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(54) **CYLINDRICAL AC/DC MAGNETRON WITH COMPLIANT DRIVE SYSTEM AND IMPROVED ELECTRICAL AND THERMAL ISOLATION**

Related U.S. Application Data

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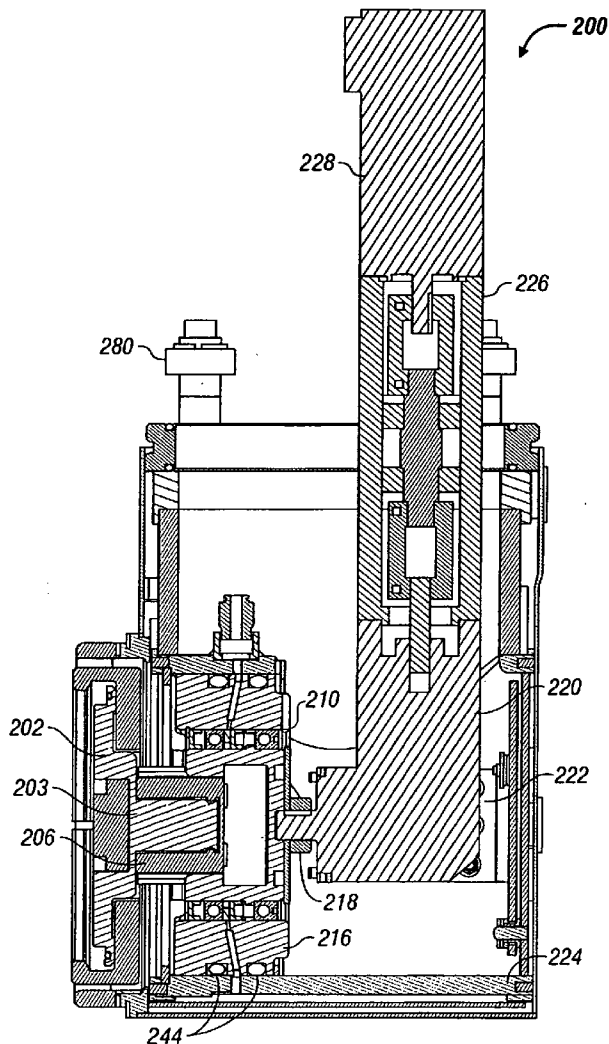
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(57) **ABSTRACT**

An AC/DC cylindrical magnetron with a drive system that absorbs large ons in the rotation of the target tube, an efficient high capacity electrical transfer and improved electrical isolation.

(21) Appl. No.: **10/840,993**

(22) Filed: **May 7, 2004**



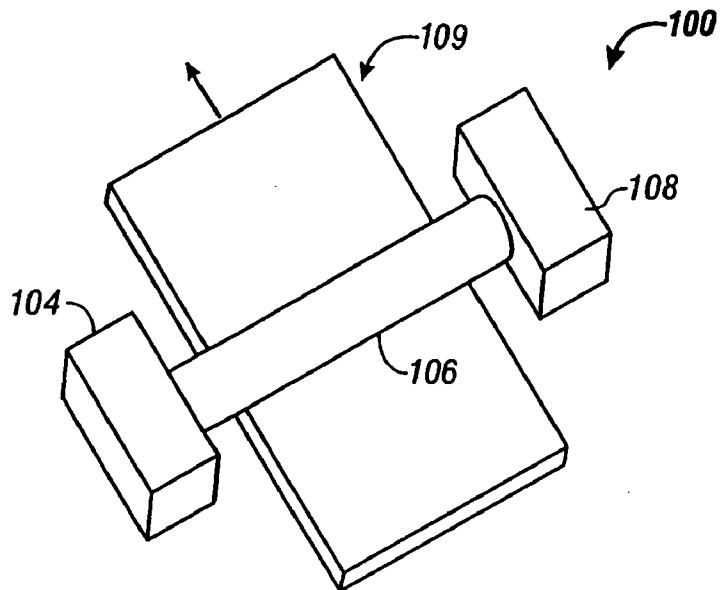


FIG. 1A (PRIOR ART)

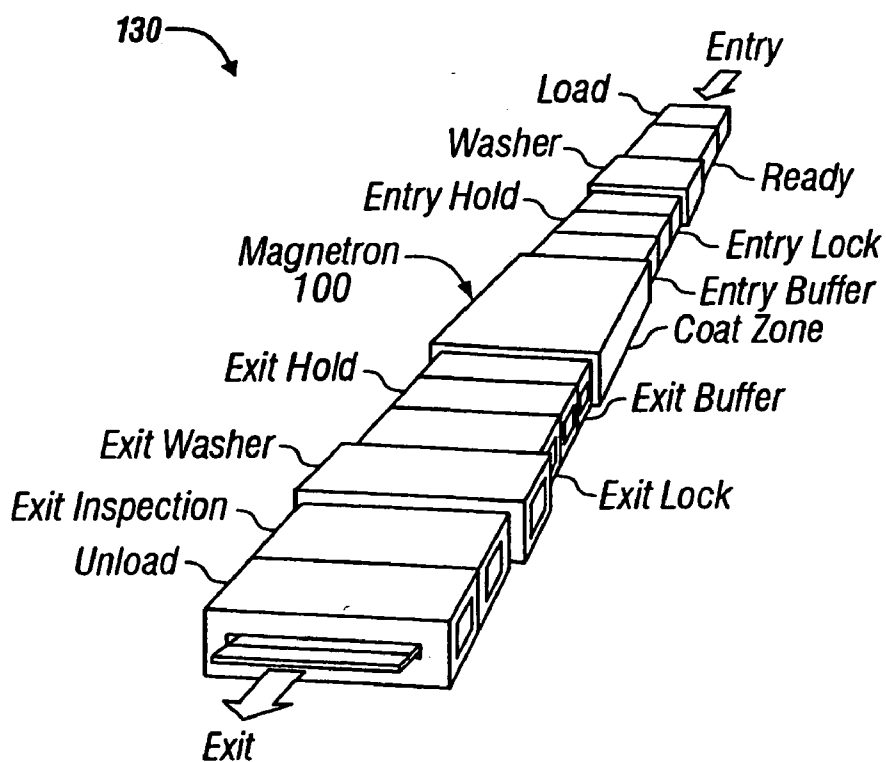


FIG. 1B (PRIOR ART)

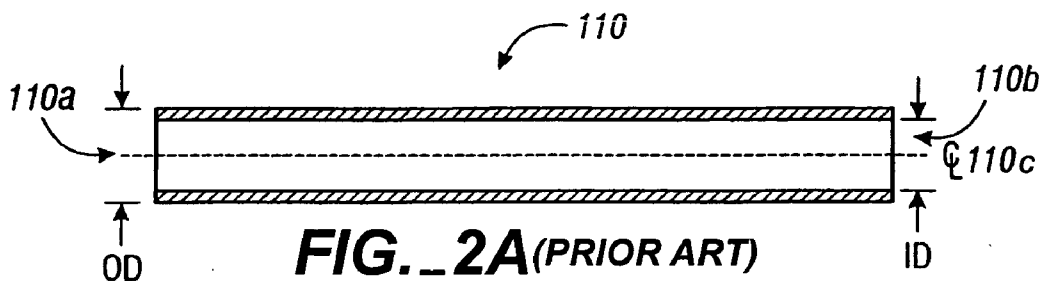


FIG. 2B (PRIOR ART)



FIG. 2C (PRIOR ART)



FIG. 2D (PRIOR ART)

