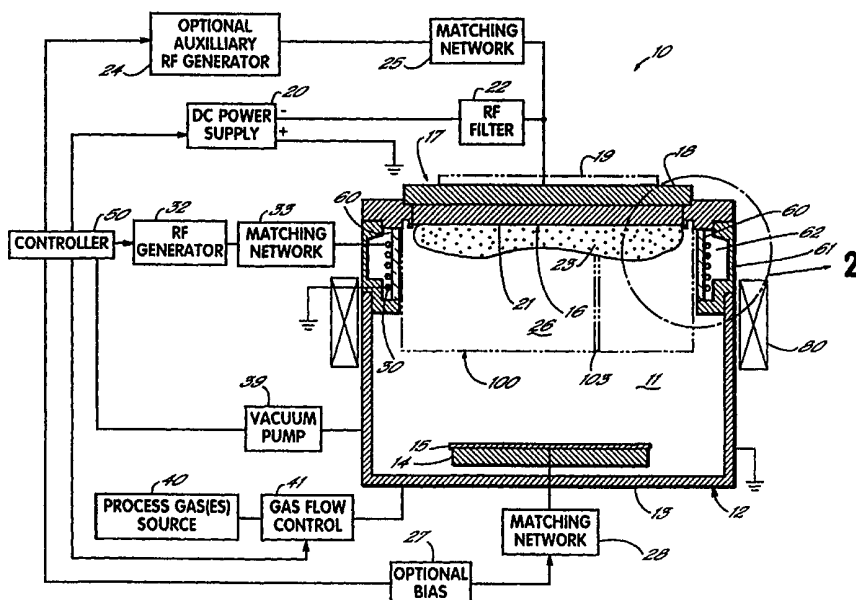




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(54) Title: SHIELD FOR IONIZED PHYSICAL VAPOR DEPOSITION APPARATUS



(57) Abstract

An ionized PVD apparatus (10) comprises an RF coil (30) surrounding space (11) within vacuum chamber (12). RF energy is coupled into the space (11) to form a secondary plasma between the substrate holder (14) and the target (16). A window (60) of dielectric material, in an opening of the wall (13) of the chamber (12), protects the coil (30) from adverse interaction with secondary plasma. Shield (100) is provided to prevent coating of window (60). Shield (100) is partitioned or slotted to form a gap (103) to prevent induced currents in the shield segments. Such shield configuration maximizes the available power to support the secondary plasma by preventing the formation of eddy currents which can heat the shield.

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SHIELD FOR IONIZED PHYSICAL VAPOR DEPOSITION APPARATUS

This application is related to the commonly assigned and copending U.S. Patent Applications Serial Nos. 08/844,751, 08/837,551 and 08/844,756 filed April 21, 1997, and hereby expressly incorporated by reference herein.

Field of the Invention:

5 This invention relates to Ionized Physical Vapor Deposition (IPVD) of coating material onto substrates, particularly sputter coating systems. The invention particularly relates to plasma processing systems that use inductively coupled plasma (ICP).

Background of the Invention:

10 The existence of sub-micron high aspect ratio features, such as vias, trenches and contact holes, in semiconductor manufacturing presents a variety of coating problems. In the manufacture of Very and Ultra Large Scale Integration (VLSI and ULSI)) semiconductor devices, contacts on the bottoms of small high aspect ratio features often must be coated with barrier layers, and the features often must be filled with conductive metals. In semiconductor device manufacturing where films are to be deposited, the application of coatings using a physical vapor deposition (PVD) process is often preferred. The deposition of films on the
15 bottoms of narrow high aspect ratio apertures by physical methods requires a high degree of directionality in the movement toward the substrate of the coating material to be deposited. It is preferable for most of the particles of coating material being deposited by predominantly physical methods to move at angles that are nearly normal to the substrate.

20 A physical deposition process, such as sputter coating, is typically carried out by placing a substrate and a target of high purity coating material into a vacuum chamber filled with an inert gas such as argon and creating a plasma in the gas. The plasma is typically generated by maintaining the target, either constantly or intermittently, at a negative potential, so that the target functions as a cathode to supply electrons that excite the gas in the chamber and form a

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plasma adjacent the target surface. The plasma generation is usually enhanced with a magnetron cathode assembly in which magnets behind the target trap these electrons over the surface of the target where they collide with atoms of the process gas, stripping electrons from atoms of gas and converting them into positive ions. The gas ions are accelerated toward the negatively charged target where they collide with the surface and eject from the target surface atoms and atomic clusters or particles of target material and secondary electrons. The ejected particles of target material are neutral in charge and propagate through the vacuum space in various directions with some striking the substrate, to which they adhere to form the film. Increasingly narrower features and higher aspect ratio features on the substrates act to decrease the acceptance angle of the aperture, thereby shadowing the sides of the features, resulting in increasingly more of the incident particles being intercepted by the sides of, and areas around, the features with increasingly fewer of the particles available to deposit on the feature bottoms.

A method of directing sputtered material that has been given renewed consideration is the process of ionized sputtering, referred to herein as Ionized Physical Vapor Deposition or IPVD. With IPVD, coating material is vaporized by being sputtered from a target using magnetron sputtering or other conventional sputtering or evaporation techniques. In sputter coating processes, sputtered particles are emitted from the target at broad angles of emission. IPVD improves the directionality by ionizing the particles and electrostatically attracted or electrically or magnetically steered in a direction normal to the substrate.

With IPVD, high density low energy plasma is created between the coating material source and the substrate. The particles of sputtered material passing through this space collide with the electrons or metastable neutrals of the ionized process gas, which strip electrons from the atoms of the coating material particles forming positively charged ions of the coating material. These positive ions of sputtered material are then accelerated toward the substrate, for example, by application of a negative bias to the substrate.

In U.S. Patent Applications Serial Nos. 08/844,751, 08/837,551 and 08/844,756 referred to above, IPVD is described in which the high density inductively coupled plasma (ICP) is generated with an RF coil positioned outside of and surrounding the chamber behind a dielectric window that forms part of the vacuum containing wall of a sputtering chamber. Shield structure is provided inside of the chamber to intercept electrically conductive sputtered material moving toward the window that would otherwise deposit on the window and form an electrical short, which would interfere with the coupling of energy from the coil and into the chamber. These patent applications discuss, among other things, various concepts in shield structure placement

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and geometry to enhance the shielding of the material from the window and to facilitate the coupling of the plasma into the chamber. The concepts provide for efficient coupling of the plasma past the shield and the avoidance of circumferential currents that interfere with or counteract the coupling of RF energy into the chamber.

5 With ICP systems for IPVD, high efficiency is desired for the coupling of energy into the chamber. Induced currents in the shields consume energy that would otherwise be available for coupling into the chamber. This consumed energy results in a heating of the shield structure, which can result in the desorption of water vapor and other gases from the shield structure that can be detrimental to the IPVD process.

10 Accordingly, there remains a need to improve shield structure in ICP IPVD systems to enhance the coupling efficiency of the ICP plasma sustaining energy into the chamber.

Summary of the Invention:

 A primary objective of the present invention is to provide an apparatus for more efficiently and effectively depositing thin films in high aspect ratio holes and trenches in VLSI and ULSI semiconductor wafers, and particularly, to provide an apparatus for conducting ionized physical vapor deposition that has a high overall efficiency, with a high ionization efficiency of the coating material and high coupling efficiency of plasma sustaining energy into an IPVD processing chamber. It is a particular objective of the present invention to provide improved shield structure for use with ICP plasma processes, particularly those in which plasma sustaining RF energy is coupled through a dielectric portion of the vacuum wall of the processing chamber.

