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Godet et al.

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(54) **ION SOURCE**

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(22) Filed: **Apr. 3, 2009**

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H01J 49/10 (2006.01)
H01J 37/08 (2006.01)
H01J 23/06 (2006.01)

(52) **U.S. Cl.** .... **250/423 R**; 250/424; 250/492.3; 315/111.81; 315/111.21; 313/363.1; 438/961

(58) **Field of Classification Search** .... 250/423 R, 250/424, 492.3; 315/111.81, 111.21; 313/363.1; 438/961
See application file for complete search history.

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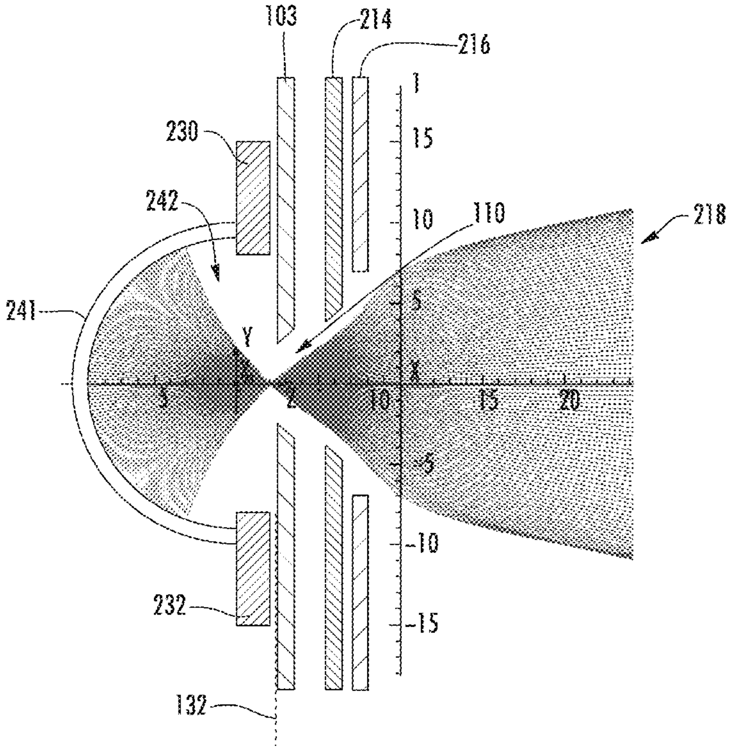
Primary Examiner—Nikita Wells

(57) **ABSTRACT**

An ion source includes an arc chamber having an extraction aperture, and a plasma sheath modulator. The plasma sheath modulator is configured to control a shape of a boundary between plasma and a plasma sheath proximate the extraction aperture. The plasma sheath modulator may include a pair of insulators positioned in the arc chamber and spaced apart by a gap positioned proximate the extraction aperture. A well focused ion beam having a high current density can be generated by the ion source. A high current density ion beam can improve the throughput of an associated process. The emittance of the ion beam can also be controlled.

16 Claims, 5 Drawing Sheets



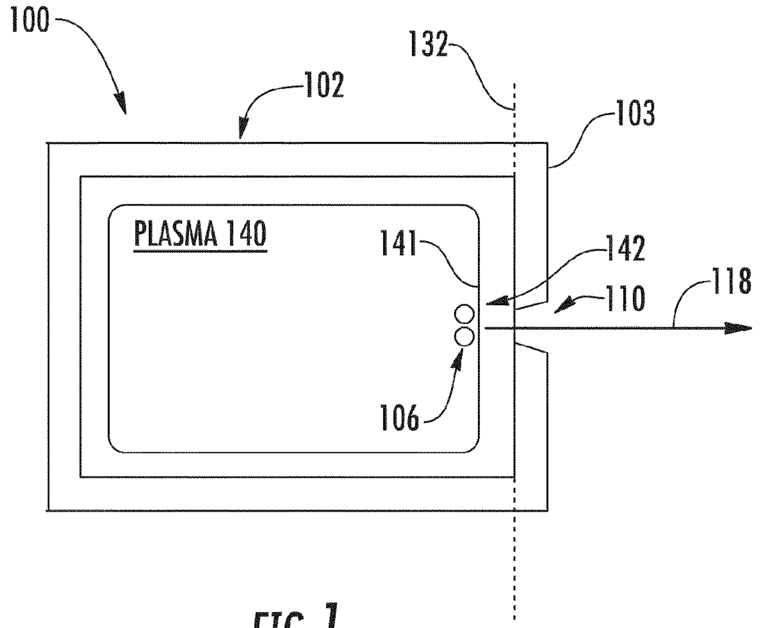


FIG. 1
(PRIOR ART)

