflected away (mirrored) from the top electrode **404**. After this first deflection, the electrons pass through the middle portion of the central mesh **402-b** and enter the lower chamber **418** of the multi-cavity energy analyzer **310**.

Since the electrons are negatively-charged, the E-field **419** in the lower chamber **418** provides an upward (repulsive) force so that the electron trajectories **420** are deflected away (mirrored) from the bottom electrode **412**. After this second deflection, the electrons pass through the outer portion of the central mesh **402-c** and impinge upon a position-sensitive detector **421**. Hence, in this embodiment, the secondary electrons pass through the central mesh **402** three times before striking the detector.

Note that, as shown in FIG. 4A, a wire mesh **430** may also be configured in front of the position-sensitive detector **421**. An adjustable electrostatic field may be created between the wire mesh **430** and the position-sensitive detector **421** by creating a potential difference between the two. The electrostatic field may point either towards the mesh **430** or towards the front surface of the detector **421**.

The direction and strength of the field may be configured so as to either suppress or remove tertiary electrons produced at the detector surface. To suppress tertiary electrons generated at the detector surface, the electrostatic field is configured to point away from the detector surface. To remove tertiary electrons generated at the detector surface, the electrostatic field is configured to point towards the detector surface. The electrostatic field also contributes to the analyzer focus.

Higher-energy secondary electrons travel farther and impinge upon the position-sensitive detector **421** at positions farther away from the z-axis. For purposes of illustration, FIG. 4B depicts the trajectories of the secondary electrons with various initial polar angles θ but with one of three example energy levels. The secondary electrons at the low-energy level land at a close radial position **423** along the position-sensitive detector **421**. The secondary electrons at the middle energy level land at a middle radial position **424** along the position-sensitive detector **421**. Finally, the secondary electrons at the high energy level land at a far radial position **425** along the position-sensitive detector **421**. In accordance with an embodiment of the invention, a lowest-energy level detectable by the position-sensitive detector **421** is $U = eV$, and a highest-energy level detectable by the position-sensitive detector **421** is $U = 2\,e\,V$, where e is an electron charge and $-V$ is the potential applied to the electrodes **404** and **412**.

One advantage of the multi-cavity energy analyzer **310** in FIGS. 4A and 4B is that the space for the detection chain stack **422** (for example, a stack of microchannel plates to increase the detection gain) is not constrained by the proximity of the target substrate **108**. This enables the full use of the radial extent of the position-sensitive detector **421**, even if high gain is needed. Another advantage of the multi-cavity energy analyzer **310** is that it reduces the background signal from tertiary electrons produced inside the analyzer cavity. This is because the tertiary electrons are less likely to follow the double-mirror Scurved path to the detector surface (compared with a more straightforward single-mirror path).

As seen in FIG. 4B, the trajectories **420** of the electrons within the multi-cavity energy analyzer **310** follow an "S" shaped curve. As such, the multi-cavity energy analyzer **310** may be thought of as an "S-Curve" energy analyzer. Since the multi-cavity energy analyzer **310** uses at least two mirror electrodes, it may also be considered to be a "tandem mirror" energy analyzer.

In accordance with an embodiment of the invention, the surface plane of the position-sensitive detector **421** is tilted approximately +11 degrees with respect to the plane of the mesh **402**. (In contrast, the position-sensitive detector **210** in FIG. 2 is tilted at an opposite angle of about -11 degrees.) Applicant has determined that, at this tilted position of +11 degrees, the first and second order focusing conditions are simultaneously satisfied, thereby providing excellent energy resolution for a substantially-large polar angle opening. For example, an energy resolution of below 1% was achieved for a polar angle opening which spanned 20 degrees.

Revolving the tilted position of the detector about the z-axis (the optical axis of the electron column) results in a conical shape. Constructing such a conical-shaped detector surface may be somewhat problematic. Hence, in accordance with an embodiment of the invention, a segmented detector surface comprising trapezoidal anodes may be used to approximate the conical shape.

FIG. 5 is a diagram depicting an example implementation of a segmented detector surface. Several trapezoidal segments **502** are shown as they are positioned around the z-axis (the optical axis of the electron column). Other implementations may have different numbers of segments **502**. A greater number of segments may be used to better approximate a conical-shaped detector surface. As indicated, the inner edge **504** of the detector surface is lower, i.e. closer to the target substrate **108**, while the outer edge **506** of the detector surface is higher, i.e. farther away from the target substrate **108**.

To approximate an ideal landing pattern with anodes on the flat detector surfaces, the anode contours on the detector surfaces may be made to be elliptical in shape. Hence, FIG. 5 also shows several example elliptic-contoured anode lines **508** which are positioned on each detector surface. The elliptic-contour shape works well because the focal surface is actually conical in shape,

Moreover, if the detector surface is segmented (and sufficient space is between segments), then each segment may be rotatable in the polar direction about the origin (R=0, z = 0). This enables the energy analyzer to sample polar ranges associated with higher or lower take-off angles.

In accordance with an embodiment of the invention, a large polar angle opening (for example, spanning about 20 degrees) may be combined with a detector surface which spans a full 360 degree range in azimuth angle ϕ. Applicants have determined that, with such a configuration, the multi-cavity energy analyzer **310** is able to collect a substantial fraction of about 30% of the secondary electron current. Furthermore, because the aforementioned focusing conditions are independent of the electron energy, the parallel acquisition of a range of energies may be made simultaneously.

