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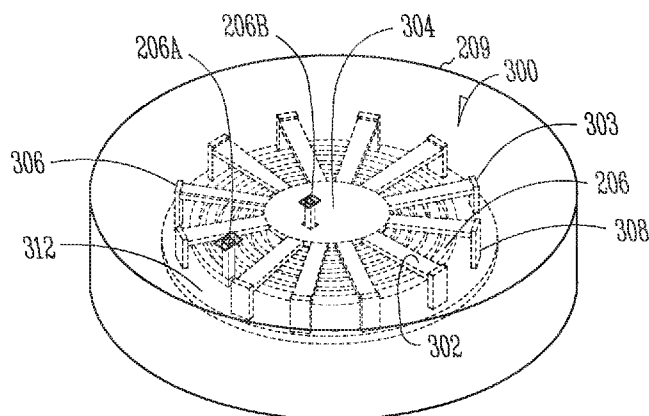
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(54) Title: MAGNETIC SHIELDING FOR PLASMA SOURCES

*Fig. 3A*

(57) **Abstract:** In some examples, a magnetic shield for a plasma source, the magnetic shield comprising a back-shell, the back-shell including an arrangement of elements of ferro-magnetic material, the back-shell sized and configured to extend at least over a portion of an RF source coil for the plasma source. In some examples, the back-shell includes a cage defined by one or more ferro-magnetic bars included in the arrangement of ferro-magnetic elements, the cage further including a plate of ferro-magnetic material, the plate defining or included in at least one wall of the cage, and wherein the plate is disposed opposite of and parallel to the arrangement of ferro-magnetic bars.



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MAGNETIC SHIELDING FOR PLASMA SOURCES

CLAIM OF PRIORITY

[0001] This application claims the benefit of priority to U.S. Patent Application No. 16/045,635, filed July 25, 2018, entitled “MAGNETIC SHIELDING FOR PLASMA SOURCES,” which is incorporated herein by reference in its entirety.

FIELD

[0002] The present disclosure relates generally to magnetic shielding for plasma sources which can be used, in one example, to reduce eddy current losses caused by plasma source enclosures.

BACKGROUND

[0003] Currently, in order to meet certain electro-magnetic compatibility and radio-frequency (RF) interference requirements in semi-conductor manufacturing, most if not all RF systems in etching, cleaning, and deposition tools are required to be enclosed in metallic enclosures. This requirement to deploy metallic enclosures can generally cause unwanted capacitive and/or inductive parasitic effects which can in turn affect the design of individual RF sub-systems and the overall RF system.

[0004] More particularly, in the case of plasma sources, the magnetic fields emanating out of the RF source coil produce circulating currents on the metallic enclosure which in turn produce heat and waste the otherwise useful power which ought to be delivered to the plasma for wafer processing purposes.

[0005] The present disclosure seeks to address, amongst other things, these drawbacks. It should be noted that the information described in this section is presented to provide the skilled artisan some context for the following disclosed subject matter and should not be considered as admitted prior art.

SUMMARY

[0006] In some examples, there is provided a magnetic shield for a plasma source, the magnetic shield comprising a back-shell (also termed a flux back-shell), the back-shell including a cage defined at least in part by an

arrangement of bars of ferro-magnetic material, the cage sized and configured to at least extend over a top side of an RF source coil for the plasma source.

[0007] In some examples, the arrangement of ferro-magnetic bars defines an open cage having an open side; and wherein a bottom side of the RF source coil, when in use, faces the open side. In some examples, the arrangement of ferro-magnetic bars defines a closed cage. The cage may include at least a plate of ferro-magnetic material, the plate defining or included in at least one wall of the cage, and wherein the plate is disposed opposite of and parallel to the arrangement of ferro-magnetic bars.

[0008] In some examples, the ferro-magnetic material includes one or more of a group of materials comprising: a nickel zinc (NiZn) ferrite, a magnesium zinc (MgZn) ferrite, a ferrite made of Nickel Magnesium (NiMg) alloy, a manganese zinc (MnZn) ferrite, a powdered-iron, and a combination thereof.

In some examples, the arrangement of ferro-magnetic bars defines at least a first wall of the cage, the arrangement including a first array of radially spaced bars extending between a first central region of the first wall of the cage and an outer dimension thereof. In some examples, the cage includes at least one wall having a circular shape. A circumference of the circular shape may be substantially equidistant from a circumference of an outer turn of the RF source coil. The first central region includes a central bar made of ferro-magnetic material. In another example, the arrangement of ferro-magnetic bars defines a second wall of the cage. The arrangement includes a second array of radially spaced bars extending between a second central region of the second wall and an outer dimension thereof, and wherein the first array is opposite of and parallel to the second array.

[0009] In some examples, the arrangement of ferro-magnetic bars includes an array of ferro-magnetic bars arranged orthogonally to each other, the orthogonal array of ferro-magnetic bar defining or included in at least one wall of the cage.

[0010] In some examples, a wafer processing chamber is provided. An example wafer processing chamber comprises an RF source coil for a chamber plasma source, and a magnetic shield comprising a back-shell, the back-shell comprising a cage defined at least in part by an arrangement of bars of ferro-

magnetic material, the cage sized and configured to at least partially enclose the RF source coil. The back-shell in the wafer processing chamber may have one or more of the back-shell elements summarized above.

[0011] In some examples, a method of magnetically shielding an RF source coil for a plasma source is described. A back-shell for the RF source coil is provided. The back-shell includes a cage defined, at least in part, by an arrangement of bars of ferro-magnetic material. The cage is sized and configured to at least extend over a top side of the RF source coil. The RF source coil is disposed in the cage.

[0012] In some examples, the arrangement of ferro-magnetic bars defines an open cage having an open side. The RF source coil is disposed in the cage such that a bottom side of the RF source coil faces the open side of the cage.

[0013] In some examples, the cage further includes at least a plate of ferro-magnetic material, the plate defining or included in at least one wall of the cage; wherein the plate is disposed opposite of and parallel to the arrangement of ferro-magnetic bars; and wherein having the RF source coil disposed in the cage further comprises having the RF source coil disposed between the plate and the arrangement of ferro-magnetic bars.

[0014] In some examples, there is provided a magnetic shield for a plasma source, the magnetic shield comprising: a back-shell, the back-shell including an arrangement of elements of ferro-magnetic material, the back-shell sized and configured to extend at least over a portion of an RF source coil for the plasma source.

[0015] In some examples, the arrangement of ferro-magnetic elements defines an open cage having an open side, and wherein a bottom side of the RF source coil, when in use, faces the open side.

[0016] In some examples, the arrangement of ferro-magnetic elements defines a closed cage.

[0017] In some examples, the back-shell includes a cage defined by one or more ferro-magnetic bars included in the arrangement of ferro-magnetic elements, the cage further including a plate of ferro-magnetic material, the plate defining or included in at least one wall of the cage, and wherein the plate is disposed opposite of and parallel to the arrangement of ferro-magnetic bars.

[0018] In some examples, the ferro-magnetic material includes one or more of a group of materials comprising: a nickel zinc (NiZn) ferrite, a magnesium zinc (MgZn) ferrite, a ferrite made of Nickel Magnesium (NiMg) alloy, a manganese zinc (MnZn) ferrite, a powdered-iron, and a combination thereof.

[0019] In some examples, the arrangement of ferro-magnetic elements defines a first wall of the cage, the arrangement including a first array of radially spaced bars extending between a first central region of the first wall and an outer dimension thereof.

[0020] In some examples, the first central region includes a central bar of ferro-magnetic material.

[0021] In some examples, the arrangement of ferro-magnetic elements defines a second wall of the cage, the arrangement including a second array of radially spaced bars extending between a second central region of the second wall and an outer dimension thereof, and wherein the first array is disposed opposite and parallel to the second array.

[0022] In some examples, the cage includes at least one wall having a circular shape.

