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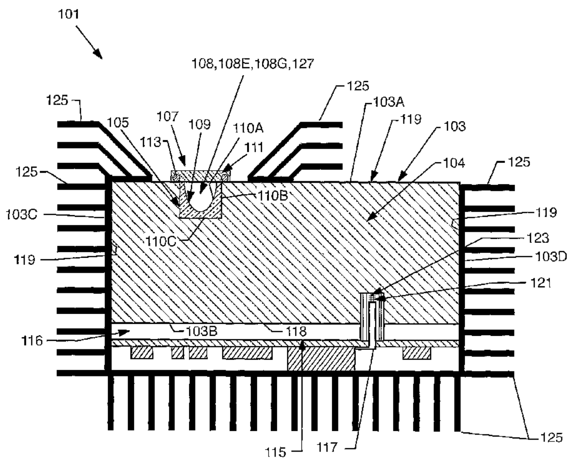

(57) Abstract: A dielectric waveguide (103) integrated plasma lamp (DWIPL) with a body (104) comprising at least one dielectric material having a dielectric constant greater than approximately 2, and having a shape and dimensions such that the body resonates in at least one resonant mode when microwave energy of an appropriate frequency is coupled into the body. A dielectric bulb (107) within a lamp chamber in the body contains a fill which when receiving energy from the resonating body forms a light-emitting plasma. The bulb is transparent to visible light and infrared radiation emitted by the plasma. Radiative energy lost from the plasma is recycled by reflecting the radiation from thin-film, multi-layer coatings on bulb exterior surfaces and/or lamp chamber surfaces back into the bulb. The lamp further includes two-or three-microwave probe configurations minimizing power reflected from the body back to the microwave source (115) when the source operates: (a) at a frequency such that the body resonates in a single mode, or (b) at one frequency such that the body resonates in a relatively higher mode before a plasma is formed, and at another frequency such that the body resonates in a relatively lower order mode after the plasma reaches steady state.

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PLASMA LAMP SYSTEMS AND METHODS

This application is a continuation-in-part of U.S. application Ser. No. 10/771,788 ("'788") filed on Feb. 4, 2004, entitled "Plasma Lamp With Dielectric Waveguide," which is a continuation of U.S. application Ser. No. 09/809,718 ("'718") filed on Mar. 15, 2001 and issued as Pat. No. 6,737,809 B2, also entitled "Plasma Lamp With Dielectric Waveguide," which claims priority to U.S. provisional application Ser. No. 60/222,028 ("'028") filed on Jul. 31, 2000, entitled "Plasma Lamp."

Field of the Invention

The field of the present invention relates to devices and methods for generating light, and more particularly to electrodeless plasma lamps energized by microwave radiation and having a solid dielectric waveguide integrated with at least one transparent bulb, wherein heat energy from the plasma is recycled into the bulb(s), resulting in high efficiency operation.

Related Art

Our '718 application discloses a "dielectric waveguide integrated plasma" lamp (DWIPL) including a "dielectric waveguide," viz., a waveguide coupled by a microwave probe to a source of microwave power and having a body consisting essentially of dielectric material and a side with a lamp chamber extending into the body. The source operating frequency and waveguide body dimensions are selected such that the body resonates in at least one resonant mode having at least one electric field maximum. The lamp further includes a bulb disposed within the chamber. Thus the body, chamber and bulb are integrated as a unitary structure. The bulb contains a fill mixture ("fill") that forms a light-emitting plasma when microwave power is directed by the waveguide into the bulb. The '718 application also discloses a DWIPL including a dielectric waveguide and two microwave probes. One probe, connected to a feedback means coupled between the probe and microwave source, probes the waveguide body to instantaneously sample the field amplitude and phase and provides this information via the feedback means to the source which dynamically adjusts the operating frequency to maintain at least one resonant mode within the waveguide body, thereby operating the lamp in a "dielectric resonant oscillator" mode. The '718 application further discloses DWIPL embodiments which differ according to waveguide body shape, bulb type (a hermetically sealed envelope vis-a-vis a bulb which is self-enclosed), number of bulbs (one vis-a-vis two), number of lamp chambers (one vis-a-vis two), and number of probes (one vis-a-vis two).

A continuation-in-part application Ser. No. 10/356,340 ("'340"), published as Pub. No. 2003/0178943 A1 and entitled "Microwave Energized Plasma Lamp With Solid Dielectric Waveguide," discloses advances in design of the "drive probe" which supplies microwave power to the fill, and of the "feedback probe", as well as utilization of a "start probe" to mitigate over-coupling of the drive probe, and amplifier and control circuits for two- and three-probe configurations which minimize power reflected from the body back to the source both before a plasma is formed and after it reaches steady state. The '340 application further discloses techniques for sealing a waveguide body cavity (viz., a lamp chamber) with a window or lens allowing seals to withstand large thermomechanical stresses and chamber pressures which develop during lamp operation, alternative techniques for DWIPL assembly, and waveguide bodies having two solid dielectric materials.

The '718, '340 and '788 applications asserted that quartz bulbs are unsuitable for plasma lamps of the present invention because they would be prone to failure in the 1000°C temperature regime a bulb wall containing a plasma would experience and, even if structural failure did not occur, would be unstable in their mechanical, optical and electrical properties over long periods when repeatedly cycled in temperature. The conclusion was that use of a quartz bulb would likely result in a lamp prone to early failure. However, we have recently demonstrated that quartz can be a suitable bulb material when used in the lamp embodiments disclosed herein, and moreover provides significant advantages that an opaque fill envelope or self-enclosed bulb cannot.

Summary of the Invention

In one aspect a lamp according to the invention includes a waveguide having a body including at least one dielectric material with a dielectric constant greater than approximately 2, and at least one body surface determined by a waveguide outer surface. The lamp further includes a probe within the body coupling microwave energy into the body from a source operating in a frequency range from about 0.25 to about 30 GHz. The body resonates in at least one mode having at least one electric field maximum. The body has a lamp chamber depending from the waveguide outer surface, thus determining an aperture, and the chamber is determined by a bottom surface and at least one surrounding wall surface. The lamp further includes a transparent, dielectric bulb within the chamber, and a fill within the bulb which when receiving microwave energy from the resonating body forms a light-emitting plasma.

In a second aspect a lamp includes a self-enclosed bulb closely received within a lamp chamber in a dielectric waveguide body. The chamber is determined by an aperture, and an enclosure determined by a bottom surface and at least one surrounding wall surface. The bulb has a cylindrical wall consisting of transparent dielectric material, attached to a bottom consisting of the same material. The bulb wall has a circumferential upper edge hermetically sealed to a transparent window. The exterior surface of the bulb wall is in thermal contact with the chamber wall surface, and the exterior surface of the bulb bottom is in thermal contact with the bottom surface of the chamber.

In a third aspect a lamp chamber includes a self-enclosed bulb disposed within a lamp chamber in a dielectric waveguide body. The chamber is determined by an aperture, and an enclosure determined by a bottom surface and at least one surrounding wall surface. The bulb includes a cylindrical wall, consisting of transparent dielectric material, which extends upwardly in a circumferential lip having opposed lower and upper surfaces, and is attached to a transparent bottom. The lip lower surface is hermetically sealed to a bulb support structure circumscribing the aperture and attached to the waveguide body. The bulb further includes a window hermetically sealed to the lip upper surface.

In a fourth aspect a lamp includes a lamp chamber in a dielectric waveguide body, determined by an aperture, and a shaped surface bounding a surrounding wall of dielectric material and tapering symmetrically to a bottom. The lamp further includes a self-enclosed bulb having a cylindrical, transparent wall attached to a bottom, and a window hermetically sealed to the wall. The bulb bottom is attached by a first adhesive layer to a ceramic pedestal attached by a second adhesive layer proximate to the chamber bottom. The chamber surface is shaped to direct light emitted by the plasma in the bulb so as to satisfy ray-divergence specifications levied by an optical system receiving the lamp's output radiation.

Brief Description of Drawings

FIG. 1 illustrates a sectional view of a dielectric waveguide integrated plasma lamp (DWIPL) including a waveguide having a body consisting essentially of solid dielectric material, integrated with a bulb envelope having a transparent wall and containing a light-emitting plasma.

FIG. 2 illustrates a sectional view of a DWIPL having a self-enclosed ceramic bulb separated from the waveguide body by a vacuum gap, and a sapphire window.

FIG. 3A illustrates a sectional view of a DWIPL self-enclosed bulb having a cylindrical, transparent wall and transparent bottom in thermal contact with a lamp chamber wall, and a window made of the same material as the wall and bottom.

FIG. 3B shows the **FIG. 3A** bulb with a multi-layer dielectric coating on the exterior surfaces of the bulb wall and bottom.

FIG. 4A illustrates a sectional view of a DWIPL self-enclosed bulb having a cylindrical, transparent wall extending upwardly in a lip and a transparent bottom, and separated from the waveguide body by an air gap, and a window made of the same material as the wall, lip and bottom.

FIG. 4B shows the **FIG. 4A** bulb with a multi-layer dielectric coating on the exterior surfaces of the cylindrical bulb wall and bottom.

FIG. 4C shows the **FIG. 4A** configuration with a multi-layer dielectric coating on the wall and bottom of the cylindrical lamp chamber.

FIG. 4D shows the **FIG. 4A** configuration with a multi-layer dielectric coating on the exterior surfaces of the bulb wall and bottom, and on the lamp chamber wall and bottom.

FIG. 5A illustrates a sectional view of a lamp chamber, open to air, wherein a self-enclosed cylindrical, transparent bulb is mounted on a pedestal attached to the lamp chamber bottom.

FIG. 5B is a detail view of the **FIG. 5A** bulb and pedestal.

FIG. 5C shows the **FIG. 5A** configuration with a multi-layer dielectric coating on the lamp chamber surface.

FIG. 5D shows the **FIG. 5A** configuration with a multi-layer dielectric coating on the exterior surfaces of the bulb wall and window.

FIG. 5E shows the **FIG. 5A** configuration with a multi-layer dielectric coating on the exterior surfaces of the bulb wall and window, and on the lamp chamber surface.

FIG. 5F shows the **FIG. 5A** configuration with a partial-lens, including a lens portion and a planar portion, covering the chamber aperture.

FIG. 6A is an elevational view of a bulb having a transparent, cylindrical wall concentric with and surrounded by an opaque dielectric sleeve split into two halves, and separated from the sleeve by an air gap. A multi-layer dielectric coating is on the interior surface of each sleeve-half.

FIG. 6B is an exploded plan view of the **FIG. 6A** configuration.

FIG. 7A is an elevational view of a bulb having a transparent, cylindrical wall concentric with and surrounded by a transparent dielectric sleeve split into two halves, and separated from the sleeve by an air gap. A multi-layer dielectric coating is on the exterior surface of each sleeve half.

FIG. 7B is an exploded plan view of the **FIG. 7A** configuration.

FIG. 8A is an elevational view of a bulb having a transparent, cylindrical wall concentric with and surrounded by a transparent dielectric one-piece sleeve, and separated from the sleeve by an air gap. A multi-layer dielectric coating is on the exterior surface of the sleeve.

FIG. 8B is an exploded plan view of the **FIG. 8A** configuration.