Note that the range of energies that may be detected in parallel may be limited by the overlapping of the high and low energy electrons at the detector plane such that there is a maximum theoretical high-to-low energy ratio of approximately 2.0. In this case, the spectrum from a desired energy range, for example, from a low energy of U_L to a high energy of U_H, may be acquired in approximately $N = \log(U_H/U_L) / \log(2)$ steps.

FIG. 6 is a cross-sectional diagram illustrating a resistor-like sidewall implemented using a voltage step-down array in accordance with an embodiment of the invention. In this case, the voltage step-down array depicted is used for the top inner resistor-like sidewall **406** which is arranged between the top electrode **404** and the central mesh **402**. The same basic structure may be used for the other resistor-like sidewalls (**407**, **414**, and **415**) of the energy analyzer.

As shown, the resistor-like sidewall **406** may be formed using a series of rails **602** to which are applied the step-down voltages. In the particular example illustrated, there are seven rails **602** for the sidewall **406**, and the step-down voltages are in increments of 1/8 V, where –V is the voltage applied to the top electrode **404** and the central mesh **402** is at electrical ground. (If the cavities are segmented, then the ends of corresponding inner and outer rails may be connected by radial rail segments.)

In an alternate embodiment, the resistor-like sidewalls (**406**, **407**, **414**, and **415**) may comprise sidewalls having a resistive coating. In such an embodiment, the resistive coating effectively transitions the voltage in a continuous (i.e. analog) manner from the top **404** (or bottom **412**) electrode to the central mesh **402**.

Although embodiments of the multi-cavity energy analyzer **310** which are radially-symmetric (or approximately radially-symmetric) around the z-axis are described above, other embodiments may be implemented which are radially-asymmetric around the z-axis. The multi-cavity energy analyzer **310** generally comprises three electrodes: two parallel plates which are biased negatively with respect to a mesh that is positioned in between. The surface of these electrodes need not have any specific shape. The shape of the electrodes may, for example, be rectangular or circular in nature. The electrodes will generally have different inner and outer radii, and they may span either a limited range in the azimuth angle to form one or more sectors or may occupy the full 2π radians (360 degrees). An opening within the inner radii provides space for the objective lens of the microscope which guides the primary electrons.

While the above description focuses on embodiments with electrons as the charged particles being detected by the energy analyzer, other embodiments may be used to detect other charged particles. For example, the charged particles being detected may be negatively or positively charged ions. If the charged particles being detected are positively-charged ions, then the voltages applied to the top and bottom electrodes (**404** and **412**) would be positive, and the voltage step-down arrays (**406**, **407**, **414** and **415**) would step down the positive voltage.

In addition, while the central meshes **402** is described as electrically grounded in the above-discussed embodiments, the central meshes **402** need not be grounded in accordance with other embodiments. For example, the central meshes **402** may be electrically isolated and biased with a relatively small voltage.

Furthermore, in accordance with a preferred embodiment of the invention, the central meshes **402** may be comprised of wires elongated principally in the radial direction. In this embodiment, radial perturbations of the charged-particle trajectories are advantageously reduced by minimizing the cross-wires extending in the azimuthal direction.

The above-described diagrams are not necessarily to scale and are intended be illustrative and not limiting to a particular implementation. Specific dimensions, geometries, and lens currents of the immersion objective lens will vary and depend on each implementation.

The above-described invention may be used in an automatic inspection system and applied to the inspection of wafers, X-ray masks and similar substrates in a production environment. While it is expected that the predominant use of the invention will be for the inspection of wafers, optical masks, X-ray masks, electron-beam-proximity masks and stencil masks, the techniques disclosed here may be applicable to the high speed electron beam imaging of any material (including possibly biological samples).

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. A charged-particle energy analyzer apparatus comprising:

a first electically-conductive mesh with openings for passage of charged particles, the first mesh being arranged to receive the charged particles on a first side and pass the charged particles to a second side;

a first electrode arranged such that a first cavity is formed between the second side of the first mesh and the first electrode;

a second electrically-conductive mesh with openings for passage of the charged particles, the second mesh being arranged to receive the charged particles on a second side and pass the charged particles to a first side

a second electrode arranged such that a second cavity is formed between the first side of the second mesh and the second electrode;

a third electrically-conductive mesh with openings for passage of the charged particles, the third mesh being arranged to receive the charged particles on a first side and pass the charged particles to a second side; and

a position-sensitive charged-particle detector arranged to receive the charged particles after the charged particles pass through the third mesh.

2. The apparatus of claim 1, wherein the first, second and third meshes are parts of a single mesh structure.

3. The apparatus of claim 1, wherein the first electrode comprises a first electrically-conductive plate, and wherein the second electrode comprises a second electrically-conductive plate.

4. The apparatus of claim 1, wherein the first, second and third meshes are electrically grounded, and wherein a negative voltage is applied to the first and second electrodes.

5. The apparatus of claim 1, further comprising:

resistor-like sidewalls electrically coupling the meshes to the electrodes.

6. The apparatus of claim 5, wherein the resistor-like sidewalls comprise voltage step-down arrays.

7. The apparatus of claim 5, wherein the resistor-like sidewalls comprise sidewalls with a resistive coating.

8. The apparatus of claim 1, wherein trajectories of the charged particles enter the first cavity through the first mesh, are deflected away from the first electrode, enter the second cavity through the second mesh, are deflected away from the second electrode, and exit the second cavity through the third mesh.