20 In the preferred embodiment of the invention, the plasma is produced between a coating material source and a substrate which is to be coated with coating material from the source. The purpose of the high density plasma is to ionize the coating material so that it can be electrically or magnetically directed at desired angles onto the substrate. The plasma in an IPVD apparatus generally fills the chamber and ionizes coating material particles while they are in flight and are moving from the source, such as a sputtering target, to the substrate. The ions of coating material are electrostatically accelerated or otherwise electrically or magnetically steered toward the substrate so that they impinge upon the substrate at angles that approach the normal to the substrate. Such electrostatic acceleration is preferably achieved by application of a negative bias on the substrate.

30 In the preferred embodiment of the invention, RF ionization energy is preferably coupled into the chamber by one or a plurality of coils surrounding the chamber outside of a dielectric window in the chamber wall that separates the vacuum processing space within the chamber

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from the outside environment. The window is formed of an electrically non-conductive and non-magnetic dielectric material that, whether in the wall of the chamber or elsewhere, protects and isolates the coils from adverse interaction with plasmas in the chamber. The preferred apparatus further includes shield structure withing the chamber to shield the window so that the function
5 of the window is not compromised by the effects of material deposition thereon, particularly where the coating material is a metal or other electrically conductive material.

In the preferred embodiment, a helical coil is provided surrounding the chamber from behind a mostly cylindrical window of quartz. Substantially cylindrical shield structure is further provided that surrounds the chamber in close proximity to the window that separates the coil
10 from a PVD processing chamber. The shield has therein a plurality of slits preferably in a direction parallel to an axis of the chamber, which may be defined as a line that extends through the center of the chamber perpendicular to and through the center of the substrate. By "close proximity" is meant spaced from the window a distance that is sufficiently short as to substantially prevent the formation of plasma between the shield and the window. The slits in
15 the shield structure follow the shape of the dielectric window that separates the coil from the vacuum chamber and process gas. The shield structure prevents the deposit of coating material onto the window.

When the coating material that is being deposited is electrically conductive, electrical short circuiting of the coil can occur which could prevent RF energy from being effectively
20 transmitted into the chamber. The shield is slit in such a way as to prevent the shield itself from providing a circumferential electrically conductive path that encircles the axis of the chamber and around which circumferential currents could be induced by the energy from the coil. Such circumferential currents would consume energy from the RF coil and detract from the efficiency of energy coupled into the chamber to form the high density plasma. The shield is further
25 extended sufficiently far in an axial direction to short-circuit axial electrical fields across the RF coil, thereby optimizing the efficiency of the inductive coupling of energy into the plasma and reducing capacitive components of the coupled energy. In addition, the shield is maintained in close spaced proximity to the window so as to prevent generation of plasma behind the shield so that the plasma is more efficiently generated in volume of the space through which the
30 particles of coating material travel. Preferably, the spacing of the shield from the window is not greater than the mean free path of atoms of the process gas or the minimum diffusion length of the plasma in the space.

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According to certain principles of the invention, a plurality of slits or other forms of gaps in the shield structure are provided sufficiently close together to divide the shield into sections of limited circumferential width. The width of the shield sections is sufficiently narrow to inhibit the formation of local eddy currents, induced as a result of the RF energy being coupled from the coil, in the conductive material of which the shield may be formed or any conductive film deposited on the shield structure. Preferably, at least one slit or gap interrupts the entire circumference of the shield structure, with the other slits or gaps extending substantially to the axially opposite edges of the shield structure. The sections of the shield structure may also be formed of a cylindrical array of spaced shield elements or slats. The edges of the shield structure adjacent each of the slits may overlap, being radially spaced from each other, to interrupt paths of coating material from passing through the slits onto the window. In a further alternative, the shield structure may include multiple cylindrical sections or slotted shields or arrays of slats with the gaps in the multiple surfaces being out of radial alignment with each other to interrupt direct paths for coating material to pass from the processing space in the volume around the center of the chamber and through the gaps and onto the window. The arrays or cylindrical surfaces of the shield structure are situated close to the window so that the primary formation of plasma as a result of RF energy coupled from the coils is on the inside of the shield structure.

The gaps in the shield are preferably sufficiently wide to allow the formation of plasma therein, so that the plasma will continually remove by resputtering any deposition of coating material on the window as a result of material from the source passing through the slit.

The location and configuration of the shield structure relative to the window contributes to a high efficiency of plasma generation in the space of the chamber, avoiding losses due to the generation of plasma between the shield and the coil. The plurality of gaps in the shield structure that are spaced at narrow intervals around the circumference of the structure inhibits the production of eddy currents as well as circumferential currents around the chamber, thereby further reducing the loss of energy by limiting current in the shield structure to thereby avoid a loss of coupling of energy to the central portion of the chamber. Further, heating of the shield structure that would increase contamination in the chamber is avoided. A high ionization efficiency of the sputtered material is provided.

With this embodiment, plasma generation in ineffective areas of the chamber, such as between shield structure and the coil-protecting insulator or window, is prevented, and the loss of ionization efficiency thereby is avoided. The invention is useful in IPVD systems, particularly

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those using ICP to ionize the coating material, and in other plasma processing systems such as those in which etching is carried out, particularly with ICP.

The present invention provides advantages in PVD processes that employ sputtering targets as well as evaporation sources or other sources of vaporized material that are deposited by substantially physical techniques. Reactive processes and physical processes that are enhanced by or otherwise include chemical deposition of the material may also benefit from the present invention. The invention has particular utility in connection with the deposition of metal films, but can also provide advantages in the deposition of other materials, particularly oxides and nitrides. Further, the shield structure of the invention is useful with other process that use an inductively coupled plasma produced by energy from a coil located behind a dielectric window or other protective structure that can lose its effectiveness if allowed to become coated with material present in a vapor inside of a chamber.

These and other objectives and advantages of the present invention will be more readily apparent from the following detailed description of the of the preferred embodiments of the invention, in which

Brief Description of the Drawings:

Fig. 1 is a diagrammatic cross-sectional representation of a IPVD apparatus according to one embodiment of the present invention.

Fig. 2 is an enlarged elevational diagram of a portion of **Fig. 1** illustrating an alternative form of protection for the coil.

Fig. 3 is a perspective view of one embodiment of the shield of the IPVD apparatus of **Figs. 1** and **2**.

Fig. 3A is a fragmentary top elevational view taken along line of the apparatus of **Fig. 3**.

Fig. 3B is a fragmentary top elevational view similar to **Fig. 3** of an alternative embodiment to the shield of the apparatus of **Fig. 3**.

Fig. 4 is a perspective view of an alternative and preferred embodiment of the shield of the IPVD sputtering apparatus of **Figs. 1** and **2**.

Fig. 4A is a cross-sectional view taken along line 4-4 of **Fig. 4**.

Fig. 4B is a fragmentary cross-sectional view, similar to **Fig. 3B** taken along line 4-4 of **Fig. 4** of an alternative embodiment to the shield of **Fig. 4**.

Fig. 4C is a fragmentary cross-sectional view, similar to **Fig. 4B** of an alternative embodiment of a shield having characteristics of the embodiments of both **Fig. 3** and **Fig. 4**.