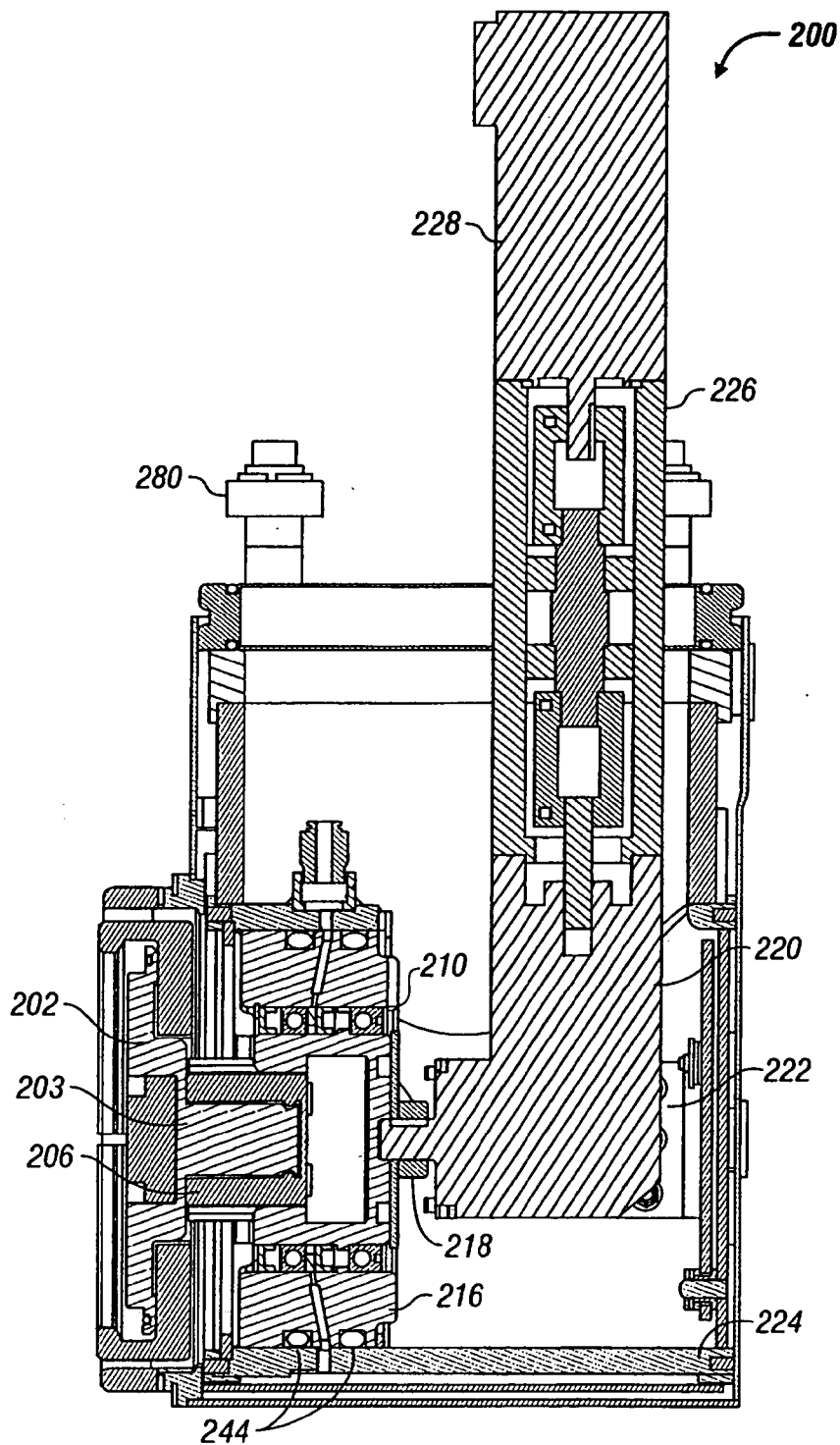


FIG. 3

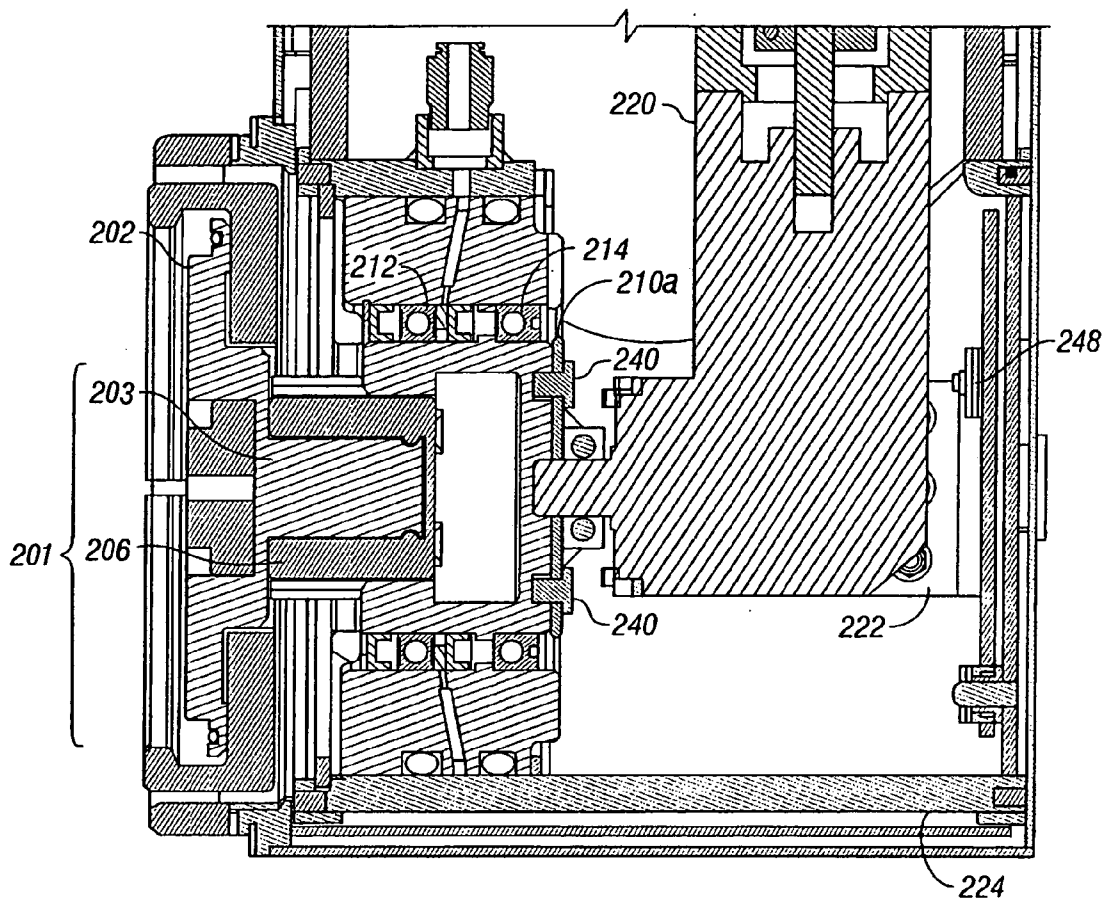


FIG._4

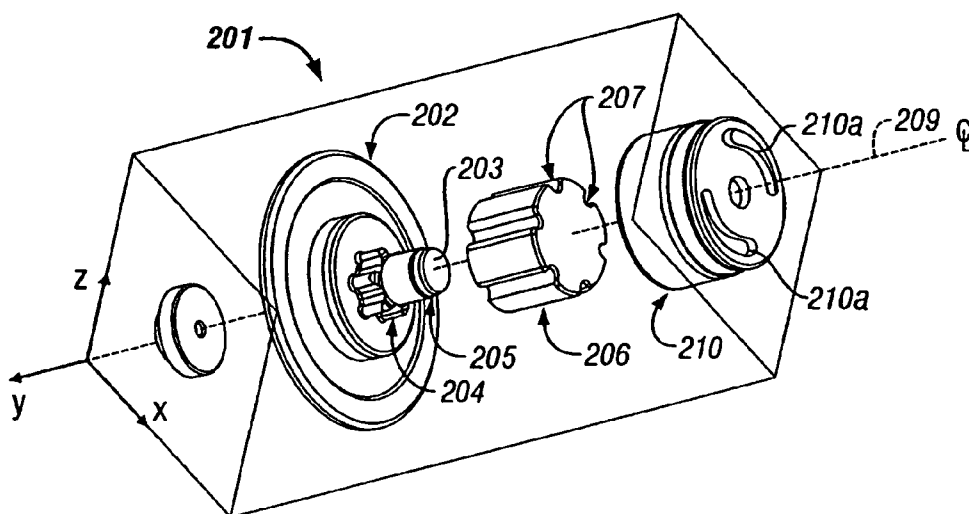


FIG._5

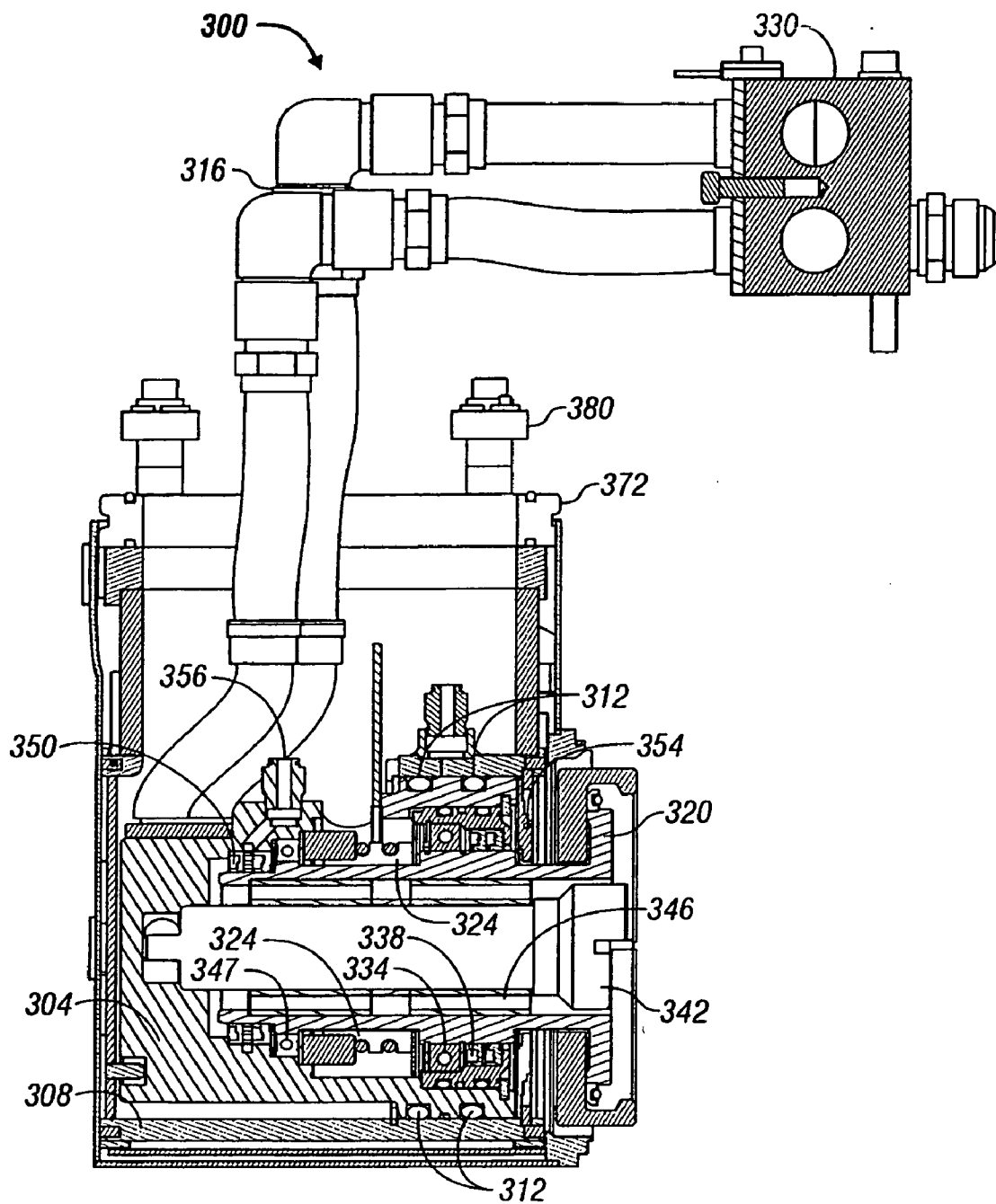


FIG. 6

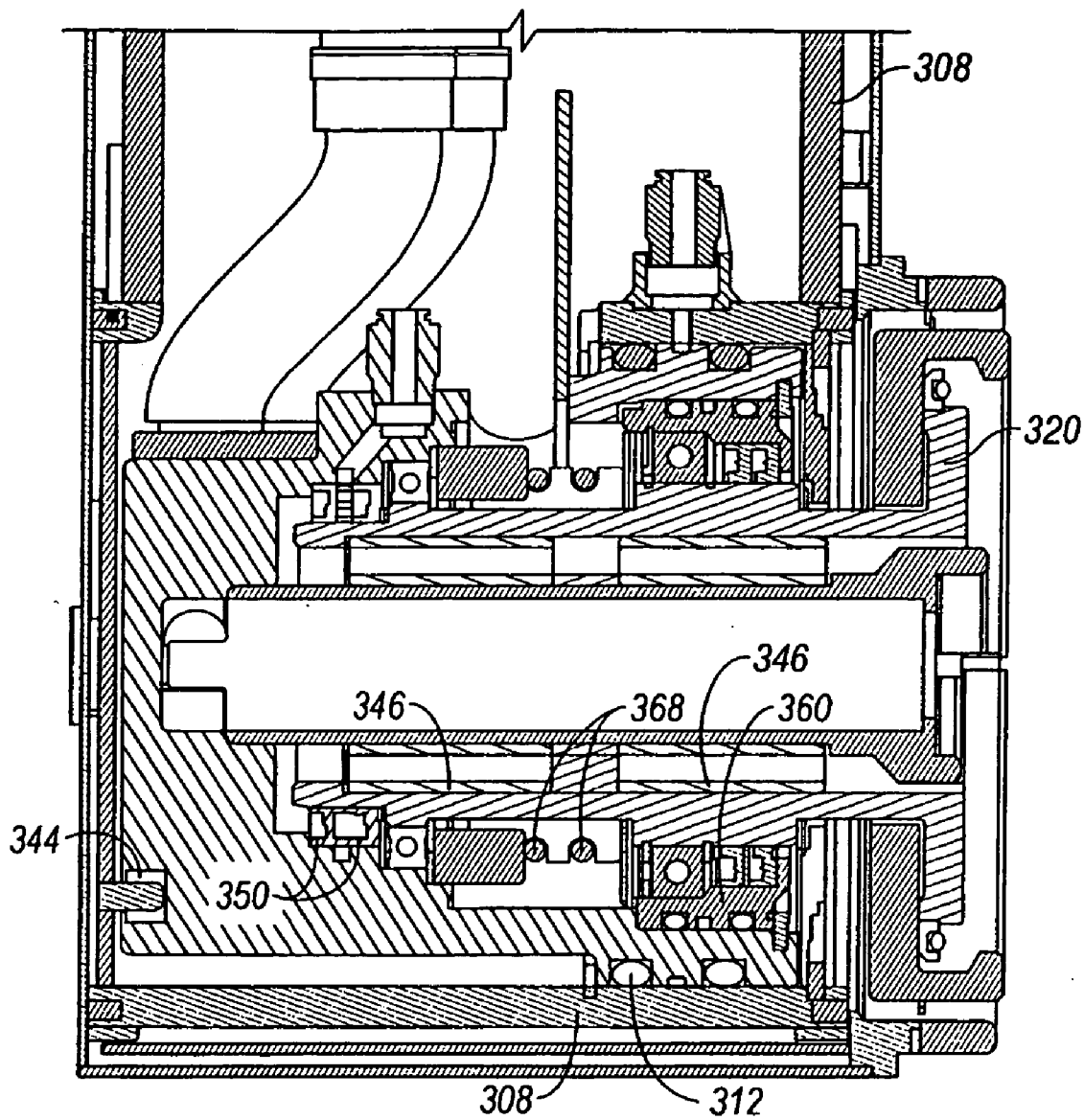


FIG. 7

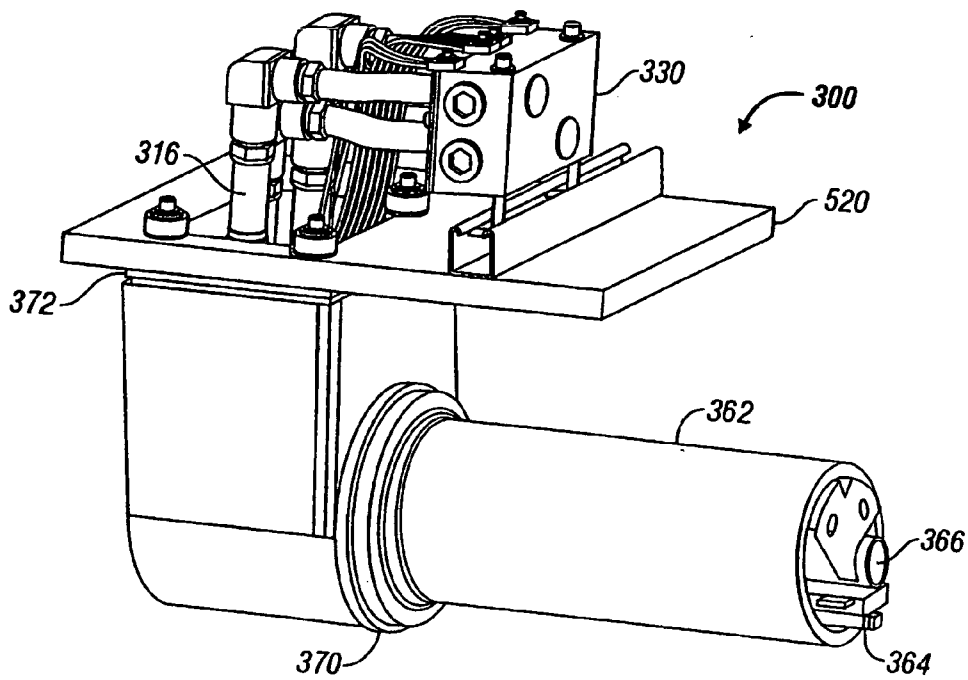


FIG. 8

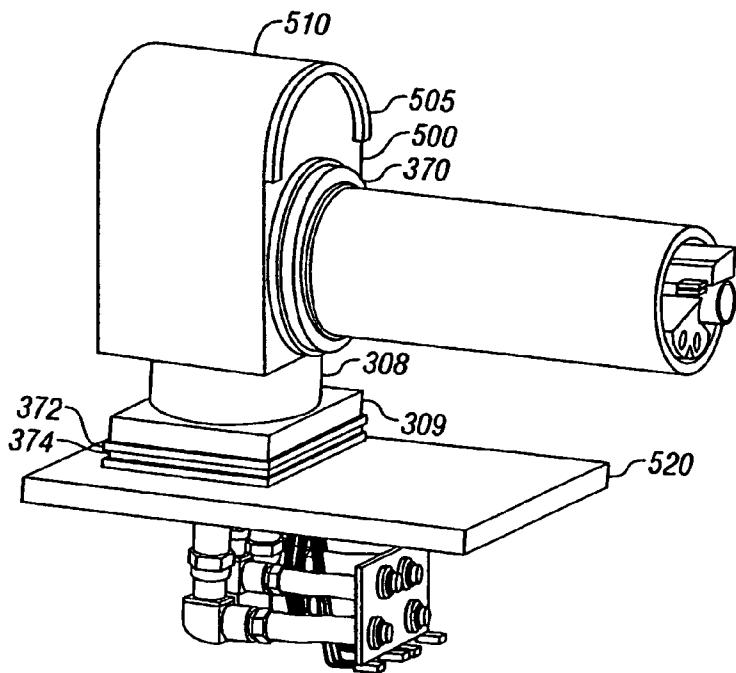


FIG. 9

FIG._10

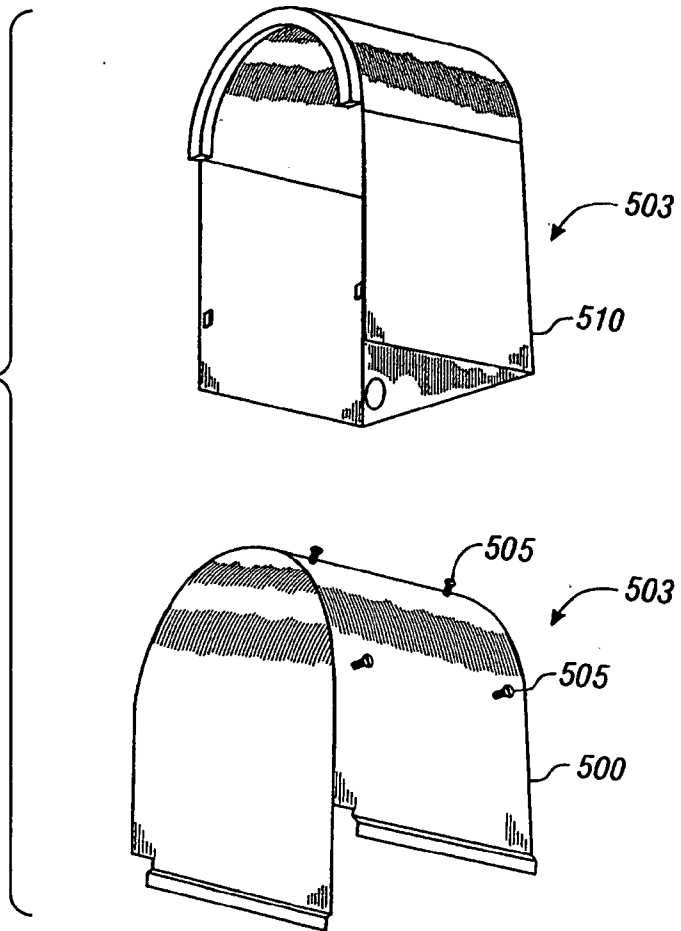
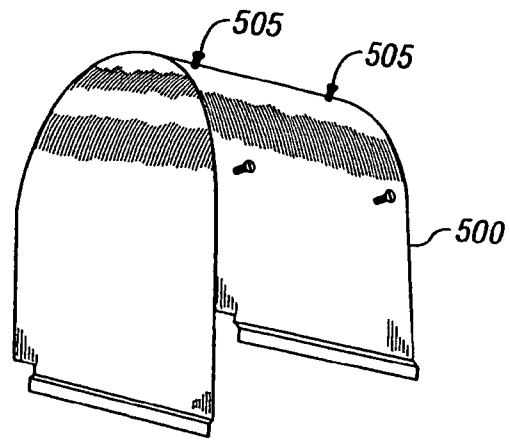


FIG._11



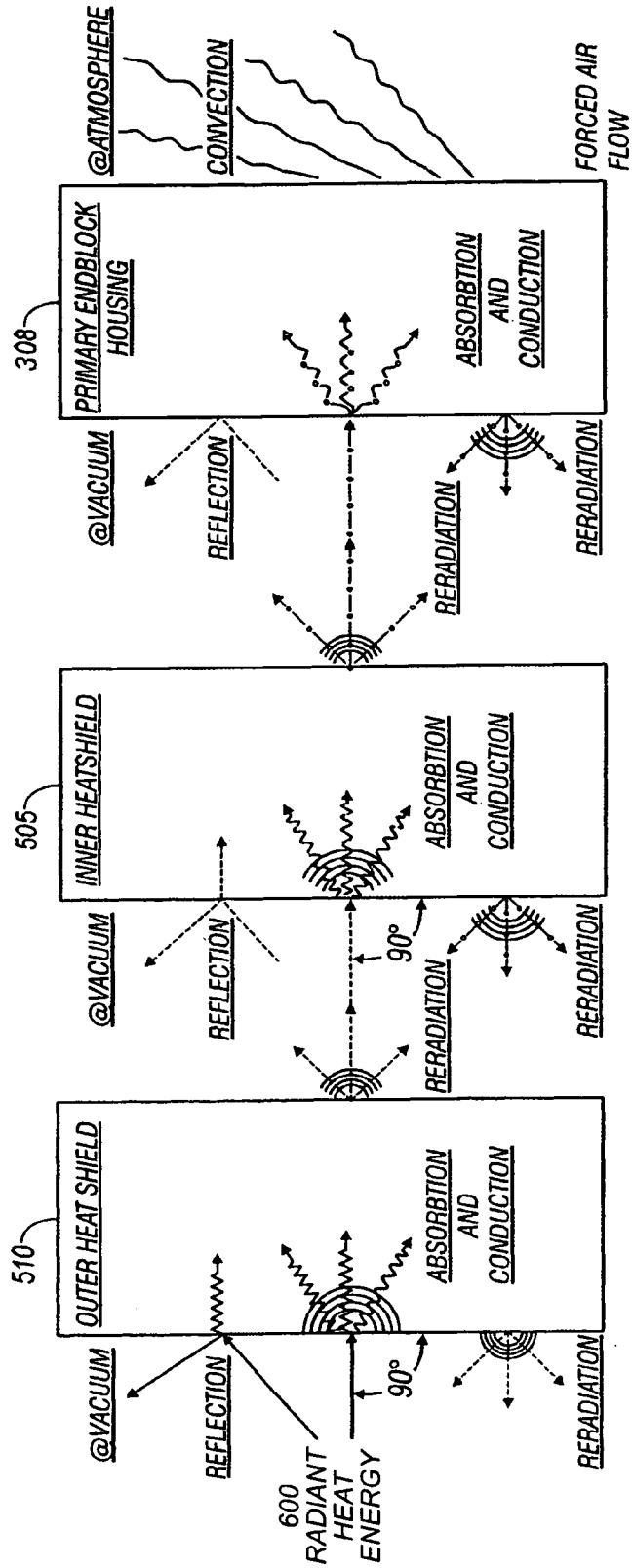


FIG. 12

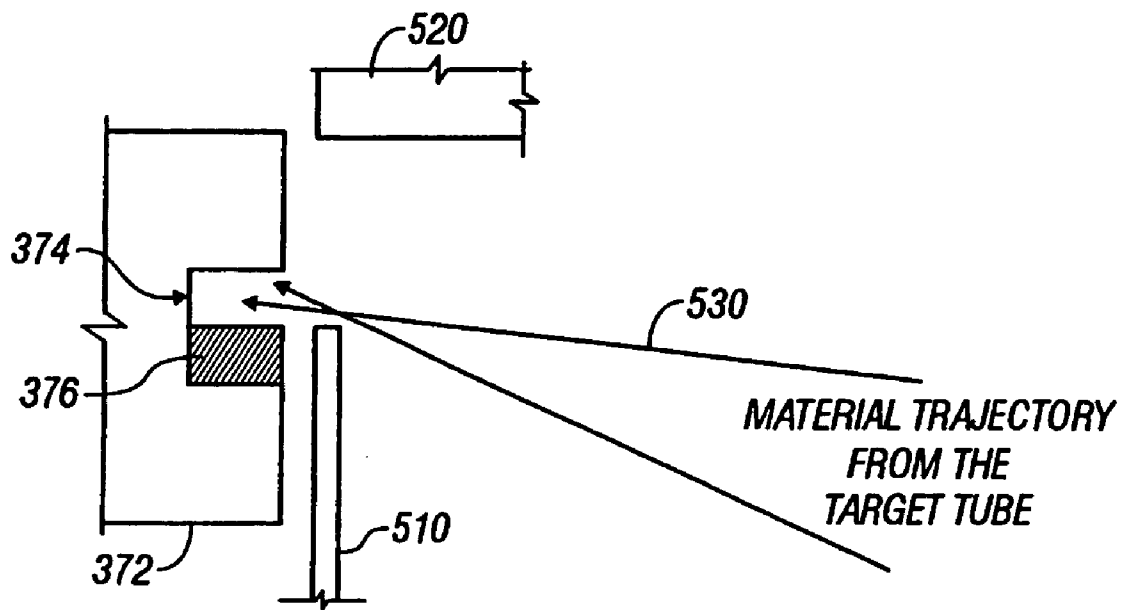


FIG. 13

**CYLINDRICAL AC/DC MAGNETRON WITH
COMPLIANT DRIVE SYSTEM AND IMPROVED
ELECTRICAL AND THERMAL ISOLATION**

BACKGROUND OF THE INVENTION

[0001] The cylindrical magnetron is used in a large coating machine for coating very large sheets of glass or other materials. One application where these sheets of glass are used is in construction of curtain wall buildings where a single glass sheet can be up to 15 feet wide by about 20 plus feet high. The sheets are run through the coating machine shortly after the glass is manufactured. Thus, these are large-scale machines which must rapidly and evenly coat glass as quickly as it can be manufactured. In addition to the quality of the coating the magnetron deposits upon the glass, dependability and serviceability of the magnetron is of the utmost importance.

