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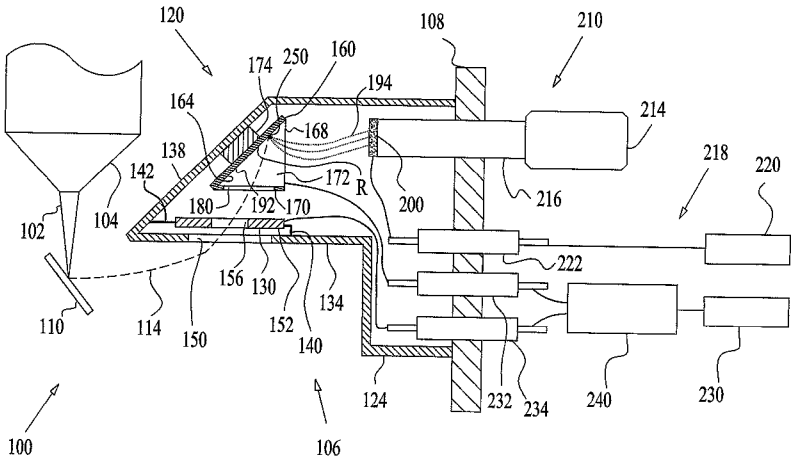
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(54) **Title**: CHARGED PARTICLE DETECTION SYSTEM AND METHOD

FIG. 2



(57) **Abstract**: A charged particle detection device comprising an electric field generator configured and operable to create an electric field defining trajectories for charged particles of different types emitted from a sample as a result of the sample interaction with a particle beam, the emitted charged particles of different types being one of the following: electrons, positive ions and negative ions, an ion-to-electron converter having a conversion surface including a continuous interaction region oriented so as to intersect the trajectories of the charged particles of different types propagating from the sample, the conversion surface operative to emit electrons in response to the surface interaction with the charged particles of the different types, and an electron detector configured and operable to receive electrons from the converter and generate output data indicative thereof.

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CHARGED PARTICLE DETECTION SYSTEM AND METHOD

REFERENCE TO CO-PENDING APPLICATIONS

Applicant hereby claims priority of U. S. Patent Application Serial No. 12/155,233, filed on May 30, 2008, entitled "Three Modes Particle Detector" which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The present invention generally relates to a charged particle detection system and method, in particular to a particle detection system capable of detecting electrons, positive ions and negative ions.

BACKGROUND OF THE INVENTION

Electrons, positive ions and negative ions are charged particles that can be emitted from a sample upon irradiation thereof by a focused ion beam. Particle detectors, which can detect both positively charged particles and negatively charged particles, are well known. These detectors typically comprise a scintillator element, which is excited by electrons that are emitted from the sample and/or generated by conversion of ions to electrons by an ion-to-electron converter. The converters used in the devices of the kind specified are designed in such a way that positive ions are allowed to impinge upon surfaces of the ion-to-electron converter and cause emission of secondary electrons from the conversion surfaces of the converter, while negatively charged particles bypass the conversion surfaces without interacting with these surfaces.

GENERAL DESCRIPTION

The present invention provides a novel particle detection system capable of detecting electrons, positive ions and negative ions.

The conventional particle detectors utilize ion-to-electron converters and are configured to allow positive ion interaction with the conversion surfaces of the converter while preventing negative ion and electron interaction with such surfaces. However, with the conventional approach, negative ions pass through a detector and impinge directly upon the surface of a scintillator element thus shortening the scintillator element surface life.

The invented approach provides for solving the above problem. Also, the invention provides for utilizing the ion-to-electron converter for converting electrons originating from a sample to secondary electrons, in addition to converting the positive and negative ions to electrons, thereby amplifying the number of electrons to be detected by the detector.

There is thus provided in accordance with an embodiment of the present invention a charged particle detection device comprising an electric field generator configured and operable to create an electric field defining trajectories for charged particles of different types emitted from a sample as a result of the sample interaction with a particle beam, the emitted charged particles of different types being one of the following: electrons, positive ions and negative ions, an ion-to-electron converter having a conversion surface including a continuous interaction region oriented so as to intersect the trajectories of the charged particles of different types propagating from the sample, the conversion surface operative to emit electrons in response to the surface interaction with the charged particles of the different types, and an electron detector configured and operable to receive electrons from the converter and generate output data indicative thereof.

In accordance with an embodiment of the present invention the conversion surface is curved or planar. Alternatively, the converter has a cross section of a right triangle geometry with a hypotenuse including the conversion surface with the continuous interaction region.

In accordance with another embodiment of the present invention the electric field generator includes a voltage supply unit operable to provide electrical biasing of the converter and the electron detector to create a desired electric field. Additionally, the device includes a grid-like electrode accommodated upstream of the converter for directing the charged particles towards the interaction region. Moreover, the electric field generator includes a high voltage power supply and a voltage divider and is operable for performing electrical biasing of the grid, the converter and the electron detector by supplying voltage thereto. Additionally, the electric field generator includes a high voltage power supply operable in communication with an external voltage divider for performing electrical biasing of the grid, the converter and the electron detector by supplying voltage thereto. Moreover, the voltage divider includes at least two resisters.

In accordance with yet another embodiment of the present invention the electron detector includes a scintillator element surface. Additionally, the conversion surface has a non-planar shape selected to minimize detection efficiency inhomogeneity within the device.

There is thus provided in accordance with another embodiment of the present invention a charged particle detector device for detecting a charged particle emitted from a sample, the detector device including a converter defining a conversion surface with a continuous region of interaction of incident charged particles of different types including positive and negative ions and electrons, the conversion surface being adapted for emitting electrons in response to interaction with the charged particles of different types, and an electron detector for receiving electrons from the converter and generating output data indicative thereof. Additionally, the conversion surface is curved or planar.

There is thus provided in accordance with yet another embodiment of the present invention a charged particle detection system including a particle beam column for generating a particle beam for exciting a sample to thereby cause emission of charged particles of different types therefrom, the emitted charged particles including at least one positive ion, negative ion and electron, and a charged particle detection device for detecting the charged particles of different types and generating output data indicative thereof, the detection device including a converter defining a conversion

surface with a continuous region of interaction of incident charged particles of different types including positive and negative ions and electrons, the conversion surface being adapted for emitting electrons in response to interaction with the charged particles of different types, and an electron detector for receiving electrons from the converter and generating output data indicative thereof.

In accordance with an embodiment of the present invention the system includes an electric field generator configured and operable to create an electric field within the detection device defining trajectories for the charged particles of different types emitted from a sample as a result of the sample interaction with the particle beam, the continuous region of interaction of the conversion surface intersecting the trajectories of the charged particles of different types. Additionally, the conversion surface is curved or planar. Moreover, the system includes a grid-like electrode accommodated upstream of the converter to direct the charged particle emitted from the sample to the region of interaction.

In accordance with another embodiment of the present invention the particle beam column includes a focused ion beam (FIB) column, a dual beam column operative to selectively emit a FIB or an electron beam, an electron beam column or a helium beam column. Additionally, the electron detector includes a scintillator element surface. Moreover, the conversion surface has a non-planar shape selected to minimize detection efficiency inhomogeneity within the particle detection device.