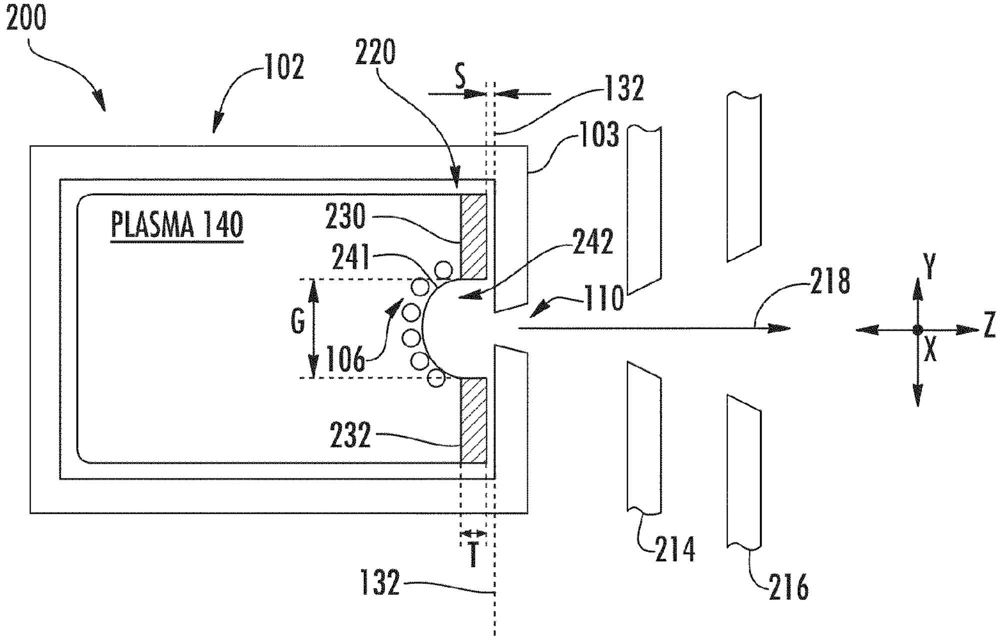


FIG. 2

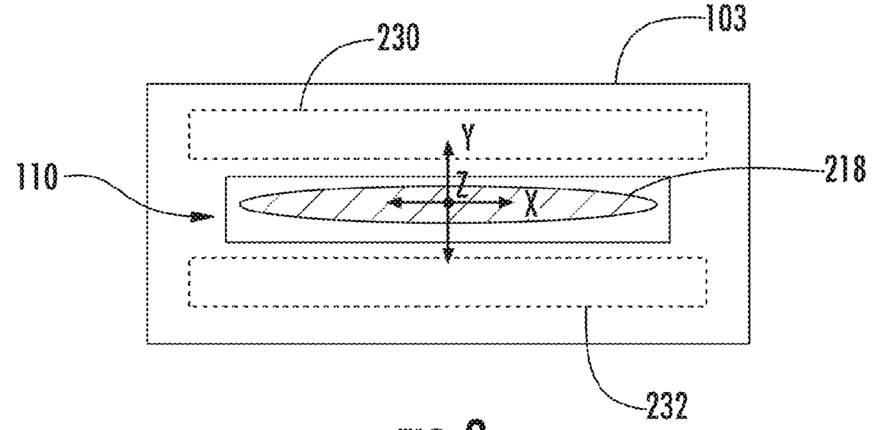

230
103
Y
110
Z
X
218
232

FIG. 3

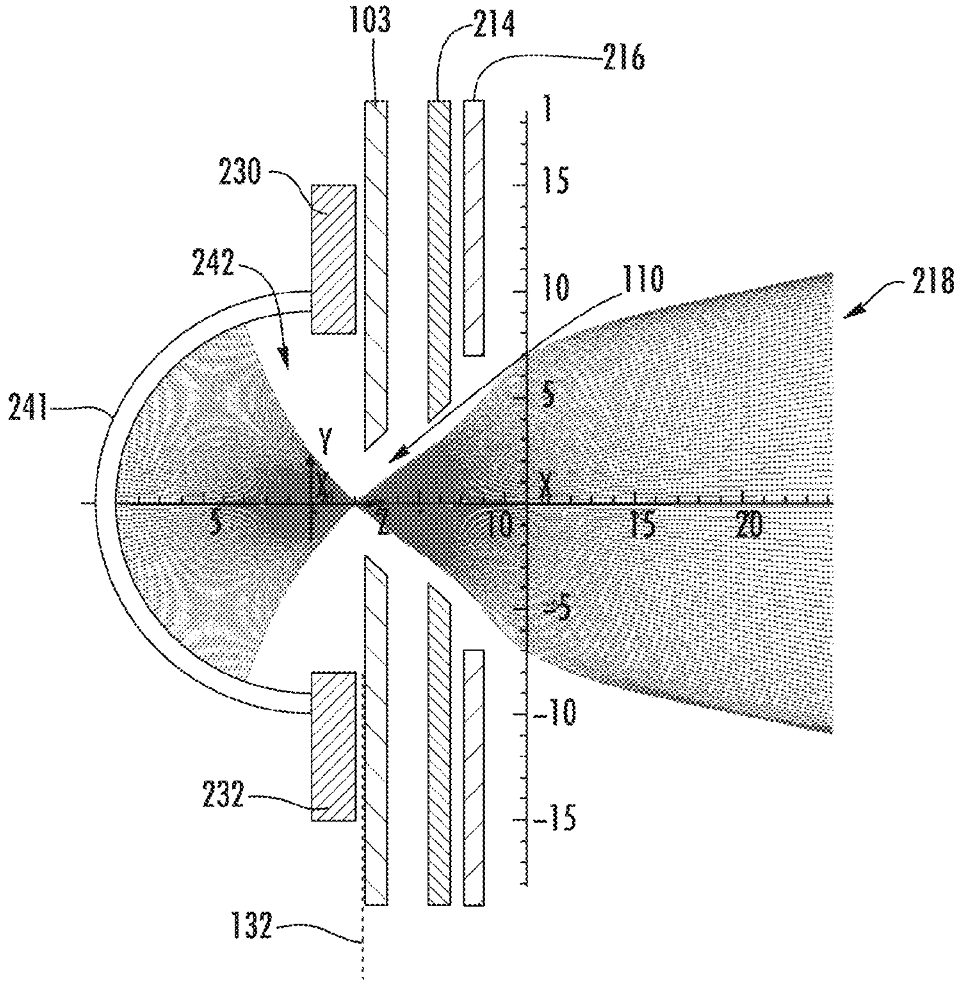

103
214
216
1
230
15
242
10
110
218
241
5
Y
X
5
Z
10
15
20
-5
-10
232
-15
132

FIG. 4

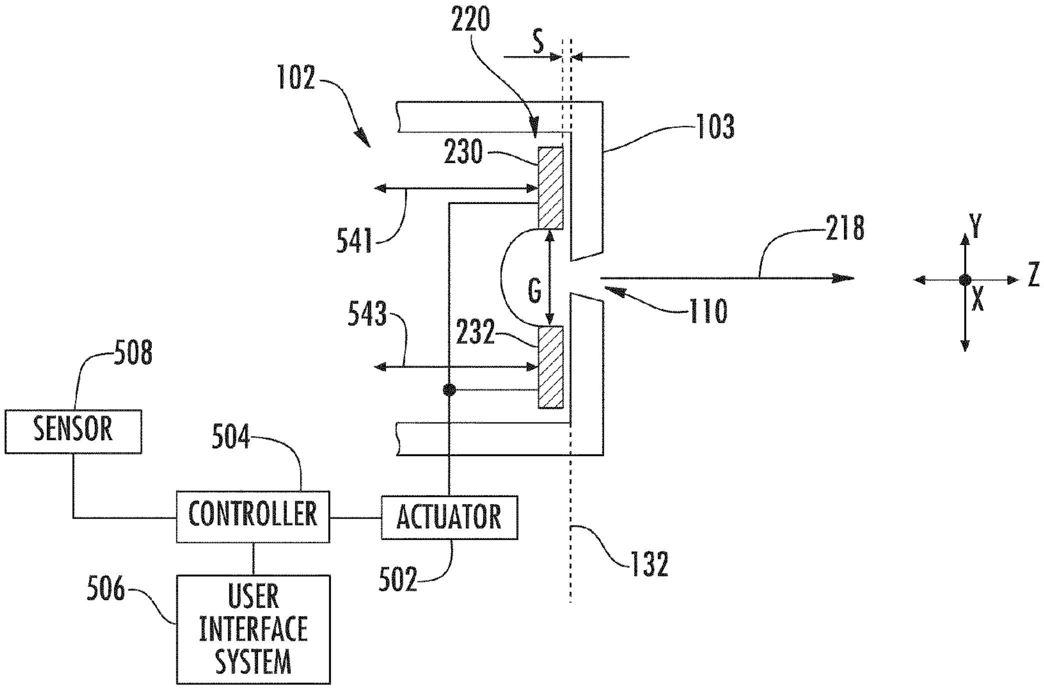

220
S
102
103
230
541
218
Y
Z
X
G
