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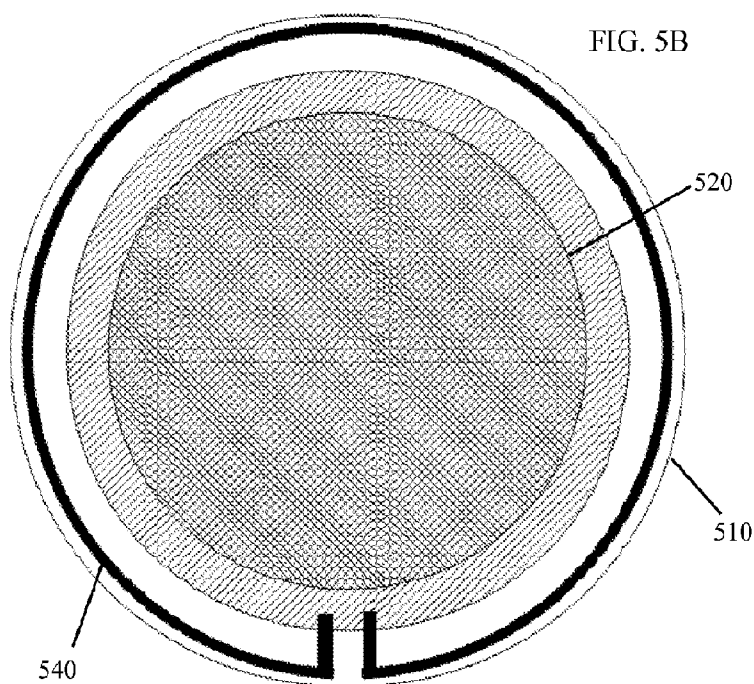
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(54) Title: HEATED ELECTROSTATIC CHUCK



(57) Abstract: Heated electrostatic chucks are provided that can improve uniformity of heating of a substrate on the electrostatic chucks, and can improve thermal performance of an electrostatic chuck relative to other thermal performance goals. One electrostatic chuck includes a ceramic structural element having a sidewall surface on an outer perimeter of the electrostatic chuck, and at least one sidewall heater element disposed on or within at least a portion of the sidewall surface.



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HEATED ELECTROSTATIC CHUCK

RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 61/973,787, filed on April 1, 2014, the entire teachings of which application are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] Electrostatic chucks (ESCs) are often utilized in the semiconductor manufacturing industry for clamping workpieces or substrates into a fixed position on a support surface during plasma-based or vacuum-based semiconductor processes such as ion implantation, etching, chemical vapor deposition (CVD) and others.

[0003] Electrostatic clamping capabilities of these ESCs, as well as workpiece temperature control, have proven to be quite valuable in processing semiconductor substrates, workpieces or wafers, such as silicon wafers. See, *e.g.*, U.S. Patent No. 8,517,392 B2 issued to Hida *et al.* on August 27, 2013.

[0004] Existing electrostatic chucks used in processes such as ion implant are chamfered to avoid implant beam strike of the chuck during angled ion beam implantation. Due to this chamfer, it is difficult to achieve uniform heating of the wafer, because the heater has a diameter that is smaller than the diameter of the wafer.

[0005] Therefore, there is a need for an improved chuck design that improves uniformity of heating of the wafer. In addition, there is a need for an improved chuck design that improves performance relative to other thermal goals.

SUMMARY OF THE INVENTION

[0006] In accordance with a version of the invention, there is provided an electrostatic chuck comprising a ceramic structural element having a sidewall surface on an outer perimeter of the electrostatic chuck, and at least one sidewall heater element disposed on or within at least a portion of the sidewall surface.

[0007] In further, related versions, the at least one sidewall heater element may be disposed on the at least a portion of the sidewall surface, or may be embedded under the at

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least a portion of the sidewall surface. The electrostatic chuck may further comprise a back side heater element disposed on an opposite side of the electrostatic chuck from a clamping surface of the electrostatic chuck.

[0008] In other related versions, the at least one sidewall heater element may comprise a heater wire. The heater wire may be mechanically retained on the at least a portion of the sidewall surface, such as by being located in a groove on the at least a portion of the sidewall surface; or may be embedded under the at least a portion of the sidewall surface. The heater wire may comprise at least one metal selected from the group consisting of aluminum, copper, titanium, molybdenum, silver, platinum, gold, nickel, tungsten, chromium, vanadium, ruthenium, iron, palladium, kovar, and manganese and mixtures, oxides and nitrides thereof. The heater wire may, for example, comprise a nichrome (NiCr) heater wire or a silver (Ag) heater wire.

[0009] In further related versions, the at least one sidewall heater element may comprise a heater element film. The heater element film may include at least one metal selected from the group consisting of aluminum, copper, titanium, molybdenum, silver, platinum, gold, nickel, tungsten, chromium, vanadium, ruthenium, iron, palladium, kovar, and manganese, and mixtures, oxides and nitrides thereof. For example, the heater element film may comprise a nichrome (NiCr) film. The heater element film may have a film thickness of less than about 100 μm , such as a film thickness is in a range of between about 1 μm and about 10 μm , or a film thickness of less than about 1 μm . The heater element film may be encapsulated with an electrically insulating and mechanically robust layer that includes one or more of a glass, alumina, a ceramic, a metal oxide, a transition metal oxide, a rare earth oxide, a metal nitride, a transition metal nitride, a rare earth nitride, a metal oxy-nitride, silicon oxide, silicon nitride, and silicon oxy-nitride.

[0010] In other related versions, the ceramic structural element may include at least one of alumina (Al_2O_3), aluminum nitride and silicon nitride; and may be of a cylindrical shape, or may comprise a chamfered sidewall surface. The at least one sidewall heater element may provide a maximum power of between about 100 W and about 2000 W.

[0011] In further related versions, the electrostatic chuck may further comprise a heater control circuit. The at least one sidewall heater element may comprise a single sidewall heater zone, and the heater control circuit may be electrically connected to control operation of the single sidewall heater zone; or the at least one sidewall heater element may comprise a

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plurality of sidewall heater zones, and the heater control circuit may be electrically connected to control operation of each sidewall heater zone of the plurality of sidewall heater zones. The electrostatic chuck may further comprise a back side heater element disposed on an opposite side of the electrostatic chuck from a clamping surface of the electrostatic chuck. The heater control circuit may be electrically connected to control operation of the at least one sidewall heater element and the back side heater element as a single heater zone of the electrostatic chuck. The at least one sidewall heater element may comprise one or more sidewall heater zones, and the back side heater element may comprise one or more back side heater zones, and the heater control circuit may be electrically connected to control operation of each of the one or more sidewall heater zones and the one or more back side heater zones. The heater control circuit may be electrically connected to control operation of at least a portion of the at least one sidewall heater element and of at least a portion of the back side heater element together as part of at least one common heater zone, and at least one of the at least one sidewall heater element and the back side heater element may comprise a further heater zone in addition to the at least one common heater zone. The sidewall heater element may provide a varying power density of heating over the at least a portion of the sidewall surface.

[0012] In another version according to the invention, there is provided an electrostatic chuck comprising a ceramic structural element having a sidewall surface, and at least one side heat shield spaced apart from the sidewall surface and configured to provide radiation heat to at least a portion of the sidewall surface. The at least one side heat shield comprises (i) a heat shield radiative surface arranged to provide the radiation heat to the at least a portion of the sidewall surface, and (ii) a shield heater element configured to heat the heat shield radiative surface. In further, related versions, such an electrostatic chuck may further comprise a back side heater element disposed on an opposite side of the electrostatic chuck from a clamping surface of the electrostatic chuck.

[0013] In another version according to the invention, there is provided an electrostatic chuck comprising at least one electrically conductive element; and a surface layer activated by a voltage in the at least one electrically conductive element to form an electric charge to electrostatically clamp a substrate to the electrostatic chuck; the surface layer being heated by the same at least one electrically conductive element by which the surface layer is activated to form the electric charge to electrostatically clamp the substrate.

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[0014] In further, related versions, the at least one electrically conductive element may provide a maximum heating power of between about 100 W and about 2000 W. The electrostatic chuck may further comprise at least one clamp power supply to power the at least one electrically conductive element to produce the voltage by which the surface layer is activated to form the electric charge to electrostatically clamp the substrate; and may further comprise at least one heater power supply to power the at least one electrically conductive element to heat the surface layer. The at least one clamp power supply may comprise at least one alternating current power supply, and the at least one heater power supply may comprise at least one direct current power supply.

[0015] Versions according to the invention have many advantages, such as enabling more uniform heating of a substrate on the electrostatic chuck, and of otherwise improving thermal performance of an electrostatic chuck.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The foregoing will be apparent from the following more particular description of example embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating embodiments of the present invention.

[0017] FIG. 1A is a side view of an electrostatic chuck with a sidewall heater element in accordance with one version of the invention.

[0018] FIG. 1B is a bottom view of an electrostatic chuck with a sidewall heater element in accordance with one version of the invention.

[0019] FIG. 2 is a bottom view of an electrostatic chuck with a wire coil sidewall heater element in accordance with one version of the invention.

[0020] FIG. 3 is a side view of an electrostatic chuck with a sidewall heater comprising a heater element film, in accordance with one version of the invention.

[0021] FIG. 4 is a schematic illustration of a fixture for pen writing a film sidewall heater element in accordance with one version of the invention.

[0022] FIGS. 5A and 5B are side and bottom views, respectively, of an electrostatic chuck that includes an embedded sidewall heater element, in accordance with a version of the invention.

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[0023] FIG. 6 is a schematic diagram of an electrostatic chuck that includes a heater control circuit, in accordance with a version of the invention.