9. The apparatus of claim 1, further comprising:

a first electrically-conductive shield arranged to shield an electrostatic field in the first cavity; and a second electrically-conductive shield arranged to shield an electrostatic field in the second cavity.

10. The apparatus of claim 1, further comprising:

a metal mesh arranged in front of a surface of the position-sensitive charged-particle detector, and an electrostatic field created by a voltage difference between the metal mesh and the surface.

11. The apparatus of claim 1, further comprising:

detector segments of the position-sensitive charged-particle detector.

12. The apparatus of claim 11, wherein the detector segments comprise trapezoidal detector surfaces.

13. The apparatus of claim 11, wherein the detector segments are rotatable in a polar direction.

14. The apparatus of claim 1, wherein the charged particles comprise electrons, the apparatus further comprising:

an electron source configured to generate a primary electron beam;

an objective lens configured to focus the primary electron beam to a spot at a surface of a target substrate; and

a deflector configured to controllably deflect the primary electron beam over the surface of the target substrate,

wherein the primary electron beam cause emission of secondary electrons from the surface of the target substrate, and

wherein trajectories of the secondary electrons go through the first and second cavities and are detected by the position-sensitive charged-particle detector.

15. A method of analyzing energies of charged particles, the method comprising:

passing the charged particles through a first electrically-conductive mesh to enter a first cavity, deflecting the charged particles away from a first electrically-conductive plate;

passing the charged particles through a second electrically-conductive mesh to exit the first cavity and enter a second cavity;

deflecting the charged particles away from a second electrically-conductive plate;

passing the charged particles through a third electrically-conductive mesh to exit the second cavity; and

detecting the charged particles with a position-sensitive detector.

16. The method of claim 15, wherein the first, second and third electrically-conductive meshes are parts of a single mesh structure.

17. The method of claim 15, wherein the electrically-conductive meshes are electrically grounded, and wherein a negative voltage is applied to the first and second electrically-conductive plates.

18. The method of claim 17, further comprising:

shielding the first cavity using a first electrically-conductive shield; and

shielding the second cavity with a second electrically-conductive shield.

19. The method of claim 15, wherein the charged particles comprise electrons, the method further comprising:

generating a primary electron beam using an electron gun;

focusing the primary electron beam to a spot at a surface of a target substrate;

causing emission of secondary electrons from the surface of the target substrate; and controllably deflecting the primary electron beam over the surface of the target substrate,

wherein trajectories of the secondary electrons emitted from the surface of the target substrate travel through the first and second cavities and are detected by the position-sensitive charged-particle detector.

20. The method of claim 15, further comprising:

applying an electrostatic field between a detector surface and a mesh in front of the detector surface so as to suppress or remove tertiary electrons generated at the detector surface.

21. The method of claim 15, further comprising:

polar rotation of segments of the position-sensitive charged-particle detector.