FIG. 9 shows the reflectance spectra of a preferred multi-layer coating consisting of SiO_2, which is transparent for wavelengths in the range 0.12-4.5 μm, for light incident normally and 30 degrees off normal.

FIG. 10A schematically depicts a DWIPL having a cylindrical body wherein a bulb and a drive probe are located at the electric field maximum of a resonant mode.

FIG. 10B schematically depicts the **FIG. 10A** DWIPL wherein the bulb is located at the electric field maximum of the **FIG. 10A** resonant mode, and a drive probe is offset from the maximum. The **FIG. 10B** probe is longer than the **FIG. 10A** probe to compensate for coupling loss due to the offset.

FIG. 11A schematically depicts a DWIPL having a rectangular prism-shaped body wherein are disposed a bulb, and a drive probe and a feedback probe connected by a combined amplifier and control circuit.

FIG. 11B schematically depicts a DWIPL having a cylindrical body wherein are disposed a bulb, and a drive probe and a feedback probe connected by a combined amplifier and control circuit.

FIG. 12 schematically depicts a first embodiment of a DWIPL utilizing a start probe. The DWIPL has a cylindrical body wherein are disposed a bulb, a drive probe, a feedback probe, and the start probe. The feedback probe is connected to the drive probe by a combined amplifier and control circuit, and a splitter, and is connected to the start probe by the amplifier and control circuit, the splitter, and a phase shifter.

FIG. 13 schematically depicts a second embodiment of a DWIPL utilizing a start probe. The DWIPL has a cylindrical body wherein are disposed a bulb, a drive probe, a feedback probe, and the start probe. The feedback probe is connected to the drive probe and the start probe by a combined amplifier and control circuit, and a circulator.

FIG. 14A schematically depicts a third embodiment of a DWIPL utilizing a start probe. The DWIPL has a cylindrical body wherein are disposed a bulb, a drive probe, a feedback probe, and the start probe. The feedback probe is connected to the drive probe and the start probe by a combined amplifier and control circuit, and a diplexer.

FIG. 14B schematically depicts an alternative configuration of the **FIG. 14A** embodiment wherein the feedback probe is connected to the drive probe by a diplexer and a first combined amplifier and control circuit, and to the start probe by the diplexer and a second combined amplifier and control circuit.

FIG. 15A schematically depicts a DWIPL wherein a start resonant mode is used before plasma formation and a drive resonant mode is used to power the plasma to steady state. The DWIPL has a cylindrical body wherein are disposed a bulb, a drive probe, and a feedback probe. A combined amplifier and control circuit connects the drive and feedback probes.

FIG. 15B schematically depicts an alternative configuration of the **FIG. 15A** embodiment wherein the feedback probe is connected to the drive probe by first and second diplexers and first and second combined amplifiers and control circuits.

FIG. 16 is a block diagram of a first configuration of the **FIGs. 11A, 11B, 15A** and **15B** combined amplifier and control circuit.

FIG. 17 is a block diagram of a second configuration of the **FIGs. 11A, 11B, 15A** and **15B** combined amplifier and control circuit.

FIG. 18 is a block diagram of a configuration of the **FIGs. 12, 13, 14A** and **14B** combined amplifier and control circuit.

Detailed Description of Embodiments

While the present invention is open to various modifications and alternative constructions, the embodiments shown in the drawings will be described herein in detail.

It is to be understood, however, there is no intention to limit the invention to the particular forms disclosed. On the contrary, it is intended that the invention cover all modifications, equivalences and alternative constructions falling within the spirit and scope of the invention as expressed in the appended claims.

As used herein, the terms "dielectric waveguide integrated plasma lamp", "DWIPL", "microwave energized plasma lamp with solid dielectric waveguide", and "lamp" are synonymous, the term "lamp body" is synonymous with "waveguide body." The term "probe" herein is synonymous with "feed" in the '718 application. The term "power", i.e., energy per unit time, is used herein rather than "energy" as in the '718 application. The terms "lamp chamber" and "hole" herein are synonymous with "cavity" in the '718 application, and are used in describing construction details, such as seals and materials, of the several DWIPL embodiments disclosed. A "lamp chamber" is defined herein as a receptacle, i.e., a hole, in a waveguide body having an aperture in a body surface which typically is coplanar with a waveguide surface exposed to the environment. The generic term "bulb" denotes (type-A) a self-enclosed, discrete structure containing a fill mixture and positioned within a lamp chamber; or (type-B) a "bulb envelope," viz., a chamber containing a fill mixture sealed from the environment by a window or lens. As used herein, the term "fill" is synonymous with "fill mixture." The term "self-enclosed bulb" is specific to type-A. The term "cavity" is used herein when describing microwave technology-related details such as probe design, coupling and resonant modes. From an electromagnetic point of view a DWIPL body is a resonant cavity. This change in terminology from the '718 application was first made in the '340 application. For simplicity and to facilitate comparison, most of the lamp chambers and/or bulbs of the lamp embodiments disclosed herein are cylindrical. However, other shapes such as rectangular prisms and ellipsoids are feasible.

FIG. 1, adapted from Fig. 1 of the '028, '718, '340 and '788 applications, shows a dielectric waveguide integrated plasma lamp with a bulb envelope made of a transparent dielectric material rather than an opaque material such as a ceramic. DWIPL **101** includes a source **115** of microwave radiation, a waveguide **103** having a body **104** consisting essentially of solid dielectric material, and a drive probe **117** coupling the source **115** to the waveguide, which is in the shape of a rectangular prism determined by opposed sides **103A**, **103B**, and opposed sides **103C**, **103D** generally transverse to sides

103A, 103B. DWIPL **101** further includes a type-B bulb **107** disposed proximate to side **103A** and preferably generally opposed to probe **117**, containing a fill **108** including a "starting" gas **108G**, such as a noble gas, and a light emitter **108E**, which when receiving microwave power at a predetermined operating frequency and intensity forms a plasma and emits light. Source **115** provides microwave power to waveguide **103** via probe **117**. The waveguide contains and guides the energy flow to a lamp chamber **105**, depending from side **103A** into body **104**, in which bulb **107** is closely received. This energy flow frees electrons from the starting gas atoms, thereby creating a plasma. In many cases the light emitter is solid at room temperature. It may contain any one of a number of elements or compounds known in the art, such as sulfur, selenium, a compound containing sulfur or selenium, or a metal halide such as indium bromide. The starting plasma vaporizes the light emitter, and the microwave powered free electrons excite the light emitter electrons to higher energy levels. De-excitation of the light emitter electrons results in light emission. Use of a starting gas in combination with a solid light emitter is not a necessity; a gas fill alone, such as xenon, can be used to start the plasma and to emit light. The preferred operating frequency range for source **115** is from about 0.25 to about 30 GHz. Source **115** may be thermally isolated from bulb **107** which during operation typically reaches temperatures between about 700°C and about 1000°C, thus avoiding degradation of the source due to heating. Preferably, the waveguide body provides a substantial thermal mass which aids efficient distribution and dissipation of heat and provides thermal isolation between the lamp and source. Additional thermal isolation of the source may be accomplished by using an insulating material or vacuum gap occupying an optional space **116** between source **115** and waveguide **103**. When the space **116** is included, appropriate microwave probes are used to couple the source to the waveguide.

Due to mechanical and other considerations such as heat, vibration, aging and shock, contact between the probe **117** and waveguide **103** preferably is maintained using a positive contact mechanism **121**, shown in **FIG. 1** as a spring-loaded device. The mechanism provides a constant pressure by the probe on the waveguide to minimize the possibility that microwave power will be reflected back through the probe rather than entering the waveguide. In providing constant pressure, the mechanism compensates for small dimensional changes in the probe and waveguide that may occur due to thermal heating or mechanical shock. Preferably, contact is made by depositing a metallic material **123** directly on the waveguide at its point of contact with probe **117** so as to eliminate gaps that may disturb the coupling.

While the waveguide body **104**, being of dielectric material, can by itself confine the microwave field to resonant modes within it, presenting the field with a conducting boundary condition at each external body surface is desirable because the confined field amplitude is increased, improving lamp efficiency, and the evanescent field outside the waveguide body, characteristic of dielectric waveguides, is attenuated. Both the increased confined field amplitude and attenuated evanescent field make oscillation inside the waveguide body less sensitive to the outside environment, and suppress stray microwave interference. A conducting boundary condition can be effected in two ways, either singly or in combination. Sides **103A, 103B, 103C, 103D** of waveguide **103**, with the exception of those surfaces depending from side **103A** into body **104** which form lamp chamber **105**, can be coated with a thin metallic coating **119** which reflects microwaves in the operating frequency range. Alternatively, a tightly fitting metallic heatsink can serve the same purpose. A preferred coating is silver. Preferred materials for the heatsink include copper and aluminum.

Bulb **107** includes a wall **109** consisting of a transparent dielectric material, preferably quartz, and is determined by a concavely arcuate interior surface **110A**, a generally cylindrical exterior surface **110B**, and a generally planar bottom surface **110C**. A window **111** attached to side **103A** using a seal **113** hermetically seals and in combination with wall **109** determines a bulb envelope **127** which contains the fill **108**, i.e., the emitter **108E** and starting gas **108G**. Because window **111** is sealed to a waveguide surface rather than to the wall **109**, matching the coefficient of thermal expansion (CTE) of the materials used for the window and wall is not critical. Consequently, sapphire, which has high light transmissivity, is a feasible material for window **111**. Preferably, surface **110A** is contoured to maximize the amount of light reflected out of bulb envelope **127** through window **111**. Window **111** may include a lens to collect and focus the emitted light. During operation when wall **109** may reach temperatures of up to about 1000°C, body **104** acts as a heatsink because wall surfaces **110B, 110C** are in thermal contact with the waveguide body **104**. Effective heat dissipation from body **104** is achieved by attaching a plurality of heat-sinking fins **125** to sides **103A, 103C** and **103D**. Much of the energy absorbed by a plasma eventually appears as heat. Because wall **109** is transparent, such heat continually exits envelope **127** in the form of infrared and visible radiation absorbed by body **104**. Compared to a similar bulb envelope with a ceramic wall, a relatively large amount of power must be provided to maintain the plasma temperature. Consequently, lamp **101** has low efficiency.

High resonant energy within the waveguide body **104**, corresponding to a high Q-value in the body (where Q is the ratio of the operating frequency to the frequency width of the resonance), results in high evanescent leakage of microwave energy into chamber **105**. Such leakage leads to quasi-static breakdown of the gas within envelope **127**, thereby generating the first free electrons. The oscillating energy of the free electrons scales as $I\lambda^2$, where I is the circulating intensity of the microwave energy and λ is the wavelength. Thus, the higher the microwave energy, the greater is the oscillating energy of the free electrons. By making the oscillating energy greater than the ionization potential of the gas, electron-neutral collisions result in efficient build-up of plasma density.

Once a plasma is formed and the incoming power is absorbed, the waveguide body's Q-value drops due to the conductivity and absorption properties of the plasma. The drop in Q-value is generally due to a change in the impedance of the waveguide. After plasma formation, the presence of the plasma in the chamber makes the chamber absorptive to the resonant energy, thus changing the waveguide impedance. This change in impedance is effectively a reduction in the overall reflectivity of the waveguide. By matching the reflectivity of the probe to be close to the reduced reflectivity of the waveguide, a relatively low net reflection back into the energy source is realized.

