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(54) THERMOELECTRIC CONTROL FOR A CRUCIBLE FOR USE WITH AN ION SOURCE

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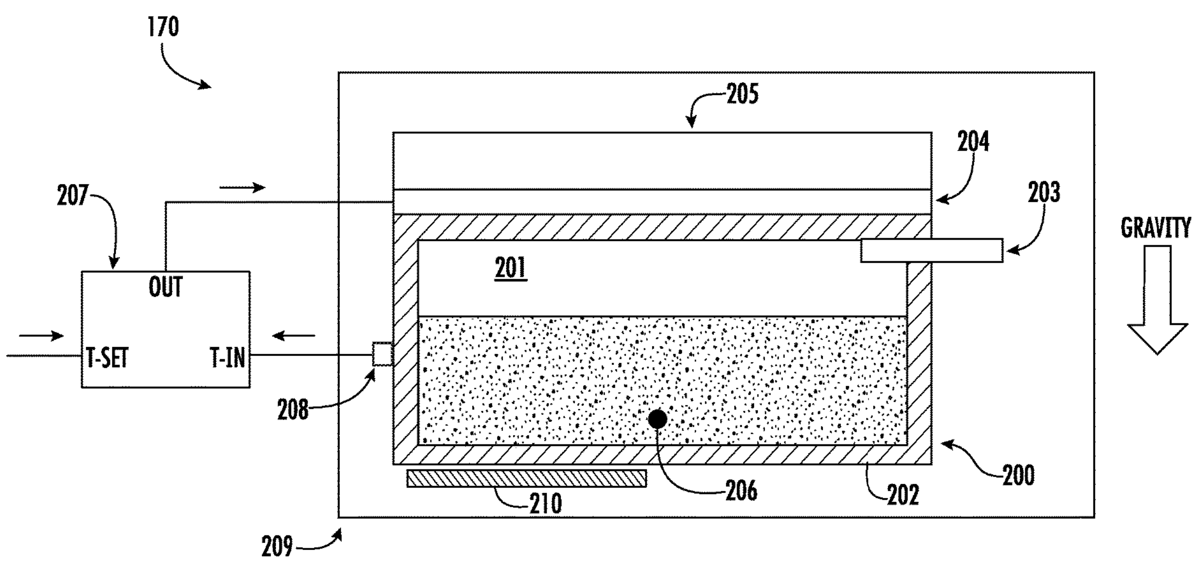
(57) **ABSTRACT**

A vaporizer that may be used to introduce vapor from a dopant material into the arc chamber is disclosed. The vaporizer includes a crucible and a thermoelectric device disposed on a surface of the crucible near the outlet. The thermoelectric device may be controlled to heat the dopant material to create dopant vapor when desired. Additionally, the thermoelectric device may also be used to quickly cool the surface on which it is disposed. Since the outlet is located near this surface, the outlet also quickly cools, allowing condensation of any dopant vapor in the outlet, thus stopping the flow of vapor into the arc chamber. Additional heaters may be used to further heat the dopant material.