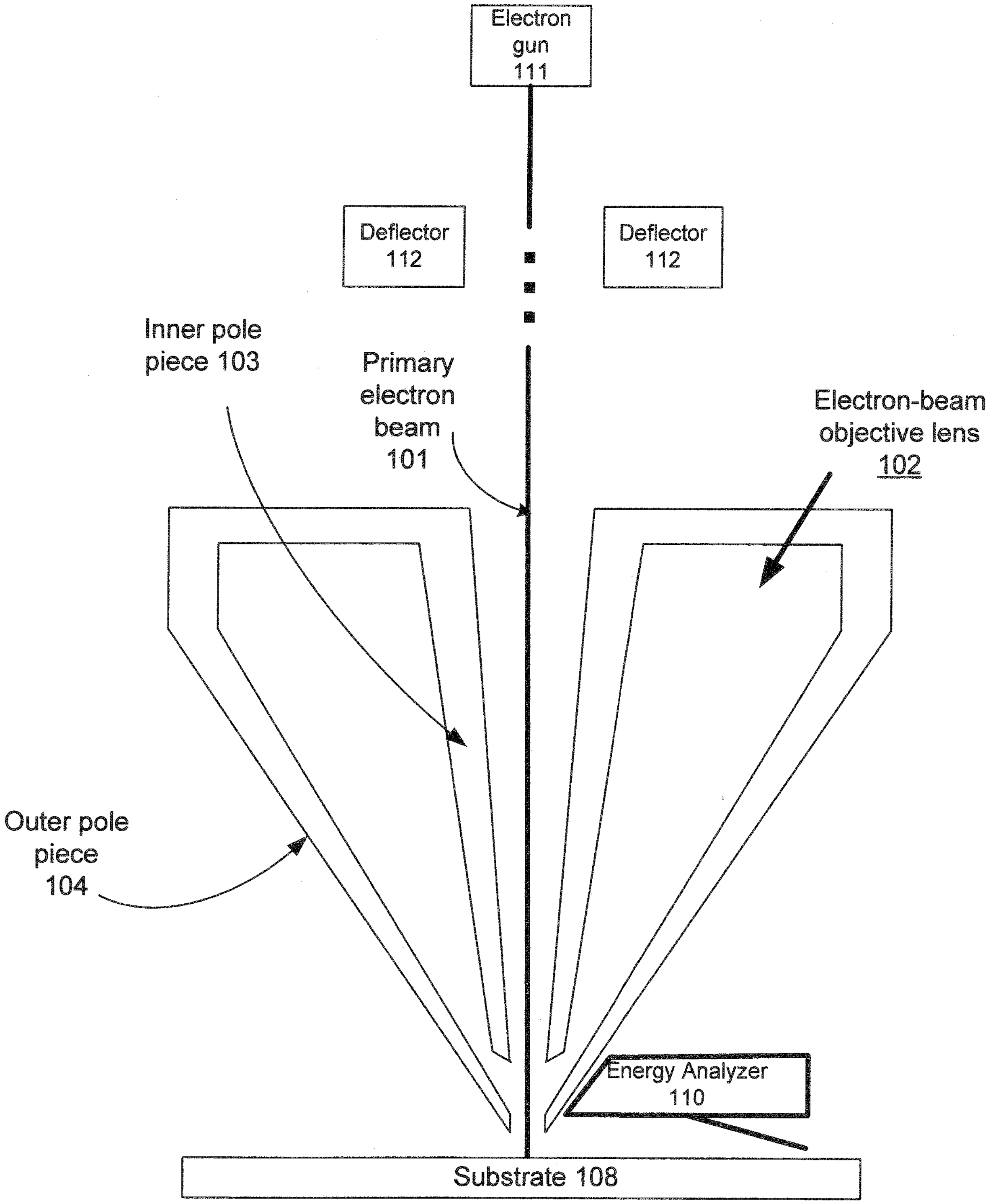


FIG. 1
(Conventional)

100

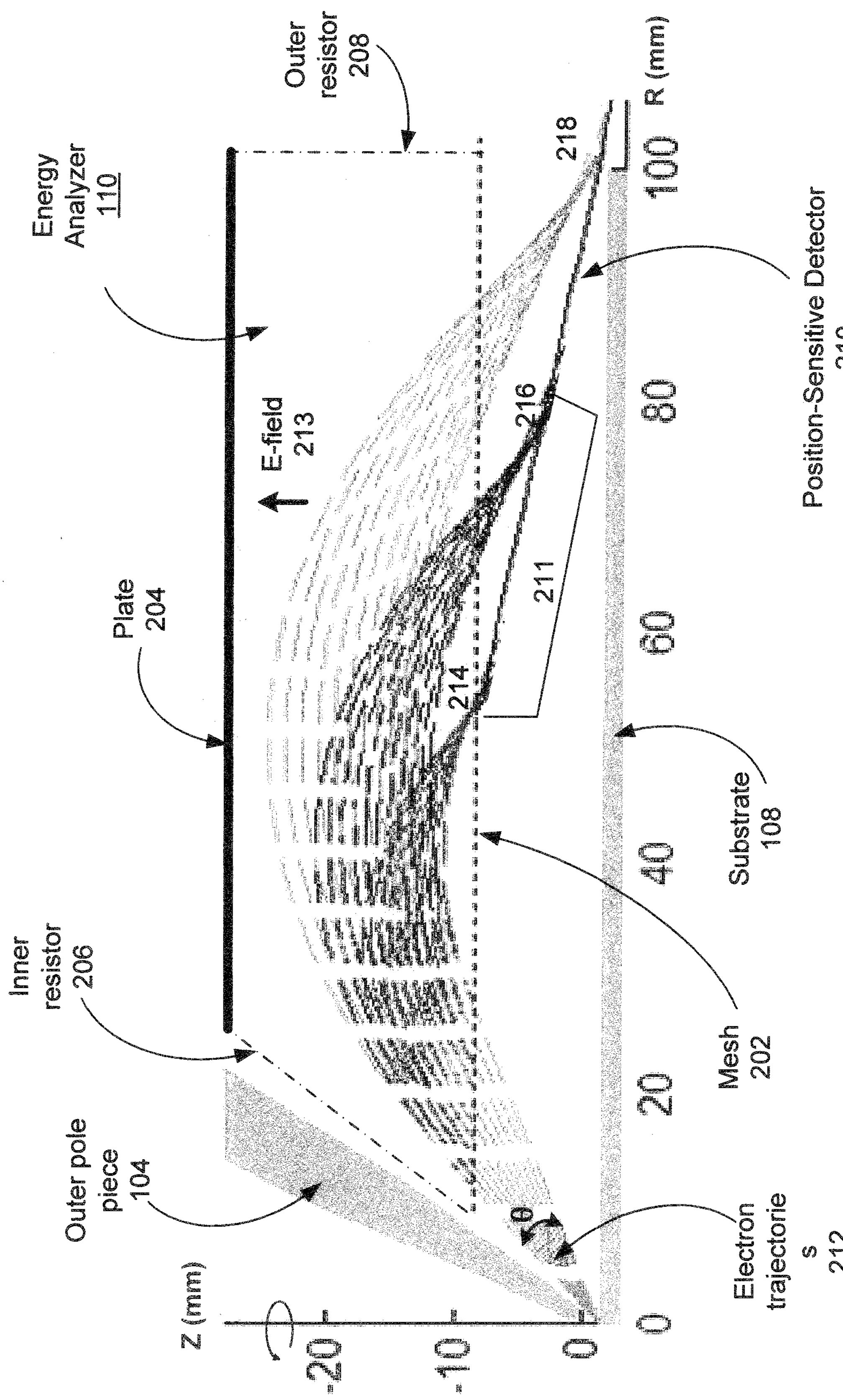


FIG. 2
(Conventional)