[0002] This is not an easy task taking into account the constraints of the process that is involved. A cylindrical magnetron sputters material from a rotating target tube onto the glass as it is transported past the target. In order to coat such a large piece of glass the target tube can be up to 15 feet in length and 6 inches in diameter and can weigh 1700 pounds. Another complication is that the sputtering actually erodes the target tube during the sputtering process, so the target tube is constantly changing shape during its serviceable lifetime. The sputtering process can require that an extremely high AC or DC power (800 Amps DC, 150 kW AC) be supplied to the target. This power transfer creates extreme heat in the target tube and the surrounding components, which must be cooled in order assure proper performance and to avoid catastrophic failure of the magnetron. Thus, water is pumped through the center of the rotating target tube at high pressure and flow rate. Efficient and effective sputtering also requires that the process take place in a vacuum or a reduced pressure relative to atmosphere. Thus the rotating target must have a very robust sealing system to prevent the high pressure water from leaking into the vacuum environment.

[0003] Rotating such a large target tube in such an environment is a difficult task. FIG. 1A depicts magnetron 100 for illustrative purposes. FIG. 1B shows magnetron 100 integrated into a large glass coating system 130. Glass coating system 130 may be several hundred feet long and contain many magnetrons. Target tube 106 is supported by two end blocks 104 and 108 as glass sheet 110 passes by. The end blocks 104 and 108 generally supply cooling water, support and rotate the target tube, support a stationary magnetic array within the rotating target tube, and transfer the large amounts of electricity needed for the sputtering process. Effectively transferring electrical power to a rotating target tube is also a complex problem. Maintaining electrical isolation in a sputtering process is also crucial to continually laying down a uniform coating on the glass. If the drive system is not properly electrically isolated from the sputtering process, it will affect the quality of coating deposited upon the glass. The sputtered material may in fact also coat the drive and electrical components of the magnetron itself rather than the glass if they are not properly isolated. Aside from resulting in a poor coating, this has many other ramifications on the continuous reliable operation of the magnetron. For further information please refer

to "Coated Glass Application and Markets" by Russel J. Hill and Steven J. Nadel, The BOC Group, 1999 (ISBN # 0-914289-01-02).