There is thus provided in accordance with a further embodiment of the present invention a method for use in detecting charged particles of different types emitted from a sample, the method including creating an electric field in a path of charged particles of different types emitted from the sample so as to direct the charged particles of different types along a trajectory towards a charged particle converter, the charged particles of different types being one of the following a positive ion, a negative ion and an electron, providing a continuous interaction region of the converter oriented to intersect trajectories of the charged particles of the different types propagating towards the converter, the interaction region being responsive to the charged particle incidence thereon to emit electrons, and detecting the emitted electrons and generating output data indicative thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description, taken in conjunction with the drawings in which

Fig. 1 is a schematic illustration of an example of a charged particle detection system according to the invention;

Fig. 2 is a simplified sectional illustration of a particle detection system constructed and operative in accordance with an embodiment of the present invention;

Fig. 3 is a simplified sectional illustration of a particle detection system constructed and operative in accordance with another embodiment of the present invention;

Fig. 4 is a simplified sectional illustration of a particle detection system constructed and operative in accordance with yet another embodiment of the present invention; and

Fig. 5 is a simplified sectional illustration of a particle detection system constructed and operative in accordance with still another embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Referring to **Fig. 1**, there is illustrated, by way of a block diagram, an example of a charged particle detection system **10** configured and operable according to the invention. System **10** comprises a charged particle detection device **12** configured according to the invention for detecting charged particle(s) **14** of different types emitted from a sample **16**, and a particle beam column **18**. Particle beam column **18** may

comprise a focused ion beam (FIB) column, a dual beam column, an electron beam column, a helium beam column or any other suitable particle beam column. The charged particle detectable by detection device **12** is an electron, a positive ion or a negative ion. A particle beam **20**, generated by column **18**, irradiates the sample **16** causing charged particle (positive/negative ion and/or electron) emission from the sample **16**. The emitted particle propagates towards detection device **12**.

As will be described further below, the detection device **12** is operable in three modes for detecting positive and negative ions and electrons, respectively, depending on a generated electric field. The detection device **12** comprises a converter **26** for generating electrons **27** in response to interaction with incident charged particles **14**, an electron detector **28**, and a control unit **30**. Optionally, the detection system **10** comprises a grid electrode **32** accommodated in the path of charged particles emitted from the same, e.g. upstream of the converter **26** with respect to propagation of the charged particle trajectories. Grid **32** may or may not be a constructional part of the detection device **12**.

The control unit **30** comprises an electric field generator **38**, which may be referred to as an electrical biasing assembly, configured and operable for creating an appropriate electric field within the detection device **12** to thereby define trajectories for charged particle (i.e. for positive and negative ion and for electron) propagation towards detector **28**. Electric field generator **38** thus comprises a voltage supply unit (not shown) to supply/maintain appropriate voltages to converter **26** and detector **28** and also to grid **32** if such grid is used in the detection device **12**.

The converter **26** has a charged particle conversion surface **40** which has a continuous surface interaction region **R** oriented to intersect the trajectories of charged particles of different types. Conversion surface **40** (at least within the interaction region **R**) is adapted for emitting electrons in response to interaction with incident charged particle(s). Electron detector **28** has a scintillator element surface **44** exposed to electron output from the converter **26**. With such appropriately oriented continuous interaction region **R**, the electric field created within the detection device **12** defines an operational mode of the device to selectively allow detection of the charged particles of any type by the electron detector **28**.

It is appreciated that electron detector **28** may be of any suitable configuration for receiving electrons and generating output data indicative thereof. For example, a Multi-Channel-Plate (MCP) or a Solid State Diode (SSD) may be employed. Alternatively, a CHANNELTRON® detector may be employed and may be commercially available at Burle Industries, Inc. of 1000 New Holland Avenue, Lancaster, PA 17601-5688 U.S.A.

Detection device **12** thus operates as a triple mode particle detection device. As will be described more specifically further below, converter **26** is electrically biasable for selectively attracting a charged particle and electron detector **28** is electrically biasable with respect to converter **26** so as to detect the electron emitted from the conversion surface **40**.

In a non-limiting example, the scintillator element surface **44** of the electron detector **28** may be set to a positive high potential typically in the range of approximately 7kV-12kV. The converter **26** may be set to a positive or negative potential with a fixed proportion factor relative to the grid **32**. The fixed proportion factor may be larger than 1, such as approximately 1.4, for example.

The converter **26** and detector **28** (its scintillator element surface **44**), as well as grid **32** if used, may be each set at a different electrical potential to create an appropriate electric field defining the trajectories of the different-type charged particles so as to selectively facilitate detection of a positive ion in a positive ion detection mode, a negative ion in a negative ion detection mode, and an electron in an electron detection mode. For example, to facilitate the positive ion detection mode, grid **32** may be set to an electrical potential of approximately -2.7 kV, converter **26** may be set to an electrical potential of approximately -3.8 kV and the scintillator element surface **44** may be set to an electrical potential of approximately +10 kV. To implement the negative ion detection mode, grid **32** may be set to an electrical potential of approximately +2.7 kV, converter **26** may be set to an electrical potential of approximately +3.8 kV and the scintillator element surface **44** may be set to an electrical potential of approximately +10 kV. In the electron detection mode, grid **32** may be set to an electrical potential of approximately +1 kV, converter **26** may be set to an electrical potential of approximately +1.4 kV and the scintillator element surface **44** may be set to an electrical potential of approximately +10 kV.

It is appreciated that grid **32**, if used, may be located at any suitable location. The provision of the grid **32** is optional. The desired electric fields can be created by appropriate potentials on the converter **26** and detector **28** (to ensure that a particle **14** emitted from a sample **16** impinges upon the conversion surface **40** of the converter **26**, and also to ensure that electrons **27** from the converter **26** are directed to the detector **28**). The following description comprises some specific but non limiting examples of the configuration of the detection system according to the invention.

Reference is made to **Fig. 2**, which is a simplified sectional illustration of a particle detection system **100** constructed and operative in accordance with an embodiment of the present invention. Particle detection system **100** comprises a particle beam **102** generated by a beam column **104,** and a charged particle detection device, also referred to as a triple mode particle detection device, which in the present example is located within a detection system chamber **106** having walls **108**. The particle beam **102** generated by column **104** irradiates a sample **110** thus urging one or more charged particles **114** to be emitted therefrom. The emitted charged particles **114** may comprise an electron, positive ion and/or a negative ion. As indicated above, beam column **104** may comprise a focused ion beam (FIB) column, a dual beam column, an electron beam column, a helium beam column or any other suitable particle beam column.

A particle detection device **120** is enclosed in a housing **124** formed of any suitable conductive material. Preferably, housing **124** is set to an electrical potential of the detection system chamber **106**. Optionally, a grid **130** is provided in the detection device, e.g. being mounted to walls **134** and **138** of the housing **124** in any suitable manner, e.g. using mounting elements **140** and **142**. Mounting elements **140** and **142** may be formed of any suitable material, typically an insulating material, such as Ertalyte® which may be commercially available at Modern Plastics of 678 Howard Avenue, Bridgeport, Connecticut, USA.

Housing **124** has an aperture **150** in its wall **134** for a charged particle **114** to pass therethrough. Thus, charged particle **114** is urged to pass the housing aperture **150** and reach grid **130** while the electric field in the detection device is such as to attract the particle towards the grid **130** (the grid **130** is electrically biased at a potential operative to attract the charged particle **114** thereto). Grid **130** may be formed of any suitable conductive material, such as stainless steal. The grid **130** may define a

planar surface **152** or any other suitable geometry, such as a curved surface, a mash, an array of spaced apart elements or any configuration operative to allow a particle to pass therethrough.