[0024] FIGS. 7A is a schematic side view of an electrostatic chuck that includes a passive reflective heat shield, in accordance with the prior art; and FIG. 7B is a schematic side view of an electrostatic chuck that includes a heated reflective heat shield, in accordance with a version of the invention.

[0025] FIG. 8 is a schematic diagram of an electrostatic chuck that uses electrodes that perform a double function of acting as both clamping electrodes and heater elements, in accordance with a version of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0026] While this invention will be particularly shown and described with references to example embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

[0027] While various compositions and methods are described, it is to be understood that this invention is not limited to the particular molecules, compositions, designs, methodologies or protocols described, as these may vary. It is also to be understood that the terminology used in the description is for the purpose of describing the particular versions or versions only, and is not intended to limit the scope of the present invention which will be limited only by the appended claims.

[0028] It must also be noted that as used herein and in the appended claims, the singular forms "a", "an", and "the" include plural reference unless the context clearly dictates otherwise. Thus, for example, reference to a "sidewall heater element" is a reference to one or more sidewall heater elements and equivalents thereof known to those skilled in the art, and so forth. Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art. Methods and materials similar or equivalent to those described herein can be used in the practice or testing of versions of the present invention. All publications mentioned herein are incorporated by reference in their entirety. Nothing herein is to be construed as an admission that the invention is not entitled to antedate such disclosure by virtue of prior invention. "Optional" or "optionally" means that the subsequently described event or circumstance may or may not

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occur, and that the description includes instances where the event occurs and instances where it does not. All numeric values herein can be modified by the term "about," whether or not explicitly indicated. The term "about" generally refers to a range of numbers that one of skill in the art would consider equivalent to the recited value (i.e., having the same function or result). In some versions the term "about" refers to $\pm 10\%$ of the stated value, in other versions the term "about" refers to $\pm 2\%$ of the stated value. While compositions and methods are described in terms of "comprising" various components or steps (interpreted as meaning "including, but not limited to"), the compositions and methods can also "consist essentially of" or "consist of" the various components and steps, such terminology should be interpreted as defining essentially closed-member groups.

[0029] A description of example embodiments of the invention follows.

[0030] FIGS. 1A and 1B are side and bottom views, respectively, of an electrostatic chuck with a sidewall heater element in accordance with one version of the invention. The electrostatic chuck 100 is generally cylindrically symmetric and has a ceramic structural element 110, such as a ceramic (e.g., alumina, or the like) body between about 2 mm and about 15 mm thick, such as between about 4 mm and about 12 mm thick, or between about 6 mm and about 10 mm thick, having an embedded electrode (not shown in FIGS. 1A and 1B) for generating chucking force. The ceramic structural element 110 has a sidewall surface 112 on an outer perimeter of the electrostatic chuck 100. The sidewall surface 112 has a chamfer to avoid implant beam strike of the chuck during angled ion beam implantation, which chamfer can be defined by a chamfer angle that is the interior angle between the sidewall surface 112 and the surface 111 of the ceramic structural element 110 that faces the chucked wafer 130. Due to this chamfer, which can be at an angle in a range of between about 30 degrees and about 60 degrees, such as an angle in a range of between about 40 degrees and about 50 degrees, or an angle in a range of between about 43 degrees and about 47 degrees, such as about 45 degrees, a back side heater 120 has a diameter that is smaller than the diameter of the wafer 130, by a difference in size of as much as about 8 mm. In the chuck of FIG. 1A, the back side heater 120 is placed underneath the ceramic structural element 110, because the back side heater 120 would interfere with the electrostatic clamp function if it were placed directly underneath the wafer 130. Because of the resulting difference in diameter between the back side heater 120 and the wafer 130, it is difficult to achieve temperature uniformity across the wafer 130, even if the back side heater 120 has an inner

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heating zone 120a that is heated to a given temperature, and an outer heating zone 120b that is heated to a higher temperature. Even with the use of multiple heating zones, because the back side heater 120 does not reach out to the edge of the wafer 130, a significant temperature roll-off has been predicted and observed toward the edge of the wafer 130.

[0031] To improve temperature uniformity across the wafer 130, in one version according to the invention, shown in FIGS. 1A and 1B, the electrostatic chuck 100 includes a sidewall heater element 140 that is disposed on at least a portion of the sidewall surface 112 of the ceramic structural element 110, for example by being looped around the sidewall surface 112 close to the top surface of the chuck 100 that holds the wafer 130. In one aspect, the sidewall heater element 140 is a heater wire. The heater wire 140 may, for example, be made of one or more metals such as aluminum, copper, titanium, molybdenum, silver, platinum, gold, nickel, tungsten, chromium, vanadium, ruthenium, iron, palladium, kovar, and manganese and mixtures, oxides and nitrides thereof, such as, for example, nichrome (NiCr) or silver (Ag) wire. The heater wire 140 is mechanically retained on the sidewall surface 112, which may be accomplished using any mechanical means of retaining the heater wire 140, including by setting the heater wire 140 in a groove, or by using suitable adhesives, an encapsulating film, clips or other mechanical retention techniques. The heater wire 140 may, for example, be set in a groove 150 that is inscribed in the ceramic structural element 110 close to the top of the ceramic structural element 110, such as about 8 mm from the top of the ceramic structural element 110. In some versions, the wire 140 can be brought closer to the top of the ceramic structural element 110 to improve the heater zone. The wire 140 can extend over only a portion of the sidewall surface 112, or around the entire circumference of the sidewall surface 112. The thermal expansion of the wire and of the ceramic structural element, when heated, can be matched as closely as possible. In one example, the groove 150 may be filled with a suitable material, such as Ceramabond™ 569, sold by Aremco Products, Inc. of Valley Cottage, NY, U.S.A., which is an example of a temperature stable ceramic cement that has the same temperature expansion as alumina, and which therefore can cause minimal wear and cracking when the ceramic structural element 110 is made of alumina. It will be appreciated that other materials could be used. Example 1, below, illustrates calculation of the wire size needed to achieve a temperature of about 650 °C (for example), under certain assumptions, and also illustrates a calculation of the expansion of the wire and the ceramic structural element.

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[0032] In other versions, the sidewall heater element 140 can be made of multiple loops of wire, one continuous loop of wire, or a wire coil 240 that is wrapped around the perimeter of the ceramic structural element 210 (shown here from the bottom, with back side heater 220), as shown in the version of FIG. 2.

[0033] A potential drawback of using a heater element in communication with a heated substrate is that a poor match of the thermal expansion coefficient (CTE) of the heater material and the substrate can lead to a loss of mechanical contact and to gaps in heat transport from the heater to the substrate. In accordance with a version of the invention, such drawbacks can be addressed by depositing a film, for example using thin film technologies, that serves as a sidewall heater element, as will be illustrated below relative to FIG. 3. Thin film technologies generally provide an intimate contact between the deposited film and the substrate. All methods known for thin film deposition (and other methods of applying a film, including thick film techniques) may lend themselves to application in versions of the invention, for example: sputter deposition, evaporation, Atomic Layer Deposition, Chemical Vapor Deposition, cathodic arc vaporization, laser ablation, pen writing, pad printing, screen printing, manual deposition with a pen or brush, and dipping.

[0034] FIG. 3 is a side view of an electrostatic chuck with a sidewall heater comprising a heater element film, in accordance with one version of the invention. The electrostatic chuck includes a heater element film 360, ceramic structural element 310, sidewall surface 312, back side heater 320 and a chucked wafer 330, and may include an encapsulating film 370. The heater element film 360 can be applied to the sidewall surface 312, having a film thickness in a range of less than about 100 μm , such as a film thickness is in a range of between about 1 μm and about 10 μm , or a film thickness of less than about 1 μm . The heater element film 360 can, for example, substantially or entirely encircle the circumference of the sidewall surface 312 of the electrostatic chuck, and can extend along the full height of the sidewall surface 312 or along only a portion of the height of the sidewall surface 312. Further, the heater element film 360 can vary in pattern, thickness, height and other geometric aspects, around different portions of the sidewall surface 312. Further, the heater element film 360 can extend over only a portion of the sidewall surface 312. The heater element film 360 can be made of one or more metals such as aluminum, copper, titanium, molybdenum, silver, platinum, gold, nickel, tungsten, chromium, vanadium, ruthenium, iron, palladium, kovar, and manganese and mixtures, oxides and nitrides thereof; in one example,

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the heater element film 360 is made of nichrome (NiCr). In some versions, the heater element film 360 can be encapsulated with encapsulating film 370, which is an electrically insulating and mechanically robust layer that includes one or more of a glass, alumina, a ceramic, a metal oxide, a transition metal oxide, a rare earth oxide, a metal nitride, a transition metal nitride, a rare earth nitride, a metal oxy-nitride, silicon oxide, silicon nitride, and silicon oxy-nitride.

[0035] The heater element film 360 of FIG. 3 may be applied, for example, by sputtering, Chemical Vapor Deposition (CVD), Physical Vapor Deposition (PVD), printing (*e.g.*, pad printing), pen writing, screen printing, plasma deposition followed by etch, plasma deposition followed by mechanical patterning, electro-deposition followed by patterning, laser deposition, electroplating, or Atomic Layer Deposition (ALD) followed by patterning. For example, sputtering or CVD deposition of the heater element film 360 can be accomplished by masking the area not to be covered, and depositing the heater element film. Alternatively, sputtering or CVD deposition of the heater element film 360 can be accomplished by material removal, by depositing the heater element film material, masking, followed by removal of unwanted material by chemical etching, bead blasting, or reactive plasma etching. Example techniques for achieving a heater element film 360 using sputter technology are outlined below in Example 2, in accordance with a version of the invention. Example 3, below, provides an example of a process to deposit a thin film, in particular a sputter process depositing NiCr, in accordance with a version of the invention. It will be appreciated that other types of films may be used.