[0023] In some examples, a circumference of the circular shape is substantially equidistant from a circumference of an outer periphery of the RF source coil.

[0024] In some examples, the arrangement of ferro-magnetic elements includes an array of ferro-magnetic bars arranged orthogonally to each other, the orthogonal array of ferro-magnetic bars defining or included in at least one wall of the cage.

[0025] In some examples, a wafer processing chamber includes an RF source coil and a magnetic shield as summarized above.

DESCRIPTION OF THE DRAWINGS

[0026] Some embodiments are illustrated by way of example and not limitation in the figures of the accompanying drawings:

[0027] **FIG. 1** is a schematic diagram of an example reaction chamber, within which methods and features of the present disclosure may be employed.

[0028] FIG. 2 is a schematic diagram of another example reaction chamber, within which methods and features of the present disclosure may be employed.

[0029] FIGS. 3A-3B are respective pictorial and side views of a magnetic shield, according to an example embodiment.

[0030] FIGS. 4A-4B are respective pictorial and side views of a magnetic shield, according to an example embodiment.

[0031] FIGS. 5A-5B are respective pictorial and side views of a magnetic shield, according to an example embodiment.

[0032] FIGS. 6A-6B are respective pictorial and side views of a magnetic shield, according to an example embodiment.

[0033] FIG. 7 is a graph illustrating comparative eddy current loss reduction percentages, as exhibited by various example embodiments.

[0034] FIG. 8 is flow chart for a method, according to an example embodiment.

[0035] FIG. 9 is a block diagram illustrating an example of a machine upon which one or more example method embodiments may be implemented, or by which one or more example embodiments may be controlled.

DESCRIPTION

[0036] The following description includes systems, methods, techniques, instruction sequences, and computing machine program products that embody illustrative embodiments of the present invention. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of example embodiments. It will be evident, however, to one skilled in the art, that the present disclosure may be practiced without these specific details.

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[0038] An example chamber in which some examples of the present disclosure may be employed, with appropriate chamber modifications for film deposition and control testing, is shown in **FIG.1** of the accompanying drawings. A typical plasma etching (or deposition) apparatus comprises a reactor in which there is a chamber through which reactive gas or gases flow. Within the chamber, the gases are ionized into a plasma, typically by radio frequency (RF) energy. The highly reactive ions of the plasma gas can react with certain materials, such as a polymer mask on a surface of a semi-conductor wafer being processed into integrated circuits (IC's).

[0039] Prior to etching, the wafer is placed in the chamber and held in proper position by a chuck or holder which exposes a top surface of the wafer to the plasma gas. There are several types of chucks known in the art. A chuck provides an isothermal surface and serves as a heat sink for the wafer. In one type, a semiconductor wafer is held in place for etching by mechanical clamping means. In another type of chuck, a semiconductor wafer is held in place by electrostatic force generated by an electric field between the chuck and wafer.

[0040] **FIG. 1** illustrates a representative capacitively-coupled plasma processing chamber 100, representing an exemplary plasma processing chamber of the types typically employed to etch a substrate. Appropriate modifications, as are known in the art, may be made for film deposition. A chuck 102 is a workpiece holder on which a substrate, such as a wafer 104, may be positioned during etching. The chuck 102 may be implemented by any suitable chucking technique, e.g., electrostatic, mechanical, clamping, vacuum, or the like. During etching, the chuck 102 is typically supplied with dual RF frequencies (a low frequency and a high frequency), for example, 2 MHz and 27 MHz, simultaneously by a dual frequency source 106.

[0041] An upper electrode 108 is located above the wafer 104. The upper electrode 108 is grounded. **FIG. 1** illustrates an etching reactor where the surface of the upper electrode 108 is larger than the surface of the chuck 102 and the wafer 104. During etching, plasma 110 is formed from etchant source gas supplied via a gas line 112 and pumped out through an exhaust line 114. An

electrical insulator ring 109 insulates the upper electrode 108 from the grounded processing chamber 100.

[0042] Confinement rings 116 may be placed between the upper electrode 108 and a bottom electrode, such as the chuck 102 in FIG. 1. In general, confinement rings 116 help confine the etching plasma 110 to the region above the wafer 104 to improve process control and to ensure repeatability.

[0043] When RF power is supplied to chuck 102 from RF power source 106, equipotential field lines are set up over wafer 104. The equipotential field lines are the electric field lines across the plasma sheath that is between wafer 104 and the plasma 110. During plasma processing, the positive ions accelerate across the equipotential field lines to impinge on the surface of wafer 104, thereby providing the desired etch effect, such as improving etch directionality. Due to the geometry of the upper electrode 108 and the chuck 102, the field lines may not be uniform across the wafer surface and may vary significantly at the edge of the wafer 104. Accordingly, a focus ring 118 may be provided to improve process uniformity across the entire wafer surface, especially along the wafer edge. With reference to FIG. 1, the wafer 104 is shown disposed within a focus ring 118, which may be formed of a suitable dielectric material such as ceramic, quartz, plastic, or the like. Thus, the presence of the focus ring 118 allows the equipotential field lines to be disposed substantially uniformly over the entire surface of the wafer 104.

[0044] An electrically conductive metallic enclosure or shield 120 substantially encircles the focus ring 118. The electrically conductive shield 120 is configured to be substantially grounded within the plasma processing chamber 100. The shield 120 prevents the presence of unwanted equipotential field lines outside of the focus ring 118.

[0045] The focus ring 118 and/or metallic enclosure 120 may also serve to meet certain electro-magnetic compatibility and radio-frequency (RF) interference requirements in semi-conductor manufacturing. Most, if not all, RF systems in etching, cleaning, and deposition tools are required to be enclosed in such a metallic enclosure 120. But the use of the metallic enclosure 120 can generally cause unwanted capacitive and/or inductive parasitic effects which can in turn negatively affect the design of individual RF sub-systems and the overall RF system. More particularly, in the case of plasma sources, the magnetic fields

emanating out of an RF source coil can produce circulating currents on the metallic enclosure which in turn produce heat and waste the otherwise useful power which ought to be delivered to the plasma 110 for wafer processing purposes. These circulating currents are generally known as eddy currents which also cancel the inductance of source coil. In some examples, this disclosure describes magnetic shielding systems and methods which can be used to reduce the eddy current losses induced by plasma source enclosures.

[0046] Another example of a representative wafer processing system 200 is shown schematically in **FIG. 2**. Here, an RF generator 202 supplies RF power to the system 200 and the function of the RF match 204 is to counter-match the dynamic plasma load in order to transfer useful power for wafer processing applications. The output of the RF match 204 is connected to an RF source coil 206 which ignites a plasma gas (supplied by a gas delivery box 208) within a wafer processing chamber 210 at a specified pressure and chemistry depending on the process recipe steps.

[0047] An aspect of this disclosure is directed to a region 209 in the wafer processing chamber 210 where the RF source coil 206 lies. The purpose of the RF source coil (or plasma antenna) 206 is to produce a strong alternating magnetic field at frequencies of interest (for example, 100kHz to 300MHz) for breaking down the atoms of the supplied gas (or plasma 110) into charged particles that aid in wafer processing like etching, deposition, and so forth. The strong magnetic field from the RF source coil 206 generates eddy current losses which reduce the overall efficiency of the system 200. Conventional attempts to address this problem have included providing a large metallic enclosure of the type described above (e.g. metallic enclosure 120, **FIG. 1**) but this still suffers from the drawbacks discussed above. Moreover, in size and energy-conscious semiconductor manufacturing companies, there are ever-increasing efforts to reduce the overall size or “footprint” of manufacturing equipment, or constraints on size imposed by customer requirements. Thus, conventional metallic enclosures 120 are becoming increasingly impractical.