The charged particle **114** passes grid **130**, via a grid space/aperture **156**, preferably configured at a central location of planer surface **152**, and propagates to a converter **160**. Converter **160** may have any suitable configuration such that a conversion surface **164** thereof, or at least an interaction region **R** thereof, is located in the propagation path of the charged particles of different types. As seen in **Fig. 2**, a cross section of converter **160** may have a right triangle geometry with conversion surface **164** defined by a hypotenuse surface between side supports **168.** Converter **160** may include a bottom support **170,** thus defining a converter vicinity **172** therein for charged particle passage therethrough away from the conversion surface **164.** Bottom support **170** is formed with an aperture **180** for charged particle passage therethrough towards the conversion surface **164.** Converter **160** may be mounted to housing **124** in any suitable manner, such as by a mounting element **174** affixing conversion surface **164** to housing wall **138.** Mounting element **174** may be formed of any suitable material, typically an insulating material, such as Ertalyte® which may be commercially available at Modern Plastics of 678 Howard Avenue, Bridgeport, Connecticut, USA.

Any suitable material for allowing high electron emission may be used for the conversion surface **164** of converter **160,** such as aluminum covered by a thin layer of aluminum oxide, for example.

A control unit **(Fig. 1)**, namely its electric field generator operates to create an appropriate electric field to direct charged particle **114** towards the converter **160,** i.e. converter **160** is electrically biased at a potential operative to attract the charged particle **114** thereto such that the charged particle **114** passes aperture **180** and impinges upon conversion surface **164** within the interaction region **R** at its surface side **192.** Consequentially, a plurality of electrons **194** are emitted from conversion surface **164** at the same surface side **192.** Thus, converter **160** operates as an ion-to-electron converter whereupon the charged particle **114** is a positive ion or a negative ion. Additionally, the same conversion surface operates as a particle **114** amplifier. For example, three electrons **194** may be emitted upon impingement of a single particle **114** on conversion surface **164.**

The so-emitted electrons **194** pass vicinity **172** and propagate towards a scintillator element surface **200** of an electron detector **210**. The scintillator element surface **200** may be coupled to a light sensor, such as a photomultiplier tube (PMT) **214** via a light guide **216** thereby yielding an electrical signal from electron detector **210**.

As described hereinabove, the grid **130**, converter **160** and scintillator element surface **200** are electrically biased so as to create an electric field capable of urging charged particle **114** of a specific type emitted from sample **110** to pass grid **130** onto converter **160** and to attract resultant electrons emitted from converter **160** to scintillator element surface **200**. It should be understood that grid **130**, converter **160** and scintillator element surface **200** may be electrically biased in any suitable manner. Also, provision of grid **130** is optional. In the case no grid is used the electric field is defined by voltage on the converter **160** and scintillator element surface **200**.

In the embodiment shown in **Fig. 2**, an electrical biasing assembly **218** of control unit comprises a switchable high voltage power supply **220** coupled to a first voltage feedthrough **222** in electrical communication with scintillator element surface **200** so as to electrically bias scintillator element surface **200**, and a switchable high voltage bipolar power supply **230** coupled to a second and a third voltage feedthrough **232** and **234**, respectively, via a voltage divider **240**. Second voltage feedthrough **232** is in electrical communication with converter **160** so as to electrically bias converter **160**, and third voltage feedthrough **234** is in electrical communication with grid **130** so as to electrically bias grid **130**.

It is appreciated that electrical biasing assembly **218** may be configured in any suitable configuration, such as will be exemplified hereinbelow with reference to **Fig. 3**. Alternatively, a plurality or single voltage power supply may be provided. The control unit may be located within particle detection system **100** or may be located externally to particle detection system **100** and is in electrical communication therewith. Additionally, the voltage power supply and/or the voltage divider may be located within particle detection system **100** or may be located externally to particle detection system **100** and are in electrical communication therewith.

The converter **160** (and also grid **130** if used) is positioned relative to sample **110** and is electrically biased so as to ensure that a charged particle **114** emitted from sample **110** is attracted to the interaction region **R** within the conversion surface of

converter **160**. Additionally, the converter **160** (and grid **130** if used) may be positioned relative to sample **110** and the converter **160** and scintillator element surface **200** are electrically biased so as to ensure that a charged particle **114** impinges upon the interaction region within the conversion surface **164** at a location where an attraction force generated by scintillator element surface **200** is greatest so as to ensure that a resultant electron emitted from conversion surface **164** is attracted to scintillator element surface **200**. This location, designated by reference numeral **250** in **Fig. 2**, is proximal to the scintillator element surface **200**.

It is appreciated that grid **130** may be located at any suitable location inside or outside the housing **124**. Additionally, grid **130** may be obviated and converter **160** may be thus electrically biased so as to ensure that a particle **114** emitted from sample **110** will impinge upon conversion surface **164**.

It is noted that features described in reference to **Fig. 1** may be identical to features described in reference to **Fig. 2**.

Reference is now made to **Fig. 3**, which is a simplified sectional illustration of a particle detection system **300** constructed and operative in accordance with another embodiment of the present invention. Particle detection system **300** comprises a particle beam **302** generated by a particle beam column **304** which in the present example is located within a detection system chamber **306** defined by chamber walls **308**, and a triple mode particle detection device. The particle beam **302** generated by column **304** irradiates a sample **310** thus causing a charged particle **314** to be emitted therefrom. The charged particle **314** may be an electron, positive ion or a negative ion. Beam column **304** may comprise an FIB column, a dual beam column, an electron beam column, a helium beam column or any other suitable particle beam column.

Triple mode particle detection device **320** comprises a housing **324**, and optionally comprises a grid **330** which may be located inside or outside the housing **324**. The housing is formed of any suitable conductive material, and is preferably set to an electrical potential of the detection system chamber **306**. In the present example, grid **330** is located inside the housing **324** being appropriately mounted to housing walls **334** and **338**, e.g. using mounting elements **340** and **342**. Charged particle **314** is directed, by electric field in the detection device, to pass a housing aperture **350** in wall **334** and reach grid **330** which is electrically biased at a potential operative to attract the charged

particle **314** thereto. As indicated above, grid **330** may be formed of any suitable conductive material, such as stainless steal, and may define any suitable configuration such as a planar surface or a curved surface **352** allowing a particle **314** to pass through grid aperture/space **356**. The latter is preferably configured at a central location of planer surface **352**.

Charged particle **314** passes through grid **330** toward a converter **360**. Converter **360** may have any suitable configuration. As exemplified in **Fig. 3**, converter **360** has a geometry similar to that of **Fig. 2**, namely having a right triangle cross section with a conversion surface **364**, defined by a hypotenuse surface, between side supports **368.** Converter **360** may include a bottom surface **370** thus defining a converter vicinity therein **372** for charged particle passage therethrough away from the conversion surface **364**. Bottom support **370** is formed with an aperture **380** for charged particle passage therethrough towards the conversion surface **364**. Converter **360** may be mounted to housing **324** by a mounting element **374** affixing conversion surface **364** to housing wall **338**. Any suitable material for allowing high electron emission may be used for the conversion surface of converter **360**, such as aluminum covered by a thin layer of aluminum oxide, for example.