[0036] In another version according to the invention, the heater element film 360 can be deposited using Atomic Layer Deposition (ALD), for example using any of the techniques and ALD-deposited films taught in PCT Application No. PCT/US2015/014810, entitled "Electrostatic Chuck and Method of Making Same" filed on February 6, 2015, the entire teachings of which application are incorporated herein by reference.

[0037] Another method of depositing a heater element film in accordance with a version of the invention is by pen writing. FIG. 4 is a schematic illustration of a fixture for pen writing a heater element film in accordance with one version of the invention. As shown in FIG. 4, in one aspect, a pen 480 writes the heater element film 460 on the sidewall surface 412. The ceramic structural element 410 is mounted on a rotatable fixture 482, at an angle such that the sidewall surface 412 is level to enable gravity feed of the pen 480. After the

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film is written with a conductive material mixed with a carrier material, the material is cured to remove a carrier material, leaving only the conductive material remaining. The conductive material should be matched in coefficient of thermal expansion to the ceramic structural element 410.

[0038] Yet another method of depositing a heater element film, in accordance with a version of the invention, is by pad printing. Techniques of pad printing may be used that are taught, for example, in U.S. Patent No. 7,116,547 B2 issued to Seitz *et al.*, on October 3, 2006. A pad printed film can be made, for example, of ruthenium oxide (RuO₂).

[0039] In accordance with a further version of the invention, a sidewall heater element can be embedded under at least a portion of the sidewall surface. FIGS. 5A and 5B are side and bottom views, respectively, of an electrostatic chuck that includes an embedded sidewall heater element, in accordance with a version of the invention. The electrostatic chuck includes a ceramic structural element 510, an embedded sidewall heater element 540, sidewall surface 512 and a back side heater 520. The embedded sidewall heater element 540 may, for example, take the form of a wire, similar to heater wire 140 of FIGS. 1A and 1B; or of the heater wires 240 of FIG. 2; or of an embedded film similar to heater element film 360 of FIG. 3; or of other heater elements taught herein; with the difference that the embedded heater element 540 is embedded under the sidewall surface 512. By embedding the sidewall heater element 540, a greater thermal contact between the heater element 540 and the ceramic structural element 510 may be achieved.

[0040] In accordance with another version of the invention, a sidewall heater element is used in combination with a back side heater. Such a version may combine the advantage of the excellent temperature uniformity in the center of the electrostatic chuck, which is attainable by using the back side heater, with the advantages of providing heating that reaches the edge of the electrostatic chuck that is provided by the sidewall heater element. For example, in the version of FIGS. 5A and 5B, an embedded sidewall heater element 540 can be used in combination with a back side heater 520. It will be appreciated that other side wall heater elements taught herein can be combined with back side heaters taught herein.

[0041] FIG. 6 is a schematic diagram of an electrostatic chuck that includes a heater control circuit 690, in accordance with a version of the invention. The electrostatic chuck includes heater control circuit 690, a plurality of sidewall heater elements 640a, 640b, 640c, a plurality of back side heaters 620a, 620b, 620c, at least one temperature sensor 691a with

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sensor electrical connection 691b, a ceramic structural element 610, electrical connections 692a, 693a for side wall heater zones 692b, 693b, electrical connections 694a, 695a for back side heater zones 694b, 695b and electrical connection 696a for common heater zone 696b. Although two side wall heater zones 692b, 693b are shown, two back side heater zones 694b, 695b, and one common heater zone 696b, it will be appreciated that different numbers of heater zones for each may be used, as discussed further below, including only one side wall heater zone, more than one side wall heater zones, one back side heater zone and/or more than one back side heater zones.

[0042] In the version of FIG. 6, the heater control circuit 690 can be used to achieve optimal (or at least improved) performance for the electrostatic chuck. This can, for example, involve reaching a temperature profile on the electrostatic chuck that achieves multiple, sometimes competing performance goals. One possible performance goal is to achieve a temperature that is as uniform as possible across the entire electrostatic chuck. Another possible performance goal is to have a certain minimum temperature at any point on the electrostatic chuck. A competing possible performance goal is to minimize temperature gradient-induced stress within the electrostatic chuck to avoid breakage. As an example of the way in which performance goals can compete, the temperature drop at the edge of the electrostatic chuck can be improved by adding a second zone at the edge of the bottom heater and operating that heater at a higher power density. However, doing so also leads to higher hoop stress in the electrostatic chuck. It will be appreciated that possible performance goals in versions of the invention are not limited to the foregoing; and that one or more possible performance goals discussed herein, and other performance goals, may be performance goals that are met or may be goals relative to which performance is improved, in accordance with versions of the invention.

[0043] In one version according to the invention, a desired optimized performance can be achieved by designing the heater pattern such that the power density varies at different sections of the electrostatic chuck to compensate for different effective heat losses in different areas. This can be used with a single heater control circuit 690 having a single heating zone for all heaters on the electrostatic chuck. In this case, a common electrical connection 696a could be used to connect from the heater control circuit 690 to all heaters on the electrostatic chuck, which could include only a single side wall heater element (such as

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540 of FIGS. 5A-5B) and a single back side heater 520, or more than one of the side wall heater and/or the back side heater.

[0044] In another version according to the invention, multiple heater zones are used, which can, for example, be controlled such that the power density variation is adjusted based on temperature and boundary conditions. In particular, options include: a) having one or more back side heater zones 694b, 695b and one or more side wall heater zones 692b, 693b; b) having one or more back side heater zones 694b, 695b and/or one or more side wall heater zones 692b, 693b, in addition to using one or more common heater zones 696b that are partly on the side wall and partly on the back side of the electrostatic chuck. One or more temperature sensors 691a, with one or more corresponding sensor electrical connections 691b, can be used to provide thermal data for the control. In one example, one temperature sensor 691a with one corresponding sensor electrical connection 691b can be used for each heater zone. It will be appreciated that other arrangements of temperature sensors 691a can be used.

[0045] In one version according to the invention, a single heater zone can have different areas of the sidewall heater element (such as 540 of FIGS. 5A-5B) featuring power densities that are designed to provide optimal performance in a specific desired temperature range. In accordance with one version of the invention, optimal performance can mean an application-specific optimum of internal stress versus desired temperature profile.

[0046] In accordance with another version of the invention, multiple heater zones (such as zones 692b-696b of FIG. 6) can be strategically designed to optimize performance at a wider temperature range or in the presence of a variety of changing boundary conditions. In particular, for example, two heater zones can be used, where the bottom heater is designed to create a uniform temperature profile in the center region of the electrostatic chuck, and a second heater zone, which can be partly or entirely on the sidewall, is used to optimize the performance at different temperatures or under different boundary conditions.

[0047] In addition, in versions according to the invention, the side wall heater does not necessarily have to be uniform in its power density, but can be designed to vary in power density to optimize performance, for example by being of varying geometry over the sidewall surface of the electrostatic chuck. This can be done with both single zone and multi-zone sidewall heater designs.

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[0048] In accordance with a version of the invention, the heater control circuit 690 can receive thermal data, such as temperature data, from one or more sensors 691a via sensor electrical connection 691b, and, based on the thermal data, can control operation of one or more of the heater zones 692b-696b, for example to adjust power density variation based on temperature and boundary conditions, or to achieve other thermal performance goals. By applying appropriate voltages to the heater zones 692b-696b, the heater control circuit 690 can control the power delivered through the side wall heater elements 640a-640c and back side heaters 620a-620c. The heater control circuit 690 may, for example, include one or more microprocessors specially programmed to perform such control of the operation of the heater zones.

[0049] It will be appreciated that, although versions of the invention are discussed herein as being able to optimize performance relative various thermal performance goals, they may also merely improve performance relative to one or more of such thermal performance goals.

[0050] FIGS. 7A is a schematic side view of an electrostatic chuck that includes a passive reflective heat shield, in accordance with the prior art; and FIG. 7B is a schematic side view of an electrostatic chuck that includes a heated reflective heat shield, in accordance with a version of the invention. Radiation loss is the primary source of heat loss of a heated chuck in vacuum. One concept of retaining the heat at the side wall of an electrostatic chuck, in accordance with the prior art, is to surround the edge of the heated electrostatic chuck with a heat shield 742 (see FIG. 7A) that radiates most of the infrared light emitted from the edge of the chuck back to the edge. The heat radiated out from the chuck is indicted in FIGS. 7A and 7B by darker shaded arrows 744 pointing away from the chuck. A very well designed and executed heat shield, in accordance with the prior art, can work very well, but not perfectly. The reflectivity is always less than one hundred percent, so that the heat shield 742 will never reflect all of the heat lost at the edge. This is shown in FIG. 7A by lighter shaded arrows 745 pointing towards the chuck, depicting reflected infrared radiation. In addition, some fraction of the reflected infrared radiation will be lost, either by the infrared light missing the heat shield altogether, or by reflected rays not reflecting to the edge.