[0048] In some examples, a “back-shell” is provided to address the problems discussed herein. Generally speaking, a back-shell is configured to “turn back”, deflect, or change the path of a magnetic flux line in a processing chamber (e.g. 100, **FIG. 1** or 210, **FIG. 2**). In some examples, a back-shell

includes an arrangement of bars or blocks of ferro-magnetic material such as nickel zinc (NiZn), magnesium zinc (MgZn), or manganese zinc (MnZn) ferrites, a ferrite made of Nickel Magnesium (NiMg) alloy, or powdered-iron or a combination of different types thereof. A back-shell may include a planar area or grid-like magnetic shield. In some examples, the magnetic shield is provided in conjunction with metallic plates or ferrite cages designed and arranged as described below to reduce power losses and increase system efficiencies. In some examples, cold-plates or other thermal dissipation methods may also be employed to avoid thermal runaway of the ferro-magnetic materials. Some back-shell examples include a magnetic ferrite cage which may offer certain advantages. For example, in one configuration, the ferrite cage includes an assembly of discrete ferrite bars and does not need to be machined from an entire block of ferrite material. The cost of manufacture is therefore reduced accordingly. Further, air-gaps can be formed in the assembly allowing the ferrite material to cool down relatively quickly, making the overall configuration of the back-shell a more thermally stable design.

[0049] This disclosure describes example back-shell designs compatible with high RF power environments and with most thermal dissipation methods. Some examples include saturation-free gapped ferrite components for plasma etch applications. As described further below, eddy current losses in a metallic enclosure can be reduced by about 4% to 90% across different back-shell designs and magnetic concepts.

[0050] Reference is now made to **FIG. 3A** which shows a pictorial view of an example magnetic shield 300 for a plasma source. The magnetic shield 300 includes a back-shell 303 disposed in a wafer processing system 200, for example within the region 209 of the wafer processing system 200 shown in **FIG. 2**. A side view of the back-shell 303 disposed within this region 209 is shown in **FIG. 3B**.

[0051] The RF source coil 206 has power connection points 206A and 206B for providing power to the RF source coil 206. Other power supply arrangements for the RF source coil 206 are possible. As shown in **FIGS. 3A-3B**, the RF source coil 206 is substantially enclosed by the back-shell 303. The back-shell 303 defines, in this instance, an enclosed circular cage in general overall configuration. An upper part 301 of the back-shell 303 includes a number

of horizontally disposed, radially-extending ferro-magnetic bars 302. In this example, twelve such bars 302 are provided and they are equally, radially spaced apart from each other, as shown. Each ferro-magnetic bar 302 extends radially outwardly from a ferro-magnetic inner circular plate 304 of the back-shell 303 to a respective outer point on the periphery of the back-shell 303 shown at 306. At respective periphery points 306, each horizontal bar 302 meets, or is joined to, a corresponding vertically-disposed ferro-magnetic bar 308. The inner plate 304, the horizontal bars 302, and the vertical bars 308 define the upper part 301 of the back-shell 303 and, in combination, define an open cage or basket, as shown. The open cage has an open lower mouth that is closed by or at least includes a lower ferro-magnetic plate or disc 312. The RF source coil 206 lies within the volume defined by the upper part 301 and the lower ferro-magnetic plate or disc 312 of the enclosed cage. In some examples, a center bar or “core” 305 is provided to enhance the shielding or flux-shaping ability of the back-shell 303. The open cage has an open side and a bottom side of the RF source coil, when in use, faces the open side.

[0052] Reference is now made to **FIGS. 4A-4B**. Here, the magnetic shield 400 illustrated in these views also includes a back-shell 403, but in this case, the open lower mouth of the cage defined by the back-shell 403 is bridged by or at least includes a lower set of radially-spaced, ferro-magnetic bars 414 similar in configuration to the upper set of bars 302 discussed above. In the views shown in **FIGS. 4A-4B**, the upper set of bars is numbered 402. Each ferro-magnetic bar 402 extends radially outward from a ferro-magnetic inner circular plate 404 of the back-shell 403 to a respective outer point on the periphery of the back-shell 403 shown at 406. Although not visible, a corresponding ferro-magnetic inner circular plate 404 is provided on the underside of the back-shell 403. As in the embodiment described above, the back-shell 403 defines an enclosed circular cage in overall configuration and the RF source coil 206 is substantially enclosed by the back-shell 403. In this example, the cage is comprised substantially of bars, as opposed to the above arrangement in which one cage wall is defined by a circular plate, for example.

[0053] An upper part 401 of the back-shell 403 includes the upper set of bars 402 and, in this example, twelve such bars 402 are provided and they are spaced equally and radially apart from each other, as shown. Each bar 402

extends radially outwardly from a ferro-magnetic inner circular plate 404 of the back-shell 403 to an outer point on a periphery of the back-shell 403 shown at 406. At respective periphery points 406, each horizontal bar 402 meets, or is joined to, a corresponding vertically-disposed ferro-magnetic bar 408. Lower ends of the vertical, ferro-magnetic bars 408 are respectively joined to the lower set of radially-spaced, ferro-magnetic bars 414 mentioned above. The inner plate 404 (and its lower counterpart), the horizontal bars 402 and 414, and the vertical bars 408 define together an enclosed ferro-magnetic cage for the back-shell 403, as shown. The RF source coil 206 lies within the enclosed cage of the back-shell 403 when in use. In some examples, a center bar or “core” 405 is provided to enhance the shielding or flux-shaping ability of the back-shell 403.

[0054] Reference is now made to **FIGS. 5A-5B**. These views again show pictorial and side views of an example magnetic shield 500. Components similar to those described above are numbered accordingly. The cage configuration elements in this example include upper and lower sets of ferro-magnetic bars 502 and 514 each including (in this instance) only four relatively wide bars. The bars 502 and 514 are arranged in a substantially crucifix or right-angle configuration. Each bar 502 and 504 is joined at respective radially outer ends 506 to respective vertically arranged ferro-magnetic bars 508. The bars 508 each have a width that matches the width of the bars 502 and 514 to which they are joined.

[0055] An alternate cage configuration is further provided by the shape and size of the inner plates. In the embodiments above, the inner plates 304 and 404 are circular. Here, the inner plates instead include a ferro-magnetic plate 504 of square shape. Although not visible, a corresponding ferro-magnetic inner square plate is provided on the underside of the back-shell 503. The horizontal bars 502 and 514, the vertical bars 508, the square plate 504 (and its lower counterpart) define together an enclosed ferro-magnetic cage for the back-shell 503, as shown. The RF source coil 206 lies within the enclosed cage of the back-shell 503 when in use. In some examples, a center bar or core (not visible) is provided to enhance the shielding or flux-shaping ability of the back-shell 503.

[0056] Reference is now made to **FIGS. 6A-6B**. The example magnetic shield 600 depicted in **FIGS. 6A-6B** has components very similar to the upper part 301 of the back-shell 303 of the magnetic shield 300 depicted in **FIGS. 3A-**

3B which are numbered correspondingly. In this example, however, there are no lower ferro-magnetic parts. The lower mouth of the back-shell 603 is left open and is not closed off, or bridged, by a plate 304 or lower set of bars 302, 308 of the types described above, for example. The RF source coil 206 lies within a region 209 at or close to the open mouth cage of the back-shell 603 when in use.

[0057] It will be appreciated that terms such as horizontal, vertical, upper and lower and so forth are used herein with reference to these example orientations as shown in the drawings. In use, different orientations are possible, for example if the RF source coil 206 was oriented in use in a vertical plane instead of a horizontal one, as shown, the example back-shells 303, 403, 503, and 603, and the components that comprise them would assume a correspondingly different orientation accordingly.

[0058] Reference is now made to **FIG. 7** which shows a graph of comparative shielding effects, or eddy current loss reduction, of some of the embodiments discussed above. The open-mouthed version of the magnetic shield 600 shown in **FIGS 6A-6B** performed the least well of those tested, with eddy current loss reduction in the range of 5% across a range of frequencies. The magnetic shield 400 of **FIGS 4A-4B**, with the core 405, achieved better test results as a shield as shown, with eddy current loss reduction in the range 20-30% across the same range of frequencies. The magnetic shield 400 of **FIGS 4A-4B**, without a core, performed significantly better as a shield, with eddy current reduction in the range 90-95% across the same range of frequencies.