FIG. 2, which is Fig. 3B in the '028, '718 and '788 applications, illustrates a type-A (i.e., self-enclosed) bulb **140** disposed within a lamp chamber **142** in a dielectric waveguide body **144**. Bulb **140** includes a generally cylindrical wall **146** of opaque dielectric material terminating upwardly in a circumferential lip **148** having lower and upper surfaces **148L, 148U**, respectively, and attached to an opaque bottom **150**. Lower surface **148L** is hermetically sealed by a seal **152** to a bulb support structure **154** attached to body **104**. Bulb **140** further includes a window **156** hermetically sealed by a seal **158** to upper surface **148U**. Embedded in support structure **154** is an access seal **160** through which air is evacuated from the chamber **142**. Preferably, wall **146**, lip **148** and bottom **150** are made of alumina. Support structure **154** is made of material having high thermal conductivity, such as alumina, to efficiently dissipate heat from the bulb. Once a vacuum is established in chamber **142**, heat transfer between the bulb **140** and waveguide body **144** is substantially reduced.

FIG. 3A illustrates a type-A bulb and lamp chamber embodiment similar to the type-B embodiment shown in **FIG. 1**. A self-enclosed bulb **170** is closely received within a lamp chamber **172** in a dielectric waveguide body **174**. Bulb **170** includes a generally cylindrical wall **176** of transparent dielectric material attached to a bottom **178** made of the same material. Wall **176** has a circumferential upper edge **176U** hermetically sealed to a transparent window **180** by a seal **182**. Window **180** either is made of the same material as the wall and bottom or has a CTE which is very close to the CTE of that material. Preferably, the wall, bottom and window are made of quartz. The exterior surfaces **176E**, **178E**, respectively, of wall **176** and bottom **178** are in thermal contact with the surfaces of lamp chamber **172** contiguous to them, surfaces **172A**, **172B**, respectively. Preferably, wall **176** has a thickness in a range between one millimeter and ten millimeters. As in the **FIG. 1** embodiment, heat from the plasma exits the bulb wall and bottom and is absorbed by the waveguide body **174**. Thus this "bulb cavity" embodiment has low efficiency.

FIG. 3B illustrates a bulb and lamp chamber embodiment which differs from the **FIG. 3A** embodiment in one respect. The exterior surfaces **192E**, **194E**, respectively, of generally cylindrical wall **192** and bottom **194** of self-enclosed bulb **190** are coated with a thin-film, multi-layer dielectric coating **200** which allows the plasma to retain a significant fraction of its emission spectrum at its steady state operating temperature by reflecting radiation exiting the wall **192** and bottom **194** back into the bulb. It should be emphasized that the coating is not made of reflective material which, in general, prevents microwave power from heating the light-emitting plasma. Tailored, broadband reflectivity over the emission range of the plasma is instead achieved by interference among electromagnetic waves propagating through thin-film layers presenting refractive index changes at length-scales on the order of their wavelength. The number of layers and their individual thicknesses are the primary design variables. This is a well understood technology in the optical industry [see Chapters 5 and 7, H.A. McLeod, "Thin-Film Optical Filters," 3rd edition, Institute of Physics Publishing (2001)], and such coatings having a reflectivity spectrum suitable for the present invention are available commercially. For ruggedness in the harsh environment proximate to bulb **190**, one method of coating **200** is depositing layers of silicon dioxide (SiO_2), which is transparent for wavelengths between 0.12μm and 4.5μm. Another method is depositing layers of titanium dioxide (TiO_2), which is transparent to wavelengths between 0.43μm and 6.2μm. **FIG. 9** shows the reflectance spectrum **202A**, **202B**, respectively, for light incident at 30 degrees off normal and at normal incidence on a SiO_2 multi-layer substrate. This coating was formulated according to our specifications by ZC&R Coatings for Optics Inc. of Torrance, CA. Typically, coatings used in the present invention have approximately 10 to 100 layers with each layer having a thickness in a range between 0.1μm and 10μm. It is expected that a coating on the interior surface of a bulb would not survive the plasma environment.

FIG. 4A illustrates a bulb and lamp chamber embodiment similar to the **FIG.** 2 embodiment. A self-enclosed bulb **210** is disposed within a lamp chamber **212** in a dielectric waveguide body **214**. Bulb **210** includes a generally cylindrical wall **216** of transparent dielectric material extending upwardly in a circumferential lip **218** having lower and upper surfaces **218L**, **218U**, respectively, and attached to a transparent bottom **220**. Lower surface **218L** is hermetically sealed by a seal **222** to a bulb support structure **224** attached to body **214**. Bulb **210** further includes a window **226** hermetically sealed by a seal **228** to upper surface **218U**. Preferably, wall **216**, lip **218**, bottom **220** and window **226** are made of quartz. Preferably, support structure **224** is made of dielectric or metallic material having high thermal conductivity, such as, respectively, alumina or copper. The support structure **224** can be transparent to varying degrees in the emission band of the plasma at operating conditions, or opaque. In contrast to the **FIG. 2** embodiment, lamp chamber **212** is filled with air rather than evacuated. A lamp constructed according to this embodiment would have lower efficiency because heat lost from the bulb would not be recycled.

FIG. 4B illustrates a bulb and lamp chamber embodiment which differs from the **FIG. 4A** embodiment only in that the exterior surfaces **232E**, **234E**, respectively, of generally cylindrical wall **232** and bottom **234** of self-enclosed bulb **230** are coated with a thin-film, multi-layer dielectric coating **240** which allows the plasma to retain a significant fraction of its emission spectrum at its steady state operating temperature by reflecting radiation exiting the wall **232** and bottom **234** back into the bulb.

FIG. 4C illustrates a bulb and lamp chamber embodiment wherein the exterior surfaces **252E, 254E**, respectively, of generally cylindrical wall **252** and bottom **254** of self-enclosed bulb **250** are uncoated, and generally cylindrical wall surface **256** and generally planar bottom surface **258** of lamp chamber **260** are coated with a thin-film, multi-layer dielectric coating **262**. Radiation exiting the wall **252** and bottom **254** is reflected from coated surfaces **256** and **258** into bulb **250**, thereby recycling heat energy.

FIG. 4D illustrates a bulb and lamp chamber embodiment wherein the exterior surfaces **272E, 274E**, respectively, of generally cylindrical wall **272** and bottom **274** of self-enclosed bulb **270** are coated with a first thin-film, multi-layer dielectric coating **270C**, and generally cylindrical wall surface **276** and generally planar bottom surface **278** of lamp chamber **280** are coated with a second thin-film, multi-layer dielectric coating **280C**. Radiation exiting the wall **272** and bottom **274** not reflected from coated surfaces **272E** and **274E**, i.e., passing through coating **270C**, may be reflected from the coated chamber surfaces **276, 278** back through coating **270C** and into the bulb **270**. It should be noted that the coatings on the bulb and chamber surfaces need not be of identical design, but may have their spectral characteristics tailored to optimize both thermal efficiency and light output.

Referring to **FIGs. 5A** and **5B**, a lamp chamber **290** has a surface **290S** bounding a surrounding wall **290W** of dielectric material which may or may not be continuous with the dielectric material **290D** forming the waveguide body, and an open aperture **290A**. Surface **290S** tapers symmetrically to a chamber bottom **290B**, and is shaped to direct light emitted by the plasma in the bulb so as to satisfy ray-divergence specifications levied by the optical system receiving the lamp's output radiation. Such specifications would not necessarily call for either strictly convergent or strictly parallel rays; rays forming a limited numerical aperture are the most likely requirement. In practice, a paraboloidal or an ellipsoidal shape can be used as a starting design point for a lamp chamber surface. The surface shape would then be optimized using commercial ray-tracing software, taking into account the finite emission volume of the plasma in the bulb, geometric constraints imposed by a pedestal or other mount, and constraints imposed by manufacturing processes. Suitable software products include ZEMAX™, available from

Zemax Development Corporation of San Diego, CA, and CODE-V™, available from Optical Research Associates of Pasadena, CA. **FIG. 5A** shows two rays **R1, R2** emanating from self-enclosed bulb **292** and reflecting off surface **290S**. Reflection is due to the natural reflectivity of the chamber wall material, which preferably is alumina. As shown in **FIG. 5B**, bulb **292** includes a generally cylindrical, transparent wall **294** attached to a bottom **296**, and a window **298** hermetically sealed to wall **294** by a seal **300**. Preferably, the wall, bottom and window are made of quartz. Bulb **292** is mounted on a ceramic pedestal **302** by attaching generally planar bottom surface **296B** of bottom **296** to generally planar top surface **302T** of pedestal **302** with a first layer **304A** of high purity, high temperature, fast-cure ceramic adhesive such as RESBOND™ 940HT or 989, both alumina-oxide based compounds available from Cotronics Corp. of Brooklyn, NY. Bottom surface **302B** of pedestal **302** is attached to wall **290W** proximate to chamber bottom **290B** with a second layer **304B** of the ceramic adhesive.

FIG. 5C shows a modification of the **FIG. 5A** bulb and lamp chamber embodiment wherein the surface **310S** of lamp chamber **310** is coated with a thin-film, multi-layer dielectric coating **312** such as described above. Radiation exiting bulb **314** through generally cylindrical, transparent wall **316** is reflected from coated surface **310S** so heat energy cannot be recycled in the bulb.

FIG. 5D shows a modification of the **FIG. 5A** bulb and lamp chamber embodiment wherein the exterior surfaces **322E, 324E**, respectively, of generally cylindrical, transparent wall **322** and window **324** of bulb **320** are coated with a thin-film, multi-layer dielectric coating **326**. Coating **326** can be tailored so that most of the radiation from the plasma is reflected back into the bulb, providing high efficiency, while radiation in at least one selected spectral band escapes and is reflected from uncoated surface **328S** of lamp chamber **328**.

FIG. 5E shows a modification of the **FIG. 5A** bulb and lamp chamber embodiment wherein the exterior surfaces **332E, 334E**, respectively, of generally cylindrical, transparent wall **332** and window **334** of bulb **330** are coated with a thin-film, multi-layer dielectric first coating **336A**, and surface **338S** of lamp chamber **338** is coated with a thin-film, multi-layer dielectric second coating **336B**. Coatings **336A** and **336B** can be tailored so that most of the excited plasma's emission spectrum is reflected back into the bulb to recycle heat energy, while those portion(s) of the spectrum transmitted through coating **336A** are selectively reflected from coated surface **336B** so that only optically useful light is directed outwardly. This embodiment provides high efficiency and also allows tailoring coatings **336A** and **336B** to provide the precise wavelength(s) or spectral band(s) desired.