[0051] In accordance with one version of the invention, one possibility to compensate for lost infrared radiation is to actively heat the radiation shield, as shown in FIG. 7B, which includes at least one heat shield 746 spaced apart from the sidewall surface 712 of the electrostatic chuck. The heat shield 746 includes a heat shield radiative surface 747 that is

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arranged to provide radiation heat to at least a portion of the sidewall surface 712, and a shield heater element 748 that is configured to actively heat the heat shield radiative surface 747. Heat radiated out of the chuck, and out of the heat shield 746, is indicated by darker shaded arrows 744, whereas lost infrared radiation is indicated by lighter shaded arrows 745. An actively heated shield 746 would, in addition to providing reflectance, also provide net radiation energy to the edge of the electrostatic chuck if the heat shield is heated to an appropriate temperature. Because the heat shield 746 is actively heated, its primary function does not have to be that of a reflective heat shield. Almost any heated ring-like structure placed around the chuck edge can be used as a heat shield 746. Although the shield heater element 748 in FIG. 7B is drawn on the radially outer side of the heat shield 746 relative to the center of the electrostatic chuck, it will be appreciated that the shield heater element 748 can also be located on the radially inner side of the heat shield 746. The electrostatic chuck of FIG. 7B can further include a back side heater 720, which can be used in combination with the heat shield 746.

[0052] FIG. 8 is a schematic diagram of an electrostatic chuck that uses electrodes that perform a double function of acting as both clamping electrodes and heater elements, in accordance with a version of the invention. One of the reasons that a heater circuit is not deposited at or near the front surface of an electrostatic chuck, in accordance with the prior art, is that there would be an electrical interaction between the electrostatic clamp electrodes and the heater elements. Thus, in the prior art, the heater elements are placed on the back side of the electrostatic chuck. By contrast, in accordance with the version of FIG. 8, the electrodes, which are near the front surface of the electrostatic chuck, serve the double function of acting as both clamping electrodes and heater elements. There may be, for example, six electrically conductive elements 840a-840f that serve as both electrodes and heater elements, although it will be appreciated that different numbers and arrangements of electrode/heater elements 840a-840f may be used. The electrode/heater elements 840a-840f may be implemented, for example, as heater traces using any of the materials and deposition techniques taught above for use as heater element films.

[0053] In accordance with the version of FIG. 8, the circuit to power the electrode/heater elements 840a-840f uses separate sets of one or more power sources, which work independently from each other, for the heating function and the electrostatic clamping function. One of the possible circuits is shown in FIG. 8. Here, the six electrode/heater

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elements 840a-840f are powered by six independent direct current (DC) heater power supplies 897a-897f that are floating. Each of power supplies 897a-897f powers one of six phases, indicated as A+, A-, B+, B-, C+ and C-. These phases are driven by the three-phase alternating current (AC) clamp power supply 898, which includes three AC power supplies A, B and C that have a 120-degree phase angle relative to each other. The DC power supplies 897a-897f provide power for the use of the electrode/heater elements 840a-840f as heaters, whereas the AC power supplies A, B and C of power supply 898 provide power for the use of electrode/heater elements 840a-840f as clamping electrodes. The heater power supplies 897a-897f and the clamping power supplies 898 can be operated simultaneously to provide simultaneous heating and clamping. The electrostatic chuck includes a surface layer 814 that is activated by a voltage in the electrode/heater elements 840a-840f to form an electric charge to electrostatically clamp a substrate to the electrostatic chuck; and that is also heated by the same electrode/heater elements 840a-840f. The electrode/heater elements 840a-840f can, for example, provide a maximum heating power of between about 100 W and about 2000 W.

[0054] Generally, sidewall heater elements in versions according to the invention, taught herein, can provide a maximum heating power of 100 W to 2000 W, for example for an implant chuck that operates in the 600 °C temperature range, although a broad range of temperatures can be achieved. For example, workpiece temperature control can be achieved, in versions according to the invention, at temperatures in a range of between about 400 °C and about 1000 °C. In addition, back side heater elements can provide a further heating power of up to 1000 W or even up to 2000 W, in addition to the heating power provided by the sidewall heater element. Example 4, below, provides a consideration of heater design criteria from the point of view of electrical requirements, in accordance with a version of the invention.

[0055] In accordance with versions of the invention, heater elements taught herein can be used with a wide variety of different possible types of chucks, for example vacuum chucks, gravity chucks and electrostatic chucks. Further, the chucks can be used in a variety of different possible processes, including both implant processes and processes other than implant, such as etch processes.

[0056] Versions of the invention have been taught herein in which the electrostatic chuck includes a chamfered edge. Such a chamfer is used in some cases, for example for an

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electrostatic chuck used in an ion implanter, so that the side of the electrostatic chuck is not hit by the ion implant beam. For a cylindrical chuck (*i.e.*, an electrostatic chuck with a substantially right-angled edge rather than a chamfered edge), the same heat-related problems are present as exist in a chamfered electrostatic chuck – such as having a lower temperature towards the edge of the electrostatic chuck – but to a lesser extent. Therefore, it will be appreciated that versions of the invention taught herein can be used equally in a cylindrical shaped electrostatic chuck as in a chamfered electrostatic chuck.

[0057] A set of examples in accordance with versions of the inventions follows.

[0058] Example 1:

[0059] *Determination of Wire Radius*

[0060] In one aspect, the diameter of the ceramic structural element 110 (see FIG. 1A) at the top is about 298 mm. For a chamfer angle of 45 degrees, if the groove 150 is 8 mm from the top of the ceramic structural element 110, then the diameter of the groove 150 is about 290 mm, and the resulting length of the loop of wire 140 is about 911.1 mm. The wire sizes (wire radius or gauge) needed to achieve a temperature of about 650 °C for a resistance in a range of between about 5 Ω and about 25 Ω for NiCr wire are listed in Table 1. The wire radius r_w is calculated using the formula:

$$r_w = \sqrt{\frac{\rho \cdot l}{\pi \cdot R}} \quad (1)$$

[0061] where ρ is the electrical resistivity of the wire material, typically measured in Ohm meters (Ω m), R is the electrical resistance of the wire, typically measured in Ohms (Ω), and l is the length of the wire, typically measured in meters (m).

[0062] **Table 1. Wire Radius for several wire resistance values**

r_w (m)	R (Ω)	Mat. (Ω m)	Φ (in)	Awg	I (A) 649 °C
2.4×10^{-4}	5	NiCr 1.0×10^{-6}	0.0189	25 (0.0179), 24 (0.020)	4.15, 4.86
3.0×10^{-4}	5	NiCr 1.5×10^{-6}	0.0236	23 (0.0226)	5.65
1.7×10^{-4}	10	NiCr	0.0134	27 (0.0126)	

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		1.0×10^{-6}			
2.1×10^{-4}	10	NiCr 1.5×10^{-6}	0.0165	26 (0.0159)	
1.1×10^{-4}	25	NiCr 1.0×10^{-6}	0.0087		
1.3×10^{-4}	25	NiCr 1.5×10^{-6}	0.0102	30 (0.010)	2.06

[0063] *Wire Expansion from 25 °C to 650 °C*

[0064] The expansion of the wire from 25 °C to 650 °C can be calculated using the formula:

$$l = l_0 \cdot (1 + \alpha \Delta T) = 0.9111m \cdot \left(1 + 14 \cdot 10^{-6} \frac{1}{^\circ C} \cdot 625^\circ C\right) = 0.9191m \quad (2)$$

[0065] where l_0 is the initial wire length, typically measured in meters (m), α is the wire coefficient of thermal expansion per °C, and ΔT is the temperature change in °C.

[0066] By comparison, for the alumina ceramic structural element, $\alpha = 8.1 \times 10^{-6} 1/^\circ C$ from 25°C to 600 °C, and therefore $l = 0.9153$ m. In one aspect, the depth of the groove can be about 1.2 mm. With the example dimensions used above, the heated zone would increase by about 2.8 mm in radius.

[0067] Example 2

[0068] One way to achieve a sidewall heater element using sputter technology is outlined below, in accordance with a version of the invention:

1. Create a negative mask on the substrate that covers the areas that are not to be coated.

This mask can be, in its simplest form, a pattern that is applied to the substrate with tape. Another example would be a pattern that is transferred from a photo mask to the substrate through exposing photosensitive materials to the mask and removing the unwanted areas.

2. Apply the coating on all areas, masked and unmasked.
3. Remove the mask and lift off the unwanted areas off the substrate.

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[0069] An alternative way to achieve a sidewall heater element using sputter technology, in accordance with a version of the invention, is a process in which the entire substrate is covered with the heater material and a mask is applied to protect the areas of deposited film that form the heater circuit. The protective mask can be made in a similar fashion as outlined above. It will be apparent to those of skill in the art that a variety of different methods, techniques and patterns can be used to create the masks.

[0070] Example 3

[0071] As an example of a process to deposit a thin film, in accordance with a version of the invention, a sputter process depositing NiCr will be outlined here. Other than NiCr, many other materials would be suitable. A sputtered NiCr film can be created in a system that has the following features:

1. Able to create a low pressure atmosphere around the work piece, preferably in the 10^{-6} Torr range, with lower pressures being of advantage.
2. Able to mount one or more pieces of the material that is to be deposited in the chamber that is able to be electrically at a potential in respect to the chamber ("Target"). In its simplest form a piece of NiCr of the desired composition is mounted on an insulating plate connected to an appropriate power supply. Alternatively, one piece of Nickel and one piece of Chromium can be used, with independent power supplies.
3. Ability to backfill the chamber with a suitable gas to create a plasma around the target.
The gas is typically Argon, but other noble gases, and combinations of noble and reactive gases, may be used.

[0072] A typical deposition process for deposition of a sputtered NiCr film, in accordance with a version of the invention, has the following work flow:

1. Load substrate into the chamber.
2. Close and evacuate the chamber to remove ambient air and contamination associated with it. The lower the pressure the better; typical pressures are 10^{-6} Torr.
3. Backfill with appropriate gas. Typically high purity Argon is used, and the backfill pressure is typically 2 – 10 mTorr.
4. Ignite a plasma around the target that causes positive charged ions of the gas to be

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accelerated towards the target. This can be accomplished by putting a negative voltage of a few hundred volt at the target.