110
543
232
508
SENSOR
504
CONTROLLER
ACTUATOR
502
132
506
USER INTERFACE SYSTEM

FIG. 5

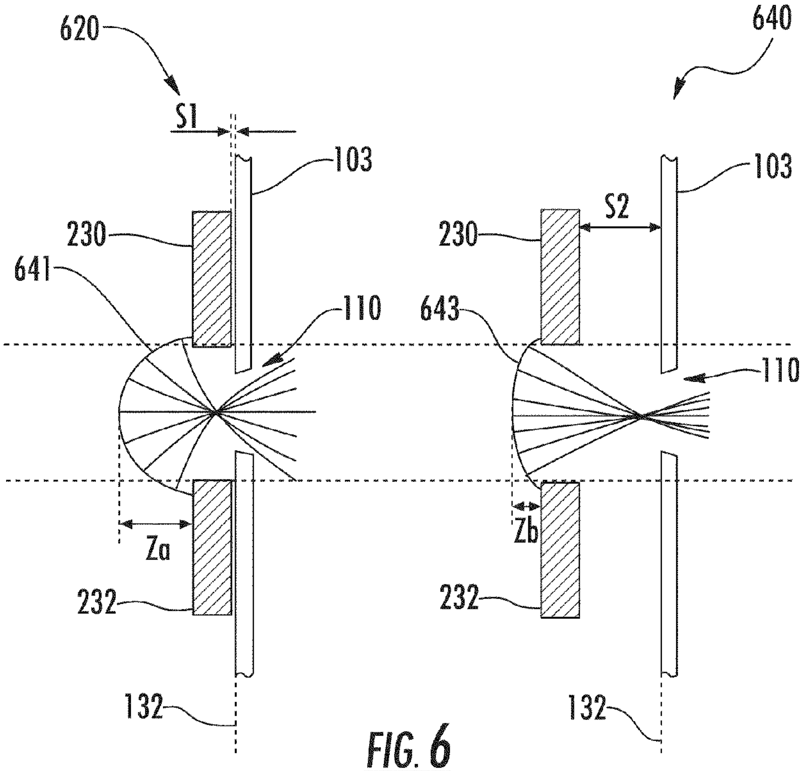

620
S1
103
230
641
110
Za
232
132
640
103
S2
230
643
110
Zb
232
132

FIG. 6

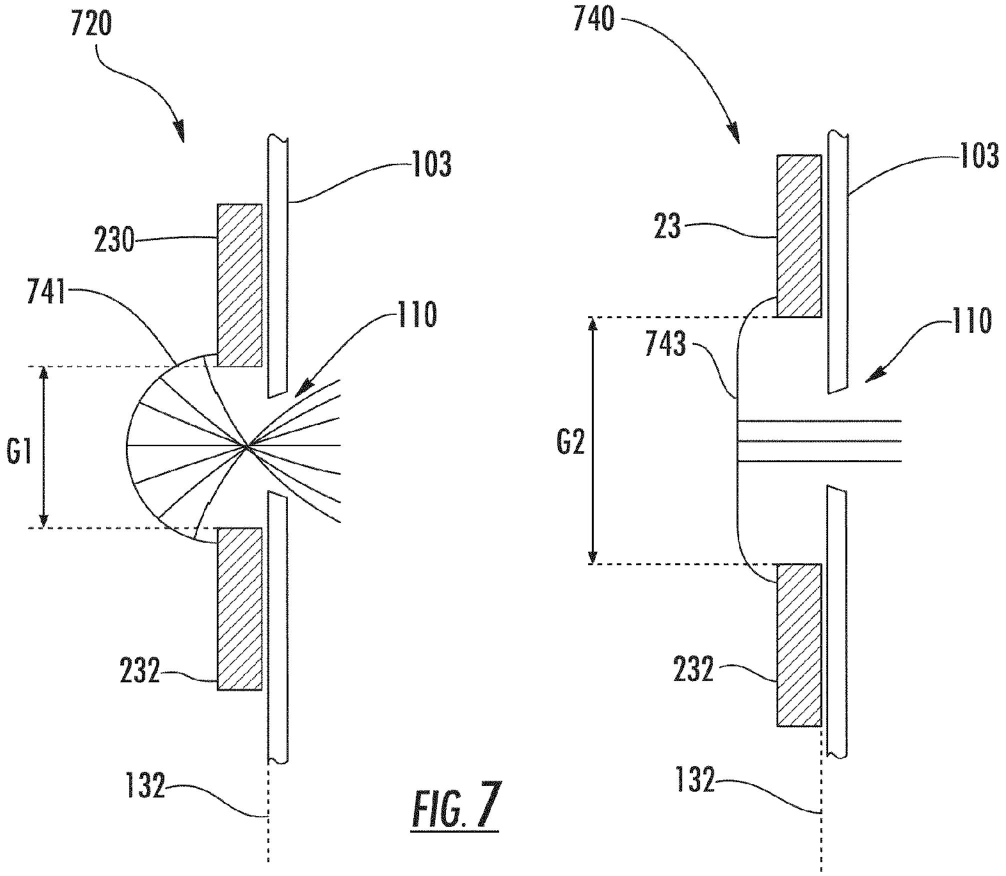

720
103
230
741
110
G1
232
132
740
103
23
743
110
G2
232
132

FIG. 7