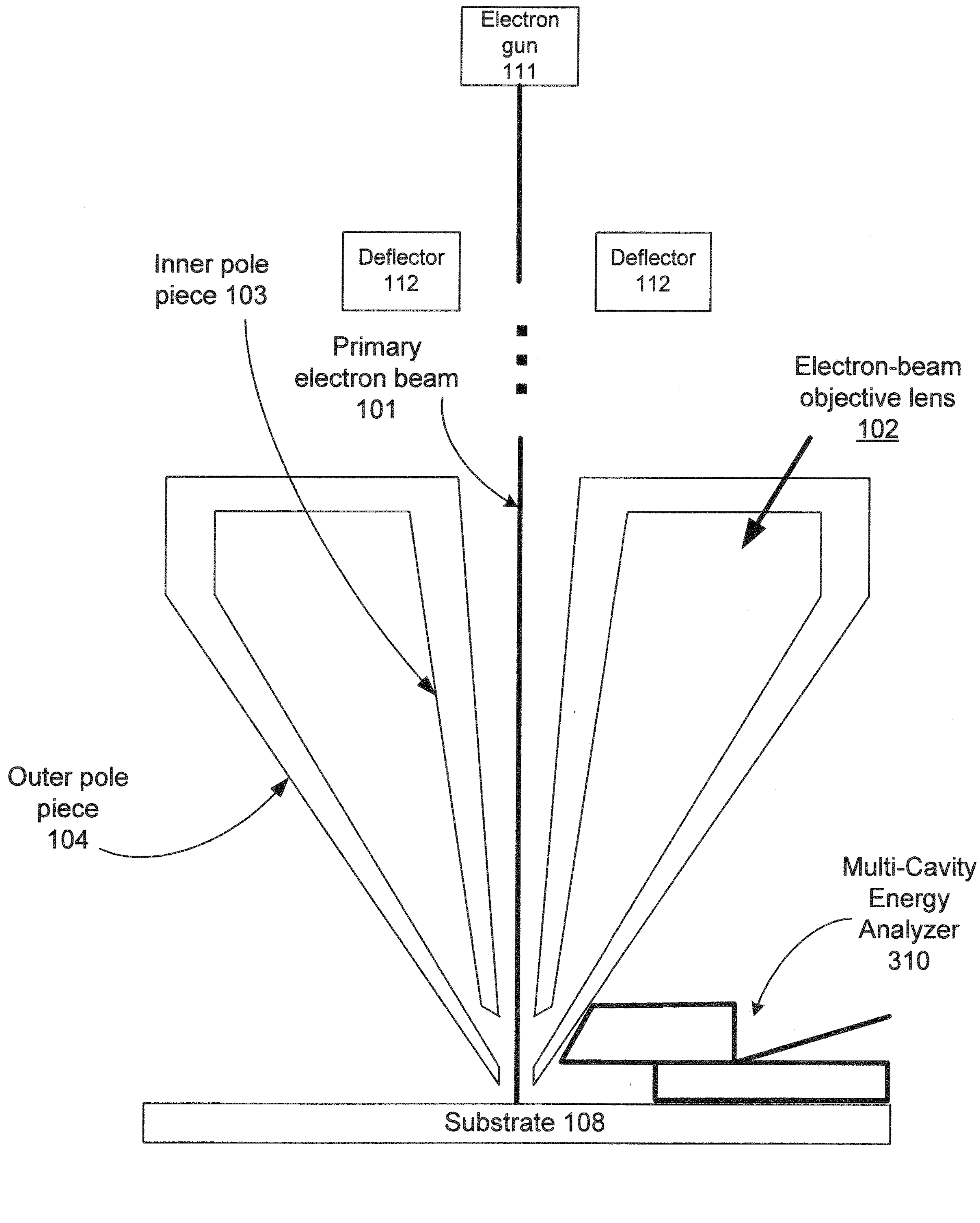

Electron gun 111
Deflector 112
Deflector 112
Inner pole piece 103
Primary electron beam 101
Electron-beam objective lens 102
Outer pole piece 104
Multi-Cavity Energy Analyzer 310
Substrate 108