5. The accelerated ion will hit the target and the momentum transfer from the impact will dislocate parts of the target material from the surface.
6. These dislocated materials are mobile in the chamber and some of them will land on the substrate to be coated.
7. At a sufficiently long time the substrate will be covered by a more or less continuous film.
8. Once the desired film parameters are reached the system can be vented and the coated substrate removed.

[0073] Example 4

[0074] *Heater Design Criteria Relative to Electrical Requirements*

[0075] In accordance with a version of the invention, the sidewall heater design has a maximum power requirement of 100 W to 2000 W for an implant chuck that would operate in the 600 degree C range. Typical power supply voltages would be in the range of 110 V to 240 V, with operation of as low as 12 V and as high as 600 V being feasible. Lower voltages would be prohibitive due to the high current necessary to supply enough power in most situations; higher than 600 V could potentially pose a problem with safety, since many insulators start to break down at that voltage, especially if operated at high temperatures. With the parameters given here the heater design criteria can be estimated.

[0076] From the basic power relation between power, current, voltage and resistance the following relation can be derived:

$$P = V \cdot I; I = V/R; \rightarrow P = V^2/R; \rightarrow R = V^2/P;$$

[0077] This leads to the following design limits:

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	P=100 W	P=2000 W
<i>R</i> at <i>V</i> =24 V (Ω)	5.8	0.3
<i>R</i> at <i>V</i> =115 V (Ω)	132.3	6.6
<i>R</i> at <i>V</i> =240 V (Ω)	576.0	28.8
<i>I</i> at <i>V</i> =24 V (A)	4.2	83.3
<i>I</i> at <i>V</i> =115 V (A)	0.9	17.4
<i>I</i> at <i>V</i> =240 V (A)	0.4	8.3

[0078] Table 2: Parameter range of heater resistance and expected current.

[0079] From this design table it is evident that a convenient choice for heaters would be 24 V or 115 V operation for the lower power range, with heater resistances ranging from 5 to 130 Ω, for high power ratings a range from 5 to 30 Ω would be reasonable. The heater then has to be designed to achieve this resistance by designing the heater with the appropriate thickness, as well as the right square count of the heater trace. (A square count is a simple way to design heater or resistive circuits by designing the circuit using “squares” of circuit elements that have a sheet resistivity measured in Ohm/square. Two squares designed in line with each other have a resistance of 2x the sheet resistivity in Ohm, two in parallel have half the sheet resistivity). It should also be taken into consideration that the resistance of the heater increases with temperature, so the design has to ensure that the heater has a low enough resistance at operating temperature to draw sufficient power.

[0080] Below outlined is a hypothetical heater design layout with a sputtered NiCr film.

[0081] The resistivity of NiCr is in the range of $\rho_{\text{NiCr}} = 1 \dots 1.5 \cdot 10^{-6} \Omega\text{m}$. The relationship between the resistance *R*, the length of the resistor trace *l*, the film thickness *h*, and the resistivity ρ is shown in Equation 1. The ratio *l*/*w* is defined as one square, symbolized by the box in the equation.

$$R = \rho_{\text{NiCr}} \cdot \frac{l}{A} = \rho_{\text{NiCr}} \cdot \frac{l}{w \cdot h} = \rho_{\text{NiCr}} \cdot \frac{\square}{h}; \rightarrow \square = \frac{R \cdot h}{\rho} \quad (1)$$

[0082] With Equation 1 an estimate of a reasonable upper and lower limit of squares can be made. The low limit would be based on a low resistant heater and the low thickness, the high limit would be based on the large resistance and the thick layer.

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$$\square = \frac{R \cdot h}{\rho} = \frac{5 \Omega \cdot 0.5 \mu\text{m}}{1 \cdot 10^{-6} \Omega\text{m}} = 2.5 \square$$

$$\square = \frac{R \cdot h}{\rho} = \frac{30 \Omega \cdot 5 \mu\text{m}}{1 \cdot 10^{-6} \Omega\text{m}} = 150 \square$$

[0083] The total length of the heater is approximately the circumference of the chuck

$$C = 2 \cdot \pi \cdot r = 2 \cdot \pi \cdot 150 \text{ mm} = 943 \text{ mm}$$

[0084] The thickness of the insulator is 0.3", at an angle of 45 degrees the largest possible width for a uniform heater strip is 10.8 mm. Leaving some space on the top and the bottom a 10 mm wide resistor strip with a length of 940 mm would lead to a designed number of squares of 94. Assuming we need 1000 W heater power and 115 V operation the resistance should be 13.2 Ω . The required film thickness can then be calculated from Equation 1 to

$$h = \frac{\square \cdot \rho}{R} = \frac{94 \cdot 1 \times 10^{-6} \Omega\text{m}}{13.2 \Omega} = 7.5 \mu\text{m}$$

[0085] This film thickness is feasible. 240 V operation may be preferable, utilizing a resistance of about 58 Ω . The film thickness then would be

$$h = \frac{\square \cdot \rho}{R} = \frac{94 \cdot 1 \times 10^{-6} \Omega\text{m}}{58 \Omega} = 1.6 \mu\text{m}$$

[0086] In summary, a NiCr film that forms a band of 10 mm width around the sidewall with a thickness of 1.6 micrometer would be an appropriate sidewall heater, in accordance with a version of the invention.

[0087] Although the invention has been shown and described with respect to one or more implementations, equivalent alterations and modifications will occur to others skilled in the art based upon a reading and understanding of this specification and the annexed drawings. The invention includes all such modifications and alterations and is limited only by the scope of the following claims. In addition, while a particular feature or aspect of the invention may have been disclosed with respect to only one of several implementations, such feature or aspect may be combined with one or more other features or aspects of the other implementations as may be desired and advantageous for any given or particular application. Furthermore, to the extent that the terms "includes", "having", "has", "with", or variants thereof are used in either the detailed description or the claims, such terms are intended to be inclusive in a manner similar to the term "comprising." Also, the term "exemplary" is merely

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meant to mean an example, rather than the best. It is also to be appreciated that features and/or elements depicted herein are illustrated with particular dimensions and/or orientations relative to one another for purposes of simplicity and ease of understanding, and that the actual dimensions and/or orientations may differ substantially from that illustrated herein.

[0088] Although the present invention has been described in considerable detail with reference to certain versions thereof, other versions are possible. Therefore the spirit and scope of the appended claims should not be limited to the description and the versions contained within this specification.

[0089] The teachings of all patents, published applications and references cited herein are incorporated by reference in their entirety.

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CLAIMS

What is claimed is:

1. An electrostatic chuck comprising:
 - a ceramic structural element having a sidewall surface on an outer perimeter of the electrostatic chuck; and
 - at least one sidewall heater element disposed on or within at least a portion of the sidewall surface.
2. The electrostatic chuck according to Claim 1, wherein the at least one sidewall heater element is disposed on the at least a portion of the sidewall surface.
3. The electrostatic chuck according to Claim 1, wherein the at least one sidewall heater element is embedded under the at least a portion of the sidewall surface.
4. The electrostatic chuck according to any one of Claims 1 to 3, further comprising a back side heater element disposed on an opposite side of the electrostatic chuck from a clamping surface of the electrostatic chuck.
5. The electrostatic chuck of Claim 1, wherein the at least one sidewall heater element comprises a heater wire.
6. The electrostatic chuck of Claim 5, wherein the heater wire is mechanically retained on the at least a portion of the sidewall surface.
7. The electrostatic chuck of Claim 6, wherein the heater wire is located in a groove on the at least a portion of the sidewall surface.
8. The electrostatic chuck of Claim 5, wherein the heater wire is embedded under the at least a portion of the sidewall surface.

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9. The electrostatic chuck of Claim 5, wherein the heater wire comprises at least one metal selected from the group consisting of aluminum, copper, titanium, molybdenum, silver, platinum, gold, nickel, tungsten, chromium, vanadium, ruthenium, iron, palladium, kovar, and manganese and mixtures, oxides and nitrides thereof.
10. The electrostatic chuck of Claim 9, wherein the heater wire comprises at least one of a nichrome (NiCr) heater wire and a silver (Ag) heater wire.
11. The electrostatic chuck of Claim 1, wherein the at least one sidewall heater element comprises a heater element film.
12. The electrostatic chuck of Claim 11, wherein the heater element film includes at least one metal selected from the group consisting of aluminum, copper, titanium, molybdenum, silver, platinum, gold, nickel, tungsten, chromium, vanadium, ruthenium, iron, palladium, kovar, and manganese and mixtures, oxides and nitrides thereof.
13. The electrostatic chuck of Claim 12, wherein the heater element film comprises a nichrome (NiCr) film.
14. The electrostatic chuck of Claim 11, wherein the heater element film has a film thickness of less than about 100 μm .
15. The electrostatic chuck of Claim 14, wherein the film thickness is in a range of between about 1 μm and about 10 μm .
16. The electrostatic chuck of Claim 14, wherein the film thickness is less than about 1 μm .