[0004] The process of sputter deposition occurs at a high electrical potential, typically in an environment of a vacuum (relative to ambient pressure), with or without the addition of a gas to that environment. This potential is attained in DC operations between distinct anodes and cathodes. Typically the target having the material to be deposited functions as the cathode in DC applications. In the case of AC operations which are achieved by the use of dual rotational targets the targets constantly alternate potential and each provides the other the function of anode and cathode to complete the electrical circuit. For electron transfer between the anode and cathode to occur they must be and remain physically and electrically isolated from each other. The present invention transfers electrical power to and from the rotating target tubes in either DC or AC mode at the high power levels required.

[0005] Additionally the materials sputtered are often times conductive of themselves. Highly conductive metals such as silver, gold, copper, nickel, chromium and titanium may be applied. These materials differ depending upon the type (color, reflectivity, etc.) of film desired. Stray material can and does collect within the operational environment surfaces. If this stray material collection is not managed it can accumulate to an extent that it can lead to the failure of the electrical isolation of the cathode and anode resulting in a short between them or the formation of conductive paths that compromise the electrical isolation of other components within the area. This will lead to poor and uneven film quality and will require that the magnetron be disassembled and cleaned, both extremely undesirable consequences. Downtime of the magnetron, and thus the glass making process, is extremely costly and inconvenient for the glass manufacturer.

[0006] In either the case of DC or AC operation there are substantial voltages and currents applied to achieve rapid deposition rates to achieve increased production. This electrical energy needs to be carefully managed to have a controllable process that is efficient and safe. To achieve this several unique and novel features have been designed into the magnetron and its endblocks.

[0007] To transfer DC or AC electrical power to or from the target tube there are several particular aspects of each form of electrical power that need to be addressed that are not readily apparent. First, in DC operation current flow is through the cross section of the conductor or interface. Second, in the AC frequency range used for sputter deposition, typically referred to as the mid-frequency range (about 30 to 80 kHz or higher), the current flow occurs along the surface, or skin, of the conductor or interface. Penetration of the current into the conductor is minimal and not an easily modeled theoretical calculation. It is dependent upon the material from which the conductor is formed and upon the frequency of the alternating current. As the frequency increases the penetration into the conductor decreases. Third, in AC operation as current, voltage and frequency increase; a phenomenon known as an inductive heating effect can occur in various electrically conductive materials. The inductive depth and magnitude of the inductive heating varies with the shape, orientation and location of the mate-

rials relative to the current path of the AC circuit. The inductive phenomenon in this sputtering application is not well understood and there is little literature or documentation available describing its effects and mitigations for practical application. What is known is that metallic conductors can be inductively heated and that the effect increases in a non-linear manner the closer the secondary material is to the AC circuit path.

[0008] Inductive heating only occurs in AC operation. As the AC frequency increases the effect increases for a given voltage and current. Inductive heating occurs when high frequency alternating current travels from one point to another through a conductor. Physical contact with the conductor is not necessary for inductive heating to occur. The alternating current induces alternating electromagnetic flux fields around the conductor. These flux fields induce circular electron flow within electrically conductive materials in the vicinity of the fields. The induced circular electron flows are termed eddy currents. The heating of materials within the alternating flux fields is dependent on physical location, material conductivity, coupling, frequency, and power density. Heating of the material increases as the material comes closer to the conductor, as the material magnetic permeability increases, as the frequency increases, and as the power density increases.

[0009] FIG. 2A illustrates a cross section of an ideal target tube. Target tube 110 has opposing faces 110a and 110b. In ideal conditions face 110a and 110b will be parallel to each other and perpendicular to the centerline 110c, the axis of rotation of target tube 110. Ideally, the inner diameter at face 110a will be concentric with the outer diameter at face 110a. Likewise, the inner diameter at face 110b will ideally be concentric with the outer diameter at face 110b, and the inner diameter of the tube will be concentric with the outer diameter anywhere along the length of the tube. In reality, this is rarely true because it is not only difficult to manufacture such a tube, but also to inspect the tube throughout its entire length, and thereafter reject it as out of spec. Furthermore, as discussed earlier, the tube actually changes shape during normal operation as material is sputtered from the tube. Face 110a and 110b may not be parallel in one or often multiple axis of reference, as shown in FIG. 2B-2D. FIG. 2B illustrates a simple sag of the target tube. FIG. 2C illustrates warpage of the target tube above and below the axis of rotation. FIG. 2C illustrates complex warpage of the target tube wherein the warping occurs in more than one plane. The net result is eccentric rotation of the target tube. The length of target tubes can also vary due to machining variations and also from elongation of the tube as it heats up. This elongation is an additional stress in a rigid support system.

[0010] Therefore there must be some allowable tolerance for the variation and imperfection in shape of the target tube. Additionally, improved electrical and thermal isolation is needed to prevent costly downtime of the magnetron and the other machines involved in the manufacturing and coating process.

SUMMARY OF THE INVENTION

[0011] The endblocks of the cylindrical magnetron provide a unique solution to the problems associated with the operational functions required for sputter deposition of

materials utilizing a cylindrical target in DC and AC applications, particularly when high current levels are required for increased rates of deposition.

[0012] The present invention adapts to a greater amount of target tube manufacturing and process related variations with angularly compliant mechanisms at each end. The mechanisms also accommodate growth or variations in length of the target tube along the axis. This compliance reduces the transmission of stress within the structure of the magnetron and allows for more consistent and reliable operation.

[0013] The invention also simplifies operational alignment, installation, compatibility for retrofit to pre-existing installation sites, assembly, and servicing characteristics.

[0014] Electrical isolation is another aspect of the invention. Redundant isolation areas are included to prevent grounding of the device and maintain the floating electrical isolation during operation both initially and over extended periods of usage without maintenance.

[0015] Another aspect of the invention are thermal systems to control and minimize the effects of heat generated at static locations where electrical power is provided to the device and at dynamic locations where electrical power is transferred within the device to rotating components. Control and minimization of AC inductive heating is achieved by material selection, construction and geometry taking into account constraints of the sputter deposition process.

[0016] Another aspect of the invention incorporates dual water and vacuum sealing to handle the dynamic flow of water through a rotating target in vacuum conditions. The dynamic water seals operate in a primary/secondary set with an unobstructed draining of the interseal area which provides a conditional alarm function while precluding the pressurization of the secondary seal, thereby increasing its operational reliability. The dynamic vacuum seals operate in a primary/secondary set with a differentially pumped interseal area between the primary and secondary seals to provide an effective initial vacuum seal engagement while also providing a backup seal and monitoring between the seals as an added feature for process operations.

[0017] Yet another aspect of the invention is the use of chromium oxide surfaces that have been diamond polished to provide wear resistant seal surfaces for both the water and vacuum rotational sealing areas.

BRIEF DESCRIPTION OF THE FIGURES

[0018] FIG. 1A illustrates a cylindrical magnetron.

[0019] FIG. 1B illustrates the magnetron as part of a glass coating system.

[0020] FIGS. 2A-2D illustrate the target tube and imperfections and variations thereof.

[0021] FIG. 3 is a cross section of drive endblock 200.

[0022] FIG. 4 is an enlarged cross section of drive endblock 200.

[0023] FIG. 5 is an exploded view of the drive assembly of drive endblock 200.

[0024] FIG. 6 is a cross section of water endblock 300.

[0025] FIG. 7 is an enlarged cross section of water endblock 300.

[0026] FIG. 8 is a perspective view of water endblock 300.

[0027] FIG. 9 is a perspective view of water endblock 300.

[0028] FIG. 10 is a perspective view of the shield assembly of water endblock 300.

[0029] FIG. 11 is a perspective view of the inner shield of water endblock 300.

[0030] FIG. 12 is an illustration of heat shielding and heat transfer.

[0031] FIG. 13 is a cross section of the isolation plate and shield assembly.

DETAILED DESCRIPTION OF THE INVENTION

[0032] Mechanical Aspects of Operation and Function

[0033] Alignment and Rotational Compliance:

[0034] The cylindrical targets are manufactured items with initial geometric variations in concentricity, perpendicularity, straightness and surface conditions. From a practical perspective the target tube cannot be perfectly made, and any controlling tolerances are progressively more difficult and costly to affect as the tolerances become smaller and the target length increases. These areas where tolerance is a crucial issue are subjected to substantial amounts of electrical power and subsequent heating necessary for and resultant from the process of sputter deposition. The operational process also induces rotational imperfections and stresses along with those already present from manufacture. Thus, the initially imperfect target tube is changing shape at any given time.

[0035] There are two principle ways to control this condition. Provide either a rigid interface or an axially compliant interface to the cylindrical target.

[0036] The rigid interface approach is an ineffective solution from a practical mechanics perspective. The large leverage arm and related forces combined with the random variations in target shape and concentricity would require a massive structure that is less effective than a smaller compliant alternative. As the interface becomes progressively more rigid the interface stresses increase disproportionately. This in turn requires the use of increasingly robust construction within a limited envelope (footprint and structure size) which is costly, and more importantly ineffective in contrast to the compliant alternative utilized by the present invention.