FIG. 3 300

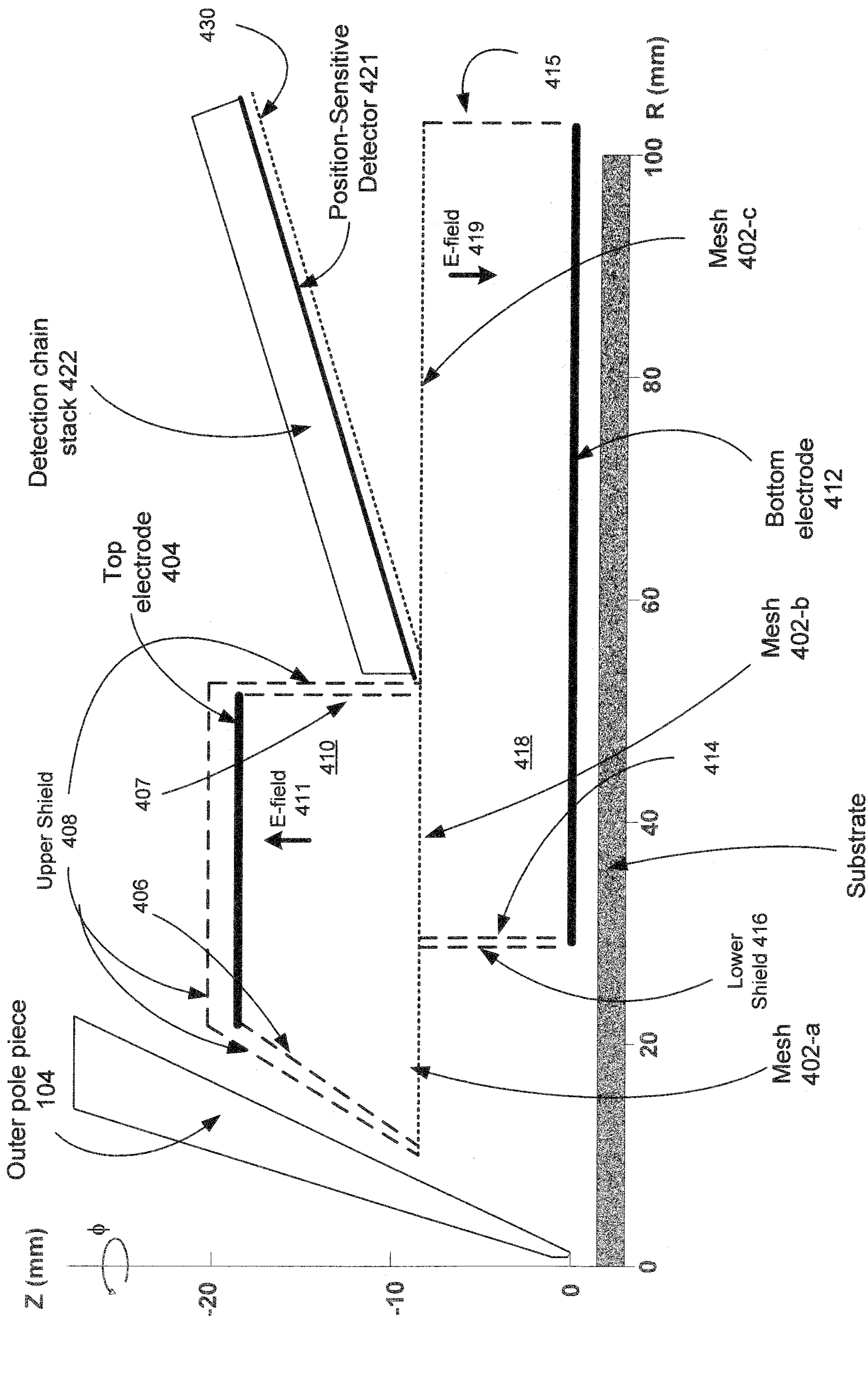