FIG. 5F shows a partial-lens cover **338** which can be used in conjunction with any of the **FIGs. 5A-E** embodiments. Cover **338**, which totally covers the chamber aperture, includes an inner lens portion **338L** and an outer planar portion **338P**, each made of a transparent material such as quartz. Planar portion **338P** is attached by an adhesive layer **333** to the waveguide wall surface **339** circumscribing the aperture. The optical prescription of the lens and the area-fraction of the lens vis-a-vis planar portions are design parameters determined using commerical ray-tracing software. Partial lens-cover **338** manipulates the divergence of rays emanating from the bulb. A fraction of the bulb's direct rays, shown schematically as rays **R1**, **R2**, are focused by lens portion **338L**, while a fraction of the bulb's reflected rays, shown schematically as rays **R3**, **R4**, pass undeflected through planar portion **338P**. A fraction of the lamp's direct rays will escape unfocused from planar portion **338P**, while a fraction of the reflected rays will be wrongly focused by lens portion **338L**. However, considering that the position of the bulb in the chamber and the chamber bottom shape can potentially be subject to form-factor constraints such that they cannot form geometries ideal for converging the bulb's output radiation, a partial-lens cover can in such circumstances improve a lamp's overall optical divergence properties.

Thin-film, multi-layer coatings applied to the exterior surfaces of plasma bulbs made of quartz or a similar material would undergo many cycles of heating to temperatures that could approach 1000°C and cooling to room temperature. The longevity of such coatings remains to be determined. **FIGs. 6A** and **6B** illustrate an embodiment which obviates this potential problem. A generally cylindrical, transparent bulb **340** made of quartz or a similar material is surrounded by first and second C-shaped half-cylinders **342A**, **342B**, respectively, having interior surfaces **344A**, **344B**, respectively, and pairs of first and second ends **346A**, **348A** and **346B**, **348B**, respectively. Surfaces **344A** and **344B** are coated with a thin-film, multi-layer coating **350**. Half-cylinders **342A**, **342B**, which may or may not be transparent, are made of a material having a CTE similar to that of coating **350**. Ends (**346A**, **346B**) and (**348A**,

348B) are joined, using a high purity, high temperature, fast-cure ceramic adhesive such as RESBOND™ 940HT or 989 alumina-oxide based compound, to form a generally cylindrical sleeve **352** concentric about bulb **340**. Preferably, sleeve **352** is separated from exterior surface **340E** of bulb **340** by an air gap **354**. Alternatively, there is no air gap. Because coating **350** is on surfaces **344A** and **344B** rather than on bulb surface **340E**, the coating is not directly subjected to extreme temperature variation due to the bulb's heating-cooling cycle. Moreover, it is subjected to the mechanical stress of the matched-CTE sleeve rather than that of the bulb.

FIGs. 7A and **7B** illustrate an embodiment similar to that in **FIGs. 6A, 6B,** wherein C-shaped half-cylinders **360A, 360B**, respectively, are made of quartz or a similar transparent material and have exterior surfaces **362A, 362B**, respectively, coated with a thin-film, multi-layer coating **364**. A sleeve **366** formed by joining the half-cylinders **360A, 360B** preferably is separated from exterior surface **368E** of bulb **368** by an air gap **370**. Alternatively, there is no air gap. Because coating **364** is insulated from bulb **368** by sleeve **366** and air gap **370**, coating **364** is subjected to much less temperature variation than coating **350**.

The two-piece sleeves shown in **FIGs. 6A, 6B** and **7A, 7B** can circumvent a potential problem in the manufacture of the thin-film, multi-layer coating. Tailoring the reflective properties of a multi-layer coating depends on being able to finely control the thickness of the individual layers. While geometric constraints on the material beams used in deposition processes typically employed to apply such coatings may make it impractical to simultaneously coat all surfaces of a cylindrical sleeve, simultaneous coating of both half-cylinders can be achieved.

FIGs. 8A and **8B** illustrate an embodiment wherein a generally cylindrical, one-piece sleeve **380** made of quartz or a similar transparent material has an exterior surface **382A** coated with a thin-film, multi-layer coating **384**. Interior surface **382B** of sleeve **380** preferably is separated from exterior surface **386E** of bulb **386** by an air gap **388**. Alternatively, there is no air gap. Coating **384** is insulated from bulb **386** by sleeve **380** and air gap **388**, so is subjected to much less temperature variation than coating **350** and about as much temperature variation as coating **364**.

We have found that for the bulb and lamp chamber embodiments shown in **FIGs. 3A-B** and **5A-F**, whether or not the bulb is enclosed in any of the **FIGs. 6A-B, 7A-B,**

8A-B sleeves, intimate mechanical contact between the bulb and/or sleeve and the surrounding support structure is often insufficient to provide adequate waste heat removal through conduction. In such cases, use of at least one high purity, high temperature, fast-cure ceramic adhesive layer between a bulb and the support structure (see **FIG. 5B**) or between sleeve outer surfaces and the support structure is necessary to provide the required heat conduction. Preferred adhesives are RESBOND™ 940HT or 989. For the bulb and lamp chamber embodiments shown in **FIGs. 4A-D**, adequate waste heat removal can be achieved by using a bulb support structure having high thermal conductivity.

A DWIPL can consist of a single integrated assembly including: a waveguide body with one or more lamp chambers each containing either a bulb envelope sealed to the environment or a self-enclosed bulb; a driver circuit and driver circuit board; a thermal barrier separating the body and driver circuit; and an outer heatsink. Alternatively, separate packages are used for: (a) the lamp body and heatsink; and (b) the driver circuit and its heatsink. For a DWIPL utilizing two probes (see **FIGs. 11A** and **11B**, and FIG. 6 of the '718 application), the body and driver circuit are connected by two RF power cables, one connecting the output of the driver circuit to the body, and the other providing feedback from the body to the driver circuit. The use of two separate packages allows greater flexibility in the distribution of lamp heat and lamp driver heat.

When microwave power is applied from the driver circuit to the lamp body, it heats the fill mixture, melting and then vaporizing the salt or halide, causing a large increase in the lamp chamber pressure. Depending on the salt or halide used, this pressure can become as high as 400 atmospheres, and the bulb temperature as high as 1000°C. Consequently, a seal attaching a window or lens to a lamp body side or the wall of a self-enclosed bulb must be extremely robust.

Electromagnetically, a DWIPL is a resonant cavity having at least one drive probe supplying microwave power for energizing a plasma contained in at least one bulb. In the following portion of the detailed description "cavity" denotes a DWIPL body. As disclosed in the '718 application, a "bulb" may be a separate enclosure containing a fill mixture disposed within a lamp chamber, or the chamber itself may be the bulb. To provide optimal efficiency, a bulb preferably is located at an electric field maximum of the resonant cavity mode being used. However the bulb can be moved away from a field maximum at the cost of additional power dissipated by the wall and cavity. The location of the drive probe is not critical, as long as it is not at a field minimum, because the desired coupling efficiency can be achieved by varying probe design parameters, particularly length and shape. **FIGs. 10A** and **10B** schematically show two cylindrical lamp configurations **400A, 400B**, respectively, both operating at the fundamental cylindrical cavity mode, commonly known as $TM_{0,1,0}$, and having a bulb **402A, 402B**, respectively, located at the single electric field maximum. Dashed curves **401A, 401B** show, respectively, the electric field distribution in the cavity. In **FIG. 10A**, a drive probe **404A** is located at the field maximum. In **FIG. 10B**, drive probe **404B** is not located at the field maximum; however, it contains a longer probe which provides the same coupling efficiency as probe **404A**. Although the $TM_{0,1,0}$ mode is used here as an example, higher order cavity modes, including but not limited to transverse electric field ("TE") and transverse magnetic field ("TM") modes, can also be used.

Drive probe design is critical for proper lamp operation. The probe must provide the correct amount of coupling between the microwave source and lamp chamber to maximize light emitting efficiency and protect the source. There are four major cavity loss mechanisms reducing efficiency: chamber wall dissipation, dielectric body dissipation, plasma dissipation, and probe coupling loss. As defined herein, probe coupling loss is the power coupled out by the drive probe and other probes in the cavity. Probe coupling loss is a major design consideration because any probe can couple power both into and out of the cavity. If the coupling between the source and cavity is too small, commonly known as "under-coupling", much of the power coming from the source will not enter the cavity but be reflected back to the source. This will reduce light emission efficiency and microwave source lifetime. If initially the coupling between the source and cavity is too large, commonly known as "over-coupling", most of the power from the source will enter the cavity. However, the cavity loss mechanisms will not be able to consume all of the power and the excess will be coupled out by the drive probe and other probes in the cavity. Again, light emission efficiency and microwave source lifetime will be reduced. In order to maximize light emission efficiency and protect the source, the drive probe must provide an appropriate amount of coupling such that reflection from the cavity back to the source is minimized at the resonant frequency. This condition, commonly known as "critical coupling", can be achieved by adjusting the configuration and location of the drive probe. Probe design parameters depend on the losses in the cavity, which depend on the state of the plasma and the temperature of the lamp body. As the plasma state and/or body temperature change, the coupling and resonant frequency will also change. Moreover, inevitable inaccuracies during DWIPL manufacture will cause increased uncertainty in the coupling and resonant frequency.

It is not practical to adjust probe physical parameters while a lamp is operating. In order to maintain as close to critical coupling as possible under all conditions, a feedback configuration is required (see FIG. 6 of the '718 application), such as lamp configurations **410A**, **410B** shown, respectively, in **FIGs. 11A** and **11B** for a rectangular prism-shaped cavity and a cylindrical cavity. A second "feedback" probe **412A**, **412B**, respectively, is introduced into a cavity **414A**, **414B**, respectively. Feedback probe **412A**, **412B**, respectively, is connected to input port **416A**, **416B**, respectively, of a combined amplifier and control circuit (ACC) **418A**, **418B**, respectively, and a drive probe **420A**, **420B**, respectively, is connected to ACC output port **422A**, **422B**, respectively. Each configuration forms an oscillator. Resonance in the cavity enhances the electric field strength needed to create the plasma and increases the coupling efficiency between the drive probe and bulb. Both the drive probe and feedback probe may be located anywhere in the cavity except near an electric field minimum for electric field coupling, or a magnetic field minimum for magnetic field coupling. Generally, the feedback probe has a lesser amount of coupling than the drive probe because it samples the electric field in the cavity with minimum increase in coupling loss.

From a circuit perspective, a cavity behaves as a lossy narrow bandpass filter. The cavity selects its resonant frequency to pass from the feedback probe to the drive probe. The ACC amplifies this preferred frequency and puts it back into the cavity. If the amplifier gain is greater than the insertion loss at the drive probe entry port vis-a-vis insertion loss at the feedback probe entry port, commonly known as S_{21}, oscillation will start at the resonant frequency. This is done automatically and continuously even when conditions, such as plasma state and temperature, change continuously or discontinuously. Feedback enables manufacturing tolerances to be relaxed because the cavity continually "informs" the amplifier of the preferred frequency, so accurate prediction of eventual operating frequency is not needed for amplifier design or DWIPL manufacture. All the amplifier needs to provide is sufficient gain in the general frequency band in which the lamp is operating. This design ensures that the amplifier will deliver maximum power to the bulb under all conditions.

In order to maximize light emission efficiency, a drive probe is optimized for a plasma that has reached its steady state operating point. This means that prior to plasma formation, when losses in a cavity are low, the cavity is over-coupled. Therefore, a portion of the power coming from the microwave source does not enter the cavity and is reflected back to the source. The amount of reflected power depends on the loss difference before and after plasma formation. If this difference is small, the power reflected before plasma formation will be small and the cavity will be near critical coupling. A feedback configuration such as shown in **FIGs. 11A** or **11B** will be sufficient to break down the gas in the bulb and start the plasma formation process. However, in most cases the loss difference before and after plasma formation is significant and the drive probe becomes greatly over-coupled prior to plasma formation. Because much of the power is reflected back to the amplifier, the electric field strength may not be large enough to cause gas breakdown. Also, the large amount of reflected power may damage the amplifier or reduce its lifetime.