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17. The electrostatic chuck of Claim 11, wherein the heater element film is encapsulated with an electrically insulating and mechanically robust layer that includes one or more of a glass, alumina, a ceramic, a metal oxide, a transition metal oxide, a rare earth oxide, a metal nitride, a transition metal nitride, a rare earth nitride, a metal oxy-nitride, silicon oxide, silicon nitride, and silicon oxy-nitride.
18. The electrostatic chuck of Claim 1, wherein the ceramic structural element includes at least one of alumina (Al_2O_3), aluminum nitride and silicon nitride.
19. The electrostatic chuck of Claim 1, wherein the ceramic structural element is of a cylindrical shape.
20. The electrostatic chuck of Claim 1, wherein the ceramic structural element comprises a chamfered sidewall surface.
21. The electrostatic chuck of Claim 1, wherein the at least one sidewall heater element provides a maximum power of between about 100 W and about 2000 W.
22. The electrostatic chuck of Claim 1, further comprising a heater control circuit.
23. The electrostatic chuck of Claim 22, wherein the at least one sidewall heater element comprises a single sidewall heater zone, and wherein the heater control circuit is electrically connected to control operation of the single sidewall heater zone.
24. The electrostatic chuck of Claim 22, wherein the at least one sidewall heater element comprises a plurality of sidewall heater zones, and wherein the heater control circuit is electrically connected to control operation of each sidewall heater zone of the plurality of sidewall heater zones.
25. The electrostatic chuck of Claim 22, wherein the electrostatic chuck further comprises a back side heater element disposed on an opposite side of the electrostatic chuck from a clamping surface of the electrostatic chuck.

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26. The electrostatic chuck of Claim 25, wherein the heater control circuit is electrically connected to control operation of the at least one sidewall heater element and the back side heater element as a single heater zone of the electrostatic chuck.
27. The electrostatic chuck of Claim 25, wherein the at least one sidewall heater element comprises one or more sidewall heater zones, and wherein the back side heater element comprises one or more back side heater zones, and wherein the heater control circuit is electrically connected to control operation of each of the one or more sidewall heater zones and the one or more back side heater zones.
28. The electrostatic chuck of Claim 25, wherein the heater control circuit is electrically connected to control operation of at least a portion of the at least one sidewall heater element and of at least a portion of the back side heater element together as part of at least one common heater zone, and wherein at least one of the at least one sidewall heater element and the back side heater element comprises a further heater zone in addition to the at least one common heater zone.
29. The electrostatic chuck of Claim 1, wherein the sidewall heater element provides a varying power density of heating over the at least a portion of the sidewall surface.
30. An electrostatic chuck comprising:
 - a ceramic structural element having a sidewall surface; and
 - at least one side heat shield spaced apart from the sidewall surface and configured to provide radiation heat to at least a portion of the sidewall surface, the at least one side heat shield comprising (i) a heat shield radiative surface arranged to provide the radiation heat to the at least a portion of the sidewall surface, and (ii) a shield heater element configured to heat the heat shield radiative surface.
31. The electrostatic chuck according to Claim 30, further comprising a back side heater element disposed on an opposite side of the electrostatic chuck from a clamping surface of the electrostatic chuck.

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32. An electrostatic chuck comprising:
- at least one electrically conductive element; and
 - a surface layer activated by a voltage in the at least one electrically conductive element to form an electric charge to electrostatically clamp a substrate to the electrostatic chuck;
 - the surface layer being heated by the same at least one electrically conductive element by which the surface layer is activated to form the electric charge to electrostatically clamp the substrate.
33. The electrostatic chuck of Claim 32, wherein the at least one electrically conductive element provides a maximum heating power of between about 100 W and about 2000 W.
34. The electrostatic chuck of Claim 32, further comprising at least one clamp power supply to power the at least one electrically conductive element to produce the voltage by which the surface layer is activated to form the electric charge to electrostatically clamp the substrate;
- and further comprising at least one heater power supply to power the at least one electrically conductive element to heat the surface layer.
35. The electrostatic chuck of Claim 34, wherein the at least one clamp power supply comprises at least one alternating current power supply, and wherein the at least one heater power supply comprises at least one direct current power supply.

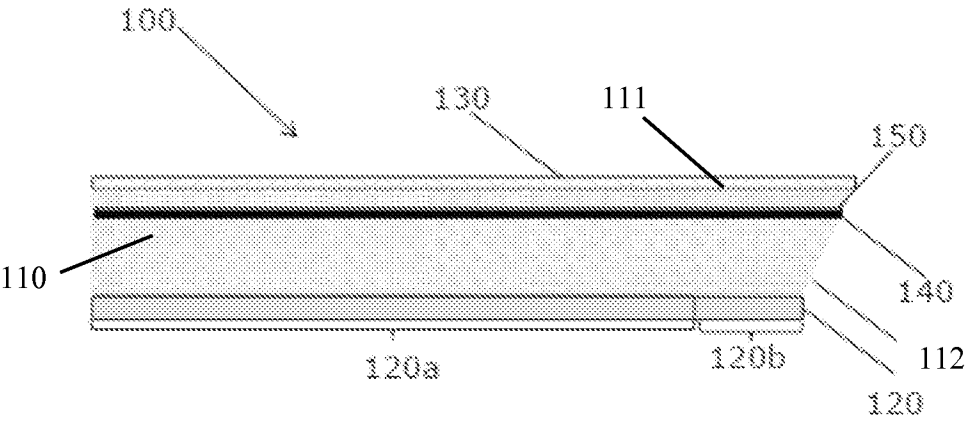


FIG. 1A

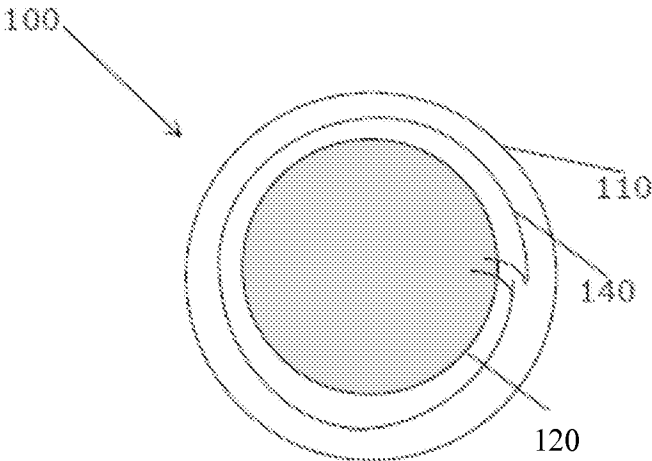
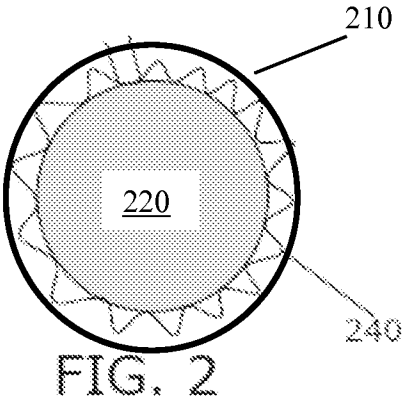