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Detailed Description of the Invention:

Fig. 1 diagrammatically illustrates a preferred embodiment of a plasma processing apparatus in the form of a sputter coating apparatus 10 configured for ionized physical vapor deposition (IPVD) and which utilizes an inductively coupled plasma (ICP) to ionize coating material. The apparatus 10 includes a processing space 11 enclosed in a chamber 12. The processing space 12 is enclosed within a gas tight chamber wall 13 which encloses the space 11 in the chamber 12 and contains gas at a high vacuum therein. Mounted in the chamber 12 at one end of the processing space 11 is a substrate support or susceptor 14 for supporting a substrate such as a semiconductor wafer 15 thereon. The wafer 15, when mounted on the substrate support 14, is parallel to and faces a target 16. The target 16 is formed of a sputter coating material that is to be deposited as a thin film on the wafer 15. The processing space 11 is maintained at an ultra high vacuum pressure level and contains a processing gas, such as argon, during processing. The space 11 lies in the chamber 12 between the substrate support 14 and the target 16.

The target 16 is part of a cathode assembly 17 mounted in the chamber 12 at an end thereof opposite the substrate support 14. The cathode assembly 17 includes a target holder 18 to which the target 16 is secured. A magnet structure 19 is typically provided behind the target holder 18 on the opposite side thereof from the substrate support 14. A dark space shield (not shown) may also be provided around the periphery of the target 16. The magnet structure 19 preferably includes magnets that produce a closed magnetic tunnel over surface 21 of the target 16 that traps electrons given off into the chamber 12 by the cathode assembly 17 when it is electrically energized to a negative potential as is familiar to one skilled in the art. The magnet structure 19 may include fixed or rotating or otherwise moving magnets, which may be permanent or electromagnets, of any one of a number of magnetron sputtering assemblies known in the art.

A power supply or source of electrical energy 20, usually a source of constant or pulsed DC power, is connected between the cathode assembly 17 and the wall 13 of the chamber 12, which is usually at ground potential and may serve as the system anode. The cathode assembly 17 is insulated from the wall 13 of the chamber 12. The power supply 20 is preferably connected to the cathode assembly 17 through an RF filter 22. An auxiliary source of energy such as an RF generator 24 may also be optionally connected to the cathode assembly 17 through a matching network 25. A bias circuit 27 is preferably provided and connected to the substrate support 14

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through a matching network 28. The bias circuit 27 applies a bias to a wafer 15 mounted on the substrate support 14. A bipolar DC supply or an RF supply can be used for this purpose.

Power from the steady or pulsed DC power supply 20 and/or RF generator 24 produces a negative potential on the surface 21 which causes electrons to be emitted from surface 21 of the target 16. Electrons are emitted from the target surface 21 and remain trapped over the surface 21 by the magnetic field generated by the magnet structure 19. These electrons strike and ionize atoms of process gas adjacent to the surface 21 of the target 16, forming a main plasma 23 adjacent to the target surface 21. This main plasma 23 becomes a source of positive ions of gas that are accelerated toward and against the negatively charged surface 21 with sufficiently high energy to eject particles of coating material from the target 16 when they strike the target surface 21.

The space 11 between the target surface 21 and the substrate support 14 has the main plasma 23 at the end thereof adjacent the target 16 and includes a remaining volume 26 that lies between the plasma 23 and the substrate 15 on the substrate support 14. The particles of sputtered material from the target 16 generally originate as electrically neutral particles on the surface 21 of the target 16 that can propagate only by momentum through the space 11, where some, but not all, pass through the plasma 23 and the volume 26 to impinge upon the substrate 15. In a conventional sputtering apparatus, neutral sputtered particles passing through the plasma 23 are not ionized significantly since the plasma 23 occupies a small volume near target surface 21, and at operating pressures and main plasma densities that are typically used, few collisions occur between the neutral sputtered particles and particles of the plasma 23. As such, in conventional sputtering, the neutral sputtered particles exit the plasma 23 mostly neutral in charge and stay neutral until deposited as a thin film on substrate 15.

For coating contacts at the bottom of high aspect ratio holes and other features and for metallizing contacts by filling the holes with conductive material, it is highly preferred in VLSI and ULSI semiconductor device manufacturing that the particles impinge onto the substrate surface in a narrow angular distribution around a line that is normal to the substrate 15, so that the particles of coating material can proceed directly into the features and onto the feature bottoms, and not strike or be shadowed by the feature sides. This perpendicular impingement of particles onto the substrate 15 is facilitated in the apparatus 10 by ionizing the sputtered particles as they pass through the volume 26, so that the particles develop an electrical charge. Once charged, the particles are electrostatically accelerated or otherwise electrically or magnetically directed into paths that are more parallel to the axis of the chamber and more

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perpendicular to the surface of the substrate 15 by the process of ionized physical vapor deposition (IPVD).

According to a preferred embodiment of the present invention, in-flight ionization of particles of coating material in the space 26 is carried out by coupling, preferably inductively, RF energy into the volume 26 by provision of an RF element that surrounds the volume 26. The RF element is preferably in the form of a coil or coil assembly 30, for example a helical coil, though coil configurations other than helical may be used. The coil 30 inductively couples energy into the process gas in the volume 26 forming a secondary plasma that generally fills the volume 26. An RF generator 32, preferably operative in the range of from 0.1 or 0.2 MHZ to 60 or 80 MHZ, at 2 MHZ for example, is connected to the coil 30 through a matching network 33 to provide the energy to the coil 30 to form the secondary plasma in the volume 26.

A source of processing gas 40 is connected to the chamber 11, through a flow control device 41. For sputter processing, the supply gas 40 is typically an inert gas such as argon. For reactive processes, additional gases such as nitrogen and oxygen can be introduced through auxiliary flow controllers. A high vacuum pump 39 is also connected to the chamber 12 to pump the chamber 12 to a vacuum level in the milli Torr or sub-milli Torr range. Pressures in the 5 to 50 milli Torr range are preferred. The pump 39 maintains the ultra high vacuum with a flow rate of process gas in a range of 5 to 300 standard cubic centimeters per second (scm).

The apparatus 10 also includes a main controller 50 that is preferably a microprocessor-based programmable controller operative to sequence and control the operation of the components discussed above. The controller 50 has outputs for controlling the energization of the cathode power supplies 20 and 24, the substrate bias power supply 27, the RF generator 32 for energizing the secondary plasma generating element that is the coil assembly 30, the gas flow control 41, the pump 39 and other controllable components of the apparatus 10.

In addition or in the alternative to the use of the bias on the substrate 15 to direct ionized coating material at angles normal to the substrate 15, a magnet 80 may be provided around the chamber 12 to produce a magnetic field in the axial direction in the chamber 12. The magnet 80 may be an electromagnet or formed of one or more permanent magnets. The fields from the magnet 80 cause the charged particles to gyrate about the lines, thereby increasing their confinement in the radial direction. In the presence of an axial electric field, the charged particles can be directed in the axial direction, moving toward the substrate and minimizing radial losses.

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Between the coil assembly 30 and the space 11 there is provided a protective structure that prevents the plasma from contacting and electrically interacting with the coil assembly 30. This structure is an electrically non-conductive material that does not impede the magnetic field surrounding the coil assembly 30 from reaching into the volume 26. One preferred form of protective structure is that of a window 60, made of a vacuum-compatible dielectric material such as quartz, in the wall 13 of the chamber 12, that is mounted to form a vacuum-tight seal with the chamber wall. The window 60 may be a single piece of electrically-insulating and magnetically-transparent material or it may be formed in joined segments thereof, to form a generally cylindrical protective structure. The coil assembly 30 depicted in the foregoing embodiments, is wound around the chamber 12, preferably outside of the window 60. Covering the coil assembly 30 on the outside thereof is a conductive metal enclosure 61, which forms a sealed cavity 62, which isolates the coil assembly 30 and also prevents electromagnetic energy from radiating from the coil assembly 30 and from within the chamber 12 to the outside of the chamber 12. The cavity 62 may be sealed from the chamber 11 but may be in communication with the outside atmosphere or it may be filled with an inert gas, at atmospheric or low pressure, such that formation of a plasma is not supported by the gas in the cavity 62 when the coil assembly 30 is energized.