Converter **360** is electrically biased at a potential operative to attract the charged particle **314** thereto such that the charged particle **314** passes aperture **380** and impinges upon conversion surface **364**. Consequentially, a plurality of electrons **390** are emitted from conversion surface **364** at the same surface side **392** onto which the charged particle **314** was incident. Thus, converter **360** operates as an ion-to-electron converter whereupon the charged particle **314** is a positive ion or a negative ion. Additionally, the same conversion surface operates as a particle **314** amplifier. For example, three electrons **390** may be emitted upon impingement of a single particle **314** on conversion surface **364**.

Electrons **390** pass vicinity **372** and impinge upon a scintillator element surface **400** of an electron detector **410**. The scintillator element surface **400** may be coupled to a light sensor, such as a PMT **414** via a light guide **416** thereby yielding an electrical signal from electron detector **410**.

As described hereinabove, converter **360** and scintillator element surface **400** (and also grid **330** if used) are electrically biased so as to cause a charged

particle **314** emitted from sample **310** to pass to converter **360** (e.g. through grid **330**) and to attract resultant electrons emitted from converter **360** to scintillator element surface **400**. In the embodiment shown in **Fig. 3**, an electrical biasing assembly **418** comprises a switchable high voltage power supply **420** coupled to a first voltage feedthrough **422** in electrical communication with scintillator element surface **400** so as to electrically bias scintillator element surface **400**, and a switchable high voltage power supply **430** coupled to a second voltage feedthrough **432** which is in electrical communication with converter **360**. Resistors **440** and **442** may be provided so as to allow voltage fed via voltage feedthrough **432** to be divided between grid **330** and converter **360** in order to electrically bias them. As seen in **Fig. 3**, resistors **440** are interconnected between housing **324** and second voltage feedthrough **432**. Resistor **440** may be of approximately 2.5GΩ resistance and resistor **442** may be of approximately 1GΩ resistance. It is appreciated that a multiplicity of resistors may be utilized and may be located at various locations within detection device **320** at various degrees of resistance.

Thus, the converter **360** is positioned relative to sample **310** and is electrically biased to ensure that a particle **314** emitted from sample **310** will be attracted to converter **360** (e.g. assisted by grid **330**) and thereby impinge upon conversion surface **364**. Additionally, the converter **360** (and grid **330**) may be positioned relative to sample **310** and electrically biased to ensure that a particle **314** interacts with the conversion surface **364** at a location wherein an attraction force generated by scintillator element surface **400** is greatest so as to ensure that a resultant electron emitted from converter **360** is attracted to scintillator element surface **400**. This location **450** is proximal to the scintillator element surface **400**.

As indicated above, grid **330** may be located at any suitable location inside or outside the housing **324**. Additionally, grid **330** may not be used at all and converter **360** may be thus electrically biased so as to ensure that a particle **314** emitted from sample **310** interacts with conversion surface **364**.

Reference is now made to **Fig. 4**, which is a simplified sectional illustration of a particle detection system **500** constructed and operative in accordance with yet another embodiment of the present invention. Particle detection system **500** is configured generally similar to the above-described examples, namely comprising a

particle beam **502** generated by a particle beam column **504** and a triple mode particle detection device **520**. Column **504** may comprise an FIB column, a dual beam column, an electron beam column, a helium beam column or any other suitable particle beam column. Column **504** is located within a detection system chamber **506** defined by chamber walls **508**, and operates to generate particle beam **502** to irradiate a sample **510** thus causing emission of a charged particle **514** (an electron, positive ion or a negative ion) from the sample **510**.

Similar to the above examples, the detection device **520** has a housing **524** (formed of any suitable conductive material and is preferably set to an electrical potential of the detection system chamber **506**) having an aperture **550** defined within a wall **534**, optionally comprises a grid **530** (e.g. mounted to housing walls **534** and **538** by respective mounting elements **540** and **542**), and comprises an electron detector **610**. Charged particle **514** is urged to pass through aperture **550** towards grid **530**, electrically biased at an appropriate potential operative to attract the charged particle **514** thereto, and to pass through a grid aperture/space **556** (e.g. at a central location of a planer surface **552** of the grid **530**) to a converter **560**. In the present non-limiting example, converter **560** has a curved conversion surface **564** between side supports **568.** Converter **560** may include a bottom surface **570** defining a converter vicinity **572** for charged particle passage therethrough away from the conversion surface **564**. Bottom support **570** is formed with an aperture **580** for charged particle passage therethrough towards the conversion surface **564**. Converter **560** may be mounted to housing **524** by a mounting element **574** affixing conversion surface **564** to housing wall **538.** Conversion surface **564** may be made of any suitable material allowing high electron emission therefrom, such as aluminum covered by a thin layer of aluminum oxide, for example.

In order to create an appropriate electrical field within the detection device, converter **560** is electrically biased at a potential operative to attract the charged particle **514** thereto such that the charged particle **514** passes aperture **580** and impinges upon conversion surface **564** at its surface side **592** resulting in emission of a plurality of electrons **590** from conversion surface **564** at the same surface side **592.** Thus, converter **560** operates as an ion-to-electron converter whereupon the charged particle **514** is a positive ion or a negative ion. Additionally, the same conversion surface

operates as a particle **514** amplifier. For example, three electrons **590** may be emitted upon impingement of a single particle **514** on conversion surface **564**.

Electrons **590** pass vicinity **572** and impinge upon a scintillator element surface **600** of electron detector **610**. As indicated above, the scintillator element surface **600** may be coupled to a light sensor, such as a PMT **614** via a light guide **616** thereby yielding an electrical signal from electron detector **610**.

As described hereinabove, converter **560** and scintillator element surface **600** (and grid **530** if used) are electrically biased so as to direct a charged particle **514** emitted from sample **510** towards an interaction region within the conversion surface of converter **560** (e.g. via grid **530**) and to attract resultant electrons **590**, emitted from converter **560**, to scintillator element surface **600**. Converter **560** and scintillator element surface **600** (and grid **530** if used) may be electrically biased using an electrical biasing assembly **618** comprising a switchable high voltage power supply **620** coupled to a first voltage feedthrough **622** in electrical communication with scintillator element surface **600** so as to electrically bias scintillator element surface **600**, and a switchable high voltage bipolar power supply **630** coupled to a second and a third voltage feedthrough **632** and **634**, respectively, via a voltage divider **640**. Second voltage feedthrough **632** is in electrical communication with converter **560** so as to electrically bias it, and third voltage feedthrough **634** is in electrical communication with grid **530** so as to electrically bias grid **530**.

In accordance with an embodiment of the present invention, the conversion surface **564** may be shaped so as to minimize inhomogeneities in a detection efficiency of the charged particles **514** irrespective of their location along an interaction region **R** of the conversion surface **564**. The detection efficiency is defined as the conversion factor of a charged particle **514** impinging on conversion surface **564**, i.e. the number of electrons **590** emitted from conversion surface **564** per single impinging charged particle **514**, multiplied by the extraction efficiency of the emitted electrons **590**, i.e. the probability that an emitted electron **590** will impinge on the scintillator element surface **600**. It should be understood that the attraction force of the scintillator element surface **600** defined by the electrical field generated by the scintillator element surface **600** in the detection device may decrease as the detection distance, i.e. the distance of a location on the conversion surface **564** from the scintillator element

surface **600**, increases. Thus, the extraction efficiency may decrease as the detection distance increases and in turn the detection efficiency may be inhomogenous along conversion surface **564**.