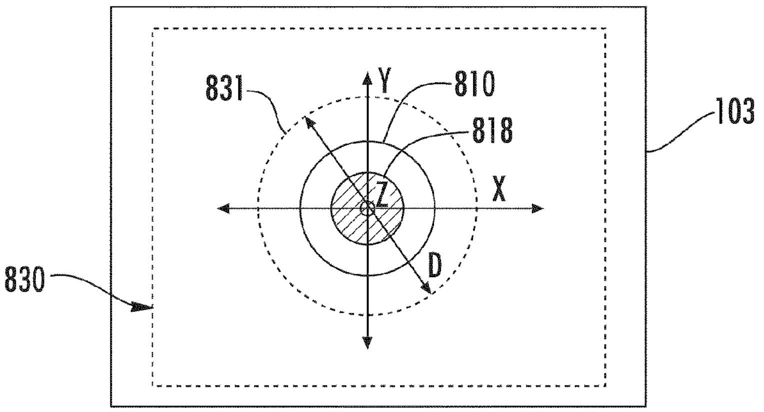

831
Y
810
818
Z
X
D
830
103

FIG. 8

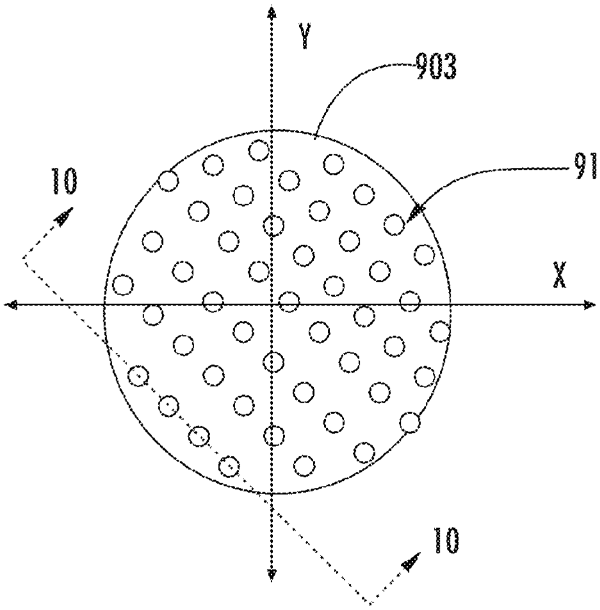


FIG. 9

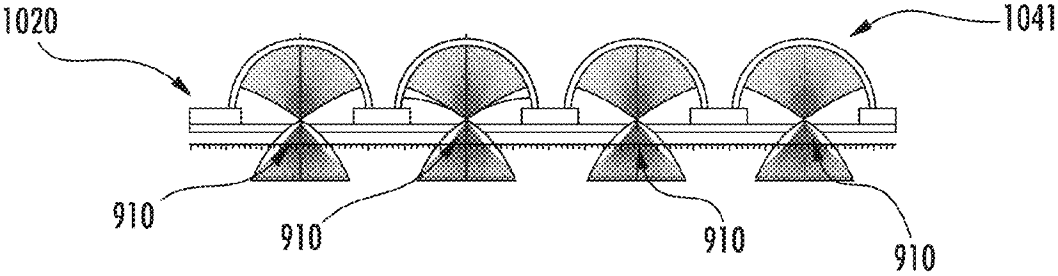


FIG. 10

ION SOURCE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to U.S. application Ser. No. 12/418,120 filed Apr. 3, 2009, which is incorporated herein by reference.