FIG. 12 shows a lamp configuration **430** which solves the drive probe over-coupling problem wherein a third "start" probe **432**, optimized for critical coupling before plasma formation, is inserted into a cavity **434**. Start probe **432**, drive probe **436**, and feedback probe **438** can be located anywhere in the cavity except near a field minimum. Power from output port **440B** of an ACC **440** is split into two portions by a splitter **442**: one portion is delivered to drive probe **436**; the other portion is delivered to start probe **432** through a phase shifter **444**. Probe **438** is connected to input port **440A** of ACC **440**. Both the start and drive probes are designed to couple power into the same cavity mode, e.g., $TM_{0,1,0}$ for a cylindrical cavity as shown in **FIG. 12**. The splitting ratio and amount of phase shift between probes **436** and **432** are selected to minimize reflection back to the amplifier. Values for these parameters are determined by network analyzer S-parameter measurements and/or simulation software such as High Frequency Structure Simulator (HFSS)™ available from Ansoft Corporation of Pittsburgh, PA. In summary, the start probe is critically coupled before plasma formation and the drive probe is critically coupled when the plasma reaches steady state. The splitter and phase shifter are designed to minimize reflection back to the combined amplifier and control circuit.

FIG. 13 shows a second lamp configuration **450** which solves the drive probe over-coupling problem. Both start probe **452** and drive probe **454** are designed to couple power into the same cavity mode, e.g., $TM_{0,1,0}$ for a cylindrical cavity such as cavity **456**. Configuration **450** further includes a feedback probe **458** connected to input port **460A** of an ACC **460**. The three probes can be located anywhere in the cavity except near a field minimum. Power from output port **460B** of ACC **460** is delivered to a first port **462A** of a circulator **462** which directs power from port **462A** to a second port **462B** which feeds drive probe **454**. Prior to plasma formation, there is a significant amount of reflection coming out of the drive probe because it is over-coupled before the plasma reaches steady state. Such reflection is redirected by circulator **462** to a third port **462C** which feeds the start probe **452**. Before plasma formation, the start probe is critically coupled so that most of the power is delivered into the cavity **456** and start probe reflection is minimized. Only an insignificant amount of power goes into port **462C** and travels back to ACC output port **460B**. Power in the cavity increases until the fill mixture breaks down and begins forming a plasma. Once the plasma reaches steady state, the drive probe **454** is critically coupled so reflection from the drive probe is minimized. At that time, only an insignificant amount of power reaches the now under-coupled start probe **452**. Although the start probe now has a high reflection coefficient, the total amount of reflected power is negligible because the incident power is insignificant. In summary, the start probe is critically coupled before plasma formation and the drive probe is critically coupled when the plasma reaches steady state. The circulator directs power from port **462A** to **462B**, from port **462B** to port **462C**, and from port **462C** to port **462A**.

FIGs. 14A and **14B** show third and fourth lamp configurations **470A, 470B** which solve the drive probe over-coupling problem. A "start" cavity mode is used before plasma formation, and a separate "drive" cavity mode is used to power the plasma to its steady state and maintain that state. Start probe **472A, 472B**, respectively, operates in the start cavity mode, and drive probe **474A, 474B,** respectively, operates in the drive cavity mode. As indicated by dashed curves **471A** and **471B**, preferably the drive cavity mode is the fundamental cavity mode and the start cavity mode is a higher order cavity mode. This is because normally it requires more power to maintain the steady state plasma with the desired light output than to break down the gas for plasma formation. Therefore it is more economical to design a DWIPL so the high power microwave source operates at a lower frequency. For a cylindrical cavity such as cavities **476A** and **476B**, the start probe **472A**, **472B**, respectively, can be critically coupled at the resonant frequency of the $TM_{0,2,0}$ mode before plasma formation, and the drive probe **474A**, **474B**, respectively, can be coupled at the resonant frequency of the $TM_{0,1,0}$ mode after the plasma reaches steady state. The feedback probe can be located anywhere in the cavity except near a field minimum of the drive cavity mode or a field minimum of the start cavity mode. The start probe can be located anywhere in the cavity except near any field minima of the start cavity mode. The drive probe should be located near or at a field minimum of the start cavity mode but not near a field minimum of the drive cavity mode. This minimizes the coupling loss of the drive probe before plasma formation so that the electric field in the cavity can reach a higher value to break down the gas. A diplexer **478A**, **478B**, respectively, is used to separate the two resonant frequencies. In **FIG. 14A**, a single ACC **480** connected at its output **480B** to diplexer **478A** is used to power both cavity modes. The two frequencies are separated by diplexer **478A** and fed to the start probe **472A** and drive probe **474A**. Feedback probe **482A** is connected to input port **480A** of ACC **480**. In **FIG. 14B**, two separate amplifiers **490**, **492** with output ports **490B**, **492B**, respectively, are used to power the two cavity modes independently. Diplexer **478B** separates the two frequencies coming out of feedback probe **482B**. In summary, the start probe operates in one cavity mode and the drive probe operates in a different mode. The feedback probe can be located anywhere in the cavity except near a field minimum of either mode. The start probe can be located anywhere in the cavity except near a field minimum of the start cavity mode. The drive probe should be located near or at a field minimum of the start cavity mode but not near a field minimum of the drive cavity mode.

An alternative to the approach shown in **FIG. 14B** is to split the feedback probe **482B** into two feedback probes, thereby eliminating the need for diplexer **478B**. The first feedback probe is located at a field minimum of the start cavity mode to couple out only the drive cavity mode, which is then amplified by ACC **490** connected at its output **490B** to drive probe **474B**. The second feedback probe is located at a field minimum of the drive cavity mode to couple out only the start cavity mode, which is then amplified by ACC **492** connected at its output **492B** to start probe **472B**. Two separate feedback loops are implemented, with the function of the diplexer separating the drive and start cavity modes being replaced by proper placement of the two feedback probes.

FIGs. 15A and **15B** show lamp configurations **500A**, **500B**, respectively, which do not include a start probe but utilize two separate cavity modes. As indicated by curves **501A** and **501B**, respectively, in cavities **502A** and **502B**, a relatively high order start cavity mode is used before plasma formation and a relatively low order drive cavity mode is used to power the plasma to steady state and maintain the state. Preferably, for economy and efficiency, the drive cavity mode again is the fundamental cavity mode and the start cavity mode is a higher order cavity mode. For example, the $TM_{0,2,0}$ mode of a cylindrical lamp cavity can be used before plasma formation, and the $TM_{0,1,0}$ mode can be used to maintain the plasma in steady state. By utilizing two cavity modes, it is possible to design a single drive probe that is critically coupled both before plasma formation and after the plasma reaches steady state, thereby eliminating the need for a start probe. The feedback probe **504A**, **504B**, respectively, can be located anywhere in the cavity except near a field minimum of either cavity mode. The drive probe **506A**, **506B**, respectively, should be located near a field minimum of the start cavity mode but not near a field minimum of the drive cavity mode. By placing the drive probe near but not at a field minimum of the start cavity mode, the drive probe can be designed to provide the small amount of coupling needed before plasma formation and the large amount of coupling required after the plasma reaches steady state when the plasma loss greatly increases. In **FIG. 15A**, a single ACC **510** having input and output ports **510A**, **510B**, respectively, is used to power both cavity modes. In **FIG. 15B**, two separate ACC's **512**, **514** are used to power the two cavity modes independently. A first diplexer **516B** separates the two frequencies coming out of feedback probe **504B** and a second diplexer **518B** combines the two frequencies going into drive probe **506B**. In summary, the drive probe is critically coupled at the start cavity mode resonant frequency before plasma formation and critically coupled at the drive cavity mode resonant frequency when the plasma reaches steady state. The feedback probe can be located anywhere in the cavity except near a field minimum of either cavity mode. The drive probe should be located near a field minimum of the start cavity mode but not near a field minimum of the drive cavity mode.

The '718 application disclosed a technique for drive probe construction wherein a metallic microwave probe is in intimate contact with the high dielectric material of the lamp body. This method has a drawback in that the amount of coupling is very sensitive to the exact dimensions of the probe. A further drawback is that due to the large temperature variation before plasma formation and after the plasma reaches steady state, a mechanism such as a spring is needed to maintain contact between the probe and body. These constraints complicate the manufacturing process and consequently increase production cost. A technique which avoids both problems is to surround a metallic microwave probe extended into a lamp body with a dielectric material having a high breakdown voltage. (Due to the large amount of power delivered within a limited space, the electric field strength near the probe's tip will be very high; therefore a high breakdown voltage material is required.) Typically, this material has a lower dielectric constant than that of the dielectric material forming the lamp body. The material acts as a "buffer" which desensitizes the dependency of coupling on probe dimensions, thereby simplifying fabrication and reducing cost. Preferred buffer materials are TEFLON™ and mullite, a refractory ceramic. The amount of coupling between the microwave source and body can be adjusted by varying the location and dimensions of the probe, and the dielectric constant of the material. In general, if the probe length is less than a quarter of the operating wavelength, a longer probe will provide greater coupling than a shorter probe. Also, a probe placed at a location with a higher field will provide greater coupling than a probe placed at a location where the field is relatively low. This technique also is applicable to a start probe or a feedback probe. The probe location, shape and dimensions can be determined using network analyzer S-parameter measurements and/or simulation software such as HFSS™.

FIG. 16 shows a circuit **520** including an amplifier **522** and a control circuit **524**, suitable for DWIPLs having only a drive probe **526** and feedback probe **528** such as shown in **FIGs. 11A, 11B, 15A** and **15B**, and exemplified here by lamp **530**. The function of amplifier **522** is to convert dc power into microwave power of an appropriate frequency and power level so that sufficient power can be coupled into lamp body **532** and lamp chamber **534** to energize a fill mixture and form a light-emitting plasma.

Preferably, amplifier **522** includes a preamplifier stage **536** with 20 to 30 dB of gain, a medium power amplifier stage **538** with 10 to 20 dB of gain, and a high power amplifier stage **540** with 10 to 18 dB of gain. Preferably, stage **536** uses the Motorola MHL21336, 3G Band RF Linear LDMOS Amplifier, stage **538** uses the Motorola

MRF21030 Lateral N-Channel RF Power MOSFET; and stage **540** uses the Motorola MRF21125 Lateral N-Channel RF Power MOSFET. These devices as well as complete information for support and bias circuits are available from Motorola Semiconductor Products Sector in Austin, Texas. Alternatively, stages **536**, **538** and **540** are contained in a single integrated circuit. Alternatively, stages **536** and **538**, and control circuit **524** are packaged together, and high power stage **540** is packaged separately.