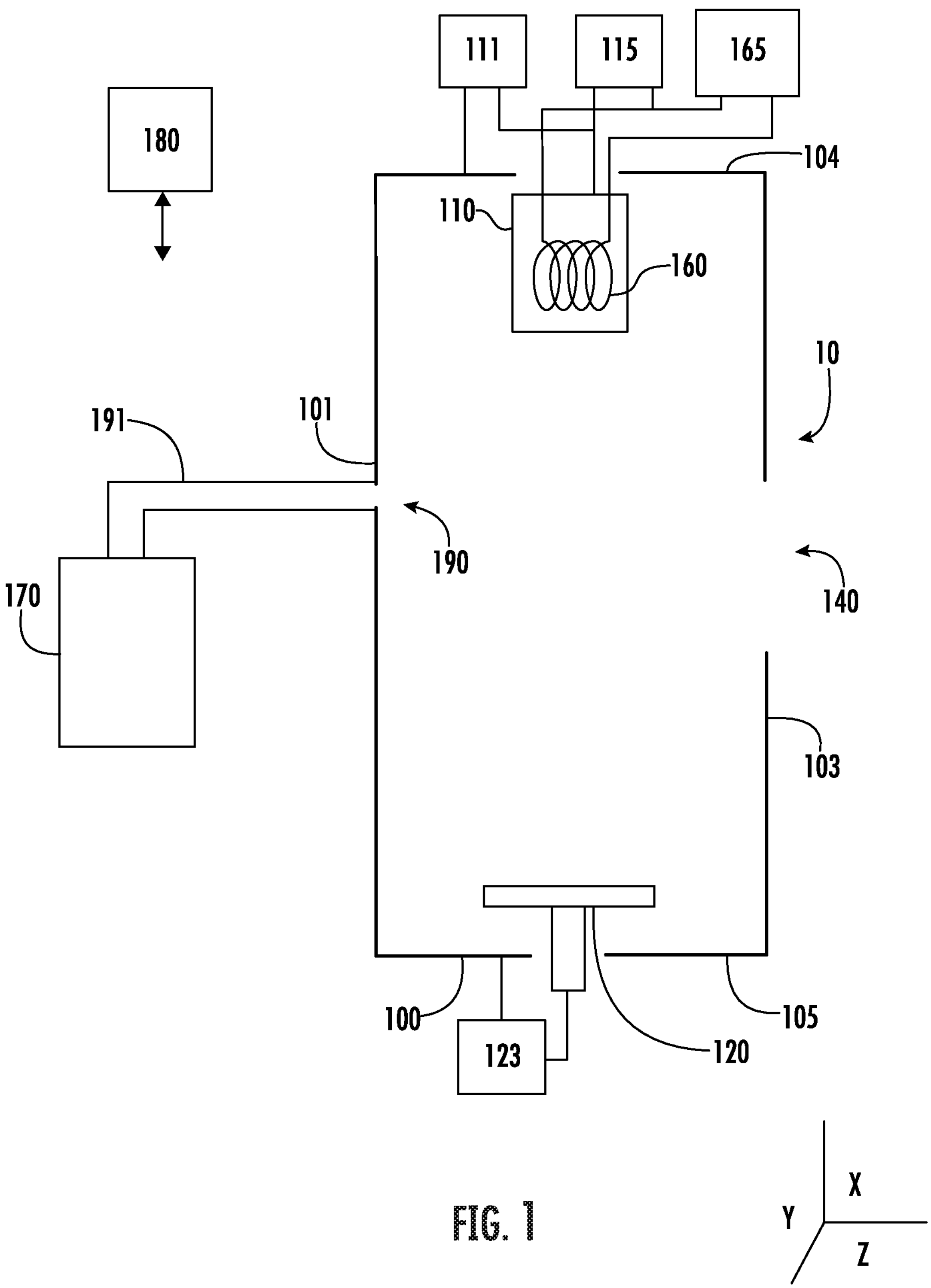

111
115
165
180
104
110
160
10
101
191
190
140
170
103
100
123
120
105
X
Y
Z

FIG. 1

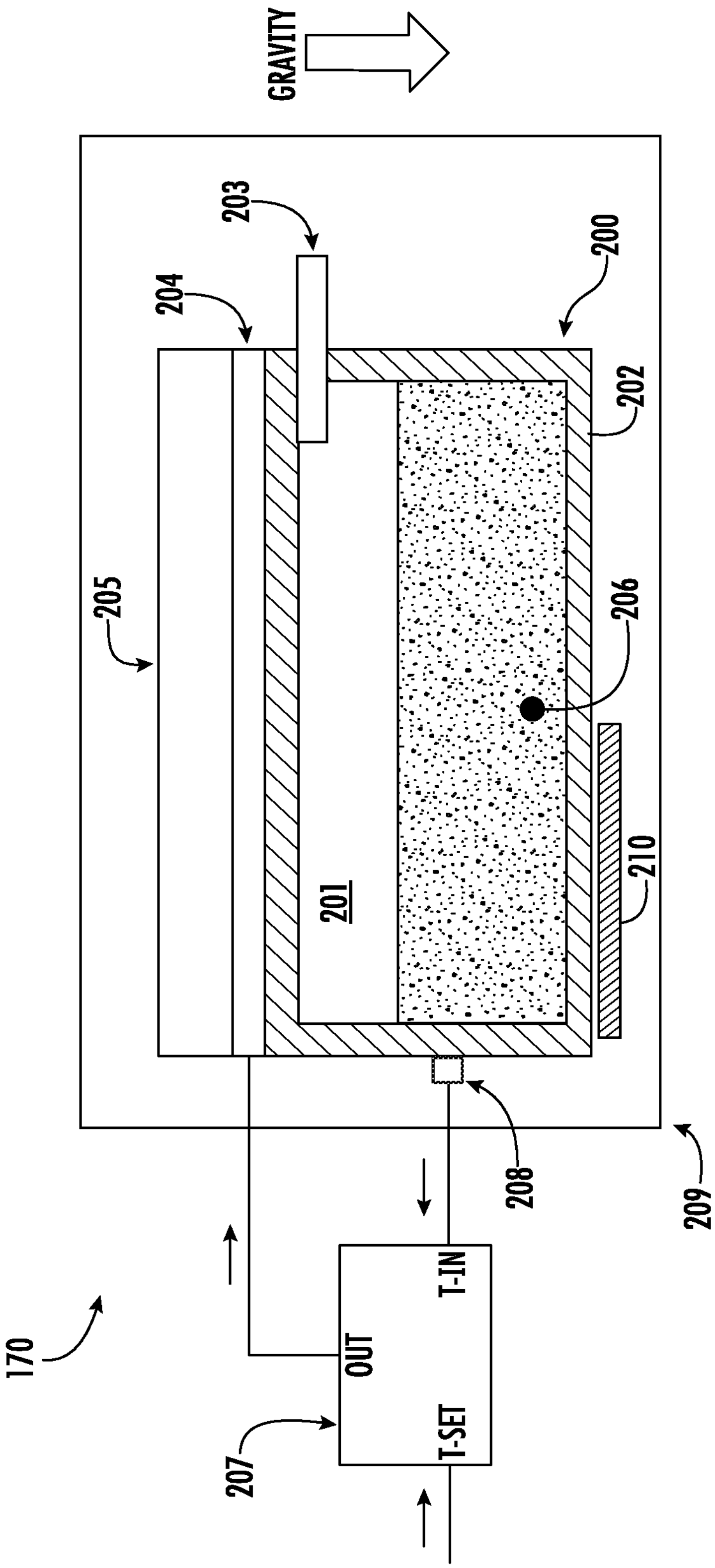

GRAVITY
203
204
200
202
205
206
201
210
208
209
170
207
OUT
T-IN
T-SET

FIG. 2

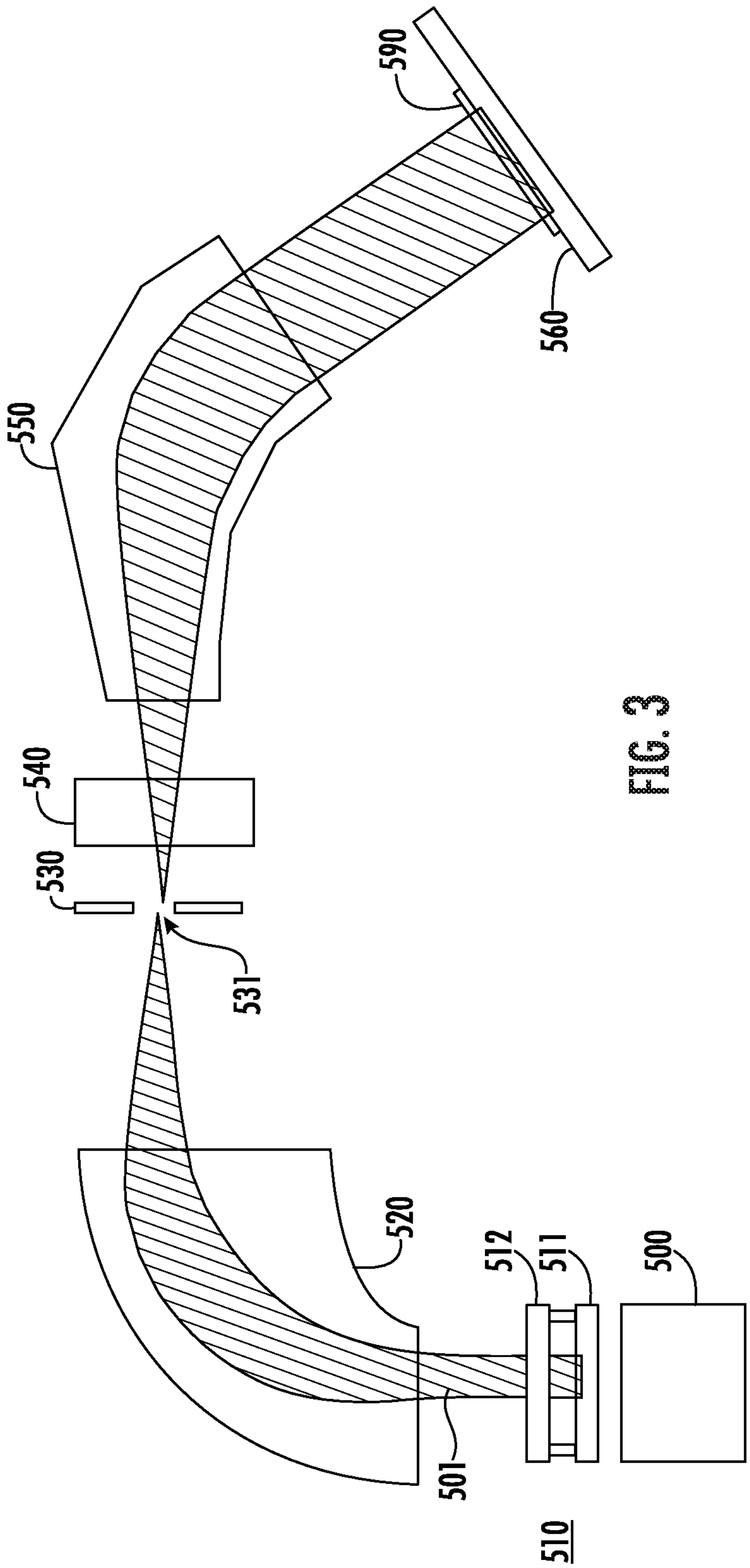



FIG. 3

# THERMOELECTRIC CONTROL FOR A CRUCIBLE FOR USE WITH AN ION SOURCE

## FIELD

**[0001]** Embodiments of the present disclosure relate to a crucible for use with an ion source and more particularly, a crucible that utilizes temperature control using a thermoelectric device.

## BACKGROUND

**[0002]** Various types of ion sources may be used to create the ions that are used in semiconductor processing equipment. For example, an indirectly heated cathode (IHC) ion source operates by supplying a current to a filament disposed behind a cathode. The filament emits thermionic electrons, which are accelerated toward and heat the cathode, in turn causing the cathode to emit electrons into the arc chamber of the ion source. The cathode is disposed at one end of an arc chamber. A repeller may be disposed on the end of the arc chamber opposite the cathode. The cathode and repeller may be biased so as to repel the electrons, directing them back toward the center of the arc chamber. In some embodiments, a magnetic field is used to further confine the electrons within the arc chamber. A plurality of sides is used to connect the two ends of the arc chamber.

**[0003]** An extraction aperture is disposed along one of these sides, proximate the center of the arc chamber, through which the ions created in the arc chamber may be extracted.

**[0004]** In certain embodiments, it may be desirable to create ions of a particular species, which at room temperature does not have any gaseous compounds that are suitable for use in an ion source. Examples of such species are aluminum and indium. In these cases a vaporizer is installed in close proximity to the arc chamber and the hot vapor from a solid charge in the vaporizer is introduced into the arc chamber as a gas. For the two examples given above this solid material could be aluminum-trichloride or indium-triiodide. However, these vaporizers have slow transition times (i.e., warm up and cool down times), making it difficult to switch modes of operations quickly.