FIELD

This disclosure relates to ion sources, and more particularly to an ion source having a plasma sheath modulator.

BACKGROUND

An ion source is a critical component of an ion implanter and other processing equipment. The ion source generally includes an arc chamber which accepts a feed gas. The feed gas is ionized in the arc chamber by differing techniques known in the art to generate plasma. The plasma is generally a quasi-neutral collection of ions (usually having a positive charge) and electrons (having a negative charge). The plasma has an electric field of about 0 volts per centimeter in the bulk of the plasma. The plasma is bounded by a region generally referred to as a plasma sheath. The plasma sheath is a region that has fewer electrons than the plasma. The light emission from this plasma sheath is less intense than the plasma since fewer electrons are present and hence few excitation-relaxation collisions occur. Hence, the plasma sheath is sometimes referred to as "dark space."

Turning to FIG. **1**, a cross sectional view of a known ion source **100** is illustrated having an arc chamber **102**. The arc chamber **102** includes a sidewall **103** having an extraction aperture **110**. A feed gas (not illustrated) is ionized in the arc chamber **102** to generate plasma **140** having a plasma sheath **142** proximate the extraction aperture **110**. The boundary **141** between the plasma **140** and the plasma sheath **142** proximate the extraction aperture is generally parallel to a plane **132** defined by an interior surface of the sidewall **103** depending on the plasma density of the plasma **140** and the electric field generated by an extraction electrode assembly (not illustrated). Ions **106** are extracted by the extraction electrode assembly into a well-defined ion beam **118**.

One drawback with this conventional ion source is the lack of ion beam focusing originating from the extraction aperture **110**. Ions **106** are accelerated across the plasma sheath **142** at about right angles to the boundary **141** between the plasma **140** and the plasma sheath **142**. Since the boundary **141** is generally parallel to the plane **132**, there is little angular spread control of the ions **106** that form the ion beam **118**. Another drawback with this conventional ion source is the shape of the boundary **141** limits the number of ions **106** that can be accelerated across the same through the extraction aperture **110**. This can limit the ion beam current density achievable from the ion source. Ion beam current density is a beam current value per unit area typically expressed in milliamperes per square centimeters (mA/cm^2). A relatively higher beam current density is desirable in some instances and can improve the throughput performance of a given process. Yet another drawback with a conventional ion source is that the shape of the boundary **141** is determined by the plasma density of the plasma **140** and the strength of the electric field. For example, for a given plasma density, a high extraction electric field may cause a concave boundary. A decrease in plasma density may cause a convex boundary. All these facts limit emittance control of the ion beam from the conventional ion source. The emittance of an ion beam is generally spatial and angular distributions of the ion beam, and can also be defined roughly as the product of beam diameter and angular spread in transverse momentum at each point.

Accordingly, there is a need for an ion source which overcomes the above-described inadequacies and shortcomings.

SUMMARY

According to a first aspect of the disclosure, an ion source is provided. The ion source includes an arc chamber having an extraction aperture, and a plasma sheath modulator. The plasma sheath modulator is configured to control a shape of a boundary between plasma and a plasma sheath proximate the extraction aperture.

According to another aspect of the disclosure, a method of generating an ion beam from an ion source is provided. The method includes generating plasma in an arc chamber of the ion source having an extraction aperture, and controlling a shape of a boundary between the plasma and a plasma sheath proximate the extraction aperture.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present disclosure, reference is made to the accompanying drawings, in which like elements are referenced with like numerals, and in which:

FIG. **1** is a cross sectional view of a conventional ion source consistent with the prior art;

FIG. **2** is a cross sectional view of an ion source consistent with an embodiment of the disclosure;

FIG. **3** is a view of one embodiment of the sidewall of the arc chamber of FIG. **2**;

FIG. **4** is a cross sectional view consistent with FIG. **2** illustrating trajectories of ions accelerated across the boundary of FIG. **2**;

FIG. **5** is a block diagram of a system to control spacing of a plasma sheath modulator;

FIG. **6** is a partial cross sectional view illustrating ion trajectories at different vertical positions of the plasma sheath modulator of FIG. **5**;

FIG. **7** is a partial cross sectional view illustrating ion trajectories at different horizontal gap positions of the plasma sheath modulator of FIG. **5**;

FIG. **8** is a view of another embodiment of a sidewall of an arc chamber of an ion source consistent with the disclosure;

FIG. **9** is a view of another embodiment of a sidewall of an arc chamber of an ion source consistent with the disclosure having a plurality of apertures; and

FIG. **10** is a cross sectional view taken along the lines **10-10** of FIG. **9**.