[0037] The compliant approach is effective in that it adjusts to a wide range of initial and operationally induced variables in the rotation of the cylindrical target. The axial compliance of the cylindrical magnetron of the present invention is similar to the motion of the human hand and wrist about the axis of the lower arm. The hand (target) can rotate while pivoting. Similarly, the components of the endblocks rotate while pivoting in order to accommodate variation in the size and shape of the cylindrical target due changes during the sputtering process or due to manufacturing imperfections, and can also accommodate alignment

imperfections. The design and operation of a cylindrical magnetron according to an embodiment of the present invention will now be discussed with reference to the Figures.

[0038] Simply stated the device consists of two endblock assemblies that provide physical support to a dynamic cylindrical target and static magnetic array within the target. One endblock provides location, support and rotation to the target tube assembly. This endblock is termed the Drive Endblock (DE). A second endblock provides location, support, water cooling and electrical power transfer for DC or AC operation to the target tube assembly. This endblock is termed the Water Endblock (WE). Imperfect axial rotation is absorbed and accommodated in both endblocks.

[0039] Drive Endblock:

[0040] The drive endblock is illustrated in FIGS. 3-5. FIG. 3 is a cross section of drive endblock 200. FIG. 4 is an enlarged cross section of the drive area of drive endblock 200. FIG. 5 is an exploded view of drive assembly 201.

[0041] The drive endblock 200 interfaces to the target tube assembly (not shown) via drive endcap 202. Drive endcap 202 has a multi-lobed spline 204 on drive endcap core 203. Axial compliance, or freedom of movement about the axis first occurs at the interface between the drive endcap core 203, which has a male multi-lobe spline 204 and insulating member 206. Insulating member 206 has an internal female multi-lobed spline (not shown) that mates with the endcap core with a limited amount of designed in looseness to provide a first compliant coupling with angular or rotational freedom. The inner diameter (ID) of insulating member 206 is larger than the outer diameter (OD) of endcap core 203 and the spline 204 is smaller than the female multi lobed spline of insulating member 206. Thus, the drive endcap 202 can pivot about axis of rotation 209 at this first axially compliant coupling between drive endcap 202 and insulating member 206. "Axially compliant" means that a component, in this case drive endcap 202 can pivot or move about the axis (+/-x and +/-z direction) and can move along the axis (+/-y direction), while rotating about the axis. The drive components do not have a shaft at the axis of rotation and thus are not limited in their range of movement in relation to the axis of rotation.

[0042] Referring to FIG. 5, the insulating member 206 is held onto the endcap core 203 by the use of a detent interface 205 between the endcap core 203 and the insulating member 206. The detent retention holds the insulating member without secondary fasteners. This makes changing the target tube a relatively straightforward operation. To couple drive endcap 202 to insulating member 206, the endcap core 203 is heated, for example by putting it into warm water. It is then inserted into insulating member 206 and detent interface 205 snaps into position. Upon subsequent cooling it is then loosely held into position. This loosely held together grouping of drive endcap 202 and insulating member 206 can be popped apart with a screwdriver for disassembly, but will otherwise remain together during assembly and normal operation. For assembly, insulating member 206 is easily slid into drive cup 210. The assembly of drive endcap 202 and insulating member 206 can move and pivot about axis of rotation 209 within drive cup 210 at this second "axially compliant" coupling. Insulating member 206 also has an external male multi-lobed spline 207. This external spline

207 slip fits to the mating internal multi-lobed female spline drive cup **210**. This engagement provides for a second axially compliant coupling to provide angular freedom as well as freedom of movement along the axis to accommodate thrust. Thus, the assembly of drive endcap **202** and insulating member **206** can move and pivot about axis of rotation **209** at this second axially compliant coupling within drive cup **210**.

[**0043**] The outboard face of drive cup **210** has opposing slots **210a** to accommodate drive pins **240** on drive plate **218** secured to the output shaft of gearbox **220**. Slots **210a** are elongated so it is easy to line up drive cup **210** with drive plate **218** and gearbox **220**. As the gearbox rotates, the pins will eventually contact the ends of slots **211** and initiate rotation of endcap **202** and thus the target tube (not shown). This interface between the pins **240** and drive cup **210** is a third axially compliant interface.

[**0044**] The gearbox **220** in FIG. 4 has a mounting structure that allows limited radial and angular deflection. Thus, gearbox **220** itself is axially compliant. Gearbox **220** is mounted to primary housing **224** with compliant isolating gearbox mount bracket **222**. Gearbox mount bracket **222** utilizes soft bushings **248** to allow vertical and horizontal movement of the gearbox **220** within drive endblock **200**. Thus the gearbox itself can also accommodate longitudinal and vertical movement of the target tube and drive assembly **201**. This allows for only the transmission of rotational force from the gearbox **220** to the splined drive cup **210** without adversely affecting the angular degree of freedom of the splined drive cup **210** and isolation housing **216** subassembly. This mounting structure also reduces or eliminates any radial and axial thrust load forces from being transmitted into the gearbox **220**.

[**0045**] Drive endblock **200** also provides longitudinal clearance to allow for any thermal expansion/contraction or manufacturing tolerance variances of the target tube. Any variations in length of the target tube, and of the combination of drive assembly **201** and the target tube is accommodated by expansion gap **240** within drive cup **210**.

[**0046**] The splined drive cup **210** is rigidly supported by two bearings **212** and **214** along its length within isolation housing **216**. The isolation housing **216** fits within the primary housing **224** and is flexibly supported by the primary housing with two compliant seal rings **244** that provide another compliant coupling to accommodate imperfect rotation about axis **209**. The isolation housing **216** is retained within the primary housing **224** such that variations in length of the target tube, and of the combination of drive assembly **201** and the target tube are accommodated. The compliant seal rings **244** allow for longitudinal (along the axis) movement of the target tube and drive assembly to allow for thermal or manufacturing tolerance induced variations. Bushings **280** also accommodate movement of primary housing **224** within endblock **200**.

[**0047**] The Water Endblock:

[**0048**] The water endblock **300** is illustrated in FIGS. 6, 7, and 8. FIG. 6 is a cross section of the overall endblock, and FIG. 7 is an enlarged cross section of the endblock. FIG. 8 is a perspective view of water endblock **300** together with a part of the target tube.

[**0049**] The water endblock **300** generally supports the rotating target tube **362** while circulating water through the target tube, and providing the electrical power to the target tube for the sputtering process. Water arrives through the dual purpose water manifold/electrical block **330**. This brass block is not only a water manifold, but also acts as an electrical manifold and heat sink. For convenience during the assembly process and for subsequent maintenance including replacement of the electrical components and the target tube, the electrical supply lines are broken into replaceable segments. Power is brought to the manifold **330** by a first set of segments (not shown) and connected to segments **340** leading to the target tube. The junction of these segments (not shown) is at the water manifold/electrical block **330**. The high current and voltage carried by these segments is transferred at the water manifold so that the high heat that will develop at the junction between the wire segments is dissipated by the water cooled brass block **330**. The water then flows through flexible water lines **316** made of a compliant material such as rubber. In FIGS. 6 and 7, only two of the four water lines are shown. In FIG. 8 all four water lines can be seen.

[**0050**] Flexible water lines **316** enter the water endblock primary housing (WEPH) **308** and connect to water endblock isolation housing (WEIH) **304**. WEIH **304** incorporates a water spindle **320** that accomplishes multiple functions such as supporting and locating a stationary magnetic array internal to the target tube **362**, transferring the electrical power to/from the target tube **362** via the electrical brush blocks **324** and providing the interface for the supply and return flow of target tube cooling water through water lines **316**. The water spindle **320** is isolated from direct electrical contact with the primary housing **308** by the isolation housing **304**. Water spindle **320** is made of **304** stainless steel because the strong electrical field surrounding the spindle and the current flowing through the spindle will not produce large amounts of inductive heat in a cylindrical form made of **304** stainless steel. Simply stated, **304** stainless steel has been found to be largely immune to the effects of inductive heating, especially in cylindrical geometries.

[**0051**] Within water spindle **320** is another spindle—anti-rotation spindle **342**. Dual vacuum seals **350** are located between WEIH **304** and water spindle **320** and seal the high pressure water from the surrounding vacuum environment and vice versa. Between the two seals a water sensor determines if the first seal has been breached and triggers a status alert at the user interface. The water sensor is connected to and monitors interseal cavity port **356**. Flow through water bushings **346** are located between water spindle **320** and anti-rotation spindle **342**. The anti-rotation spindle **342** holds the magnetic array **364** within the target tube stationary while the water spindle **320** is rotating around it and water is flowing within and around the anti-rotation spindle **342**.

[**0052**] Water first passes through anti-rotation spindle **342** and then through a support tube **366** that supports the magnetic array through the length of the target tube **362**. The support tube **366** has a smaller diameter than the target tube and fits concentrically (or eccentrically) within the target tube **362**. The water travels to drive endblock **200** within support tube **366** and then returns within target tube **362** outside of support tube **366** in the opposite direction and back into the water endblock **300**. It enters water endblock

300 in the gap between water spindle **320** and anti-rotation spindle **342**. It then flows through flow-through bushings **348** and exits the isolation housing **304** through water lines **316**.