[0059] Further combinations of the exemplary back-shell configurations described above are possible. For example, the magnetic shields 300, 400, 500, and 600, shown in **FIGS. 3A-6B**, include circular cage configurations. With appropriate modification, square or rectangular cage configurations are possible. These configurations may be formed by bars 302 or plates 304 making up sides of the cages. The bars 302 may, for example, be regularly or irregularly spaced or may be of different dimensions and thicknesses with respect to each other to suit a given application, for example. The regularly spaced bars 302 of the circular cage configurations described above may not be regularly spaced, in some examples. Various combinations and sizes of cage are possible.

[0060] Other configurable design parameters for magnetic shields 300, 400, 500, 600 may include the spacing between the different bars 302, the

number of bars 302 to be used, the spacing between the bars 302 and the RF source coil 206, the bars-to-enclosure spacing, varying combinations of different shielding concepts, and one or more combinations of different ferro-magnetic materials. Specially engineered or optimized solutions may differ for different applications. Some design criteria may involve aspects such as source power levels ranging from 100W to 50kW, source frequencies ranging from 100 kHz to 300 MHz, the frequency-dependence of loss in enclosure and the ferro-magnetic material itself, and different RF source coil geometries.

[0061] For example, the frequency-dependent permeability, permittivity, and loss-characteristics of NiZn ferrite from a Ferroxcube material (material-4B2) may be taken into account during the design of a magnetic back-shell configured for a particular application. NiZn may be preferred in some instances due to its low permittivity which in turn reduces a capacitive parasitic effect between the coils of the RF source coil 206 and the back-shell (e.g. 303, 403, 503, and 603) enclosing it. Higher magnetic permeability materials such as MnZn material may be advantageous in containing magnetic fields, however, these materials may include a higher dielectric constant which may cause, in turn, increased RF coupling to ground reference. Thus, many combinations and configurations of back-shell materials and components are possible.

[0062] The present disclosure also includes example methods. In one example, with reference to **FIG. 8**, a method 800 of magnetically shielding an RF source coil 206 for a plasma source comprises, at least: at operation 802, providing a back-shell (e.g. 303, 403, 503, and 603) for the RF source coil 206; at operation 804, forming the back-shell (e.g. 303, 403, 503, and 603) by defining a cage for the back-shell (e.g. 303, 403, 503, and 603) using an arrangement of bars (e.g. the horizontal or vertical bars described and illustrated in **FIGS. 3A-6B**) of ferro-magnetic material; and, at operation 806, sizing and configuring the cage to at least partially enclose the RF source coil 206 when in use.

[0063] In some examples, the method 800 further comprises defining at least one wall of the cage by forming an array of radially spaced bars extending between a central region of the at least one wall of the cage and an outer dimension thereof. The method 800 may also including forming the back-shell to include any one or more of the back-shell features or elements described herein.

[0064] In some examples, a non-transitory machine-readable medium includes instructions 924 that, when read by a machine 900, cause the machine 900 to control operations in methods comprising at least the non-limiting example operations summarized above. FIG. 9 is a block diagram illustrating an example of a machine 900 upon which one or more example process embodiments described herein may be implemented, or by which one or more example process embodiments described herein may be controlled. In alternative embodiments, the machine 900 may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine 900 may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 900 may act as a peer machine in a peer-to-peer (P2P) (or other distributed) network environment. Further, while only a single machine 900 is illustrated, the term “machine” shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions 924 to perform any one or more of the methodologies discussed herein, such as via cloud computing, software as a service (SaaS), or other computer cluster configurations.

[0065] Examples, as described herein, may include, or may operate by, logic, and/or a number of components or mechanisms. Circuitry is a collection of circuits implemented in tangible entities that include hardware (e.g., simple circuits, gates, logic, etc.). Circuitry membership may be flexible over time and underlying hardware variability. Circuitries include members that may, alone or in combination, perform specified operations when operating. In an example, hardware of the circuitry may be immutably designed to carry out a specific operation (e.g., hardwired). In an example, the hardware of the circuitry may include variably connected physical components (e.g., execution units, transistors, simple circuits, etc.) including a computer-readable medium physically modified (e.g., magnetically, electrically, by moveable placement of invariant massed particles, etc.) to encode instructions 924 of the specific operation. In connecting the physical components, the underlying electrical properties of a hardware constituent are changed (for example, from an insulator to a conductor or vice versa). The instructions 924 enable embedded hardware (e.g., the execution units or a loading mechanism) to create members of the

circuitry in hardware via the variable connections to carry out portions of the specific operation when in operation. Accordingly, the computer-readable medium is communicatively coupled to the other components of the circuitry when the device is operating. In an example, any of the physical components may be used in more than one member of more than one circuitry. For example, under operation, execution units may be used in a first circuit of a first circuitry at one point in time and reused by a second circuit in the first circuitry, or by a third circuit in a second circuitry, at a different time.

[0066] The machine (e.g., computer system) 900 may include a hardware processor 902 (e.g., a central processing unit (CPU), a hardware processor core, or any combination thereof), a graphics processing unit (GPU) 903, a main memory 904, and a static memory 906, some or all of which may communicate with each other via an interlink (e.g., bus) 908. The machine 900 may further include a display device 910, an alphanumeric input device 912 (e.g., a keyboard), and a user interface (UI) navigation device 914 (e.g., a mouse). In an example, the display device 910, alphanumeric input device 912, and UI navigation device 914 may be a touch screen display. The machine 900 may additionally include a mass storage device (e.g., drive unit) 916, a signal generation device 918 (e.g., a speaker), a network interface device 920, and one or more sensors 921, such as a Global Positioning System (GPS) sensor, compass, accelerometer, or another sensor. The machine 900 may include an output controller 928, such as a serial (e.g., universal serial bus (USB)), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate with or control one or more peripheral devices (e.g., a printer, card reader, etc.).

[0067] The mass storage device 916 may include a machine-readable medium 922 on which is stored one or more sets of data structures or instructions 924 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 924 may also reside, completely or at least partially, within the main memory 904, within the static memory 906, within the hardware processor 902, or within the GPU 903 during execution thereof by the machine 900. In an example, one or any combination of the hardware processor 902, the GPU 903, the main memory 904, the static

memory 906, or the mass storage device 916 may constitute machine-readable media 922.

[0068] While the machine-readable medium 922 is illustrated as a single medium, the term “machine-readable medium” may include a single medium, or multiple media, (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions 924.

[0069] The term “machine-readable medium” may include any medium that can store, encode, or carry instructions 924 for execution by the machine 900 and that cause the machine 900 to perform any one or more of the techniques of the present disclosure, or that can store, encode, or carry data structures used by or associated with such instructions 924. Non-limiting machine-readable medium examples may include solid-state memories, and optical and magnetic media. In an example, a massed machine-readable medium comprises a machine-readable medium 922 with a plurality of particles having invariant (e.g., rest) mass. Accordingly, massed machine-readable media are not transitory propagating signals. Specific examples of massed machine-readable media may include non-volatile memory, such as semiconductor memory devices (e.g., electrically programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; and CD-ROM and DVD-ROM disks. The instructions 924 may further be transmitted or received over a communications network 926 using a transmission medium via the network interface device 920.

[0070] Although an embodiment has been described with reference to specific example embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader scope of the invention. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense. The accompanying drawings that form a part hereof, show by way of illustration, and not of limitation, specific embodiments in which the subject matter may be practiced. The embodiments illustrated are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed herein. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this

disclosure. This Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

[0071] Such embodiments of the inventive subject matter may be referred to herein, individually and/or collectively, by the term “invention” merely for convenience and without intending to voluntarily limit the scope of this application to any single invention or inventive concept if more than one is in fact disclosed. Thus, although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the above description.