DETAILED DESCRIPTION

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. The invention, however, may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

Turning to FIG. **2**, a cross sectional view of an ion source **200** consistent with an embodiment of the disclosure is illustrated. The ion source **200** includes an arc chamber **102** having a sidewall **103** with an extraction aperture **110**. The ion source **200** further includes a plasma sheath modulator **220** to control a shape of a boundary **241** between the plasma **140** and the plasma sheath **242** proximate the extraction aperture **110**. An extraction electrode assembly extracts ions **106** from the plasma **140** and accelerates them across the plasma sheath **242** to a desired extraction energy of a well-defined ion beam **218**. The extraction electrode assembly may include the sidewall **103** functioning as an arc slot electrode, a suppression electrode **214** and a ground electrode **216**. The suppression electrode **214** and the ground electrode **216** each have an aperture aligned with the extraction aperture **110** for extraction of the well-defined ion beam **218**. To aid with explanation, a Cartesian coordinate system is defined where the ion beam **218** travels in the Z direction. The X-Y plane is perpendicular to the Z direction which can change depending on the direction of the ion beam.

In the embodiment of FIG. **2**, the plasma sheath modulator **220** includes a pair of insulators **230**, **232** positioned in the arc chamber **102**. In other embodiments, the modulator may include only one insulator. The insulators **230**, **232** may be fabricated of quartz, alumina, boron nitride, glass, porcelain, silicon nitride, etc. The pair of insulators **230**, **232** may be a pair of sheets having a thin, flat shape. In other embodiments, the pair of insulators **230**, **232** may be other shapes such as tube shaped, wedge shaped, and/or have a beveled edge. The pair of insulators **230**, **232** defines a gap there between having spacing (G). The pair of insulators **230**, **232** may also be positioned a vertical spacing (S) above the plane **132** defined by an interior surface of the sidewall **103** having the extraction aperture **110**.

In operation, a feed gas (not illustrated) is supplied to the arc chamber **102**. Examples of a feed gas include, but are not limited to, BF_3, PH_3, AsH_3, B_2H_6, He, H_2, Ar, and GeH_4. The feed gas may originate from a gas source or may be vaporized from a solid source depending on the desired species. The feed gas is ionized in the arc chamber **102** to generate plasma **140**. Those skilled in the art will recognize differing types of ion sources that generate plasma in differing ways such as, e.g., an indirectly heated cathode (IHC) source, a Bernas source, a RF source, a microwave source, and an electron cyclotron resonance (ECR) source. An IHC source generally includes a filament positioned in close proximity to a cathode, and also includes associated power supplies. The cathode (not illustrated) is positioned in the arc chamber **102**. As the filament is heated, electrons emitted by the filament are accelerated towards the cathode to provide for heating of the cathode. The heated cathode, in turn, provides electrons into the arc chamber that have ionizing collisions with the gas molecules of the feed gas to generate plasma.

An extraction electrode assembly including the sidewall **103**, the suppression electrode **214**, and the ground electrode **216** extracts ions **106** from the plasma **140** in the arc chamber **102** into the well-defined ion beam **218**. The ions **106** are accelerated across the boundary **241** and the plasma sheath **242** through the gap between the pair of insulators **230**, **232**. The sidewall **103** functioning as an arc source electrode may be biased by a power supply to the same large potential as the arc chamber **102**. The suppression electrode **214** may be biased at a moderately negative value to prevent electrons from entering back into the arc chamber **102**. The ground electrode **215** may be at ground potential. The strength of the electric field generated by the electrode assembly may be tuned to achieve a desired beam current and energy.

Advantageously, the plasma sheath modulator **220** controls a shape of the boundary **241** between the plasma **140** and the plasma sheath **242** proximate the extraction aperture **110**. To control the shape of the boundary **241** the plasma sheath modulator **220** modifies or influences the electric field within the plasma sheath **242**. When the plasma sheath modulator **220** includes the pair of insulators **230**, **232**, the boundary **241** may have a concave shape relative to the plasma **140** as illustrated in FIG. **2**. Depending on a number of factors including, but not limited to, the horizontal spacing (G) between the insulators **230**, **232**, the vertical spacing (S) of the insulators above the plane **132**, the insulator material including its dielectric constant, the thickness (T) of the insulators **230**, **232**, and other process parameters of the ion source, the shape of the boundary **241** can be controlled.

The shape of the boundary **241** between the plasma **140** and the plasma sheath **242** together with the electric field gradients within the plasma sheath **242** control parameters of the ion beam. For example, the angular spread of the ions **106** can be controlled to assist with ion beam focusing. For instance, with the boundary **241** having a concave shape relative to the plasma, there is a large angular spread of ions accelerated across the boundary to assist with beam focusing. In addition, the ion beam current density of the ion beam **218** can also be controlled. For example, compared to the boundary **141** of one conventional ion source, the boundary **241** has a larger area to extract additional ions. Hence, the additional extracted ions contribute to an increased ion beam current density. Accordingly, with all other parameters being equal, the shape of the boundary **241** can provide a focused ion beam with a high ion beam current density. Furthermore, the emittance of the ion beam can also be controlled by controlling the shape of the boundary **241**. Consequently, the beam quality of the extracted ion beam can be well defined for a given particle density and angular distribution.

Turning to FIG. **3**, a view of one embodiment of the sidewall **103** and extraction aperture **110** is illustrated looking upstream in the Z direction so the ion beam **218** is coming out of the page. As shown, the extraction aperture **110** may to have an elongated rectangular shape to permit extraction of the ion beam **218**. In this instance, the ion beam **218** has a long dimension in the X direction at least a few times greater than its width in the Y direction. This type of beam is referred to in the art as a "ribbon beam." Although shown with its long dimension oriented in the X direction, the long dimension may be oriented in any desired direction, e.g., is the long dimension of the ribbon beam may be in the Y direction or any other angle relative to the X and Y directions. The insulators **230**, **232** are shown in phantom and may have a rectangular sheet shape as illustrated to control the shape of the boundary **241** between the plasma **140** and the plasma sheath **242**.