Amplifier **522** further includes a PIN diode attenuator **542** in series with stages **536**, **538** and **540**, preferably connected to preamplifier stage **536** to limit the amount of power which the attenuator must handle. Attenuator **542** provides power control for regulating the amount of power supplied to lamp body **532** appropriate for starting the lamp, operating the lamp, and controlling lamp brightness. Since the amplifier chain formed by stages **536**, **538** and **540** has a fixed gain, varying the attenuation during lamp operation varies the power delivered to body **532**. Preferably, the attenuator **542** acts in combination with control circuit **524**, which may be analog or digital, and an optical power detector **544** which monitors the intensity of the light emitted and controls attenuator **542** to maintain a desired illumination level during lamp operation, even if power conditions and/or lamp emission characteristics change over time. Alternatively, an RF power detector **546** connected to drive probe **526**, amplifier stage **540** and control circuit **524** is used to control the attenuator **542**. Additionally, circuit **524** can be used to control brightness, i.e., controlling the lamp illumination level to meet end-application requirements. Circuit **524** includes protection circuits and connects to appropriate sensing circuits to provide the functions of over-temperature shutdown, over-current shutdown, and over-voltage shutdown. Circuit **524** can also provide a low power mode in which the plasma is maintained at a very low power level, insufficient for light emission but sufficient to keep the fill mixture gas ionized. Circuit **524** also can shut down the lamp slowly by increasing the attenuation. This feature limits the thermal shock a lamp repeatedly experiences and allows the fill mixture to condense in the coolest portion of the lamp chamber, promoting easier lamp starting.

Alternatively, attenuator **542** is combined with an analog or digital control circuit to control the output power at a high level during the early part of the lamp operating cycle, in order to vaporize the fill mixture more quickly than can be achieved at normal operating power. Alternatively, attenuator **542** is combined with an analog or digital control circuit which monitors transmitted and/or reflected microwave power levels through an RF power detector and controls the attenuator to maintain the desired power level during normal lamp operation, even if the incoming power supply voltage changes due to variations in the ac supply or other loads.

FIG. 17 shows an alternative circuit **560** including an amplifier **562** and a control circuit **564**, suitable for supplying and controlling power to the body **566** and lamp chamber **568** of a DWIPL **570** having a drive probe **572** and feedback probe **574,** such as shown in **FIGs. 11A, 11B, 15A** and **15B**. A "starting" bandpass filter **580A** and an "operating" bandpass filter **580B**, in parallel and independently selectable and switchable, are in series with the **FIG. 16** amplifier chain and preferably, as in **FIG. 16**, on the input side of the chain. Filters **580A** and **580B** filter out frequencies corresponding to undesired resonance modes of body **566**. By selecting and switching into the circuit a suitable filter bandpass using first and second PIN diode switches **582A**, **582B**, the DWIPL **570** can operate only in the cavity mode corresponding to the selected frequency band, so that all of the amplifier power is directed into this mode. A pin diode attenuator **584** is connected between pin diode switch **582A** and feedback probe **574**. By switching in filter **580A**, a preselected first cavity mode is enabled for starting the lamp. Once the fill mixture gas has ionized and the plasma begun forming, a selected second cavity mode is enabled by switching in filter **580B**. For a short time, both filters provide power to the lamp to ensure that the fill mixture remains a plasma. During the period when both filters are switched in, both cavity modes propagate through body **566** and the amplifier chain. When a predetermined condition has been met, such as a fixed time delay or a minimum power level, filter **580A** is switched out, so that only the cavity mode for lamp operation can propagate through the amplifier chain. Control circuit **564** selects, deselects, switches in, and switches out filters **580A** and **580B**, following a predetermined operating sequence. An optical power detector **586** connected to control circuit **564** performs the same function as detector **544** in the **FIG. 16** embodiment.

FIG. 18 shows a circuit **600** including an amplifier **602** and an analog or digital control circuit **604**, suitable for supplying and controlling power to the body **606** and lamp chamber **608** of a DWIPL **610** having a drive probe **612**, a feedback probe **616** and a start probe **614**, such as shown in **FIGs. 12, 13, 14A** and **14B**. The feedback probe **616** is connected to input **536A** of preamplifier **536** through a PIN diode attenuator **618** and a filter **620**. The start probe **614** is designed to be critically coupled when lamp **610** is off. To start the lamp, a small amount of microwave power is directed into start probe **614** from preamplifier stage **536** or medium power stage **538** of the amplifier chain. The power is routed through a bipolar PIN diode switch **622** controlled by control circuit **604**. Switch **622** is controlled to send RF microwave power to start probe **614** until the fill mixture gas becomes ionized. A sensor **624A** monitors power usage within body **576**, and/or a sensor **624B** monitors light intensity indicative of gas ionization. A separate timer control circuit, which is part of control circuit **604**, allocates an adequate time for gas breakdown. Once the gas has been ionized, control circuit **604** turns on switch **622** which routes microwave power to high power stage **540** which provides microwave power to drive probe **612**. For a short time, start probe **614** and drive probe **612** both provide power to the lamp to ensure that the fill mixture remains a plasma. When a predetermined condition has been met, such as a fixed time period or an expected power level, control circuit **604** turns off switch **622** thereby removing power to start probe **614** so that the plasma is powered only by drive probe **612**. This provides maximum efficiency.

To enhance the Q-value (i.e., the ratio of the operating frequency to the resonant frequency bandwidth) of the DWIPL **610** during starting, the control circuit **604** can bias the transistors of high power stage **540** to an impedance that minimizes leakage out of probe **612** into stage **540**. To accomplish this, circuit **604** applies a dc voltage to the gates of the transistors to control them to the appropriate starting impedance.

While several embodiments for carrying out the invention have been shown and described, it will be apparent to those skilled in the art that additional modifications are possible without departing from the inventive concepts detailed herein. It is to be understood, therefore, there is no intention to limit the invention to the particular embodiments disclosed. On the contrary, it is intended that the invention cover all modifications, equivalences and alternative constructions falling within the spirit and scope of the invention as expressed in the appended claims.

CLAIMS

What is claimed is:

1. A lamp comprising:

   a waveguide body comprising material having a dielectric constant greater than 2;

   a bulb adjacent to the waveguide body;

   a first thin-film, multi-layer dielectric coating between the waveguide body and the bulb; and

   a power source coupled to the waveguide body to provide power to the waveguide body.

2. The lamp of claim 1, wherein the waveguide body forms an opening and at least a portion of the bulb positioned in the opening.
3. The lamp of any of the preceding claims, wherein the bulb is spaced apart from the waveguide body.
4. The lamp of any of the preceding claims, further comprising a ceramic adhesive between the waveguide body and the bulb.
5. The lamp of any of the preceding claims, wherein the first thin-film, multi-layer dielectric coating is on the bulb.
6. The lamp of any of the preceding claims, wherein the first thin-film, multi-layer dielectric coating is on the waveguide body.
7. The lamp of any of the preceding claims, further comprising a sleeve between the bulb and the waveguide body.
8. The lamp of any of the preceding claims, wherein the first thin-film, multi-layer dielectric coating is on the sleeve.
9. The lamp of any of the preceding claims, wherein the sleeve is transmissive and the first thin-film, multi-layer dielectric coating is on an outer surface of the sleeve.
10. The lamp of any of the preceding claims, wherein the sleeve comprises quartz.
11. The lamp of any of the preceding claims, wherein the sleeve is spaced from the bulb.
12. The lamp of any of the preceding claims, wherein the sleeve comprises two pieces.
13. The lamp of any of the preceding claims, wherein the first thin-film, multi-layer

dielectric coating is a reflector.

14. The lamp of any of the preceding claims, wherein the first thin-film, multi-layer dielectric coating comprises layers of silicon dioxide (SiO_2).
15. The lamp of any of the preceding claims, wherein the first thin-film, multi-layer dielectric coating comprises layers of titanium dioxide (TiO_2).
16. The lamp of any of the preceding claims, wherein the reflectance of the first thin-film, multi-layer dielectric coating at 30 degrees off normal incidence is greater than 90% for wavelengths in the range of 500 nanometers to 900 nanometers.
17. The lamp of any of the preceding claims, wherein the reflectance of the first thin-film, multi-layer dielectric coating at normal incidence is greater than 90% for wavelengths in the range of 600 nanometers to 800 nanometers.
18. The lamp of any of the preceding claims, wherein the first thin-film, multi-layer dielectric coating has more than 10 layers.
19. The lamp of any of the preceding claims, wherein the first thin-film, multi-layer dielectric coating has less than 100 layers.
20. The lamp of any of the preceding claims, wherein each layer of the first thin-film, multi-layer dielectric coating has a thickness of at least 0.1 μm.
21. The lamp of any of the preceding claims, wherein each layer of the first thin-film, multi-layer dielectric coating has a thickness of no more than 10 μm.
22. The lamp of any of the preceding claims, further comprising a second thin-film, multi-layer dielectric coating.
23. The lamp of any of the preceding claims, wherein the second thin-film, multi-layer dielectric coating is on the bulb.
24. The lamp of any of the preceding claims, wherein the second thin-film, multi-layer dielectric coating is on the waveguide body.
25. The lamp of any of the preceding claims, wherein the second thin-film, multi-layer dielectric coating is a reflector.
26. The lamp of any of the preceding claims, wherein the second thin-film, multi-layer dielectric coating comprises layers of silicon dioxide (SiO_2).
27. The lamp of any of the preceding claims, wherein the second thin-film, multi-layer dielectric coating comprises layers of titanium dioxide (TiO_2).
28. The lamp of any of the preceding claims, wherein the reflectance of the second

thin-film, multi-layer dielectric coating at 30 degrees off normal incidence is greater than 90% for wavelengths in the range of 500 nanometers to 900 nanometers.

29. The lamp of any of the preceding claims, wherein the reflectance of the second thin-film, multi-layer dielectric coating at normal incidence is greater than 90% for wavelengths in the range of 600 nanometers to 800 nanometers.

30. The lamp of any of the preceding claims, wherein the second thin-film, multi-layer dielectric coating has more than 10 layers.

31. The lamp of any of the preceding claims, wherein the reflectance of the second thin-film, multi-layer dielectric coating has less than 100 layers.

32. The lamp of any of the preceding claims, wherein each layer of the second thin-film, multi-layer dielectric coating has a thickness of at least 0.1 μm.

33. The lamp of any of the preceding claims, wherein each layer of the second thin-film, multi-layer dielectric coating has a thickness of no more than 10 μm.

34. The lamp of any of the preceding claims, wherein the waveguide body forms a lamp chamber containing the bulb.

35. The lamp of any of the preceding claims, wherein the bulb is positioned on a pedestal in the lamp chamber.

36. The lamp of any of the preceding claims, wherein the power source provides power at a frequency in the range of 0.5 to 30 GHz

37. The lamp of any of the preceding claims, wherein the waveguide body resonates when the power is provided at the frequency in the range of 0.5 to 30 GHz.

38. The lamp of any of the preceding claims, wherein the bulb contains a fill that forms a plasma when the power is provided at the frequency in the range of 0.5 to 30 GHz.

39. The lamp of any of the preceding claims, wherein the power source is an amplifier.

40. The lamp of any of the preceding claims, wherein the amplifier obtains feedback from the waveguide body.

41. The lamp of any of the preceding claims, wherein the bulb is transparent.

42. The lamp of any of the preceding claims, wherein the bulb comprises quartz.

43. A lamp comprising:

a lamp body;

a bulb adjacent to the lamp body;

at least two thin-film, multi-layer dielectric coatings between the lamp body and the bulb; and

a power source configured to couple power to the bulb.