In order to compensate for the decreasing extraction efficiency, the conversion surface **564** is shaped so as to increase the conversion factor as the detection distance increases. Generally, the conversion factor may increase as a grazing angle of a particle **514** impinging on the conversion surface **564** decreases. Thus by forming the conversion surface **564** as a concave surface, wherein the grazing angle decreases as the detection distance increases, the conversion factor will increase as the detection distance increases and thus the detection efficiency inhomogeneity along the conversion surface **564** is minimized.

Turning to **Fig. 4**, it is seen that due to the curvature of the conversion surface **564**, at a location **660** on conversion surface **564**, which is in relative proximity to the scintillator element surface **600**, the grazing angle **664** of a particle **666** impinging on conversion surface **564** is relatively large. Accordingly, at a location **670** on conversion surface **564**, which is in relative distance to the scintillator element surface **600**, the grazing angle **674** of a particle **676** impinging on conversion surface **564** is relatively small, thus the efficiency inhomogeneity along the conversion surface **564** is minimized. In a non-limiting example, upon impingement of potassium particles on a conversion surface formed of aluminum oxide, the conversion factor at a normal incidence angle is 5.27 and increases to 19.75 wherein the grazing angle is 10°.

It is appreciated that the curvature of the conversion surface **564** may be determined in accordance with the specific parameters, such as the detection distance, for example, of a given particle detection system. This can be achieved by simulating impingement of particles on a conversion surface within a given particle detection system so as to determine the optimal conversion surface curvature operative to provide a homogenous detection efficiency along the conversion surface.

It is further noted that the curvature of conversion surface **564** may be formed with a constant radius of curvature or, alternatively, with a variable radius of curvature.

As indicated above, grid **530** may be located at any suitable location inside or outside the housing **524**, and may not be used at all, in which case converter

560 is appropriately electrically biased to ensure that a charged particle 514 emitted from sample 510 will impinge upon conversion surface 564.

Reference is now made to Fig. 5, which is a simplified sectional illustration of a particle detection system 700 constructed and operative in accordance with still another embodiment of the present invention. Particle detection system 700 comprises a particle beam 702 generated by a particle beam column 704, which may comprise an FIB column, a dual beam column, an electron beam column, a helium beam column or any other suitable particle beam column. Column 704 is located within a detection system chamber 706 defined by chamber walls 708, and operates to generate particle beam 702 to irradiate a sample 710 thus causing emission of a charged particle 714 (an electron, positive ion or a negative ion) from the sample 710.

A detection device 720 comprises a housing 724 (formed of any suitable conductive material and is preferably set to an electrical potential of the detection system chamber 706), a grid 730 (the provision of which is optional) mounted to housing walls 734 and 738 by respective mounting elements 740 and 742, a converter 760 and an electron detector 810. The charged particle 714 is directed to pass a housing aperture 750 defined within wall 734 towards grid 730 due to an appropriate electric field obtained by electrically biasing the grid 730 at a potential operative to attract the charged particle 714 thereto.

The charged particle 714 passes grid 730 to converter 760, via a grid aperture 756, preferably configured at a central location of planer surface 752 defined by grid 730. Converter 760 may be formed with a conversion surface 764 defining a substantially planar continuous interaction region R. The planar conversion surface 764 is seen in Fig. 5 to be generally perpendicular to a scintillator element surface 770 described in further detail hereinbelow. Converter 760 may be mounted to housing 724 by a mounting element 774 affixing conversion surface 764 to housing wall 738.

Converter 760 is electrically biased at a potential operative to attract the charged particle 714 thereto such that the charged particle 714 impinges upon conversion surface 764 at its surface side 792, and a plurality of electrons 790 are emitted from said surface side 792. Thus, converter 760 operates as an ion-to-electron converter whereupon the charged particle 714 is a positive ion or a negative ion. Additionally, the same conversion surface operates as a particle 714 amplifier. For

example, three electrons **790** may be emitted upon impingement of a single particle **714** on conversion surface **764**.

Electrons **790** impinge upon scintillator element surface **770** of electron detector **810**. The scintillator element surface **770** may be coupled to a light sensor, such as a photomultiplier tube **814** via a light guide **816** thereby yielding an electrical signal from electron detector **810**.

Converter **760** and scintillator element surface **770** (and grid **730** if used) are electrically biased so as to force a charged particle **714** emitted from sample **710** to pass to the interaction region **R** within the conversion surface of converter **760** and to attract resultant electrons **790** emitted from converter **760** to scintillator element surface **770**. Converter **760** and scintillator element surface **770** (and grid **730** if used) are appropriately electrically biased to create a desired electric field defining the trajectories of the emitted charged particle to interact with the converter. In the embodiment shown in **Fig. 5** an electrical biasing assembly **818** comprises a switchable high voltage power supply **820** coupled to a first voltage feedthrough **822** in electrical communication with scintillator element surface **770** so as to electrically bias scintillator element surface **770**, and a switchable high voltage bipolar power supply **830** coupled to a second and a third voltage feedthrough **832** and **834**, respectively, via a voltage divider **840**. Second voltage feedthrough **832** is in electrical communication with converter **760** so as to electrically bias converter **760** and third voltage feedthrough **834** is in electrical communication with grid **730** so as to electrically bias grid **730**.

The converter **760** (and grid **730**) may be positioned relative to sample **710** and may be electrically biased to ensure that a charged particle **714** emitted from sample **710** will be attracted to the interaction region **R** of converter **760**. Additionally, the converter **760** (and grid **730**) may be positioned relative to sample **710** and may be electrically biased to ensure that a charged particle **714** interacts with the conversion surface **764** at a location wherein an attraction force generated by scintillator element surface **770** is greatest so as to ensure that a resultant electron emitted from converter **760** is attracted to scintillator element surface **770**. This location **850** is proximal to the scintillator element surface **770**.

It will be appreciated by persons skilled in the art that the present invention is not limited by what has been particularly shown and described herein

above. Rather the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove as well as variations and modifications which would occur to persons skilled in the art upon reading the specifications and which are not in the prior art.

CLAIMS

1. A charged particle detection device comprising:

an electric field generator configured and operable to create an electric field defining trajectories for charged particles of different types emitted from a sample as a result of the sample interaction with a particle beam, the emitted charged particles of different types being one of the following: electrons, positive ions and negative ions;

an ion-to-electron converter having a conversion surface comprising a continuous interaction region oriented so as to intersect the trajectories of the charged particles of different types propagating from the sample, said conversion surface operative to emit electrons in response to the surface interaction with the charged particles of different types; and

an electron detector configured and operable to receive electrons from the converter and generate output data indicative thereof.

2. A device according to claim 1, wherein said conversion surface is curved or planar.

3. A device according to claim 1, wherein the converter has a cross section of a right triangle geometry with a hypotenuse comprising said conversion surface with the continuous interaction region.

4. A device according to any one of claims 1-3, wherein the electric field generator comprises a voltage supply unit operable to provide electrical biasing of the converter and the electron detector to create a desired electric field.

5. A device according to any one of claims 1-4, comprising a grid-like electrode accommodated upstream of the converter for directing the charged particles towards said interaction region.

6. A device according to claim 5, wherein the electric field generator comprises a high voltage power supply and a voltage divider and is operable for

performing electrical biasing of said grid, said converter and said electron detector by supplying voltage thereto.

7. A device according to claim 5, wherein the electric field generator comprises a high voltage power supply in communication with an external voltage divider for performing electrical biasing of said grid, said converter and said electron detector by supplying voltage thereto.