While the window 60 itself is not electrically conductive, it is susceptible to the accumulation of a coating of material sputtered from the target 16, which may be electrically conductive. Electrical conductivity in or on the window 60 supports the induction of currents around the chamber 12. Such currents reduce, cancel or otherwise undermine the effectiveness of the RF coupling of energy from the coil assembly 30 to the secondary plasma in the volume 26. Such conductivity of coating on the window 60, particularly in the azimuthal (circumferential) direction, that is, a direction that extends around the chamber 12, produces an inductively coupled short circuit, can negate all or much of the energy inductively coupled into the volume 26.

To prevent such buildup of conductive sputtered material on the window 60, the preferred apparatus further includes a shield or shield array 100. **Fig. 1** illustrates a generally cylindrical shield structure 100 provided between the space 11 and the window 60. The shield 100 is preferably in close proximity to the inside surface of the window 60. The shield 100 shadows the window 60 from coating material vapor in the processing space 11 of the chamber 12 and as well as from material sputtered from the target 16 or any other surface

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in the chamber 12. The shield 100 preferably blocks substantially all direct line-of-sight paths between any point on the surface 21 of the target 16 and the window 60.

Further according to this embodiment, the shield 100 has a plurality of longitudinal gaps therein, as illustrated by longitudinal slit 103 in **Fig. 1**, that is parallel to the axis of the chamber 12. Shields with a single or a plurality of gaps therein will interrupt such undesirable circumferential currents. Gaps such as slit 103 substantially interrupt circumferential paths in the shield 100 around the chamber 12. This prevents the induction of circumferential or azimuthal currents in the shield 100.

In addition, the shield 100 has an axial extent beyond the axial extent of the coil assembly 30 that reaches substantially the full effective axial extent of the electric field from the coil assembly 30. As a result, the electrically conductive shield 100 effectively suppresses electric fields in the secondary plasma that are parallel to the axis of the chamber 12, preventing such axial electric fields that would capacitively shield the coil assembly 30 from the volume 26 and thereby undermine the coupling efficiency of energy to the volume 26 from the coil assembly 30. It is preferred that the shield 100 extend axially from behind the plane of the surface 21 of the target 16 to at least beyond the window 60 and coil assembly 30. With this configuration, the shield 100 more effectively short-circuits axial electric fields in the secondary plasma, thereby enhancing the inductive coupling of energy from the coil assembly 30 into the secondary plasma.

The preferred embodiment of the invention also produces a high coupling efficiency of energy from the coil assembly 30 into the volume 26 due to a close spacing of the shield 100 from and its proximity to the window 60. This spacing is maintained at a distance that is preferably not more than the mean free path of atoms or molecules in the gas or the minimum diffusion length of the secondary plasma within the chamber 12. This close shield-to-window spacing is in contrast to other embodiments described below, which permit formation of plasma adjacent a window or coil protecting non-conductive structure and behind any shield structure that is provided. Avoiding plasma formation behind the window has a tendency of increasing the percentage of energy from the coil or other plasma-generating electrode into the volume through which the sputtered particles pass, thereby increasing the effective plasma and thus the ionization efficiency of the sputtered material. In the apparatus 10, it is contemplated that processing gas pressures in the range of about 5 to 50 milli-Torr will be used. The mean free path of argon gas at such pressures is from 11 mm to 1.0 mm, respectively. As a result, the preferred spacing of the shield 100 from the window 60 is approximately 1.0 to 15 mm.

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Slits or gaps such as slit 103 are preferably made greater than approximately 15 mm in width. The width of the slit 103 is sufficiently wide to allow the secondary plasma to form in the slit 103 in order to clean sputtered material that might deposit on the edges of the shield 100 adjacent the slit 103, or on the window 60 as a result of sputtered material that passes through the slit 103. Such secondary plasma that forms in the slit 103 will extend against the window 60 in the vicinity of the slit 103 and continuously remove, by resputtering the material that deposits on the window 60 at the slit 103.

In lieu of a window 60, the coil assembly 30 may be alternatively embedded in an electrical insulation block 66 within the chamber 12, as illustrated in Fig. 2, where the insulation block 66 functions in a manner similar to that of the window 60 to isolate the coil assembly 30 from the plasma in the chamber 11 and from sputtered material. The shield 100 is configured relative to the insulation 66 in the same way it is configured relative to the window 60, in Fig. 1.

Rather than having a single slit 103, the shield 100 according to one preferred embodiment of the invention is illustrated in Figs. 3 and 3A as formed of two generally cylindrical arrays, including an outer shield array 101 and an inner shield array 102, of narrow axially oriented generally rectangular segments or sections 105 separated by axially oriented gaps 106. The gaps 106 preferably have the characteristics and properties of the slit 103 described above. The sections 106 are preferably of equal width and spaced at intervals that are effective to prevent locally circulating or eddy currents. The length of the intervals is preferably approximately from 3 to 5 centimeters, center to center, where the RF energy is at approximately 2 MHZ. The ideal interval length may vary with the electrical resistance or thickness of the shield sections and generally may be made smaller where the wave length of the energy from the RF generator 32 is shorter.

The outer and inner arrays 101 and 102 are mounted at their opposite ends to respective outer and inner edges 111 and 112 of spacer rings 113 and 114. The sections 105 are preferably made of aluminum or alumina and the spacer rings may also be made of aluminum or alumina or of a dielectric material such as quartz. The sections 105 are arranged on the rings 113, 114 such that the gaps 106 of the inner array 102 generally align radially with the centers of the sections 105 of the outer array 101, while similarly the gaps 106 of the outer array 101 generally align radially with the centers of the sections 105 of the inner array 102.

In an alternative embodiment, the shield arrays may be in the form of shields 101a, 102a and formed of sheet material sections 105a such as illustrated in Fig. 3B, with the gaps formed therein as oppositely facing slots 106a and 106b. The slots 106a, 106b may be formed with their

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opposite slot edges 107a,108a and 107b,108b oppositely offset from the cylindrical surfaces of the respective array 101a,102a so that the slots face in opposite directions, as illustrated by the arrows 109a, 109b, thereby more effectively blocking all paths of possible straight line movement of material from the volume 26 of the space 11 onto the window 60 or insulating material 66.

Figs. 4 and 4A illustrates an alternative form of shield 100a, with elongated slots 106c formed therein that have lengths slightly less than the lengths of the shield 100a. The sections 105b between the slots 106c have the same general characteristics as the sections 105 described above. Such a shield 100a may be substituted for either or both of the shield arrays 101 and 102 of **Figs. 3, 3A and 3B**. **Fig. 4B** illustrates slots 106d formed as a sidewardly facing slot as are slots 106d in sections 105c similar to slots 106a and 106b of **Fig. 3B**. While the multiple layered shield 100 of **Figs. 3-3B** is preferred, particularly where the apparatus 10 is a coating apparatus such as an IPVD apparatus, the shield 100a may also be used as a single layer shield. A single shield 100a is suitable where the material from which the window 60,66 is to be shielded is material etched from the surface of a substrate, where the amount of material from an etched substrate from which the window is to be shielded is small, rather than in coating processes where material from a target from which the window is to be shielded is relatively large.