44. The lamp of claim 43, wherein the lamp body is a waveguide for the power from the power source and the power is coupled to the bulb through the lamp body.

45. The lamp of any of claims 43 and 44, wherein at least one of the thin-film, multi-layer dielectric coatings is on the bulb.

46. The lamp of any of claims 43, 44 and 45, wherein at least one of the thin-film, multi-layer dielectric coatings is on the lamp body.

47. The lamp of any of claims 43, 44, 45 and 46 wherein each of the thin-film, multi-layer dielectric coatings is a reflector.

48. The lamp of any of claims 43, 44, 45, 46 and 47 wherein the bulb comprises quartz.

49. The lamp of any of claims 43, 44, 45, 46, 47 and 48 wherein the lamp body comprises a dielectric material having a dielectric constant greater than 2.

50. A lamp comprising:

a lamp body;

a bulb adjacent to the lamp body;

a ceramic adhesive between the lamp body and the bulb; and

a power source configured to couple power to the bulb.

51. The lamp of claim 50, wherein the lamp body is a waveguide for the power from the power source and the power is coupled to the bulb through the lamp body.

52. The lamp of any of claims 50 and 51 wherein the lamp body comprises a dielectric material having a dielectric constant greater than 2.

53. The lamp of any of claims 50, 51 and 52, wherein the power source provides power at a frequency in the range of 0.5 to 30 GHz

54. The lamp of any of claims 50, 51, 52 and 53, wherein the lamp body resonates when the power is provided at the frequency in the range of 0.5 to 30 GHz.

55. The lamp of any of claims 50, 51, 52, 53 and 54, further comprising at least one thin-film, multi-layer dielectric coating between the lamp body and the bulb.

56. The lamp of any of claims 50, 51, 52, 53, 54 and 55 wherein the lamp body provides a pedestal for the bulb.

57. The lamp of any of claims 50, 51, 52, 53, 54, 55 and 56, wherein the bulb comprises quartz.

58. A lamp comprising:

a waveguide body comprising material having a dielectric constant greater than 2;

a transparent bulb adjacent to, and spaced apart from, the waveguide body;

a reflective coating between the waveguide body and the bulb; and

a power source coupled to the waveguide body to provide power to the waveguide body.

59. The lamp of claim 58, wherein the bulb comprises quartz.

60. The lamp of any of claims 58 and 59, wherein the reflector comprises a thin-film, multi-layer dielectric coating.

61. The lamp of any of claims 58, 59 and 60, wherein the reflector comprises a sleeve around the bulb.

62. A method for recycling radiative energy in a lamp comprising a waveguide body comprising material having a dielectric constant greater than 2, a bulb adjacent to the waveguide body, and a power source coupled to the waveguide body to provide power to the waveguide body, the method comprising:

applying a thin-film, multi-layer dielectric coating, reflecting plasma radiation back into the bulb, to at least one exterior surface of the bulb.

63. A method for recycling radiative energy in a lamp comprising a waveguide body comprising material having a dielectric constant greater than 2, a bulb adjacent to the waveguide body, and a power source coupled to the waveguide body to provide power to the waveguide body, the method comprising:

applying a thin-film, multi-layer dielectric coating, reflecting plasma radiation back into the bulb, to at least one interior surface of the waveguide body.

64. A method for recycling radiative energy in a lamp comprising a waveguide body comprising material having a dielectric constant greater than 2, a bulb adjacent to the waveguide body, and a power source coupled to the waveguide body to provide power to the waveguide body, the method comprising:

applying a first thin-film, multi-layer dielectric coating, reflecting plasma radiation back into the bulb, to at least one exterior surface of the bulb; and

applying a second thin-film, multi-layer dielectric coating, reflecting plasma radiation back into the bulb, to at least one interior surface of the waveguide body.

65. The lamp of any of claims 62, 63 and 64, wherein the number of layers in each said thin-film, multi-layer dielectric coating is in a range between 10 and 100.

66. The lamp of any of claims 62, 63 and 64, wherein the thickness of each layer in each said thin-film, multi-layer dielectric coating in a range between 0.1 μm and 10 μm.

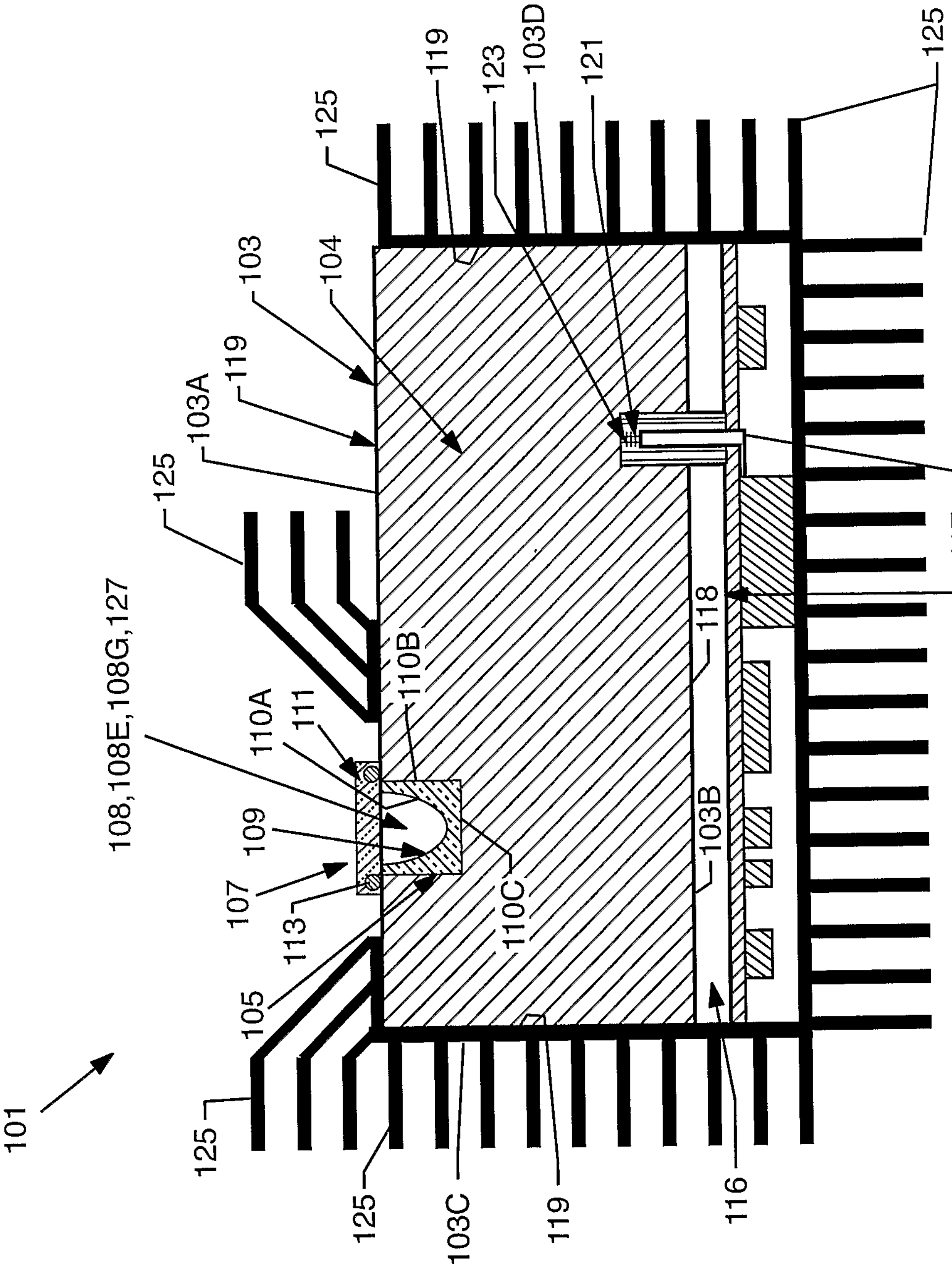

101
125
125
103C
119
116
105
113
107
109
108,108E,108G,127
111
110A
110B
110C
103B
118
125
103A
119
103
104
119
123
103D
121
125
117
115
125