FIG. 1B



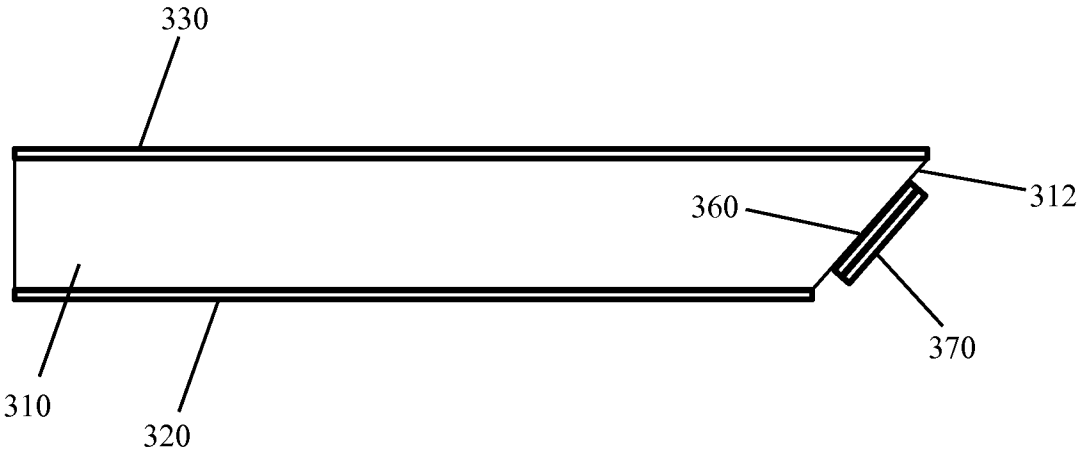


FIG. 3

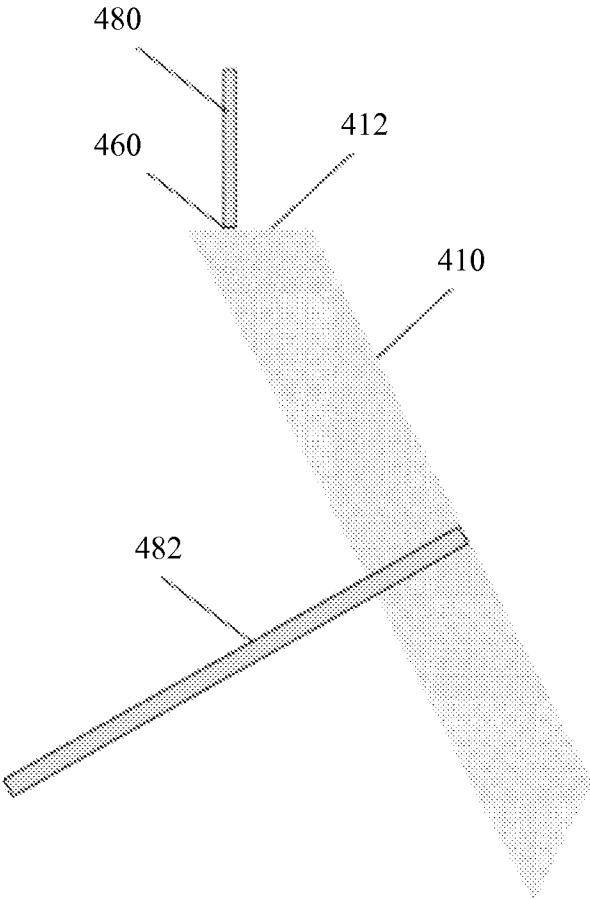


FIG. 4

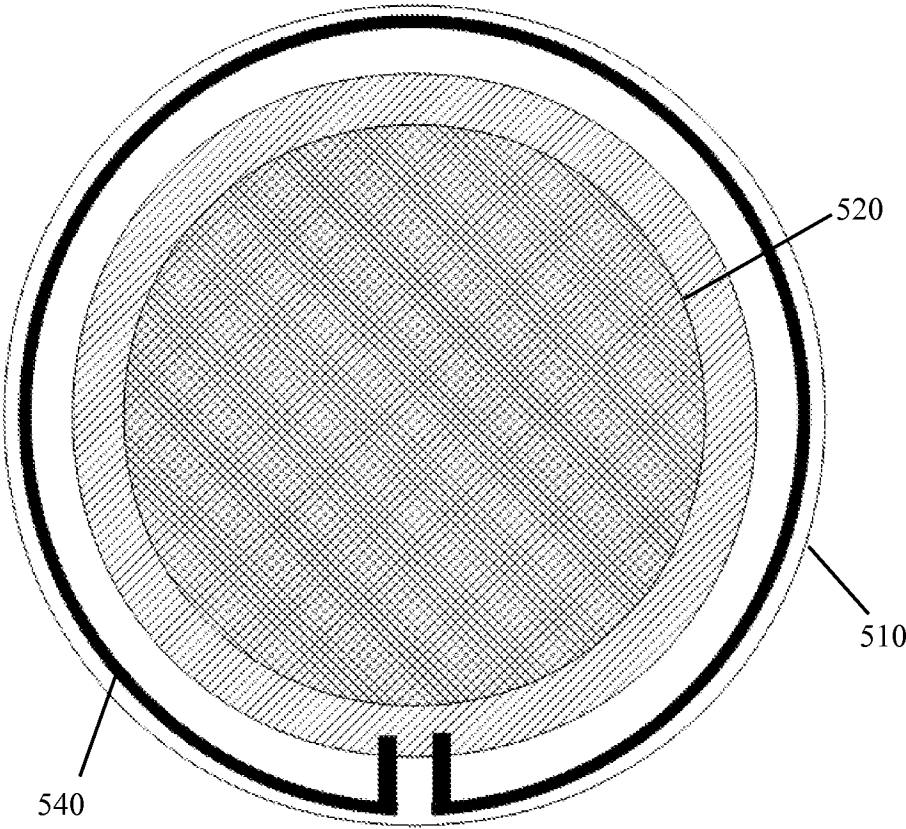
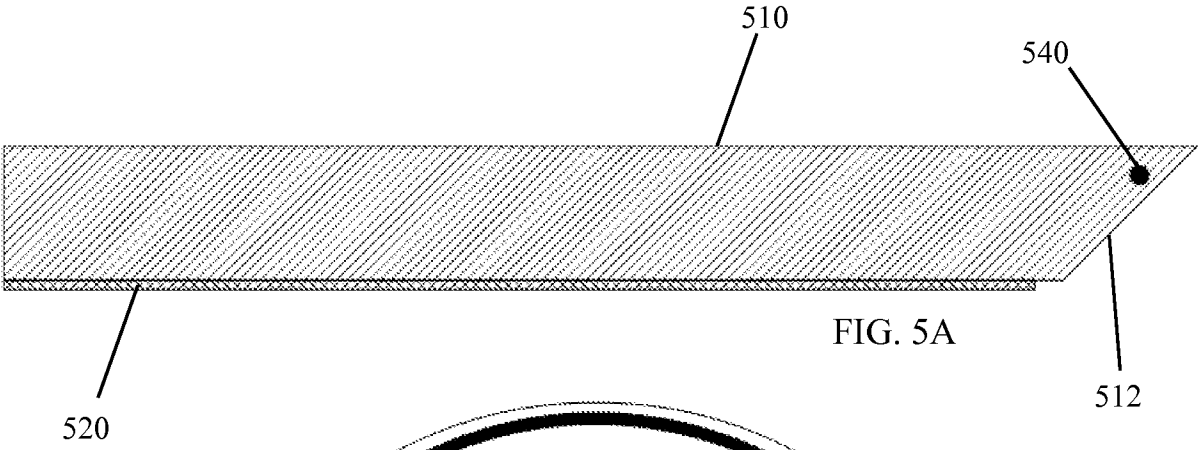


FIG. 5B

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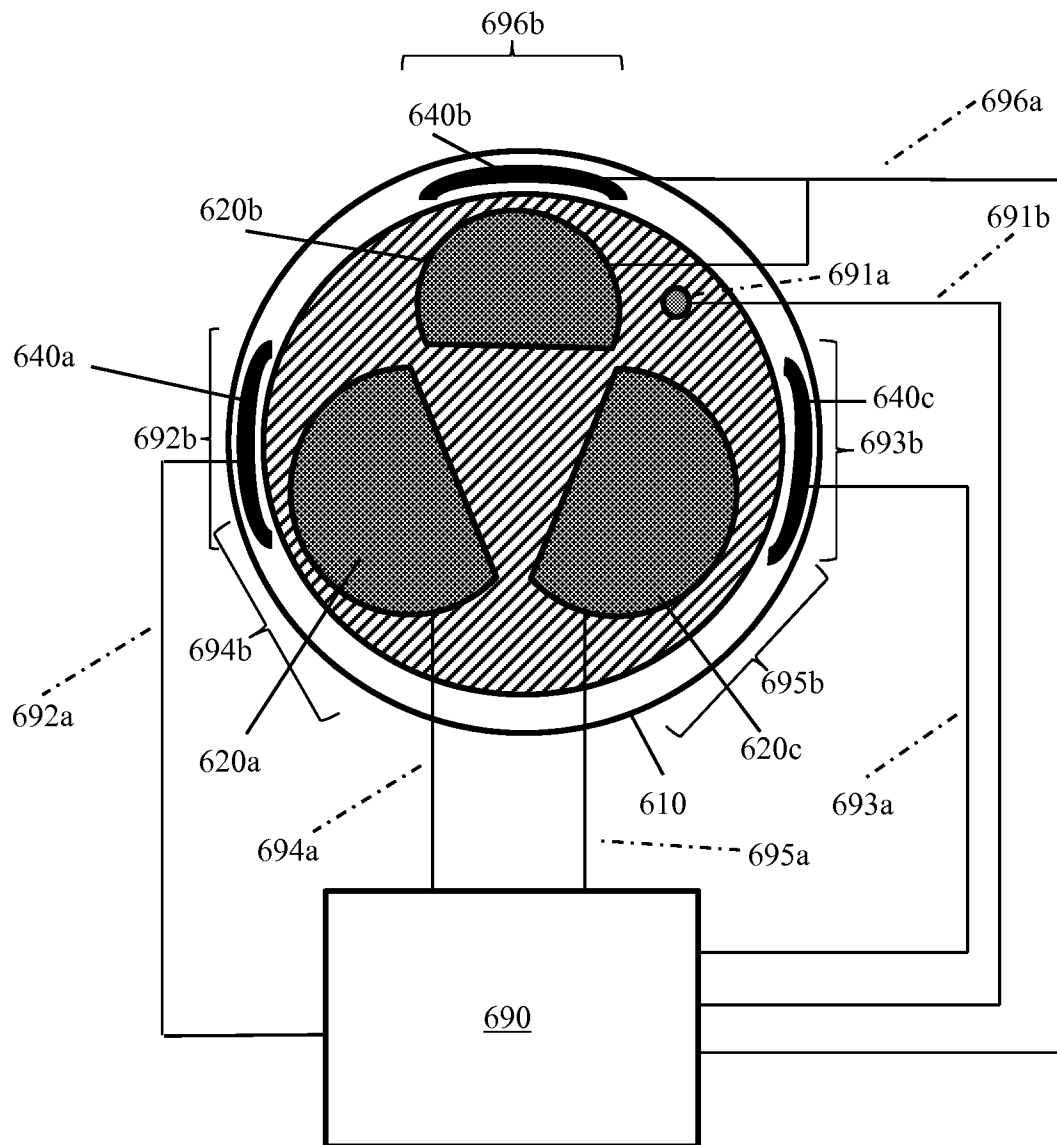
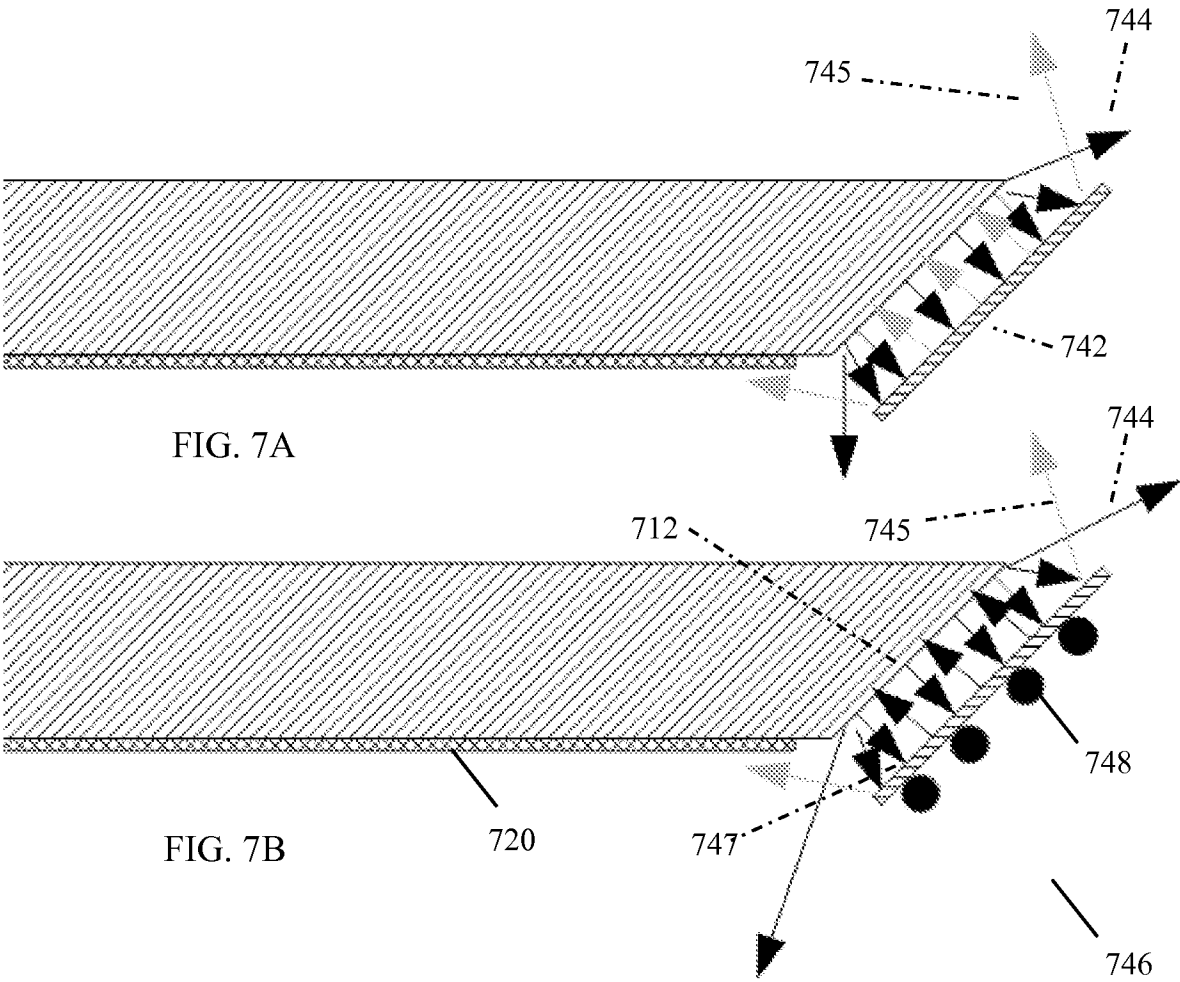