CLAIMS

1. A magnetic shield for a plasma source, the magnetic shield comprising:
a back-shell, the back-shell including an arrangement of elements of ferro-magnetic material, the back-shell sized and configured to extend at least over a portion of an RF source coil for the plasma source.
2. The magnetic shield of claim 1, wherein the arrangement of ferro-magnetic elements defines an open cage having an open side, and wherein a bottom side of the RF source coil, when in use, faces the open side.
3. The magnetic shield of claim 1, wherein the arrangement of ferro-magnetic elements defines a closed cage.
4. The magnetic shield of claim 1, wherein the back-shell includes a cage defined by one or more ferro-magnetic bars included in the arrangement of ferro-magnetic elements, the cage further including a plate of ferro-magnetic material, the plate defining or included in at least one wall of the cage, and wherein the plate is disposed opposite of and parallel to the arrangement of ferro-magnetic bars.
5. The magnetic shield of claim 1, wherein the ferro-magnetic material includes one or more of a group of materials comprising: a nickel zinc (NiZn) ferrite, a magnesium zinc (MgZn) ferrite, a ferrite made of Nickel Magnesium (NiMg) alloy, a manganese zinc (MnZn) ferrite, a powdered-iron, and a combination thereof.
6. The magnetic shield of claim 4, wherein the arrangement of ferro-magnetic elements defines a first wall of the cage, the arrangement including a first array of radially spaced bars extending between a first central region of the first wall and an outer dimension thereof.
7. The magnetic shield of claim 6, wherein the first central region includes a central bar of ferro-magnetic material.

8. The magnetic shield of claim 6, wherein the arrangement of ferro-magnetic elements defines a second wall of the cage, the arrangement including a second array of radially spaced bars extending between a second central region of the second wall and an outer dimension thereof, and wherein the first array is disposed opposite and parallel to the second array.
9. The magnetic shield of claim 8, wherein the cage includes at least one wall having a circular shape.
10. The magnetic shield of claim 9, wherein a circumference of the circular shape is substantially equidistant from a circumference of an outer periphery of the RF source coil.
11. The magnetic shield of claim 4, wherein the arrangement of ferro-magnetic elements includes an array of ferro-magnetic bars arranged orthogonally to each other, the orthogonal array of ferro-magnetic bars defining or included in at least one wall of the cage.
12. A wafer processing chamber including the RF source coil and the magnetic shield of claim 1.