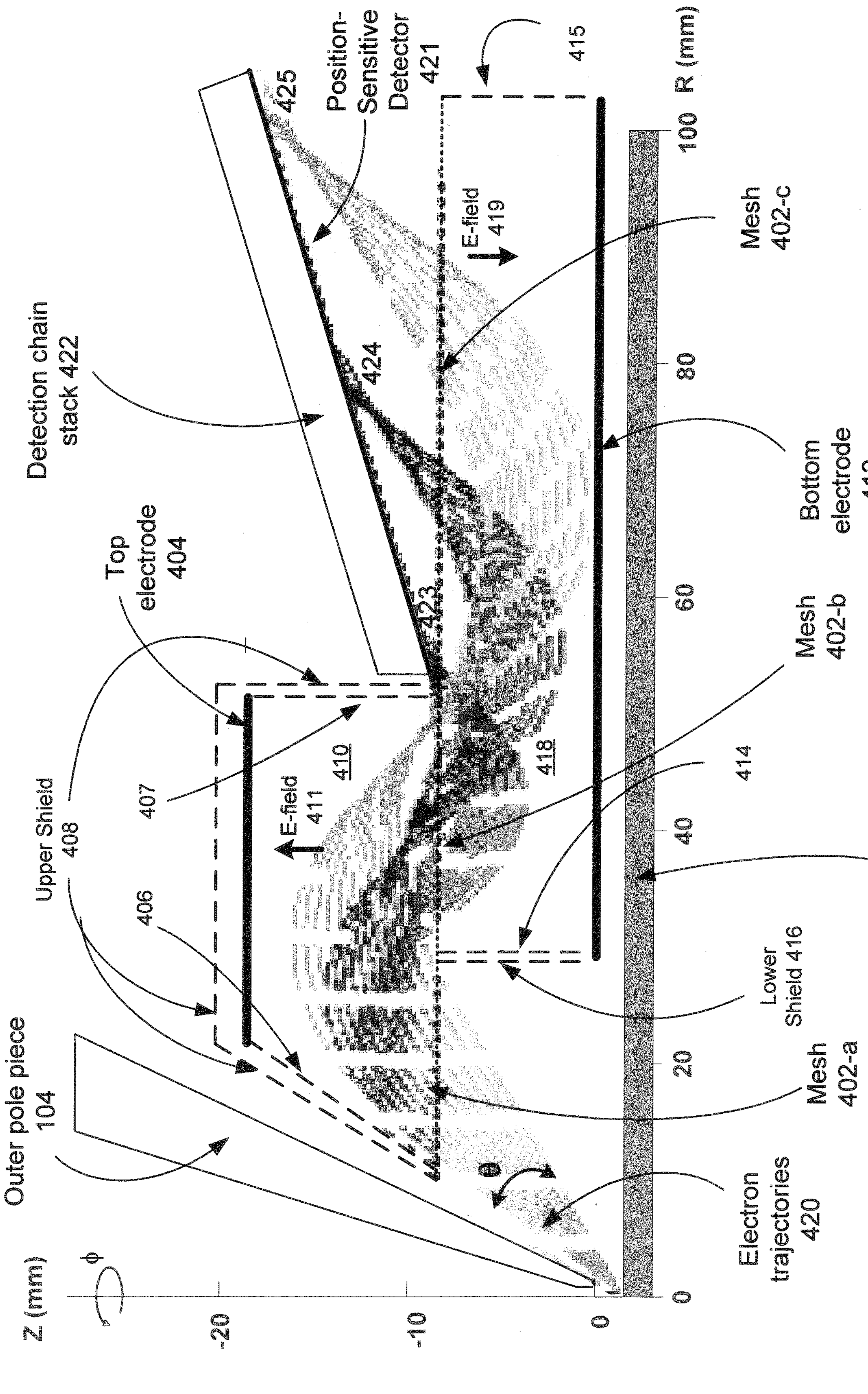
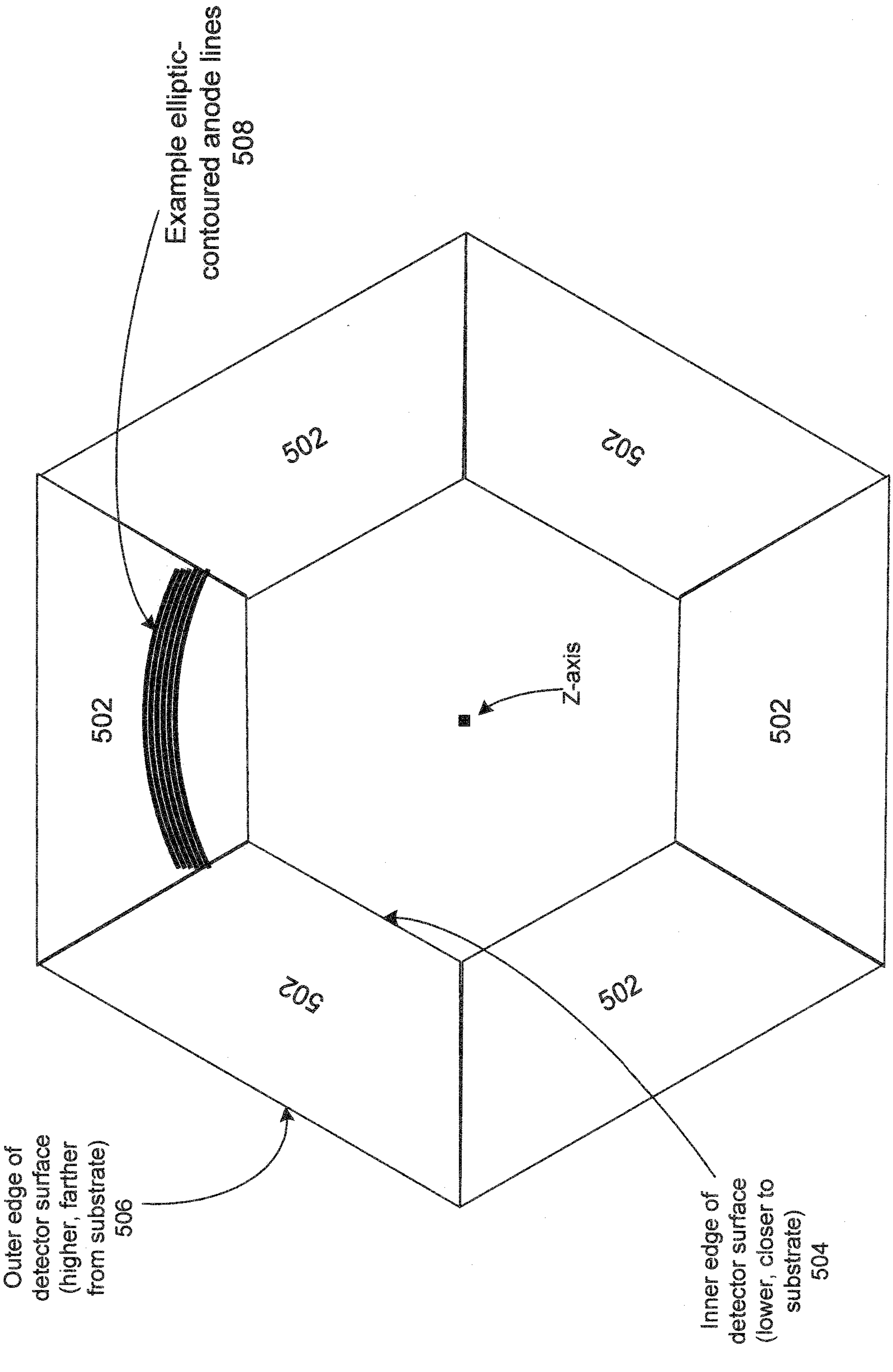