A further alternative 100b to the shield 100,100a is illustrated in cross-section in **Fig. 4B**. The shield 100b includes a single slotted layer having one gap 103a such as the gap 103 of **Fig. 3**, that extends the complete axial dimension of the shield 100b. The remaining gaps 106d are in the form of slots 106c of the embodiment of **Fig. 4A**, which is similar to the outer layer 101 of the embodiment of **Fig. 3A**. The function of the inner layer 102 of **Fig. 3A** is provided by ends 107c, 108c of sections 105c welded to interrupt straight line paths from the volume 26 onto the window 60.

Shields 100,100a,100b configured as described above, prevent the generation of eddy currents in local sections 105-105c of the shields 100,100a,100b thereby preventing the loss of power that could otherwise be use for the plasma and prevent heating of the shields due to eddy current flow.

Those skilled in the art will appreciate that the implementation of the present invention herein can be varied, and that the invention is described in preferred embodiments. Accordingly, additions and modifications can be made, and details of various embodiments can be interchanged, without departing from the principles and intentions of the invention.

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What is claimed is:

1. An ionized physical vapor deposition apparatus comprising:

a vacuum chamber to contain a gas maintained at a vacuum pressure level and having a vacuum processing space therein, the chamber having an axis defining an axial dimension parallel thereto, a circumferential dimension extending around the axis and a radial dimension perpendicular to the axis;

a source of vapor deposition material in communication with the vacuum processing space;

a substrate support centered on and perpendicular to the axis at one end of the vacuum processing space;

a coil extending around the vacuum processing space;

electrically non-conductive protective structure between the coil and the vacuum processing space physically isolating the coil from plasma in the vacuum processing space;

an RF energy source connected to the coil and operative to energize the coil so as to inductively couple RF energy through the electrically non-conductive protective structure into the vacuum processing space to energize a plasma in the gas in the vacuum processing space to ionize deposition material in the vacuum processing space emitted by the source of vapor deposition material; and

a shield extending around the vacuum processing space inside of the chamber proximate to the electrically non-conductive protective structure, the shield including:

a plurality of closely spaced concentric cylindrical arrays of shield layers, each having a plurality of axially extending gaps therein to interrupt circumferential conductive paths in the shield around the chamber and to divide the shield into segments of the circumferential dimension that are sufficiently narrow to substantially impede induction, by the RF energy, of eddy currents in the shield, the axially extending gaps and circumferential segments of two adjacent layers being arranged so that each of the axially extending gaps of a first layer of the two adjacent layers is in radial alignment with a segment of a second layer of the two adjacent layers so as to interrupt straight paths of travel of coating material from the vacuum processing space to the electrically non-conductive structure, and

the shield includes dielectric spacers connected between the concentric cylindrical arrays of shield layers electrically insulating the concentric cylindrical arrays of shield layers from each other and maintaining spacing between adjacent concentric cylindrical arrays of shield layers.

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2. The apparatus of claim 1 wherein:

the vacuum chamber includes a gas tight chamber wall having a window therein formed of the electrically non-conductive structure; and

5 the coil is located outside of the chamber and extending around the chamber wall outside of the window.

3. The apparatus of claim 1 wherein:

10 the shield is electrically conductive to electrically short circuit substantially all axial electric field in the plasma.

4. The apparatus of claim 1 further comprising:

15 a bias potential generator connected to the substrate support to electrically bias a substrate on the substrate support to accelerate ions of the deposition material from the plasma in the vacuum processing space in a direction toward and normal to the substrate.

5. The apparatus of claim 1 further comprising:

20 a magnet surrounding the chamber having a magnetic field that is oriented axially in the vacuum processing space within the chamber.

6. The apparatus of claim 1 wherein:

25 atoms of the gas within the chamber have a mean free path such that the axially extending gaps are sufficiently greater than the mean free path of atoms of the gas in the chamber to permit formation of plasma in the vacuum processing space.

7. The apparatus of claim 1 wherein:

the coil has an axial length and the shield has an axial length that is at least the axial length of the coil.

30 8. The apparatus of claim 1 wherein:

the segments of the shield are physically separated from each other by the axially extending gaps and are electrically insulated from each other.

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9. An ionized physical vapor deposition apparatus comprising:

a vacuum chamber having a processing space enclosed therein to be maintained at a vacuum pressure level having an axis therethrough defining an axial direction;

a sputtering target centered on the axis at one end of the chamber;

5 a substrate support centered on the axis in the chamber at an end thereof opposite the target and facing the target to support a substrate thereon parallel to the target;

a dielectric window surrounding the axis and the processing space between the substrate support and the target;

at least one coil surrounding the axis and the dielectric window;

10 a target power supply connected to the target and operative to generate a plasma to sputter coating material from the target and into the processing space;

an RF energy source connected to the coil and operative to energize the coil to inductively couple RF energy through the dielectric window to energize an inductively coupled plasma in the processing space to ionize coating material sputtered from the target into the processing space;

15 means for electrically or magnetically directing motion of the ionized coating material from the processing space and toward a substrate on the substrate support;

an electrically conductive shield encircling the chamber inside of the dielectric window and in close proximity thereto, and

20 the shield including:

a plurality of closely spaced concentric cylindrical arrays of shield layers, each shield layer having a plurality of axially extending gaps therein to interrupt circumferential electrically conductive paths in the shield, the axially extending gaps dividing the shield layers into respective pluralities of segments in an azimuthal direction around the axis that are sufficiently narrow to substantially impede induction, by the RF energy, of eddy currents in the shield, the axially extending gaps and segments of the shield layers being arranged so that each of the axially extending gaps of one layer of the shield layers is in radial alignment with a segment of an adjacent layer, to interrupt straight paths of travel of coating material from the processing space to the electrically non-conductive structure, and

30 dielectric spacers between and interconnecting the concentric cylindrical arrays of shield layers to electrically insulate the concentric cylindrical arrays of shield layers

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from each other and maintaining spacing between the concentric cylindrical arrays of shield layers.

5 **10.** The apparatus of claim 11 wherein:

the processing space is configured to contain atoms of gas therein having a mean free path, and the shield and the dielectric window have a spacing therebetween that is not more than the mean free path of the atoms of the gas in the processing space in the chamber so as to avoid plasma formation behind the shield.

10

11. The apparatus of claim 11 wherein:

the ionized coating material directing means includes a bias potential generator connected to the substrate support to electrically bias a substrate on the substrate support to accelerate ions of the sputtered coating material in a direction normal to the substrate.

15

12. The apparatus of claim 11 further comprising:

the ionized coating material directing means includes a magnet surrounding the chamber having a magnetic field oriented axially in the processing space.

20

13. The apparatus of claim 11 wherein:

the processing space configured to contain atoms of the gas therein having a mean free path, and the axially extending gaps in the shield are sufficiently greater than the mean free path of the atoms of the gas in the processing space to permit formation of plasma in the axially extending gaps.

25

14. The apparatus of claim 11 wherein:

the coil has an axial length and the shield has an axial length that is at least the axial length of the coil.

30

15. The apparatus of claim 11 wherein:

the shield includes an array of a plurality of segments that are physically separated from each other by the axially extending gaps and are electrically insulated from each other.

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16. The apparatus of claim 11 wherein:

the dielectric window forms part of a gas tight chamber wall, the coil being located radially outward of the dielectric window outside of the chamber.

5 17. The apparatus of claim 11 wherein:

the coil is positioned inside of the chamber; and

the dielectric window is located inside the chamber between the coil and the processing space.