**[0005]** Therefore, it would be beneficial if there were a vaporizer that did not suffer from these drawbacks.

## SUMMARY

**[0006]** A vaporizer that may be used to introduce vapor from a dopant material into the arc chamber is disclosed. The vaporizer includes a crucible and a thermoelectric device disposed on a surface of the crucible near the outlet. The thermoelectric device may be controlled to heat the dopant material to create dopant vapor when desired. Additionally, the thermoelectric device may also be used to quickly cool the surface on which it is disposed. Since the outlet is located near this surface, the outlet also quickly cools, allowing condensation of any dopant vapor in the outlet, thus stopping the flow of vapor into the arc chamber. Additional heaters may be used to further heat the dopant material.

**[0007]** According to one embodiment, a vaporizer is disclosed. The vaporizer comprises a crucible having a plurality of walls that define a crucible chamber; and a thermoelectric device disposed against at least one wall of the crucible. In some embodiments, the vaporizer includes an isothermal block, wherein the thermoelectric device is disposed between the isothermal block and the at least one wall. In certain embodiments, the isothermal block is maintained at a near constant temperature. In some embodiments, the thermoelectric device is configured to heat the at least one wall in a first mode and cool the at least one wall in a second mode. In certain embodiments, an outlet from the crucible chamber is disposed near the at least one wall, such that in the second mode, cooling of the at least one wall allows vapor from a dopant material disposed within the crucible chamber to condense in the outlet, so as to inhibit flow of vapor from the crucible chamber to an ion source. In some embodiments, the vaporizer includes a thermal controller in communication with the thermoelectric device, the thermal controller comprising a bipolar voltage output to allow operation in the first mode and the second mode. In certain embodiments, a direction of DC current from the bipolar voltage output determines a mode of operation and an amplitude of the DC current determines an amount of heating or cooling provided by the thermoelectric device. In some embodiments, the vaporizer includes a temperature sensor disposed against one wall of the crucible chamber, wherein the thermal controller uses information from the temperature sensor to control the bipolar voltage output. In some embodiments, the vaporizer includes a thermal controller in communication with the thermoelectric device, the thermal controller comprising a unipolar voltage output to allow operation in the first mode; and a second voltage source to allow operation in the second mode. In some embodiments, a secondary heater is used to supplement heat provided by the thermoelectric device in the first mode. In certain embodiments, the secondary heater comprises a second thermoelectric device, a resistive heater or heat pipes.

**[0008]** According to another embodiment, an ion implantation system is disclosed. The ion implantation system comprises an ion source to generate an ion beam; one or more beamline components located downstream from the ion source to direct the ion beam toward a workpiece holder; and a vaporizer in communication with the ion source to supply a dopant vapor to the ion source; wherein the vaporizer comprises a crucible chamber to hold a dopant material and a thermoelectric device disposed against at least one wall of the crucible chamber. In some embodiments, the vaporizer comprises an isothermal block, wherein the thermoelectric device is disposed between the isothermal block and the at least one wall. In certain embodiments, the isothermal block is maintained at a near constant temperature. In some embodiments, the vaporizer is adapted to operate in two modes, wherein, in a first mode, at least a portion of the crucible chamber is heated by the thermoelectric device and wherein, in a second mode, at least a portion of the crucible chamber is actively cooled by the thermoelectric device to cause condensation of the dopant vapor. In some embodiments, the vaporizer comprises a thermal controller in communication with the thermoelectric device, the thermal controller comprising a bipolar voltage output to allow operation in the first mode and the second mode. In certain embodiments, a direction of DC current from the bipolar voltage output determines a mode of operation and an amplitude of the DC current determines an amount of heating or cooling provided by the thermoelectric device. In some embodiments, the vaporizer comprises a thermal controller in communication with the thermoelectric device, the thermal controller comprising a unipolar voltage output to allow operation in the first mode; and a second voltage source to allow operation in the second mode. In some embodiments, the vaporizer comprises a secondary heater to supplement heat provided to the crucible chamber by the thermoelectric device in the first mode. In certain embodiments, the secondary heater comprises a second thermoelectric device, a resistive heater or heat pipes.

## BRIEF DESCRIPTION OF THE FIGURES

**[0009]** For a better understanding of the present disclosure, reference is made to the accompanying drawings, which are incorporated herein by reference and in which:

**[0010]** FIG. **1** is an indirectly heated cathode (IHC) ion source for introducing vapor in accordance with one embodiment;

**[0011]** FIG. **2** is a diagram showing a cross section of the vaporizer of FIG. **1**; and

**[0012]** FIG. **3** is an ion implantation system that utilizes the ion source and crucible described herein.

## DETAILED DESCRIPTION

**[0013]** As noted above, certain dopants, such as aluminum and other metals, are typically provided into an arc chamber using a vaporizer. The present disclosure describes a crucible that overcomes the shortcomings of the prior art.

**[0014]** FIG. **1** shows an IHC ion source **10** in communication with the vaporizer **170**. The IHC ion source **10** includes an arc chamber **100**, comprising two opposite ends, and walls **101** connecting to these ends. The walls **101** of the arc chamber **100** may be constructed of an electrically conductive material and may be in electrical communication with one another. In some embodiments, a liner may be disposed proximate one or more of the walls **101**. A cathode **110** is disposed in the arc chamber **100** at a first end **104** of the arc chamber **100**. A filament **160** is disposed behind the cathode **110**. The filament **160** is in communication with a filament power supply **165**. The filament power supply **165** is configured to pass a current through the filament **160**, such that the filament **160** emits thermionic electrons. Cathode bias power supply **115** biases filament **160** negatively relative to the cathode **110**, so these thermionic electrons are accelerated from the filament **160** toward the cathode **110** and heat the cathode **110** when they strike the back surface of cathode **110**. The cathode bias power supply **115** may bias the filament **160** so that it has a voltage that is between, for example, 200V to 1500V more negative than the voltage of the cathode **110**. The cathode **110** then emits thermionic electrons on its front surface into arc chamber **100**.