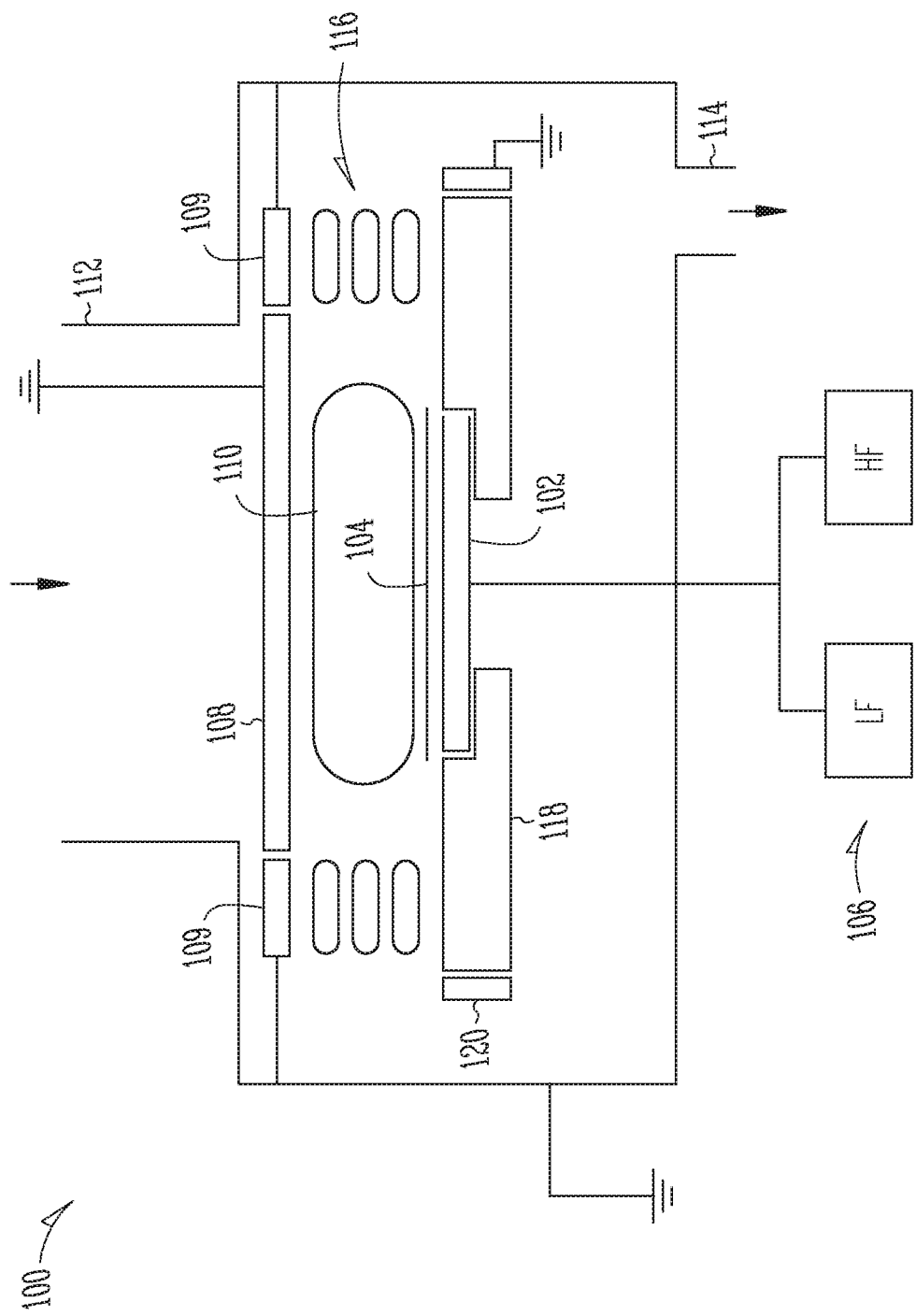


Fig. 1

200

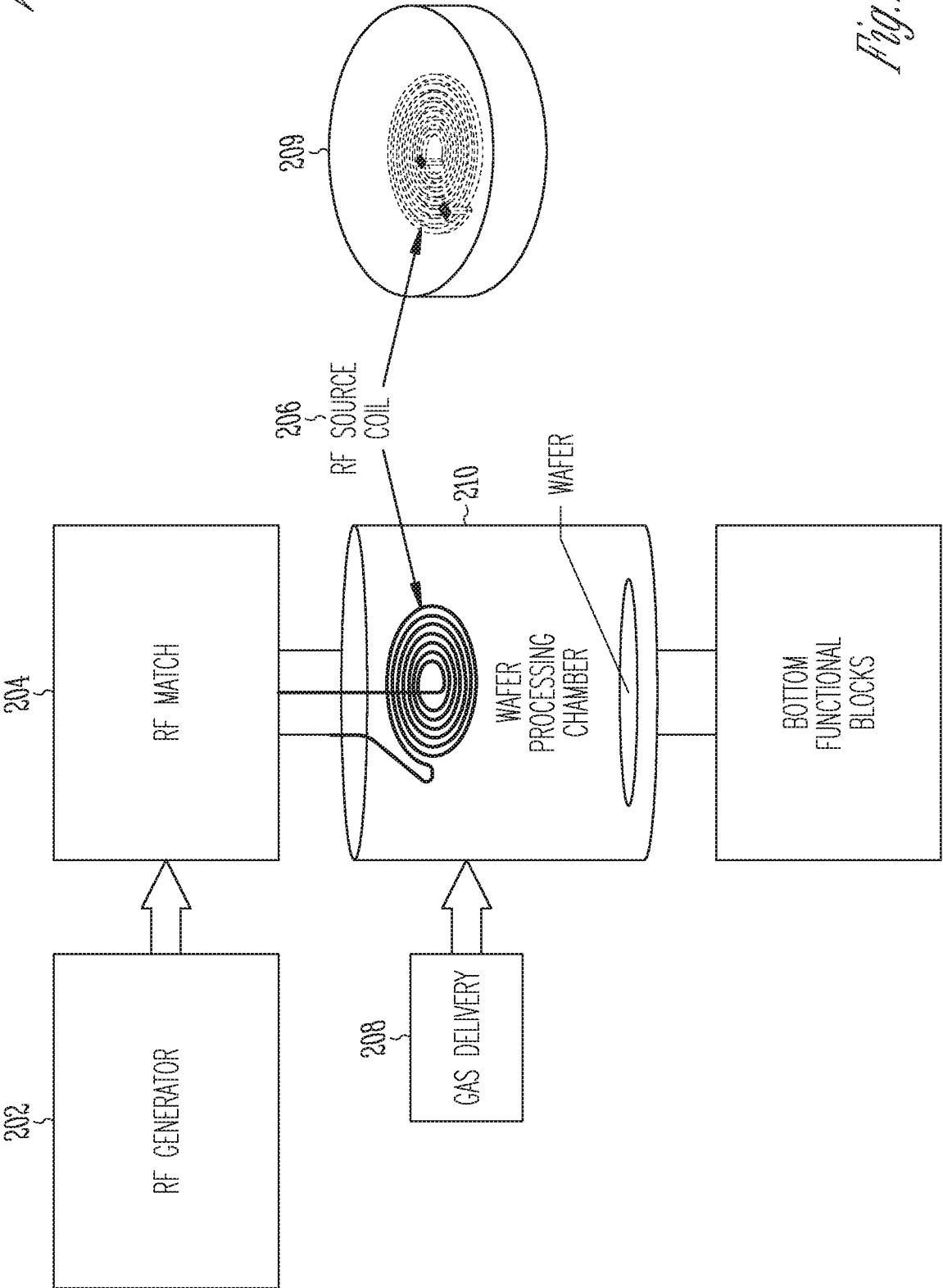


Fig. 2

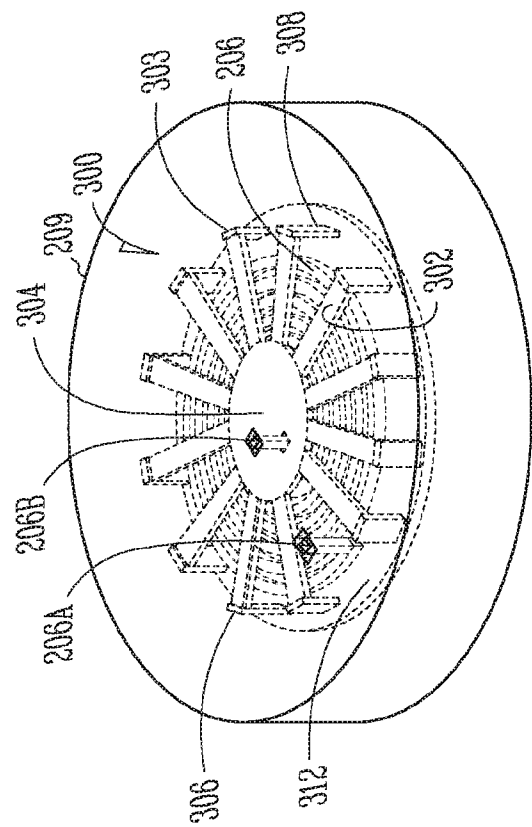


Fig. 3A

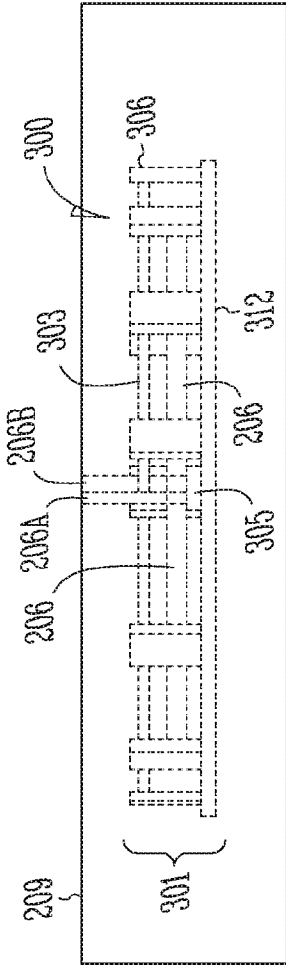


Fig. 3B

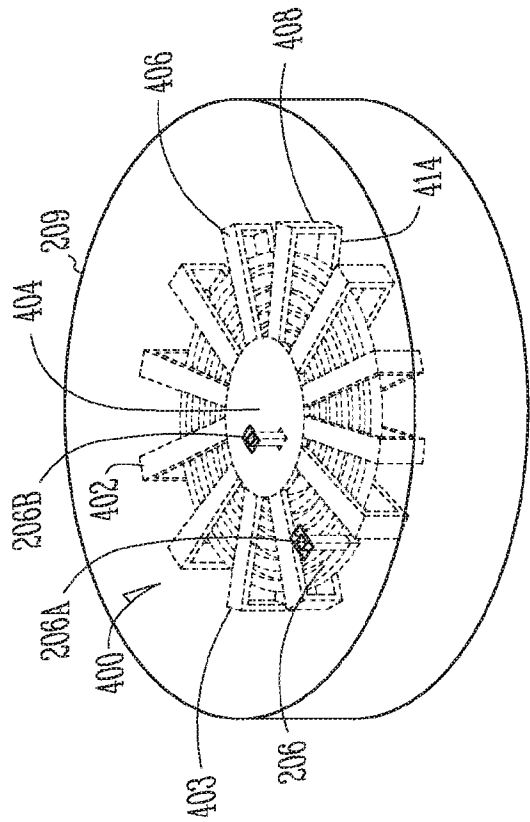


Fig. 4A