10 18. The apparatus of claim 11 wherein:

the RF energy source is operative to energize the coil at a frequency between 0.1 MHZ and 60 MHZ.

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19. A plasma processing apparatus comprising:

a vacuum sputtering chamber having an axis therethrough defining an axial direction, opposite ends and a gas tight sidewall extending circumferentially around the axis and the vacuum sputtering chamber between the opposite ends, the gas tight sidewall having a dielectric window therein extending around the vacuum sputtering chamber;

a support in the chamber at one end thereof to support a surface thereon from which material is to be sputtered;

a coil outside of the chamber and surrounding the dielectric window;

an RF energy source connected to the coil to energize the coil to inductively couple RF energy through the dielectric window to produce an inductively coupled plasma within the vacuum sputtering chamber;

a shield extending circumferentially around the chamber inside of and in proximity to the dielectric window, the shield having a plurality of axially extending gaps therein spaced at intervals around the axis of the chamber so as to substantially interrupt circumferential electrical current paths around the vacuum sputtering chamber and to divide the shield into segments sufficiently narrow to substantially impede eddy currents in the shield;

the shield including a plurality of closely spaced concentric shield layers, each having a plurality of the axially extending gaps therein dividing each shield layer into respective pluralities of segments; and

the axially extending gaps and segments in the shield layers being arranged so that each of the axially extending gaps of one layer of the shield layers is in radial alignment with a segment of an adjacent shield layer, to substantially interrupt straight paths of travel of coating material from a processing space in the vacuum sputtering chamber to the dielectric window.

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20. The apparatus of claim 24 wherein:

the shield layers are electrically conductive to electrically short-circuit substantially all axial electric field in the plasma.

5

21. The apparatus of claim 24 wherein:

the chamber has atoms of the gas therein having a mean free path sufficiently less than the axially extending gaps to permit formation of plasma in the axially extending gaps.

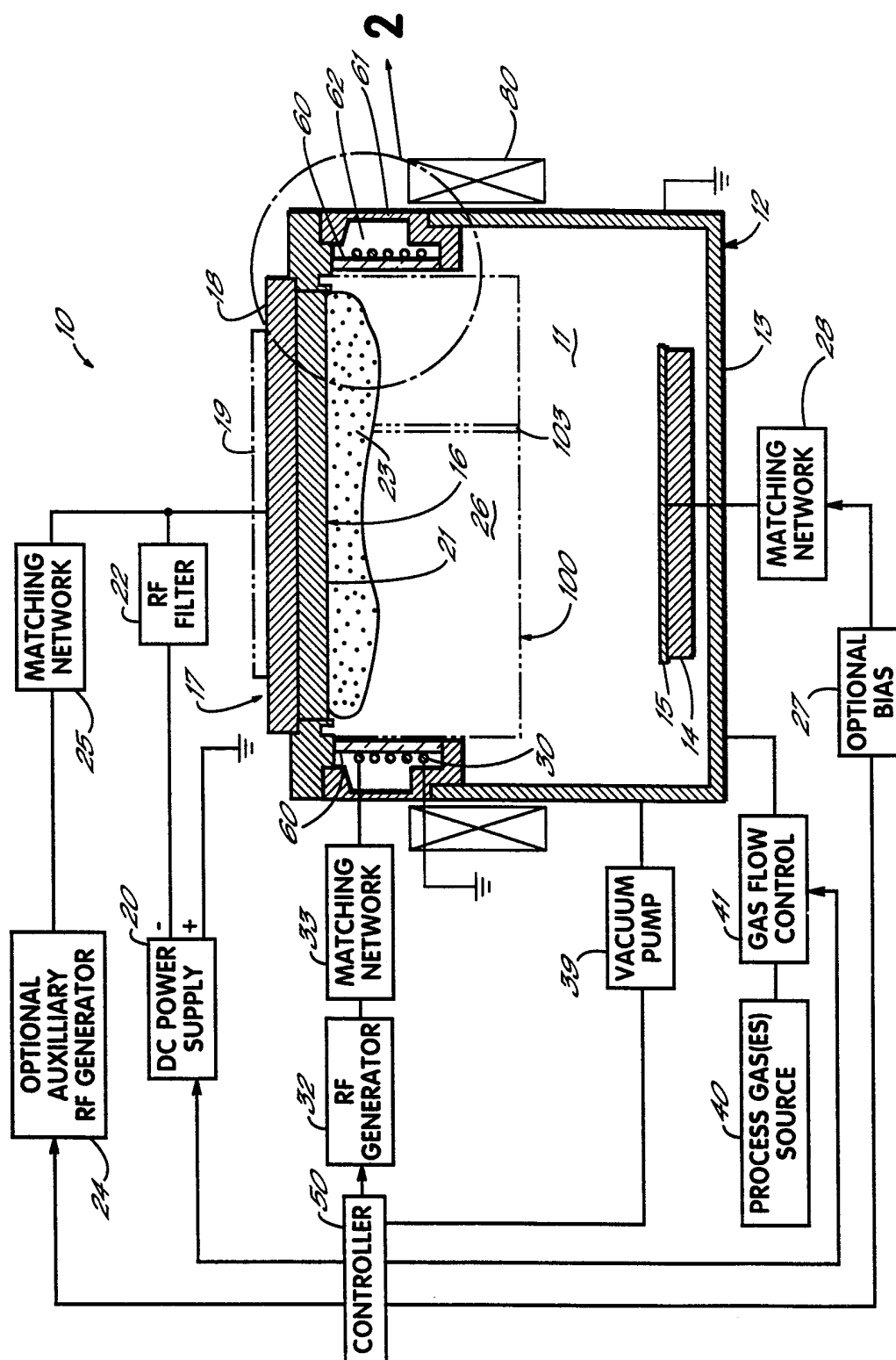
22. The apparatus of claim 24 wherein:

10

the shield has a length in the axial direction that is at least the axial length of the coil.

23. The apparatus of claim 24 wherein:

the segments of the shield are electrically insulated from each other.



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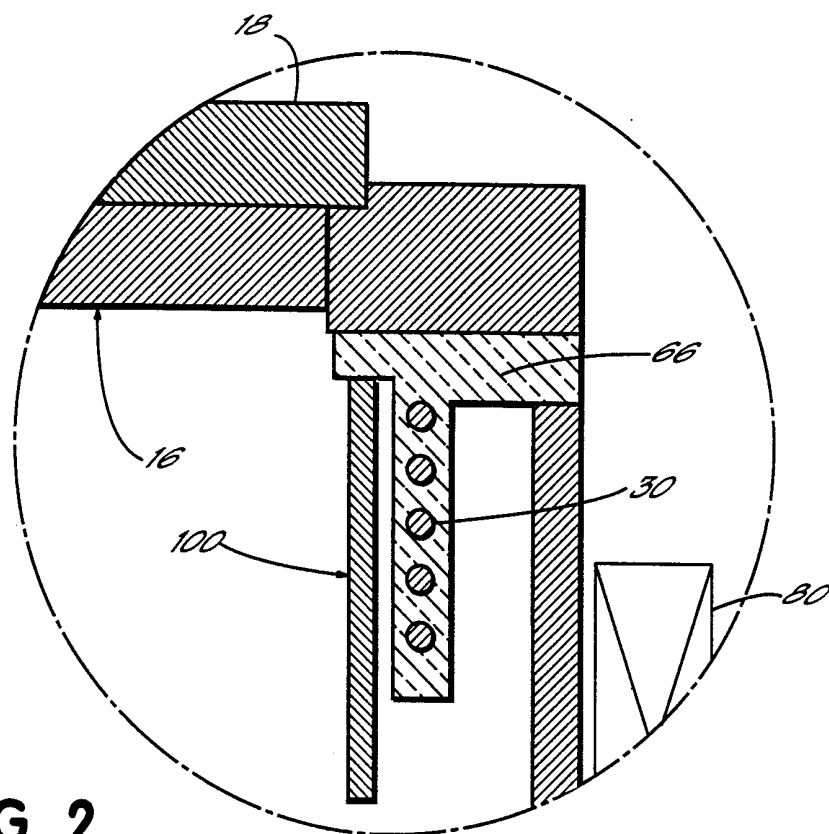