**[0015]** Thus, the filament power supply **165** supplies a current to the filament **160**. The cathode bias power supply **115** biases the filament **160** so that it is more negative than the cathode **110**, so that electrons are attracted toward the cathode **110** from the filament **160**. In certain embodiments, the cathode **110** may be biased relative to the arc chamber **100**, such as by arc power supply **111**. In other embodiments, the cathode **110** may be electrically connected to the arc chamber **100**, so as to be at the same voltage as the walls **101** of the arc chamber **100**. In these embodiments, arc power supply **111** may not be employed and the cathode **110** may be electrically connected to the walls **101** of the arc chamber **100**. In certain embodiments, the arc chamber **100** is connected to electrical ground.

**[0016]** On the second end **105**, which is opposite the first end **104**, a repeller **120** may be disposed. The repeller **120** may be biased relative to the arc chamber **100** by means of a repeller bias power supply **123**. In other embodiments, the repeller **120** may be electrically connected to the arc chamber **100**, so as to be at the same voltage as the walls **101** of the arc chamber **100**. In these embodiments, repeller bias power supply **123** may not be employed and the repeller **120** may be electrically connected to the walls **101** of the arc chamber **100**. In still other embodiments, a repeller **120** is not employed.

**[0017]** The cathode **110** and the repeller **120** are each made of an electrically conductive material, such as a metal or graphite.

**[0018]** In certain embodiments, a magnetic field is generated in the arc chamber **100**. This magnetic field is intended to confine the electrons along one direction. The magnetic field typically runs parallel to the walls **101** from the first end **104** to the second end **105**. For example, electrons may be confined in a column that is parallel to the direction from the cathode **110** to the repeller **120**. Thus, electrons do not experience any electromagnetic force to move in this direction. However, movement of the electrons in other directions may experience an electromagnetic force.

**[0019]** Disposed on one side of the arc chamber **100**, referred to as the extraction plate **103**, may be an extraction aperture **140**. In FIG. **1**, the extraction aperture **140** is disposed on a side that is perpendicular to the page. A gas inlet **190** may be disposed on one wall of the arc chamber **100**.

**[0020]** Further, the IHC ion source **10** may be in communication with the vaporizer **170**. The vaporizer **170** is used to vaporize a solid dopant material, such that the dopant vapor travels from the vaporizer **170** through vapor channel **191** and enters the arc chamber **100** via gas inlet **190**.

**[0021]** A controller **180** may be in communication with one or more of the power supplies such that the voltage or current supplied by these power supplies may be modified. The controller **180** may also be in communication with the thermal controller, coolers and heaters as described below. The controller **180** may include a processing unit, such as a microcontroller, a personal computer, a special purpose controller, or another suitable processing unit. The controller **180** may also include a non-transitory storage element, such as a semiconductor memory, a magnetic memory, or another suitable memory. This non-transitory storage element may contain instructions and other data that allows the controller **180** to perform the functions described herein.

**[0022]** FIG. **2** shows the vaporizer **170** in more detail. The vaporizer **170** includes a crucible **200** comprising a plurality of walls **202** that define a crucible chamber **201**. In some embodiments, the walls **202** may be made from a refractory metal, or may be constructed from graphite. The walls **202** may define a rectangular prism, a cylinder or another suitable shape. An outlet **203** may be disposed in one of these walls **202**, and may be positioned to be near the top of the crucible **200** such that vapor passes through the outlet **203**. In some embodiments, the outlet **203** may have a round cross-section. In certain embodiments, the round cross-section may have a diameter between 1⁄16" and **14"**. In other embodiments, a different shaped outlet may be used, such as one having a larger surface area to cross-sectional area ratio than a circle to facilitate faster condensation. Specifically, gravity draws the dopant material **206** within the crucible chamber **201** to the bottom of the crucible **200**. The top of the crucible **200** is defined as the portion of the crucible **200** furthest from the bottom.

**[0023]** A thermoelectric device **204** is sandwiched between one or more walls **202** of the crucible **200** and an isothermal block **205**. Specifically, the thermoelectric device **204** is pressed against the exterior surface of one or more walls **202** that are near the outlet **203**. These walls may include the wall in which the outlet **203** is disposed, or walls adjacent to that wall. These one or more walls may be referred to as temperature controlled walls. For example, in FIG. **2**, the crucible **200** is shaped as a rectangular prism, where the outlet **203** is located near the top of one of the side walls. The thermoelectric device **204** is disposed against the top wall, which is near the outlet **203** and adjacent to the wall containing the outlet **203**. Note that if the crucible was tilted, the thermoelectric device **204** may still be disposed along the wall **202** that is adjacent to or near the outlet **203**.

**[0024]** The isothermal block **205** may be a block of material that maintains a near constant temperature. This may be achieved by utilizing a sufficiently large block such that the heat transferred to and from the thermoelectric device **204** have little effect on the overall temperature of the isothermal block **205**. In another embodiment, the isothermal block **205** may have one or more fluid channels therethrough that allow the flow of a fluid that circulates through the fluid channels to maintain the isothermal block **205** at a constant or near constant temperature. In certain embodiments, the term "near constant" refers to a temperature that does not vary by more than +20° C. In some embodiments, the isothermal block **205** is maintained at or near 25° C.