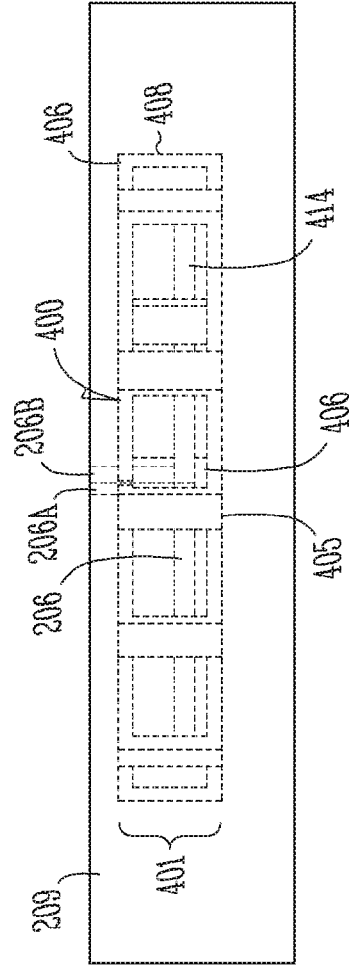


Fig. 4B

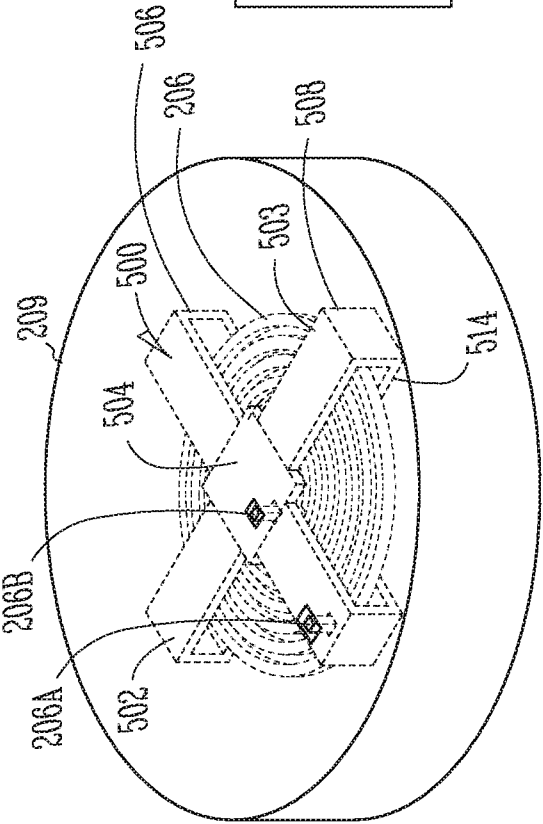


Fig. 5A

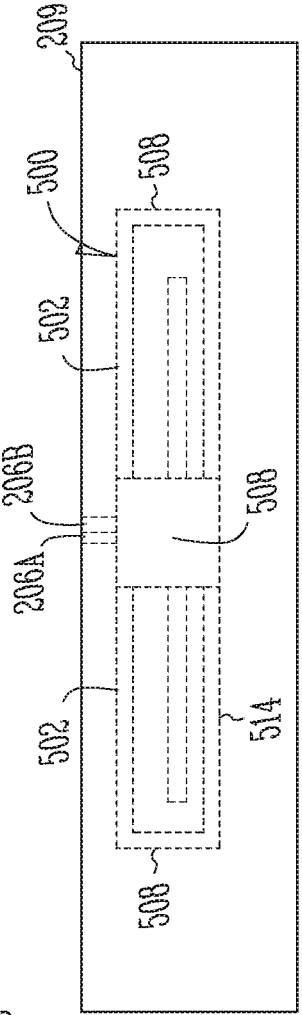


Fig. 5B

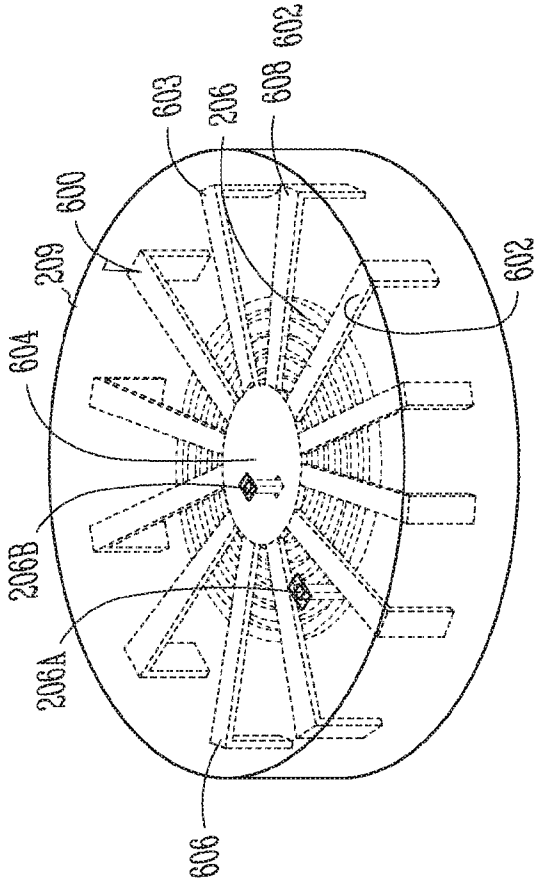


Fig. 6A

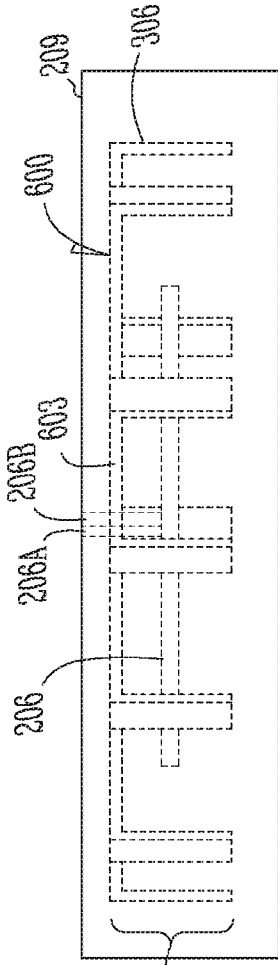
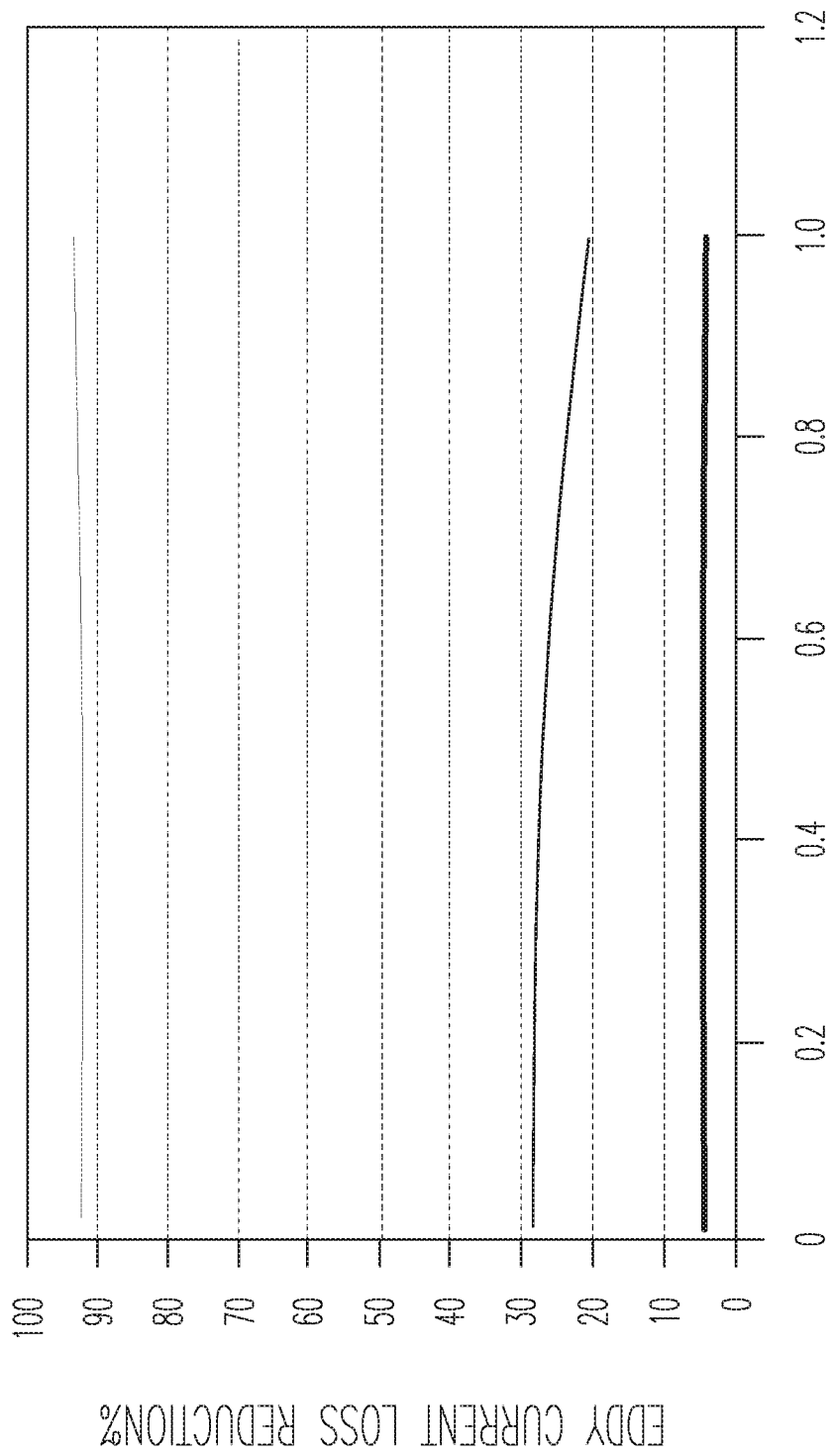