[0053] Power is applied to the water spindle **320** by brush blocks **324**, which then transfer the power to the target tube **362** between water end block **300** and drive endblock **200** shown in FIGS. 3-5. The current travels from brush blocks **324** through water spindle **320** towards the target tube **362**. Brush blocks **324** are flanked on both sides by bearings so that water spindle **320** can rotate within isolation housing **304**, primary housing **308** and water endblock **300**. On the outboard side (away from the target tube) is outboard bearing **346** which is conventional bearing made of steel or other commonly employed material. On the inboard side (towards the target tube) of the brush blocks **324** is bearing **334**. Thus the current passes by inboard bearing **334** on a path to the target tube but does not pass by outboard bearing **346**. Bearing **334** is a full ceramic bearing. The ceramic material has the advantage of being non-conductive, which means it will not heat up due to AC induction resulting from the current flow even though bearings **334** contact water spindle **320** in the current path from the brush blocks **324** to the target tube. The area of water spindle **320** that comes in contact with ceramic bearing **334** and water seals **350** is the most critical for bearing performance and water sealing. This area of water spindle **320** has a wear resistant, precision ground, hard chromed, and polished contact surface. This surface is created by depositing a hard chrome layer and then precision diamond lapping it. The ceramic bearing **334** is supported by bearing and seal carrier **360**. Carrier **360** also supports dual vacuum seals **354** that serve to seal the high pressure water from the surrounding environment which is maintained at a vacuum for the sputtering process.

[0054] The compliance within the water endblock **300** occurs at the interface of the WEIH **304** and the WEPH **308**. The isolation housing **304** is supported within the primary housing **308** by two compliant seal rings **312** that provide support but also angular freedom. WEIH **304** is retained within WEPH **308** with a relatively high amount of clearance between the outer surfaces of WEIH **304** and the inner surfaces of WEPH **308** so that WEIH **304** can "wobble" within WEPH **308**. This "wobble room" or clearance is provided so that eccentric or axial movement of the target tube is absorbed by movement of WEIH **304** within WEPH **308**. Maintaining the clearance and thus electrical isolation (non contact) is essential for the sputtering process. The compliant seal rings **312** are made of rubber or any other well known compliant material allow for this movement, as are water lines **316** and bushing **344**.

[0055] Electrical Power Transfer and Isolation:

[0056] The electrical power transfer interface occurs within the Water endblock assembly **300** shown in FIGS. 6, 7, and 8. There are four semi-cylindrical radial brush segments that are kept in forced compressive contact to a **304** stainless steel (SST) spindle shaft **320** which has a wear resistant hard chromed, precision ground, and polished contact surface. They are arranged around the diameter of the spindle shaft. The compressive inward force exerted on the brush segments **324** toward the spindle **320** is accomplished by two garter type springs **368** designed to provide an optimized contact force. The optimal force is a compro-

mise: high compression increases the electrical transfer rate but the friction taxes the drive system, whereas low compression and friction allow easy rotation but result in poor electrical transfer efficiency. Also, as the contact force is progressively decreased the electrical interface becomes less efficient which may lead to arcing at the interface. If the contact force is progressively increased the resultant friction at the interface increases which results in excessive brush wear and increasing rotational drag. Thus, an amount of force sufficient to prevent arcing yet resulting in adequate brush life must be maintained by the system.

[0057] For continuous DC operations the electrical transfer interface (the brush blocks, wiring to the brush blocks, and the water spindle) was designed to conservatively and reliably handle currents of 800 AMPS. For continuous AC operations the electrical transfer interface was designed to conservatively and reliably handle operations of 150 kW. There is reserve capability in both DC and AC operation to allow for excess transient loads and potential higher power level operations should more powerful power supplies become available.

[0058] As discussed in the background the effects of inductive heating are quite dramatic in a high powered AC system. The heating of materials within the alternating flux fields is dependent on physical location, material conductivity, coupling, frequency, and power density. Heating of the material increases as conductive material comes closer to the conductor, as the material magnetic permeability increases, as the frequency increases, and as the power density increases.

[0059] Experimentation has shown that the inductive effect occurs only in relation to regions surrounding the current path. This experimentation has demonstrated that if a portion of a component is at an AC electrical potential but is not conducting current the region surrounding this portion does not inductively heat. This device uses full ceramic bearings, non-inductive materials and non-metallic low drag rotational seal rings to eliminate inductive heating effects in the most critical areas surrounding the current path. The experimentally recognized material characteristics associated with 304 SST for metal components minimizes inductive heating effects.

[0060] Ceramic bearings are typically utilized in chemical process applications where other materials may pose a contamination problem, or in high speed applications where they are desired because of the lower mass of the bearing and the durability of the material, or in high temperature applications where they are relatively unaffected by the temperature and have the ability to run with little or no lubrication. In this device the use of a full ceramic bearing is unique in that this type of bearing will not inductively heat. Similarly non-metallic low drag rotational seals are used for vacuum seals **354** to avoid the unwanted inductive heat generation.

[0061] Electrical Isolation:

[0062] Electrical isolation is achieved through multiple redundant features. Generally, the endblocks have shields surrounding primary housings that intern surround internal isolation housings, as can be seen in FIGS. 8 through 11. Additionally, the components within the isolation housings are electrically isolated from each other where appropriate.

[0063] The magnetron electrically floats the primary housings and shields of both the drive endblock **200** and the water endblock **300** for operational integrity. This is accomplished by the use of electrically insulating materials and design features. Although these features are common to both endblocks they will now be described with regard to the water endblock **300**. Water endblock numbers are the same as drive endblock numbers except the water endblock numbers commence with 3xx whereas drive endblock numbers commence with 2xx. Common to both endblocks are isolation bushings **280/380** surrounding the mounting bolts that adhere the source cover to the primary endblock housing. A substantial isolation plate **372** is located between the primary housing **308**'s mounting flange **309**, the inner shield **500** and the source cover **520**. This isolation plate **372** incorporates a perimeter groove **374**. This groove **374** is incorporated into isolation plate **372** in order to handle the accumulation of surplus deposition, which will be discussed later. The isolation plate **372** also incorporates visual design features to assure proper orientation at assembly.

[0064] The design and function of inner and outer heat and deposition debris shields **500** and **510** are common to both endblock assemblies. Mounted on the external process side of the primary endblock housing are inboard and outboard isolation rings that locate and electrically isolate the shield assemblies from the primary housing. Outboard isolation ring **370** can be seen in **FIG. 8**. Beneath the outboard isolation ring **370** is the inboard isolation ring (not shown).

[0065] Referring to **FIGS. 9 and 10**, two shields can be seen, an inner shield **500** and an outer shield **510**. Inner shield **500** fits within outer shield **510**, and both inner shield **500** and outer shield **510** are placed on the primary housing of either the drive endblock **200** or water endblock **300** described earlier. The water endblock is shown in **FIGS. 8 and 9**. The inner shield **500** is electrically isolated from both the primary housing **308** described earlier and from outer shield **510**. On the outboard face of the inner shield **500** are several shouldered insulating bushings **505** that maintain an insulating gap between the shields thus allow the shield to be fastened to the primary housing **308** while maintaining electrical isolation of both shields **500** and **510** relative to the primary housing **308**.

[0066] The outer shield **510** interfaces with the perimeter of the isolation plate **372** located between the primary housing and the source cover **520** as can be seen in **FIG. 8**. This interface is shown in further detail in **FIG. 13**. The groove **374** in the perimeter of the isolation plate **372** and outer shield **510** form a shadow barrier **376**. The process of sputter deposition, as mentioned previously, generates surplus deposition material **530** which depending upon the process and target material can be conductive. The shield **510** in conjunction with groove **374** form a non-contacting 'shadow' barrier **376** surrounding the end blocks **200** and **300**. The shield **510** floats electrically isolated from the endblock primary housing **308** (in the case of the water endblock **300**) and the source cover **520**. The potentially conductive surplus deposition material **530** coats anything in the interior of the process area, including the shield **510**.

[0067] This stray material **530** could form a conductive link between shield **510** and isolation plate **372** if not for the shadow space. Because the shield **510** is positioned in front of the groove **374** in the trajectory of the incoming material

530 from the target tube, the material cannot possibly conductively link the shields to the source cover **520** or primary housing behind the source cover. There will always remain a shadow space or gap in the buildup of stray material that may occur. In other words, the shadow barrier **376** precludes the formation of a conductive link of operational plasma from forming a short circuit. In particular the interface between the shield assembly **503** and the base of source cover **520** is protected from this occurrence by the shadow barrier **376** formed by the lip of the shield and the perimeter groove of the isolation plate. This allows for protracted periods of process operation without maintenance because if the conductive link is formed the magnetron will have to be disassembled and cleaned. This is because the sputter deposition process would be less efficient and the coating deposited upon the glass may also be uneven and varied in quality because of this short circuit. This electrical isolation provides protection from voltages exceeding 100,000 volts and is applicable to both DC and AC process operations.

[0068] Within the shields, the endblocks feature secondary isolation housings within the primary housings. The isolation housings are supported on non-conductive compliant seal rings within the primary housings (that interface to the target tube). The endblocks electrical isolation designs diverge at this point and will be explained separately.

[0069] Drive Endblock **200**:

[0070] In addition to the above mentioned electrically isolating features, the drive endblock **200** incorporates isolating features within the drive assembly **201** seen in **FIGS. 3-5**. Drive assembly **201** incorporates a metallic spline cup **210**. This spline cup **210** interfaces with insulating member **206**, which intern interfaces with drive endcap **202**, which intern interfaces with the target tube. Thus, the target tube is isolated from gearbox **220** and the other components within the primary housing **224**. While this benefit is readily apparent, there is a secondary aspect. In the low pressure (vacuum) operational environment necessary for proper sputtering, there can occur a cathode/anode effect if the spline cup **210** is at any potential varying even slightly from ground. This slight potential can result in arcing between the spline cup **210** and other components of the system. To preclude this from occurring the gearbox mounting bracket **222** isolates the gearbox from the primary endblock housing **224** through the use of insulating components and bushings. There is an isolating adapter **226** between the servo drive motor **228** and the gearbox **220** to ensure that a ground potential does not occur via the servo motor **228** case ground or the servo power and controller circuits (not shown). This system of multiple and redundant isolation ensures that the dynamic components such as gearbox **220**, drive assembly **201**, target tube **362** and servo motor **228** are isolated from each other and precludes the formation of any potential of a cathode/anode effect.