**[0025]** The thermoelectric device **204** utilizes the Peltier effect to convert DC current into heat transfer. Specifically, in FIG. **2**, one side of the thermoelectric device **204** is maintained at constant or near constant temperature due to its contact with the isothermal block **205**. If the DC current through the thermoelectric device **204** flows in a first direction, heat is transferred from the side adjacent to the isothermal block **205** to the side adjacent to the wall **202** of the crucible **200**. This first mode serves to heat the wall **202**. If, conversely, the DC current through the thermoelectric device **204** flows in a second direction, heat is transferred from the side adjacent to the wall **202** of the crucible **200** to the side adjacent to the isothermal block **205**. This second mode serves to cool the wall **202**. Thus, the direction of DC current flow determines the direction of heat transfer while the magnitude of the DC current determines the amount of heat transfer. In other words, the direction of DC current flow determines the mode of operation and the magnitude of the DC current determines the amount of heating or cooling provided by the thermoelectric device **204**.

**[0026]** In one embodiment, the thermoelectric device **204** is in communication with a thermal controller **207** that may include a bipolar voltage output. The thermal controller **207** receives an input from a temperature sensor **208**. The temperature sensor **208** may be a thermocouple or another type of sensor. The temperature sensor **208** may be disposed along one of the walls **202** of the crucible **200**. In one embodiment, the temperature sensor **208** may be disposed against a wall **202** that is contacted by the dopant material **206**, such as the bottom wall or the lower portion of a side wall. In operation, the thermal controller **207** receives a set temperature (labelled T-SET) as an input, and also receives the information from the temperature sensor **208**. The set temperature may be provided by another controller, such as controller **180**. Based on the difference between these two temperatures, the thermal controller **207** determines the direction of DC current flow through the thermoelectric device **204**. For example, if the set temperature is greater than the temperature indicated by the temperature sensor **208**, the thermal controller **207** will flow DC current through the thermoelectric device **204** in the first direction to add heat to the crucible **200**. If the set temperature is less than the temperature indicated by the temperature sensor **208**, the thermal controller **207** will flow DC current through the thermoelectric device **204** in the second direction to remove heat from the crucible **200**. Thus, the thermal controller **207** is able to heat or cool the crucible **200**, using the isothermal block **205** as a heat sink or heat source, depending on the direction of heat transfer. In certain embodiments, the thermal controller **207** may receive temperature information from one or more additional temperature sensors. For example, in some embodiments, a temperature sensor may be disposed on or near the thermoelectric device **204**. In this way, the thermal controller **207** may control the DC current such that the temperature of the thermoelectric device **204** never exceeds a predetermined temperature threshold.

**[0027]** The vaporizer **170**, which includes the crucible **200**, the thermoelectric device **204**, the temperature sensor **208** and the isothermal block **205**, are disposed within a vacuum chamber **209**, with the IHC ion source **10** and are thermally insulated from all other components within the vacuum chamber **209** as much as is practical. Connections for power, signals, and facilities pass through the wall of vacuum chamber **209** into atmosphere. The thermal controller **207** may be disposed in atmospheric conditions.

**[0028]** In operation, a dopant material **206** is placed in the crucible chamber **201**. The dopant material **206** is in solid form, and may be aluminum or a different metal. Gravity will force the dopant material **206** to the bottom of the crucible chamber **201**. The controller **180** may instruct the thermal controller **207** to generate dopant vapor. In response, the set temperature for the thermal controller **207** is set to a first temperature, which is an elevated temperature. This elevated temperature may be up to 300° C. or more in some embodiments. The first temperature may be high enough to vaporize the dopant material **206**. The dopant vapor then flows through outlet **203** and vapor channel **191** to the arc chamber **100**. At a later time, it may be desirable to stop the flow of dopant vapor to the ion source. The controller **180** may instruct the thermal controller **207** to stop the flow of dopant vapor. In response, the set temperature is set to a second temperature, which is lower than the first temperature. This second temperature may be sufficiently low such that dopant vapor condenses on the temperature controlled wall. In some embodiments, this second temperature may be less than 30° C. In some embodiments, the second temperature may be between 15° C. and 30° C. This second temperature may be based on the vapor pressure of the dopant material **206**. Further, since the outlet **203** is near the temperature controlled wall, dopant vapor condenses within the outlet, effectively blocking the passage of any dopant vapor still in the crucible chamber **201** from exiting. Thus, as the dopant material **206** cools, it condenses on the temperature controlled wall and within the outlet **203**. The next time that dopant vapor is requested, the set temperature is changed to the first temperature. This first temperature is sufficient to vaporize any condensed dopant in the outlet **203**

and on the temperature controlled wall, allowing the flow of dopant vapor to the arc chamber **100**.

**[0029]** Thus, the thermoelectric device **204** provides several functions. First, when set to the second temperature, the temperature controlled wall causes the condensation of dopant vapor on the wall as well as within the outlet **203**. This prevents the flow of dopant vapor to the ion source. Second, when set to the first temperature, the temperature controlled wall causes the vaporization of dopant material that may have condensed within the outlet **203**. Third, in some embodiments, the temperature controlled wall also causes the vaporization of the dopant material **206**.