8. A device according to claim 6 or 7, wherein said voltage divider comprises at least two resisters.

9. A device according to any one of claims 1-8, wherein said electron detector comprises a scintillator element surface.

10. A device according any one of claims 1-9, wherein the conversion surface has a non-planar shape selected to minimize detection efficiency inhomogeneity within said device.

11. A charged particle detector device for detecting a charged particle emitted from a sample, the detector device comprising:

a converter defining a conversion surface with a continuous region of interaction of incident charged particles of different types comprising positive and negative ions and electrons, said conversion surface being adapted for emitting electrons in response to interaction with the charged particles of different types; and

an electron detector for receiving electrons from the converter and generating output data indicative thereof.

12. A device according to claim 11 wherein said conversion surface is curved or planar.

13. A charged particle detection system comprising:

a particle beam column for generating a particle beam for exciting a sample to thereby cause emission of charged particles of different types therefrom, the emitted charged particles comprising at least one positive ion, negative ion and electron; and

a charged particle detection device for detecting the charged particles of different types and generating output data indicative thereof, the detection device comprising:

a converter defining a conversion surface with a continuous region of interaction of incident charged particles of different types, said conversion surface being adapted for emitting electrons in response to interaction with the charged particles of different types; and

an electron detector for receiving electrons from the converter and generating output data indicative thereof.

14. A system according to claim 13, comprising an electric field generator configured and operable to create an electric field within the detection device defining trajectories for the charged particles of different types emitted from said sample as a result of the sample interaction with said particle beam, said continuous region of interaction of the conversion surface intersecting the trajectories of the charged particles of different types.

15. A system according to claim 14, wherein said conversion surface is curved or planar.

16. A system according to claim 14 or 15, comprising a grid-like electrode accommodated upstream of the converter to direct the charged particles emitted from the sample to said region of interaction.

17. A system according to any one of claims 13-16, wherein the particle beam column comprises a focused ion beam (FIB) column, a dual beam column, an electron beam column or a helium beam column.

18. A system according to any one of claims 13-17, wherein said electron detector comprises a scintillator element surface.

19. A system according any one of claims 13-18, wherein said conversion surface has a non-planar shape selected to minimize detection efficiency inhomogeneity within said particle detection device.

20. A method for use in detecting charged particles of different types emitted from a sample, the method comprising:

creating an electric field in a path of charged particles of different types emitted from the sample so as to direct the charged particles of different types along a trajectory towards a charged particle converter, said charged particles of different types being one of the following: a positive ion, a negative ion and an electron;

providing a continuous interaction region of the converter oriented to intersect trajectories of the charged particles of different types propagating towards the converter, said interaction region being responsive to the charged particle incidence thereon to emit electrons; and

detecting the emitted electrons and generating output data indicative thereof.

FIG. 1

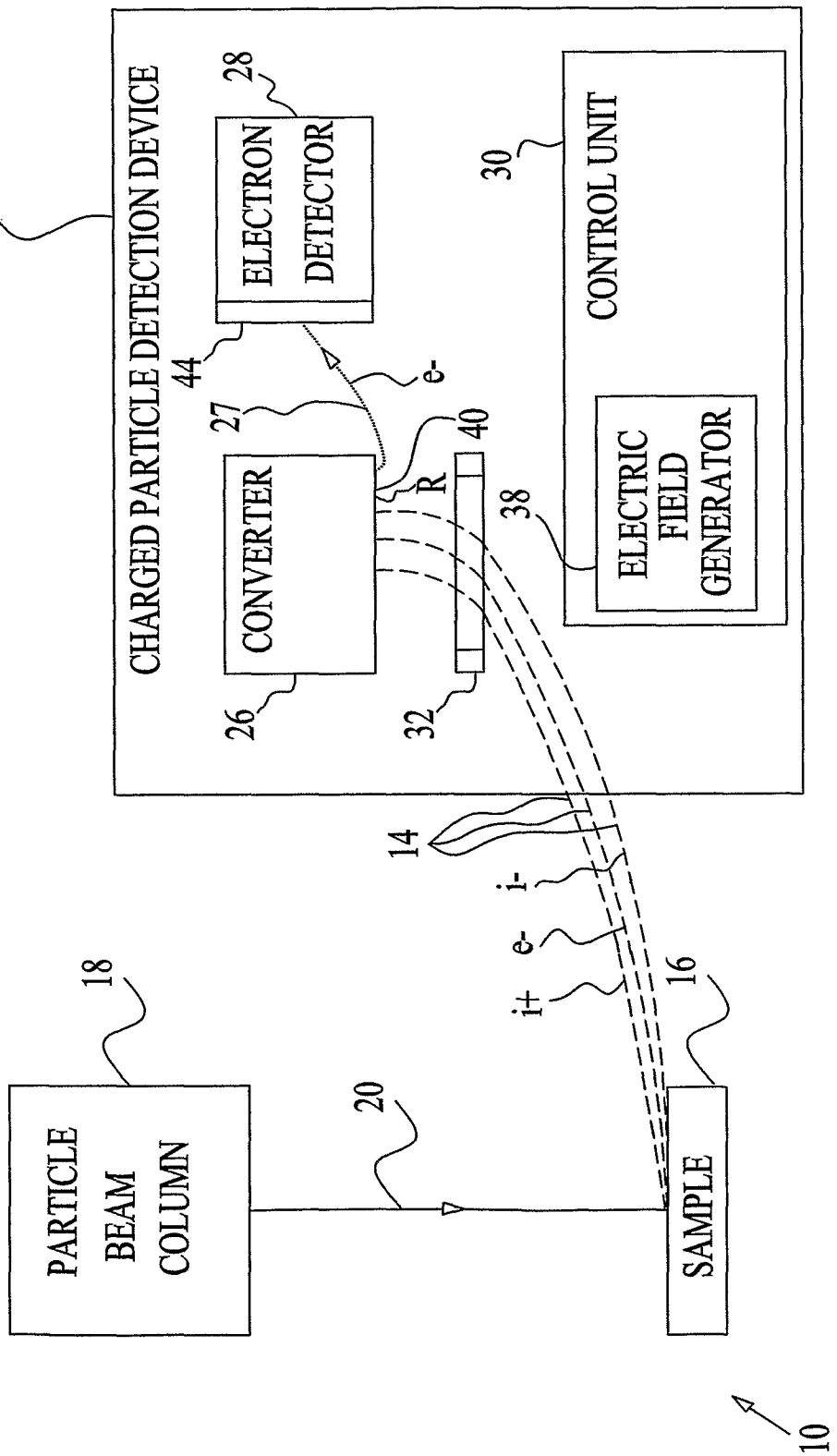

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CHARGED PARTICLE DETECTION DEVICE
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ELECTRIC FIELD GENERATOR
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PARTICLE BEAM COLUMN
SAMPLE
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FIG. 2