FIG. 6



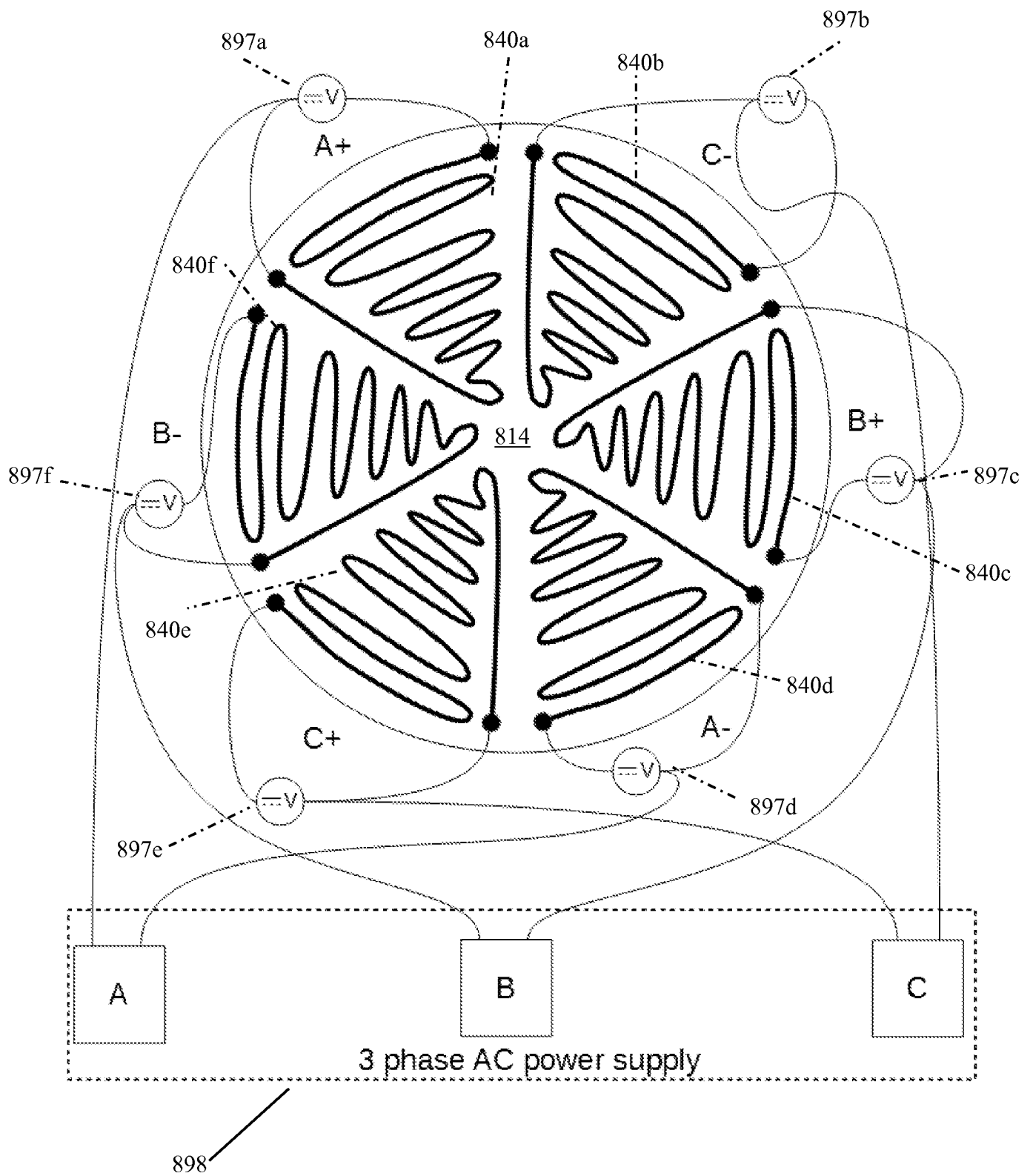


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/023877

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L21/67 H01L21/683
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	WO 2005/048341 A1 (GEN ELECTRIC [US]; OTAKA AKINOBU [JP]; YAMAZAKI KAZUYOSHI [JP]) 26 May 2005 (2005-05-26) page 7, line 15; figure 1 page 12, line 12 page 8, line 8 - page 9, line 4 -----	1,2,4, 11-21 30
X A	US 2012/031889 A1 (KOMATSU TOMOHITO [JP]) 9 February 2012 (2012-02-09) abstract; figures 1, 3A,3B -----	1,3-10, 22-29 30
X A	US 2007/258186 A1 (MATYUSHKIN ALEXANDER [US] ET AL) 8 November 2007 (2007-11-08) abstract; figure 1 ----- -/--	1,3-10, 22-29 30



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

17 September 2015

Date of mailing of the international search report

24/09/2015

Name and mailing address of the ISA/

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Authorized officer

Oberle, Thierry

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/023877

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/280453 A1 (KOELMEL BLAKE [US] ET AL) 13 November 2008 (2008-11-13)	30,31
A	abstract; figure 2 paragraphs [0056], [0060], [0084] -----	1
X	US 2007/209933 A1 (YOSHIOKA KEN [JP] ET AL) 13 September 2007 (2007-09-13) paragraphs [0024], [0031]; figure 1 -----	32-35

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/023877

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2015/023877

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2005048341	A1	26-05-2005	CN 1795551 A 28-06-2006
			DE 112004001044 T5 28-09-2006
			JP 4278046 B2 10-06-2009
			JP 2005142496 A 02-06-2005
			KR 20060097562 A 14-09-2006
			TW 200532842 A 01-10-2005
			US 2006098379 A1 11-05-2006
			WO 2005048341 A1 26-05-2005

US 2012031889	A1	09-02-2012	CN 102362332 A 22-02-2012
			JP 5239988 B2 17-07-2013
			JP 2010225941 A 07-10-2010
			KR 20110120349 A 03-11-2011
			US 2012031889 A1 09-02-2012
			WO 2010110169 A1 30-09-2010

US 2007258186	A1	08-11-2007	US 2007258186 A1 08-11-2007
			US 2012285619 A1 15-11-2012

US 2008280453	A1	13-11-2008	CN 101911281 A 08-12-2010
			KR 20100111298 A 14-10-2010
			TW 200943472 A 16-10-2009
			TW 201320236 A 16-05-2013
			TW 201320237 A 16-05-2013
			US 2008280453 A1 13-11-2008
			WO 2009094275 A2 30-07-2009

US 2007209933	A1	13-09-2007	JP 2007242913 A 20-09-2007
			US 2007209933 A1 13-09-2007

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-31

Electrostatic chuck comprising a heater element for heating the sidewall of the chuck

2. claims: 32-35

Electrostatic chuck using electrodes that perform a double function of acting as both clamping electrodes and heater elements