**[0030]** Thus, the thermoelectric device **204** allows at least two modes of operation for the vaporizer **170**. There is a first mode of operation where the thermoelectric device **204** acts as a heater, which allows the flow of dopant vapor through the outlet **203**. Thus, in the first mode, at least a portion of the crucible chamber **201** is heated. There is also a second mode of operation, wherein the thermoelectric device **204** acts as a cooler, forcing dopant vapor to condense on the temperature controlled wall and in the outlet **203**, effectively blocking the passage of any dopant vapor to the arc chamber **100**. Thus, in the second mode, at least a portion of the crucible chamber **201** is actively cooled.

**[0031]** Further, while FIG. **2** shows one embodiment, several variations are also possible.

**[0032]** In certain embodiments, the heat provided by the thermoelectric device **204** may be supplemented when operating in the first mode. For example, a secondary heater **210** may be used to heat the surface against which the dopant material **206** is disposed. This secondary heater **210** may be a second thermoelectric device, and may be operated in the same manner as the thermoelectric device **204**. In a variation of this embodiment, the second thermoelectric device may only be used as a heater. In another embodiment, the secondary heater **210** may be a resistive heater. In this embodiment, the resistive heater may be actuated whenever the thermoelectric device **204** is being used as a heater. In another embodiment, the secondary heater **210** may be heat pipes that are embedded in one or more walls **202** of the crucible **200** which are actuated when the thermoelectric device **204** acts as a heater.

**[0033]** Note that FIG. **2** shows the thermoelectric device **204** placed against a wall different from the walls against which the dopant material is disposed. However, in another embodiment, the thermoelectric device **204** may be placed against a wall that is only in partial contact with the dopant material **206**. For example, the thermoelectric device **204** may be disposed along the right side wall in FIG. **2**. This placement still allows the thermoelectric device **204** to control the temperature within the outlet **203**. Thus, the thermoelectric device **204** may be disposed along the wall that includes the outlet **203**, along a wall adjacent to the wall that includes the outlet **203**, or along a different wall that is near the outlet **203**.

**[0034]** In another embodiment, the thermal controller **207** may utilize a unipolar voltage output. In this embodiment, the thermal controller **207** may be used when heating is requested and a second voltage source may be used in the second mode. In one embodiment, a second thermal controller may be used when cooling is requested. The selection of which of the outputs from these two thermal controllers is provided to the thermoelectric device **204** may be achieved using an analog switch or a relay. In another embodiment, the second voltage source may be a fixed voltage that may be used for cooling. Again, the appropriate signal may be selected using an analog switch or a relay.

**[0035]** FIG. **3** shows an ion implanter that may utilize the ion source described herein. The ion implanter includes an ion source **500**, which may be any of the ion sources described above. As noted above, in certain embodiments, the ion source **500** may be an IHC ion source. In another embodiment, the ion source **500** may be an RF ion source. In this embodiment, an RF antenna may be disposed against a dielectric window. This dielectric window may comprise part or all of one of the chamber walls. The RF antenna may comprise an electrically conductive material, such as copper. An RF power supply is in electrical communication with the RF antenna. The RF power supply may supply an RF voltage to the RF antenna. The power supplied by the RF power supply may be between 0.1 and 10 kW and may be any suitable frequency, such as between 1 and 100 MHZ. Further, the power supplied by the RF power supply may be pulsed. Other embodiments are also possible. For example, the plasma may be generated in a different manner, such as by a Bernas ion source, a capacitively coupled plasma (CCP) source, microwave or ECR (electron-cyclotron-resonance) ion source. The manner in which the plasma is generated is not limited by this disclosure.

**[0036]** One chamber wall, referred to as the extraction plate, includes an extraction aperture. The extraction aperture may be an opening through which the ions **501** generated in the ion source chamber are extracted and directed toward a workpiece **590**. The extraction aperture may be any suitable shape. In certain embodiments, the extraction aperture may be oval or rectangular shaped.

**[0037]** Disposed outside and proximate the extraction aperture of the ion source **500** are extraction optics **510**. In certain embodiments, the extraction optics **510** comprise one or more electrodes. In certain embodiments, the extraction optics **510** comprises a suppression electrode **511**, which is negatively biased relative to the plasma so as to attract ions through the extraction aperture. The suppression electrode **511** may be electrically biased using a suppression power supply. The suppression electrode **511** may be biased so as to be more negative than the extraction plate of the ion source **500**.

**[0038]** In some embodiments, the extraction optics **510** includes a second electrode **512**. The second electrode **512** may be disposed proximate the suppression electrode **511**. The second electrode **512** may be electrically connected to a second electrode power supply. In other embodiments, the second electrode **512** may be electrically grounded so that the second electrode power supply is not used.

**[0039]** In other embodiments, the extraction optics **510** may comprise in excess of two electrodes, such as three electrodes or four electrodes. In these embodiments, the electrodes may be functionally and structurally similar to those described above, but may be biased at different voltages.

**[0040]** Located downstream from the extraction optics **510** is a mass analyzer **520**. The mass analyzer **520** uses magnetic fields to guide the path of the extracted ions **501**. The magnetic fields affect the flight path of ions according to their mass and charge. A mass resolving device **530** that has a resolving aperture **531** is disposed at the output, or distal end, of the mass analyzer **520**. By proper selection of the magnetic fields, only those ions **501** that have a selected mass and charge will be directed through the resolving aperture **531**. Other ions will strike the mass resolving device **530** or a wall of the mass analyzer **520** and will not travel any further in the system.

**[0041]** One or more beamline components may be disposed downstream from the mass resolving device **530**. For example, a collimator **540** may be disposed downstream from the mass resolving device **530**. The collimator **540** accepts the extracted ions **501** that pass through the resolving aperture **531** and creates a ribbon ion beam formed of a plurality of parallel or nearly parallel beamlets. In other embodiments, the ion beam may be a spot beam. In this embodiment, an electrostatic scanner is used to move the spot beam in a first direction, as defined below.