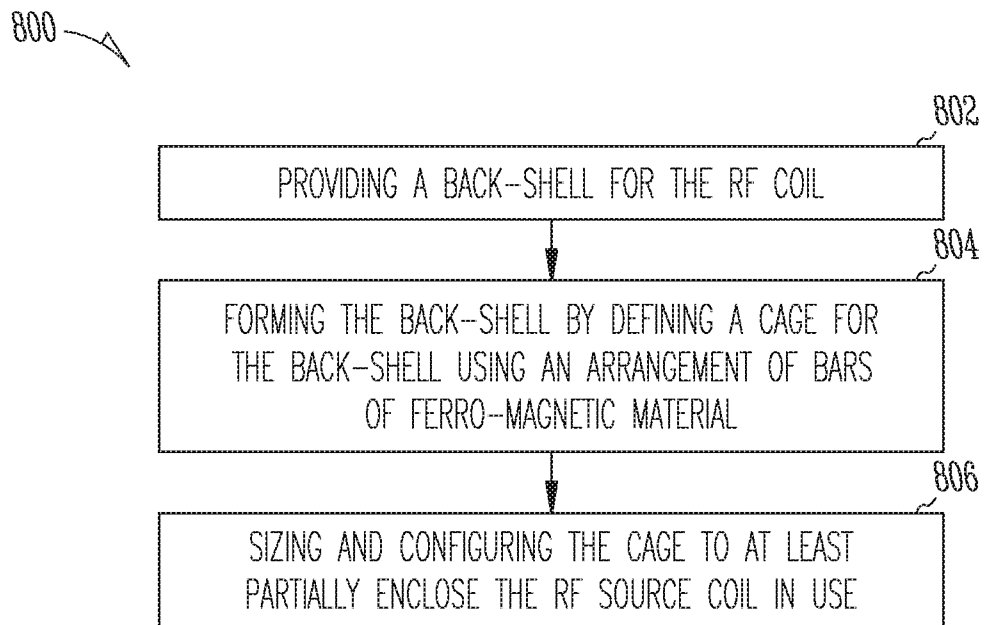
Fig. 6B

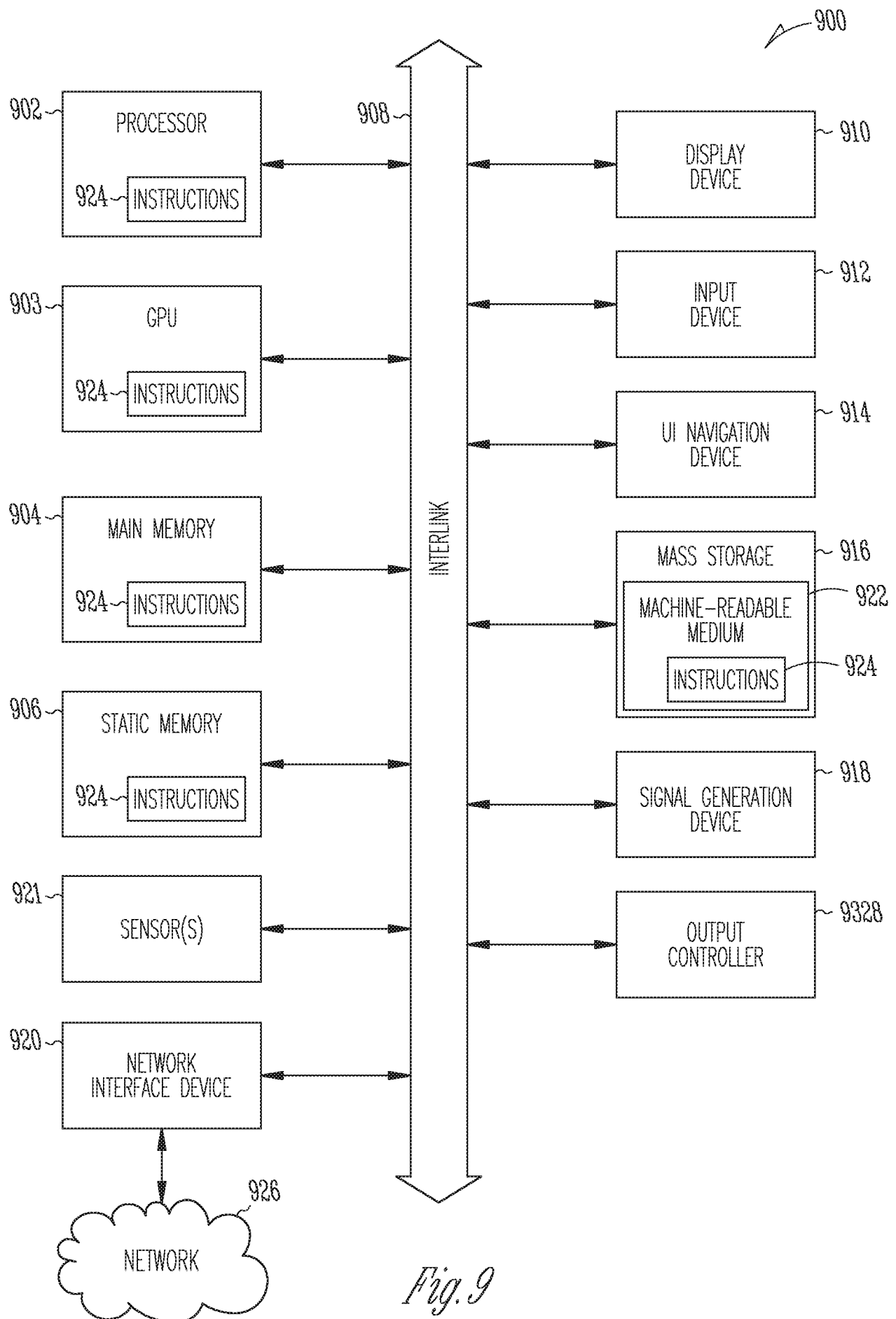
- MAGNETIC SHIELD, 600, FIGS. 6A-6B
- MAGNETIC SHIELD, 400, FIGS. 4A-4B (WITH CORE)
- MAGNETIC SHIELD, 400, FIGS. 4A-4B (WITHOUT CORE)



NORMALIZED FREQUENCY

Fig. 7

*Fig. 8*



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2019/043502**A. CLASSIFICATION OF SUBJECT MATTER****H01J 37/32(2006.01)i**

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)

H01J 37/32; C23C 16/00; C23F 001/00; H01L 21/306; H01L 21/3065

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: plasma, RF(radio frequency), coil, ferromagnetic, bar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A		8-10
Y	US 9384948 B2 (LAM RESEARCH CORPORATION) 05 July 2016 See claim 1; and figures 3A-5B.	1-7, 11-12
A	KR 10-2008-0106417 A (LAM RESEARCH CORPORATION) 05 December 2008 See the entire document.	1-12
A	KR 10-0824304 B1 (SEMES CO., LTD.) 22 April 2008 See the entire document.	1-12
A	US 2005-0194099 A1 (RUSSELL F. JEWETT JR. et al.) 08 September 2005 See the entire document.	1-12



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

02 December 2019 (02.12.2019)

Date of mailing of the international search report

03 December 2019 (03.12.2019)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

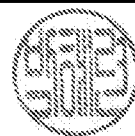


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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2019/043502

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