FIG. **4** is a partial cross sectional view of the pair of insulators **230**, **232** and extraction electrode assembly consistent with FIG. **2** illustrating simulated ion trajectories accelerated across the boundary **241** and the plasma sheath **242**. The ions are accelerated through the gap defined by the pair of insulators **230**, **232** and extracted through the extraction aperture **110**. Given the shape of the boundary **241** and electric field gradient within the plasma sheath **242**, a large angular spread of ion trajectories may be achieved which can assist with ion beam focusing. In addition, the shape of the boundary **241** enables a relatively larger number of ions to be extracted compared to a boundary shape parallel to the plane **132**. Accordingly, ion beam current density of the ion beam extracted from the ion source assembly can be increased and controlled. Beam emittance and angular spread of the ions can also be controlled.

Turning to FIG. **5**, a block diagram of another embodiment consistent with the present disclosure is illustrated where the position of the plasma sheath modulator **220** may be modified and set to a desired position. The plasma sheath modulator **220** may be the pair of insulators **230**, **232** and the spacing of the gap (G) between the insulators in the Y direction may be adjusted. The spacing (S) of the insulators **230**, **232** in the Z direction from the plane **132** defined by the interior surface of the sidewall **103** may also be adjusted. By adjusting the position of the insulators **230**, **232** the shape of the boundary **241** between the plasma and the plasma sheath may be modified. Accordingly, ion beam focusing, ion beam current density, and emittance of the ion beam may also be controlled.

To set a desired position of the insulators **230**, **232**, the system of FIG. **5** may also include an actuator **502**, a controller **504**, a user interface system **506**, and a sensor **508**. The actuator **502** may be mechanically coupled to the insulators **230**, **232** to drive them in differing directions, e.g., in the Z direction as illustrated by arrows **541**, **543** to control the spacing (S) and/or in the Y direction to control the gap (G) spacing. The controller **504** can be or include a general-purpose computer or network of general-purpose computers that may be programmed to perform desired input/output functions. The controller **504** may also include communication devices, data storage devices, and software. The user interface system **506** may include devices such as touch screens, keyboards, user pointing devices, displays, printers, etc. to allow a user to input commands and/or data and/or to monitor the system. The sensor **508** may include a Faraday sensor to sense beam current of the ion beam as is known in the art. The sensor **508** may also include a beam angle sensor to measure an angle of the beam at a particular position. Differing beam angle sensors are known in the art and one could include a shield positioned upstream one or more Faraday cups. The shield is moved across the ion beam to block different portions of the beam as it is moved relative to the downstream Faraday cup(s). The beam current readings together with the known position of the shield and Faraday cup(s) may be used to determine beam angles.

In operation, the controller **504** may be responsive to a desired ion beam current density and/or beam focusing value and/or emittance value set by a user via the user interface system **506**. The controller **504** may instruct the actuator **502** to position the insulators **320**, **322** in a desired position to achieve a desired boundary **241** shape. The controller **504** may also be responsive to sensed conditions from the sensor **508** to update and modify the position of the insulators **230**, **232** based on sensed conditions such as beam current and/or beam angle measurements and/or beam emittance.

FIG. **6** is a cross sectional view consistent with FIG. **5** to illustrate ion trajectories at differing (S) positions of the pair of insulators **230**, **232** relative to the plane **132** with all other parameters being equal. In the first shorter position **620**, the insulators **230**, **232** are positioned a first distance (S1) above the plane **132**. In a comparatively taller position **640**, the insulators **230**, **232** are positioned a second distance (S2) above the plane **132**, where (S2)>(S1). In the first position **620**, the boundary **641** between the plasma and the plasma sheath has a concave shape. The boundary **841** also has a shape that approximately approaches the shape of a portion of a circumference of a circle where an apex of the arcuate shape is a distance (Za) above a top surface of the insulator **232**. In contrast, the boundary **643** in the second position **640** has a shallower shape where the apex of the arcuate shape is a shorter distance (Zb) above the top surface of the insulator **232**, or where (Zb)<(Za).

The shape of the boundaries **641**, **643** and the electric field lines in the plasma sheath, influences the angular spread of the ions extracted from the ion source, the ion beam current density of the ion beam, and the emittance of the ion beam. For example, the angular spread of ions with the relatively shorter (S1) spacing **620** is greater than the angular spread of the ions with the relatively longer (S2) spacing **640**. In addition, the ion beam current density of the ion beam of the shorter spacing **620** is greater than that of the taller spacing **640** with all other parameters being equal given the increased extraction area for the ions. Although not illustrated in FIG. **6**, the spacing (S) positions of each insulator **230**, **232** relative to the plane **132** may also be different from each other to further influence the shape of the boundary between the plasma and the plasma sheath.

FIG. **7** is a cross sectional view consistent with FIG. **5** to illustrate ion trajectories at differing gap spacing between the insulators **230**, **232** with all other parameters being equal. In the first relatively shorter gap position **720**, the insulators **230**, **232** are positioned a first distance (G1) from one another. In a comparatively longer gap position **740**, the insulators **230**, **232** are positioned a second distance (G2) from each other, where (G2)>(G1). In the first position **720**, the boundary **741** between the plasma and the plasma sheath has a concave shape. The boundary **741** also has a shape that approximately approaches the shape of a portion of a circumference of a circle. In contrast, the boundary **743** in the second position **740** has a concave shape where a central portion of the boundary **743** is about parallel to the plane **132**. The angular spread of ions from the shorter gap position **720** provides for a comparatively larger angular spread of ions than that of the longer gap position **740**. In addition, the ion beam current density form the shorter gap position **720** is comparatively larger than that of the longer gap position **740** with all other parameters being equal given the larger area of the boundary **741** from which ions are extracted.