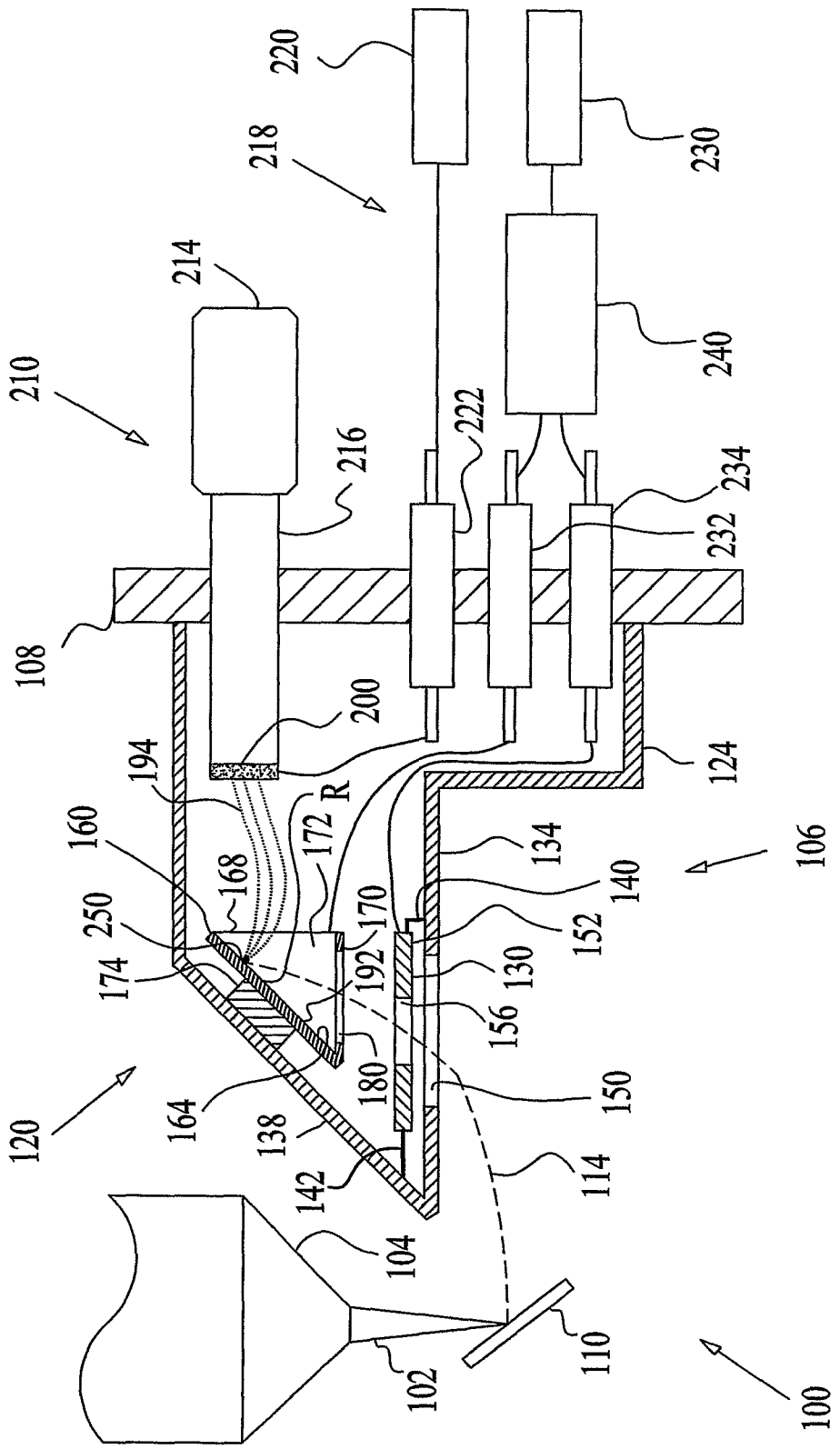

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FIG. 3

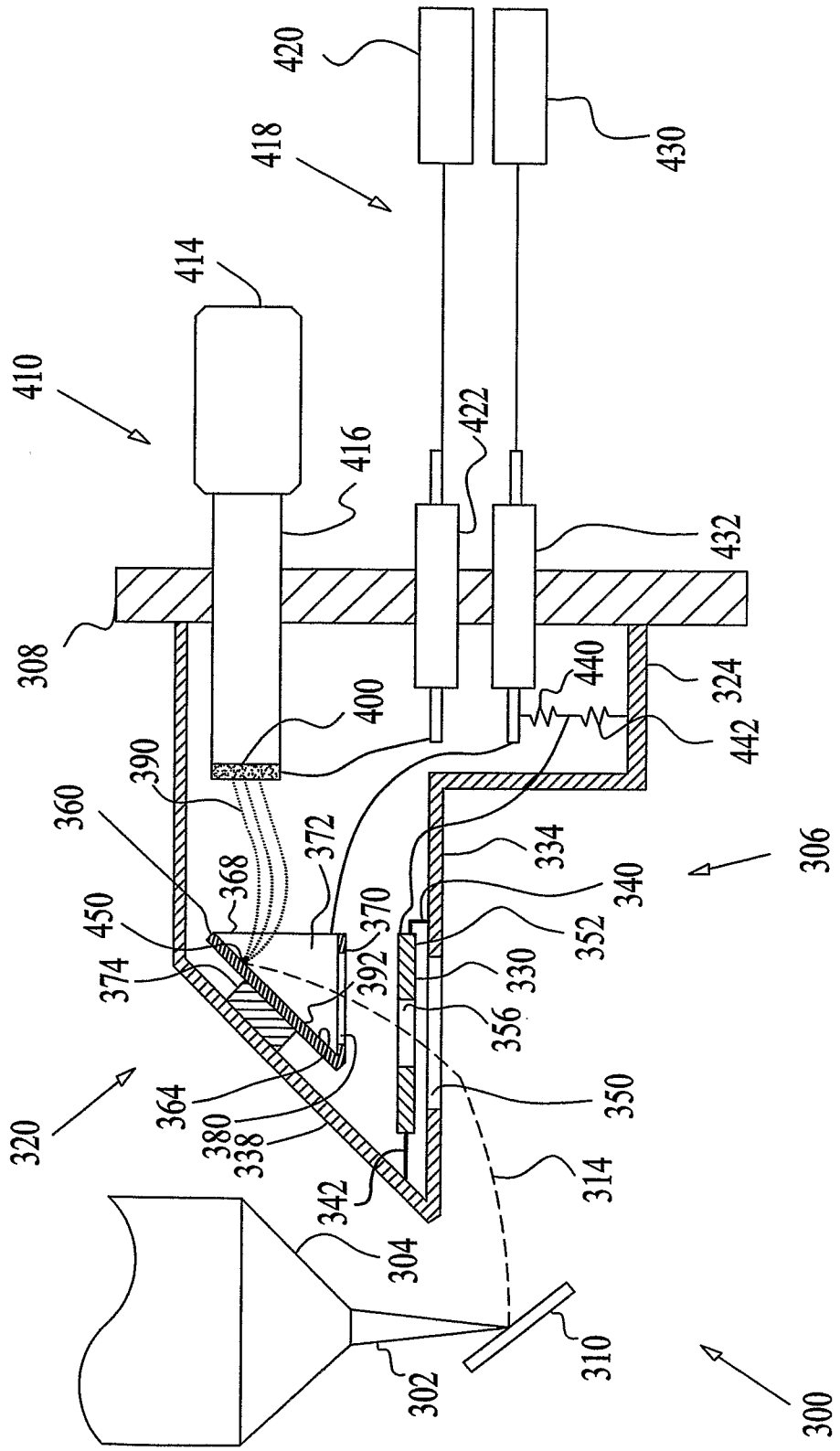

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FIG. 4