430
Position-Sensitive Detector 421
415
R (mm)
Detection chain stack 422
E-field 419
Mesh 402-c
Top electrode 404
Bottom electrode 412
Upper Shield 408
407
E-field 411
410
418
414
Mesh 402-b
406
Substrate 108
Outer pole piece 104
Lower Shield 416
Mesh 402-a
Z (mm)
φ
-20
-10
0
20
40
60
80
100

FIG. 4A



Z (mm)
φ
-20
-10
0
R (mm)
0
20
40
60
80
100
θ
Outer pole piece 104
Upper Shield 408
406
407
Top electrode 404
Detection chain stack 422
Position-Sensitive Detector 421
425
424
423
415
E-field 419
E-field 411
410
418
Mesh 402-c
Mesh 402-b
Mesh 402-a
Bottom electrode 412
414
Lower Shield 416
Substrate 108
Electron trajectories 420

FIG. 4B



Example elliptic-contoured anode lines 508
502
502
502
Z-axis
502
502
502
Outer edge of detector surface (higher, farther from substrate) 506
Inner edge of detector surface (lower, closer to substrate) 504

FIG. 5

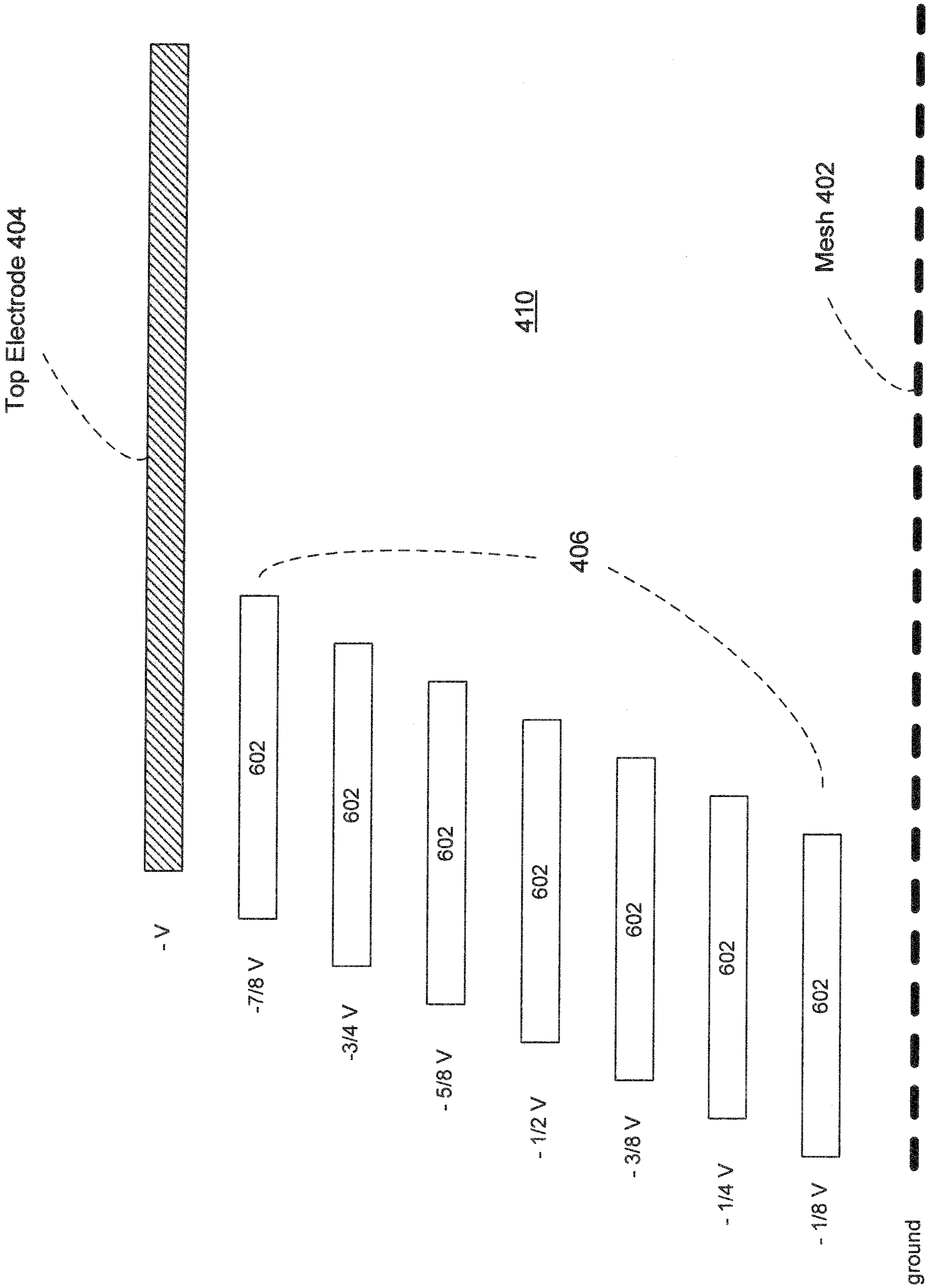

Top Electrode 404
410
Mesh 402
406
602
602
602
602
602
602
602
- V
-7/8 V
-3/4 V
- 5/8 V
- 1/2 V
- 3/8 V
- 1/4 V
- 1/8 V
ground

FIG. 6