Turning to FIG. **8**, a view of another embodiment of a sidewall **103** having a circular shaped extraction aperture **810** is illustrated looking upstream in the Z direction so the ion beam **818** is coming out of the page. In this embodiment, the ion beam **818** has an approximately circular cross sectional shape and may be referred to in the art as a "spot" beam. Although illustrated as having an approximately circular cross sectional shape, the "spot" beam typically has an irregular shape. The plasma sheath modulator **830** shown in phantom in this embodiment may be an insulator having a thin rectangular sheet shape with a circular opening **831**. Furthermore, the circular opening **831** may be concentric with the circular extraction aperture **810**. In addition, the diameter (D) of the circular opening **831** may be variable to control the shape of the plasma sheath and boundary between the plasma sheath and plasma. The variable diameter (D) may be set in response to different parameters including a desired ion beam current density of the ion beam **818**.

Turning to FIG. **9**, a view of another embodiment of a sidewall **903** of an associated arc chamber of an ion source is illustrated looking upstream in the Z direction. The sidewall **903** has a plurality of circular extraction apertures **910**. FIG. **10** is a cross sectional view taken along the lines **10-10** of FIG. **9** illustrating a plasma sheath modulator **1020** and a corresponding boundary **1041** between a plasma and the plasma sheath. Ion trajectories of ions accelerated across the boundary **1041** are also illustrated.

Accordingly, there is provided an ion source having a plasma sheath modulator configured to control a shape of a boundary between the plasma and plasma sheath proximate the extraction aperture. This enables better control of ion beam focusing as the angular spread of ions accelerated across the boundary and the plasma sheath can be better controlled. In addition, the ion beam current density of the ion beam extracted from the ion source assembly can also be controlled. Furthermore, the emittance of the ion beam can also be controlled. A high ion beam current density may be achieved by increasing the effective area from which ions are extracted to form the ion beam. A high ion beam current density can improve the throughput of an associated process.

The present disclosure is not to be limited in scope by the specific embodiments described herein. Indeed, other various embodiments of and modifications to the present disclosure, in addition to those described herein, will be apparent to those of ordinary skill in the art from the foregoing description and accompanying drawings. Thus, such other embodiments and modifications are intended to fall within the scope of the present disclosure. Further, although the present disclosure has been described herein in the context of a particular implementation in a particular environment for a particular purpose, those of ordinary skill in the art will recognize that its usefulness is not limited thereto and that the present disclosure may be beneficially implemented in any number of environments for any number of purposes. Accordingly, the claims set forth below should be construed in view of the full breadth and spirit of the present disclosure as described herein.

What is claimed is:

1. An ion source comprising:

a plasma generated within an arc chamber having an extraction aperture; and

a plasma sheath modulator configured to control a shape of a boundary between a plasma and a plasma sheath proximate the extraction aperture wherein the plasma sheath modulator comprises a pair of insulators defining a gap there between, and wherein the shape of the boundary about the gap is a concave shape.

2. The ion source of claim **1**, wherein the plasma sheath modulator is positioned in the arc chamber.

3. The ion source of claim **2**, wherein the pair of insulators comprises a pair of insulting sheets, and the extraction aperture has a slit shape.

4. The ion source of claim **2**, further comprising an actuator mechanically coupled to at least one insulator of the pair of insulators to adjust a spacing of the gap.

5. The ion source of claim **2**, further comprising an actuator mechanically coupled to the pair of insulators to adjust a position of the pair of insulators.

6. The ion source of claim **2**, wherein the pair of insulators are fabricated of quartz.

7. The ion source of claim **2**, wherein the plasma sheath modulator is positioned in response to a desired ion beam current density of an ion beam extracted through the extraction aperture.

8. The ion source of claim **2**, wherein the plasma sheath modulator is positioned in response to a desired angular spread of ions of an ion beam extracted through the extraction aperture.

9. The ion source of claim **2**, wherein the plasma sheath modulator is positioned in response to a desired emittance of an ion beam extracted through the extraction aperture.

10. The ion source of claim **2**, wherein the extraction aperture has a circular shape, and the plasma sheath modulator is an insulating sheet having a circular opening.

11. The ion source of claim **10**, wherein the circular opening of the insulating sheet is concentric with the circular shape of the extraction aperture, and wherein the circular opening has a variable diameter that is set in response to a desired ion beam current density of an ion beam extracted through the extraction aperture.

12. A method of generating an ion beam from an ion source, the method comprising:

generating a plasma in an arc chamber of the ion source having an extraction aperture;

controlling a shape of a boundary between the plasma and a plasma sheath proximate the extraction aperture wherein the controlling operation comprises creating a gap defined by a pair of insulators, and wherein the shape of the boundary about the gap is a concave shape.

13. The method of claim **12**, wherein the controlling operation comprises positioning a plasma sheath modulator in the arc chamber.

14. The method of claim **13**, further comprising positioning the plasma sheath modulator in response to a desired ion beam current density of the ion beam extracted through the extraction aperture.

15. The method of claim **13**, further comprising positioning the plasma sheath modulator in response to a desired emittance of the ion beam extracted through the extraction aperture.

16. The method of claim **12**, further comprising adjusting a spacing of the gap.

* * * * *