FIG. 2

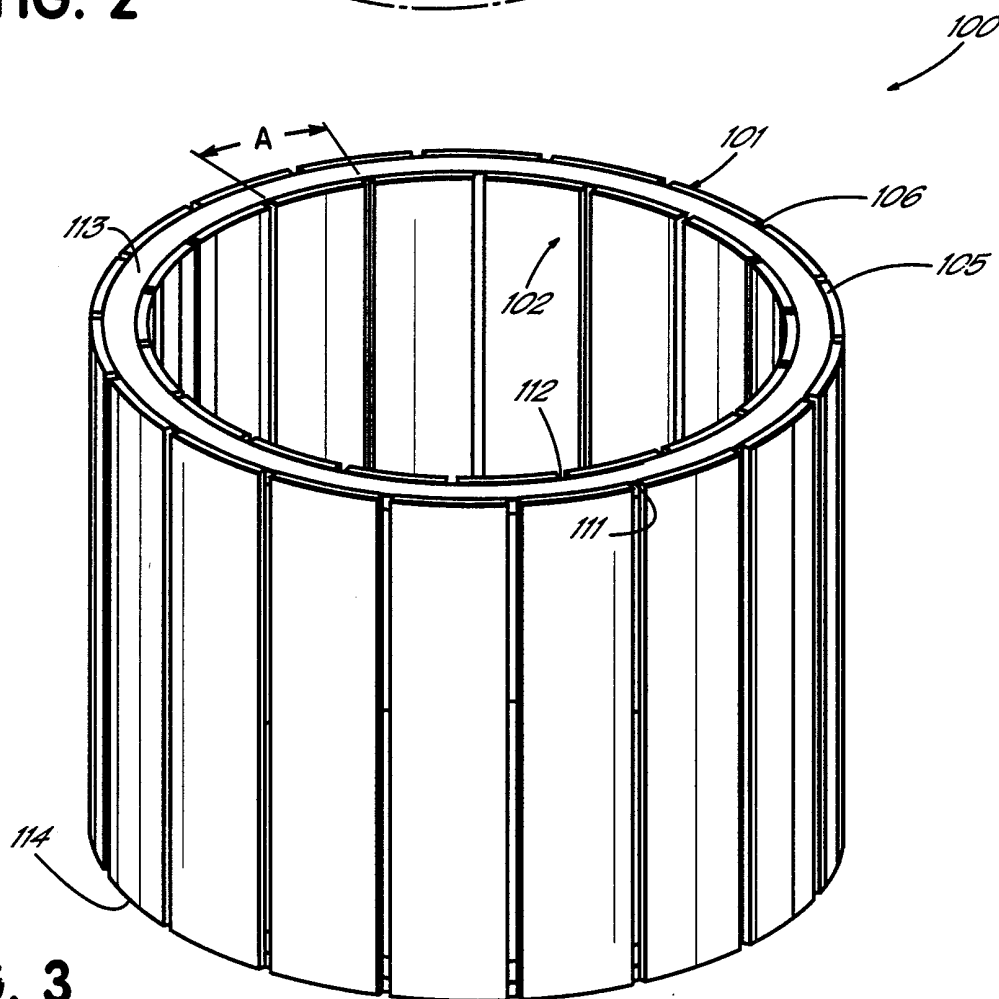


FIG. 3

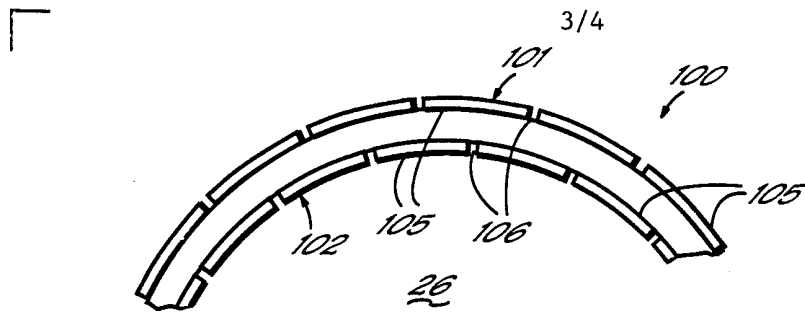


FIG. 3A

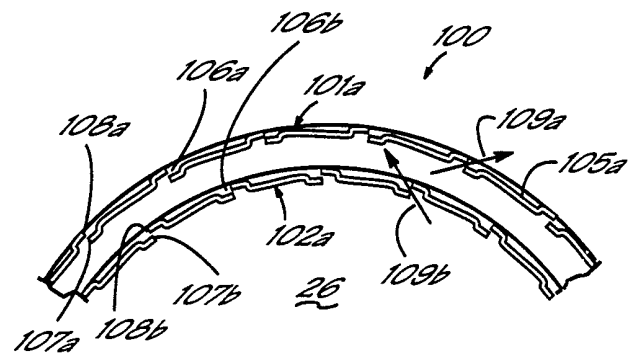


FIG. 3B

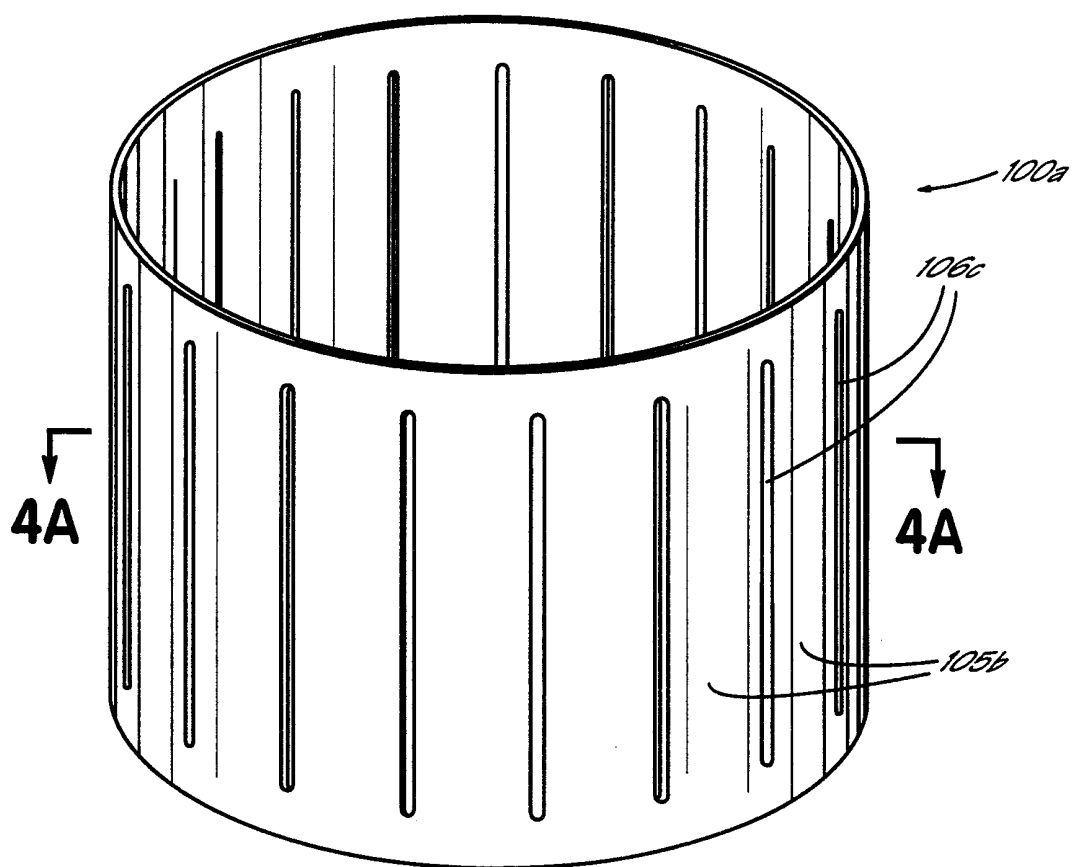


FIG. 4

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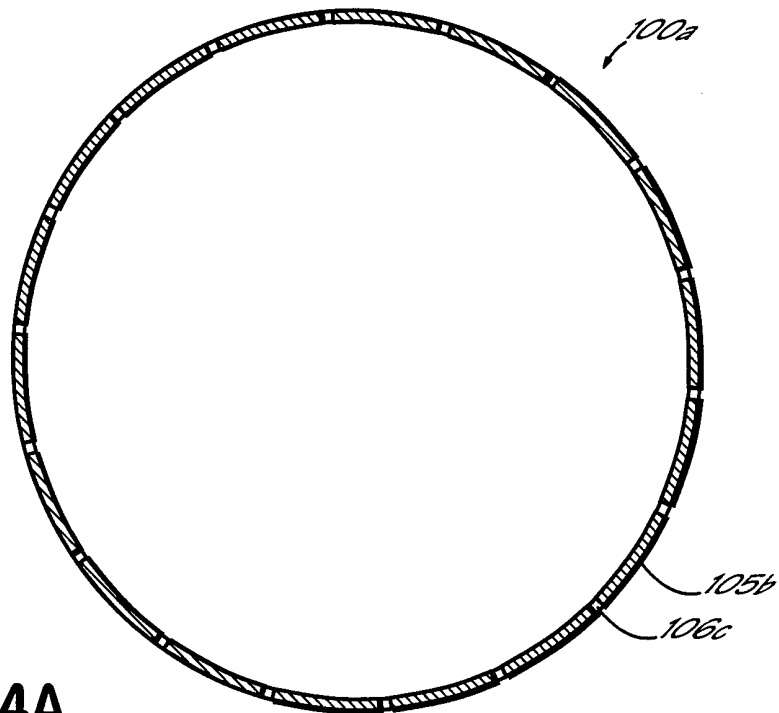


FIG. 4A

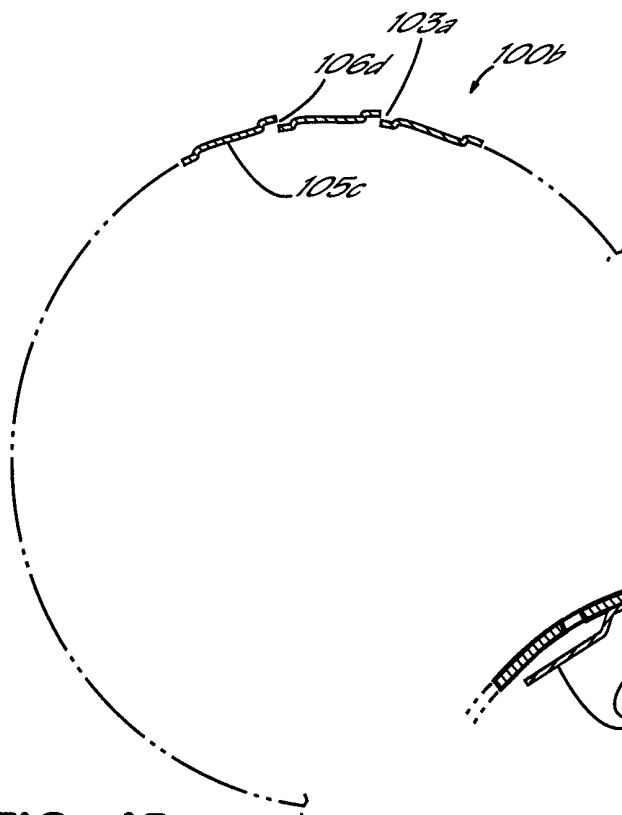


FIG. 4B

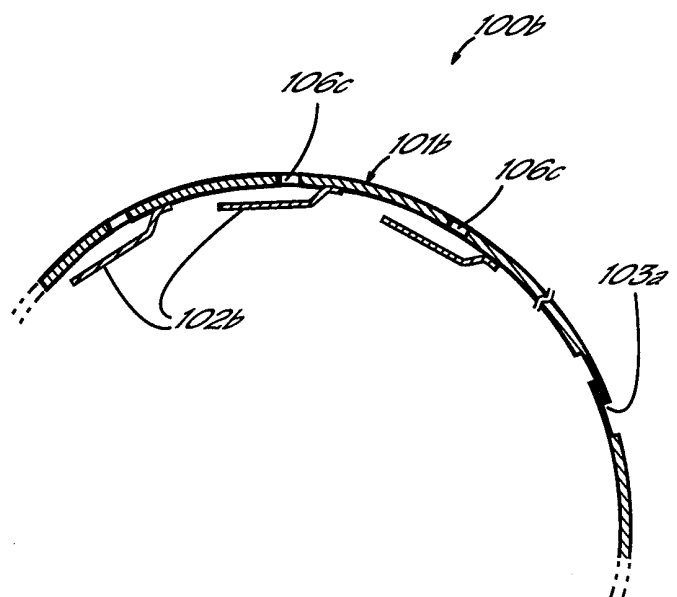


FIG. 4C

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/15289

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : C23C 14/32

US CL : 204/298.11, 298.08

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)

U.S. : 204/298.11, 298.08, 298.01, 298.02, 298.06, 298.11, 192.12

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)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---- Y	US 5,763,851 A (FORSTER et al) 09 June 1998, whole reference.	1-4, 6-11, and 13-23 ----- 5 and 12
X --- Y	EP 0782172 A2 (APPLIED MATERIALS, Inc.) 02 July 1997, whole reference.	1-4, 6-11, and 13-23 ----- 5 and 12
Y, P	US 5,800,688 A (LANTSMAN et al) 01 September 1998, whole reference.	1-23
Y	US 5,431,799 A (MOSELY et al) 11 July 1995, col. 4, lines 36-50; col. 6, lines 24-31; Fig. 2).	5 and 12



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	*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
A document defining the general state of the art which is not considered to be of particular relevance	*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
E earlier document published on or after the international filing date	*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
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)	*A* document member of the same patent family
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	

Date of the actual completion of the international search

16 AUGUST 1999

Date of mailing of the international search report

26 OCT 1999

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/15289

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,178,739 A (BARNES et al) 12 January 1993, col. 5, lines 22-28 and Fig. 1.	5 and 12
A	EP 0801413 A1 (VARIAN ASSOCIATES, Inc.) 15 October 1997.	1-23
A	EP 0836218 A2 (APPLIED MATERIALS, Inc.) 15 April 1998.	1-23