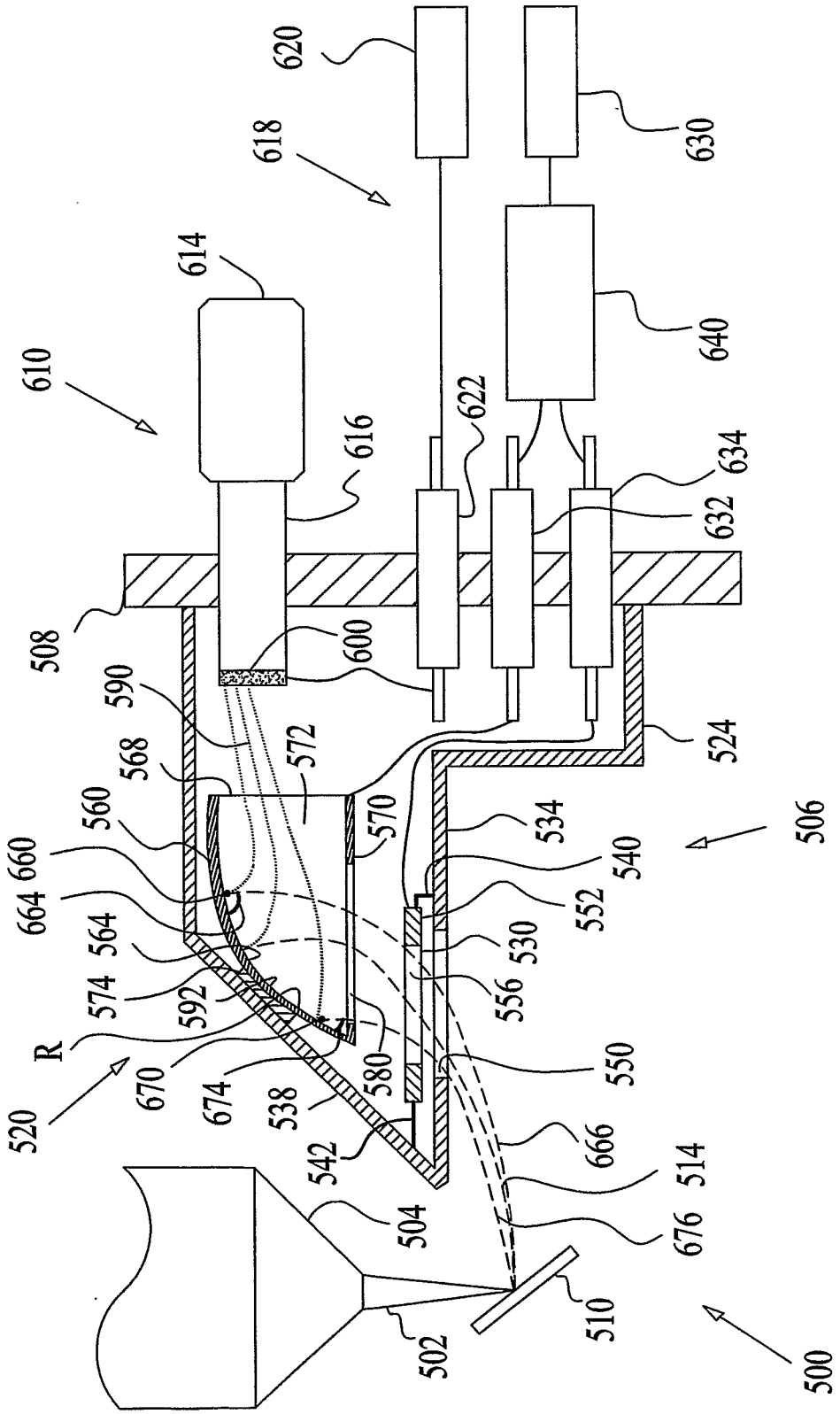
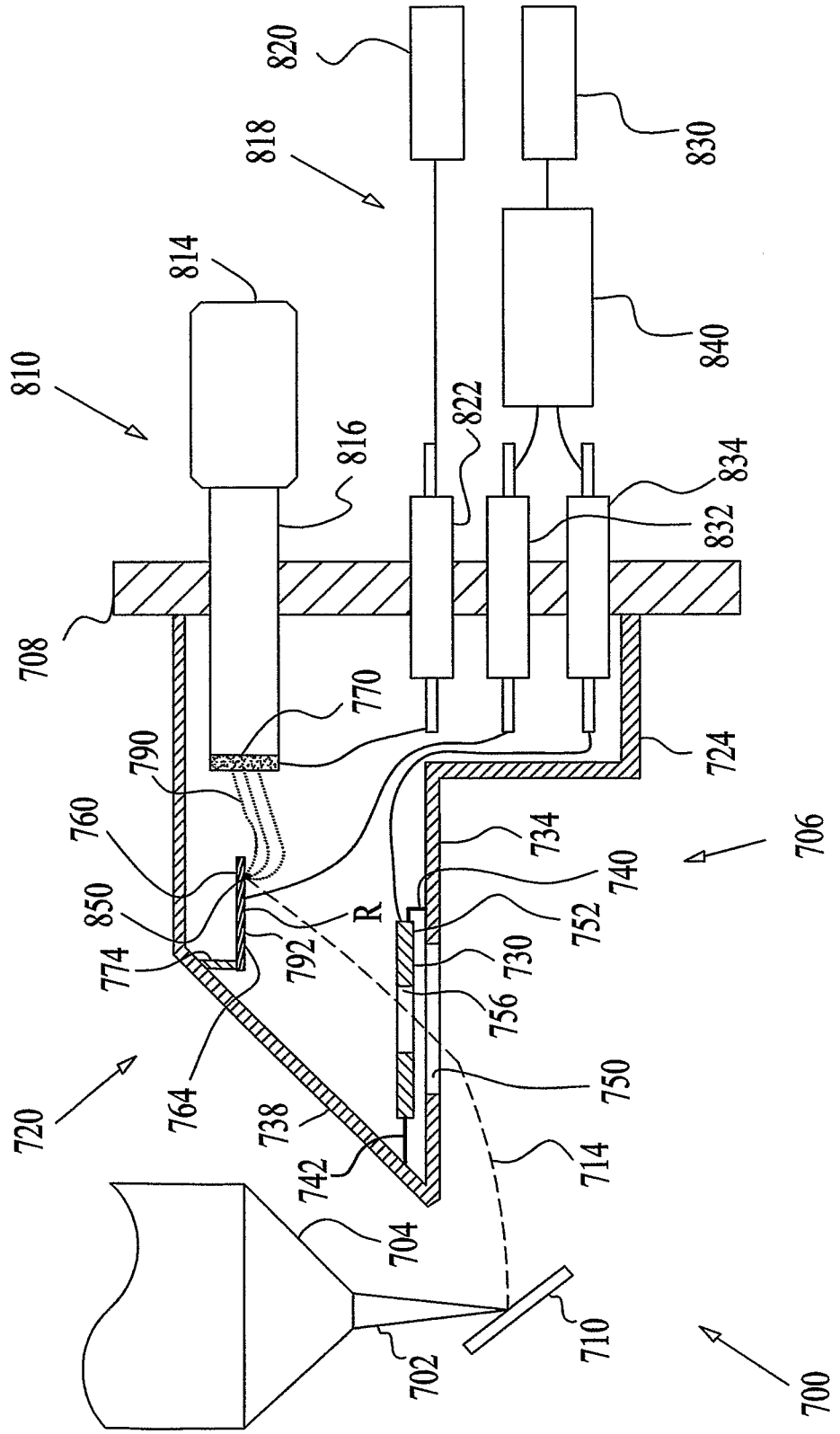

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FIG. 5


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