**[0042]** Located downstream from the collimator **540** may be an acceleration/deceleration stage **550**. The acceleration/deceleration stage **550** may be an electrostatic filter. The electrostatic filter is a beam-line lens component configured to independently control deflection, deceleration, and focus of the ion beam. The output from the acceleration/deceleration stage **550** may be a ribbon ion beam having a width in the first direction, which is much greater than its height in the second direction. Located downstream from the acceleration/deceleration stage **550** is the workpiece holder **560**.

**[0043]** The workpiece **590**, which may be, for example, a silicon wafer, a silicon carbide wafer, or a gallium nitride wafer, is disposed on the workpiece holder **560**. The workpiece holder **560** may be moved in the second direction, which is perpendicular to the first direction, to allow the entirety of the workpiece **590** to be processed by the ion beam.

**[0044]** The embodiments described above in the present application may have many advantages. First, by using a thermoelectric device **204**, it is possible to both heat the crucible as well as cool it. The ability to cool the outlet **203** allows it to become blocked, stopping the passage of vapor to the arc chamber **100**. Thus, this crucible, unlike traditional vaporizers, provides fast turn off times. Additionally, the thermoelectric device **204** may be one or more thin sheets of material, having a thickness of between 3 to 5 mm in some embodiments. This allows the heating of the crucible to be performed in a very small volume, allowing a large crucible chamber to be used in the same space currently utilized by conventional vaporizers.

**[0045]** 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. Furthermore, 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**. A vaporizer, comprising:

a crucible having a plurality of walls that define a crucible chamber; and

a thermoelectric device disposed against at least one wall of the crucible.

**2**. The vaporizer of claim **1**, further comprising an isothermal block, wherein the thermoelectric device is disposed between the isothermal block and the at least one wall.

**3**. The vaporizer of claim **2**, wherein the isothermal block is maintained at a near constant temperature.

**4**. The vaporizer of claim **1**, wherein the thermoelectric device is configured to heat the at least one wall in a first mode and cool the at least one wall in a second mode.

**5**. The vaporizer of claim **4**, wherein an outlet from the crucible chamber is disposed near the at least one wall, such that in the second mode, cooling of the at least one wall allows vapor from a dopant material disposed within the crucible chamber to condense in the outlet, so as to inhibit flow of vapor from the crucible chamber to an ion source.

**6**. The vaporizer of claim **4**, further comprising a thermal controller in communication with the thermoelectric device, the thermal controller comprising a bipolar voltage output to allow operation in the first mode and the second mode.

**7**. The vaporizer of claim **6**, wherein a direction of DC current from the bipolar voltage output determines a mode of operation and an amplitude of the DC current determines an amount of heating or cooling provided by the thermoelectric device.

**8**. The vaporizer of claim **6**, further comprising a temperature sensor disposed against one wall of the crucible chamber, wherein the thermal controller uses information from the temperature sensor to control the bipolar voltage output.

**9**. The vaporizer of claim **4**, further comprising a thermal controller in communication with the thermoelectric device, the thermal controller comprising a unipolar voltage output to allow operation in the first mode; and a second voltage source to allow operation in the second mode.

**10**. The vaporizer of claim **4**, further comprising a secondary heater to supplement heat provided by the thermoelectric device in the first mode.

**11**. The vaporizer of claim **10**, wherein the secondary heater comprises a second thermoelectric device, a resistive heater or heat pipes.

**12**. An ion implantation system, comprising:

an ion source to generate an ion beam;

one or more beamline components located downstream from the ion source to direct the ion beam toward a workpiece holder; and

a vaporizer in communication with the ion source to supply a dopant vapor to the ion source;

wherein the vaporizer comprises a crucible chamber to hold a dopant material and a thermoelectric device disposed against at least one wall of the crucible chamber.

**13**. The ion implantation system of claim **12**, wherein the vaporizer comprises an isothermal block, wherein the thermoelectric device is disposed between the isothermal block and the at least one wall.

**14**. The ion implantation system of claim **13**, wherein the isothermal block is maintained at a near constant temperature.

**15**. The ion implantation system of claim **12**, wherein the vaporizer is adapted to operate in two modes, wherein, in a first mode, at least a portion of the crucible chamber is heated by the thermoelectric device and wherein, in a second mode, at least a portion of the crucible chamber is actively cooled by the thermoelectric device to cause condensation of the dopant vapor.

**16**. The ion implantation system of claim **15**, wherein the vaporizer comprises a thermal controller in communication with the thermoelectric device, the thermal controller comprising a bipolar voltage output to allow operation in the first mode and the second mode.

**17**. The ion implantation system of claim **16**, wherein a direction of DC current from the bipolar voltage output determines a mode of operation and an amplitude of the DC current determines an amount of heating or cooling provided by the thermoelectric device.

**18**. The ion implantation system of claim **15**, wherein the vaporizer comprises a thermal controller in communication with the thermoelectric device, the thermal controller comprising a unipolar voltage output to allow operation in the first mode; and a second voltage source to allow operation in the second mode.

**19**. The ion implantation system of claim **15**, wherein the vaporizer comprises a secondary heater to supplement heat provided to the crucible chamber by the thermoelectric device in the first mode.

**20**. The ion implantation system of claim **19**, wherein the secondary heater comprises a second thermoelectric device, a resistive heater or heat pipes.

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