[0071] Water Endblock **300**:

[0072] The Water endblock isolation housing **304** incorporates a spindle **320** that accomplishes multiple functions such as supporting and locating a stationary magnetic array internal to the target tube (through anti-rotation spindle **342**), transferring the electrical power to/from the target tube via the electrical brush blocks **324** and providing the interface for the supply and return flow of target tube cooling water

through water lines **316**. The spindle **320** is isolated from direct electrical contact with the primary housing **308** by isolation housing **304**. The electrical brush blocks **324** are also within isolation housing **304**. The brush block leads (not shown) are individually insulated and are routed as a centrally located bundle within the primary endblock housing **124** to the water manifold/electrical block **330**. The water supply and return lines **316** are insulated and incorporate flexible segments between the isolation housing **308** and the water manifold/electrical block **330**. The water manifold/electrical block **330** is mounted on an electrically isolating plate, isolation plate **372**, mounted to the interior top surface of the source cover **520** seen in **FIGS. 8 and 9**.

[0073] Thermal Aspects of operation and Function:

[0074] Heat affecting the device is generated from multiple sources. Primarily heat: 1.) is generated at the electrical transfer and interface locations, 2.) results from inductive heating in AC operations, 3.) is generated by the movements of the drive components, and 4.) is radiated from the sputter deposition process. The device uses several approaches to minimize, eliminate, and remove residual heat where possible.

[0075] Electrical Power Transfer Heating:

[0076] Heating due to the transfer of electrical power to and from the target tube has been controlled, minimized or eliminated by several features. First, conservatively oversized electrical conductors for DC and AC operations minimize heat generation. Second, conservative or oversized electrical junctions or interfaces such as the large contact face of brush blocks **324** upon water spindle **320** and at the junction of conductors **340** to water manifold/electrical block **330**. Third is the minimization or elimination of physical structures subject to AC inductive heating, which was previously discussed. This particular aspect also aids in raising the operational efficiency by reducing the power losses associated with inductive heating effects. This is because if an element is inductively heated the increased temperature results in increased resistance and thus decreases the conductivity and the efficiency of the system.

[0077] Location of the brush block segments **324** directly upon the water cooled spindle **320** ensures that whatever residual heating that may occur at this interface is immediately quenched. Also the location of the supply and return water lines and the external power supply junction in the same block **330** ensures that whatever residual heating that may occur at this interface is immediately quenched.

[0078] Drive System Heating:

[0079] The heat created from the drive system and rotation of the target tube is minimized by reducing the torque needed to turn the target tube and other related components. Additionally, heat that is generated is cooled with forced air cooling within the primary housings **308** and **224**. In prior designs this was typically accomplished via water cooling within the primary housings often resulting in condensation when the temperature of the housings dropped below the ambient dew point. This condensation within the endblocks resulted in degradation and short circuiting of electrical components within the primary housings. With dynamic forced air flowing within the primary housings, precludes the formation of gross condensation within the housing.

[0080] Referring to **FIGS. 9-12**, the shields and heat transfer of radiant heat from the sputtering process will be described. **FIG. 12** in particular illustrates the heat transfer between the shield components and the primary housing.

[0081] The transfer of heat in a vacuum between a non-contacting source, i.e. process plasma, and the device is that of radiant heat transfer. To minimize this transfer of heat to the interior of either endblock a multi piece curved shield assembly **503** surrounds each endblock. The multi-piece shields of the water endblock **300** are seen in **FIGS. 9-11**.

[0082] As seen in **FIG. 12**, the radiant heat energy **600** from the process arrives at the left side of the page. Radiant broad spectrum energy is absorbed in a line of sight path from the heat source to the shield surface. If the incident angle is perpendicular to the shield surface a majority of the energy is absorbed into the shield. As the angle of incidence diverges from the perpendicular there is an increased percentage of that energy which is reflected away and never absorbed. Therefore heat shields **505** and **510** are curved and designed so that the incident angle is other than perpendicular wherever possible. Heat that arrives at an angle of less than or greater than 90 degrees is partially reflected whereas heat that arrives at ninety degrees is predominantly absorbed by outer heat shield **510**. Note that there is a vacuum on both sides of outer heat shield **510**, and therefore convection is not possible.

[0083] Heat that is absorbed by outer heat shield **510** is re-radiated from both sides equally. The surfaces of the shields are reflective in order to minimize the absorption. The heat that is re-radiated towards inner heat shield **505** is partially reflected and partially absorbed by inner heat shield **505**. It is then re-radiated once again in both directions, part back towards outer heat shield **510** and part towards primary endblock housing **308**. Thus, only a small fraction of the radiant heat energy **600** that arrived from the process at outer heat shield **510** is transferred from inner heat shield **505** to primary endblock housing **308**. Once again at primary endblock housing **308** a portion of the heat energy is absorbed. Once absorbed the energy is re-radiated from both sides of primary endblock housing **308**. Between primary endblock housing **308** and inner heat shield **505** there is a vacuum, but within primary endblock housing **308** there is atmospheric pressure. The air within the housing is circulated and vented and thus the air molecules will largely absorb the heat through convection. Therefore only a very small fraction of the radiant heat energy **600** from the high energy sputtering process is actually transferred to the interior of primary endblock housing **308**, and what is transferred is cooled by the forced air flow. This forced air also removes the internally generated heat from either the drive mechanisms inside drive endblock **200** or the electrical transfer system inside water endblock **300**. If the intense heat from rotating the target tube and the high powered sputtering process is not effectively dealt with, the magnetron will have a very short service life between repairs or will fail entirely after a short time. Mitigating the heat requires water cooling of the components, multiple heat shielding, and forced air cooling.

[0084] While particular embodiments of the present invention and their advantages have been shown and described, it should be understood that various changes, substitutions, and alterations can be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

- 1. A cylindrical magnetron comprising:
 a target tube;
 a first endblock comprising:
 a motor;
 a gearbox; and
 a drive assembly between the gearbox and the target tube with one or more axially compliant interfaces between gears of the drive assembly such that the assembly accommodates imperfect rotation of the target tube.
- 2. The magnetron of claim 1 further comprising:
 a second endblock comprising:
 an inner housing comprising:
 a water cooled spindle
 an electrical transfer system including brush blocks contacting the surface of the spindle.
 an outer housing;
 compliant seal rings between the inner and outer housing whereby the inner housing can move within the outer housing to absorb imperfect rotation of the target tube.
- 3. The magnetron of claim 1 further comprising:
 an inner housing within the first endblock, the gearbox and drive assembly within the inner housing;
 an outer housing; and
 compliant seal rings between the inner and outer housing whereby the inner housing can move within the outer housing to absorb imperfect rotation of the target tube.
- 4. The magnetron of claim 3 wherein the imperfect rotation of the target tube includes eccentric rotation about the axis of rotation of the target tube or movement of the target tube along the axis of rotation.
- 5. The magnetron of claim 1 wherein the drive assembly comprises first, second and third gears, the rotating motion from the gearbox transferred from the gearbox to the first gear, the rotating motion from the first gear transferred to the second gear, and the rotating motion from the second gear transferred to the third gear.
- 6. The magnetron of claim 5 wherein the second gear is located between the first and third gear and is electrically insulating.
- 7. The magnetron of claim 5 wherein an axially compliant interface of the one or more axially compliant interfaces is between the first and second gear.
- 8. The magnetron of claim 5 wherein an axially compliant interface of the one or more axially compliant interfaces is between the second and third gear.
- 9. The magnetron of claim 5 wherein the third gear is coupled to the target tube.

- 10. The magnetron of claim 5 wherein the first gear has one or more slots, and wherein one or more protrusions of the gearbox rotate freely within the slots until encountering the end of the slot and thereafter rotate the entire third component.
- 11. The magnetron of claim 10 wherein the one or more protrusions are aligned nywhere within the one or more slots during assembly of the magnetron.
- 12. A sputtering device having a rotating target tube suspended between first and second endblocks, the first endblock having a suspension and drive system comprising:
 a primary housing;
 a secondary housing held within the primary housing by insulative and pliable components such that the secondary housing can move within the primary housing, the secondary housing comprising a system of interlocking male and female components rotating about an axis and coupling the gearbox to the target tube.
- 13. The sputtering device of claim 12 wherein the first endblock further comprises a gearbox held within the primary housing by insulative and pliable components such that the gearbox can move within the primary housing.
- 14. The sputtering device of claim 12 wherein the interlocking male and female male and female components are free to move with six degrees of freedom about the axis of rotation.
- 15. A device for plasma coating a substrate having a target tube that rotates about an axis of rotation, the device comprising:
 a motor;
 a gearbox;
 a driveline linking the gearbox and the target tube, the driveline able to pivot
 about the axis of rotation.
- 16. The device of claim 15 wherein the driveline comprises one or more male and one or more female interconnecting components
- 17. The device of claim 16 wherein one of the male or female interconnecting components is made of an insulating material thereby insulating the motor and gearbox from the target tube.
- 18. The device of claim 15 wherein the driveline is further able to move along the axis of rotation to absorb imperfect rotation of the target tube.
- 19. The sputtering device of claim 15 further comprising a rotating shaft that transfers power to the target tube.
- 20. The sputtering device of claim of claim 19 further comprising one or more brush blocks that transfer power to the rotating shaft.
- 21-59. (Cancelled)

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