FIG. 1

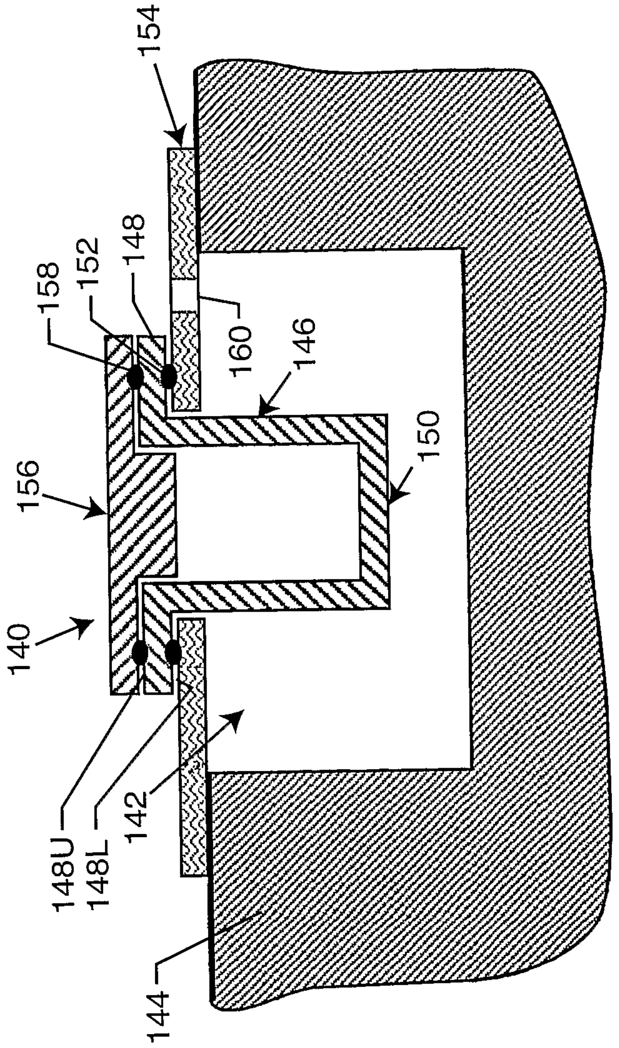


FIG. 2
PRIOR ART

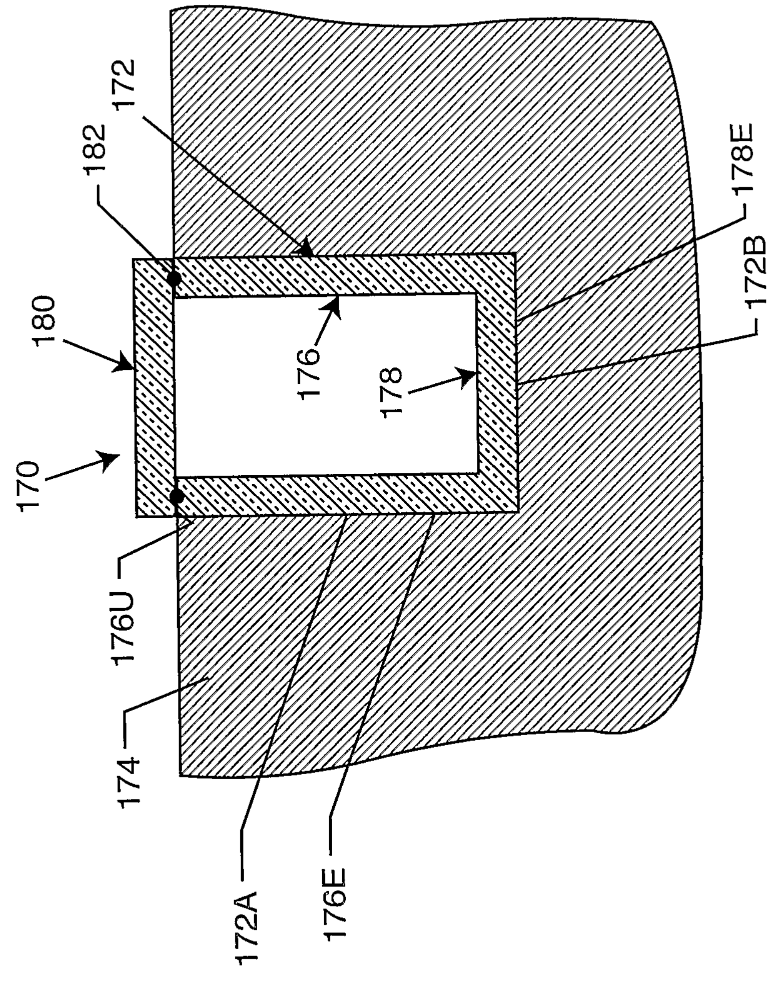


FIG. 3A

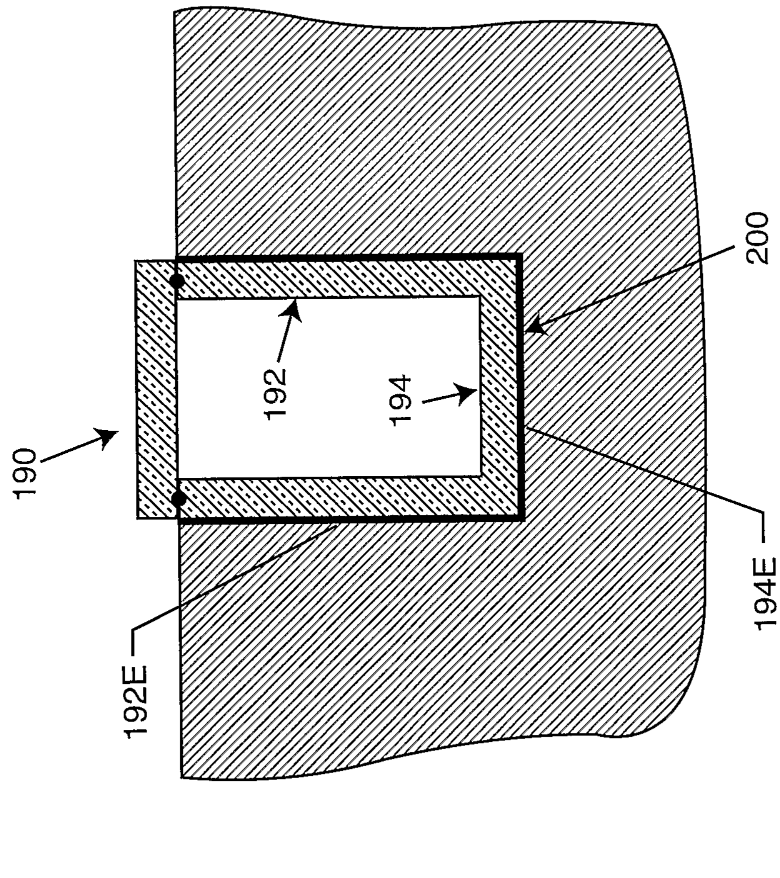


FIG. 3B

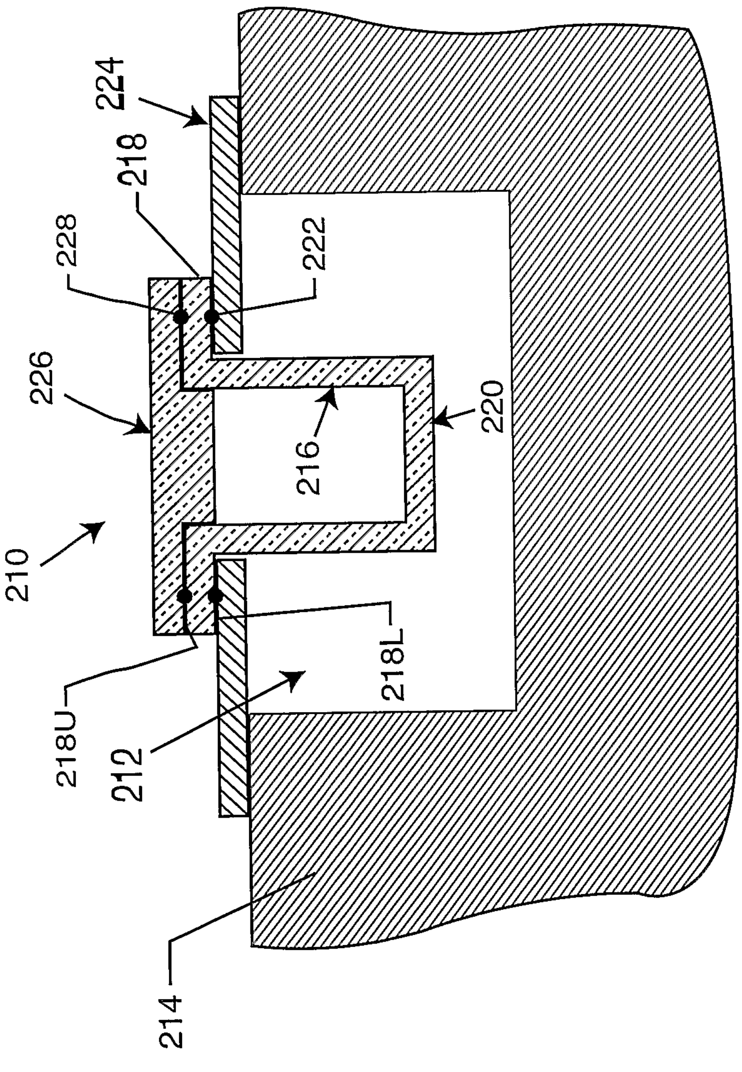


FIG. 4A

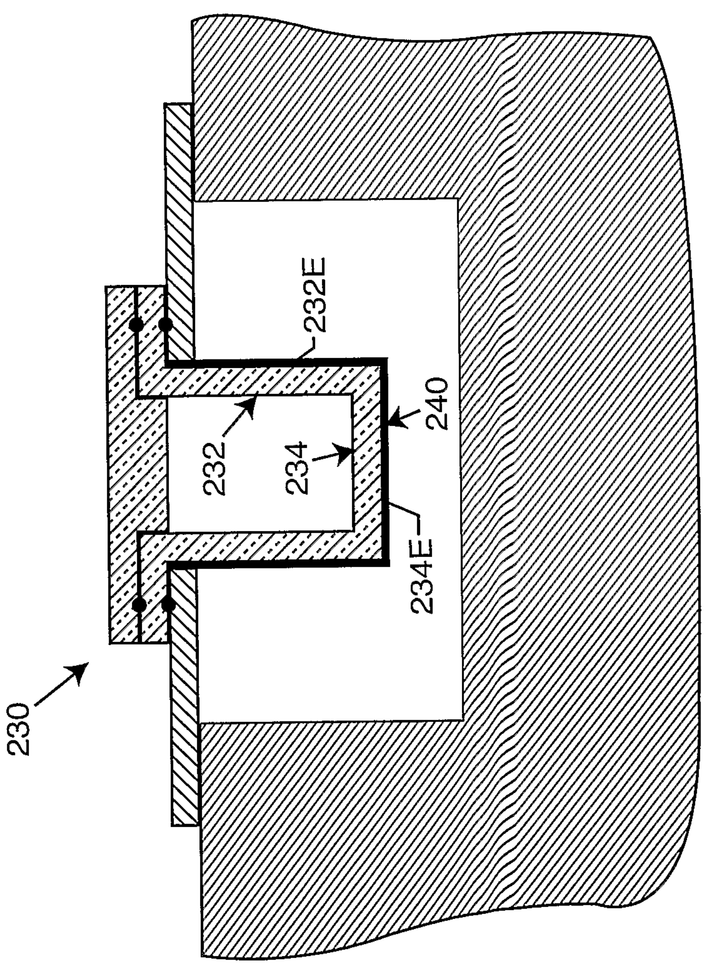


FIG. 4B

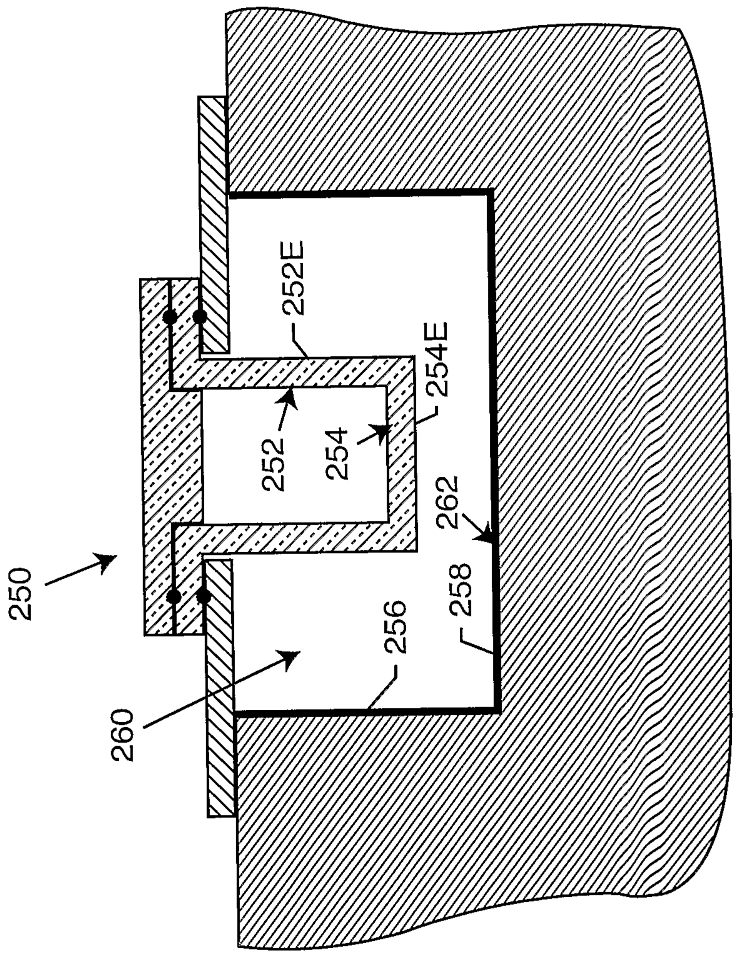


FIG. 4C

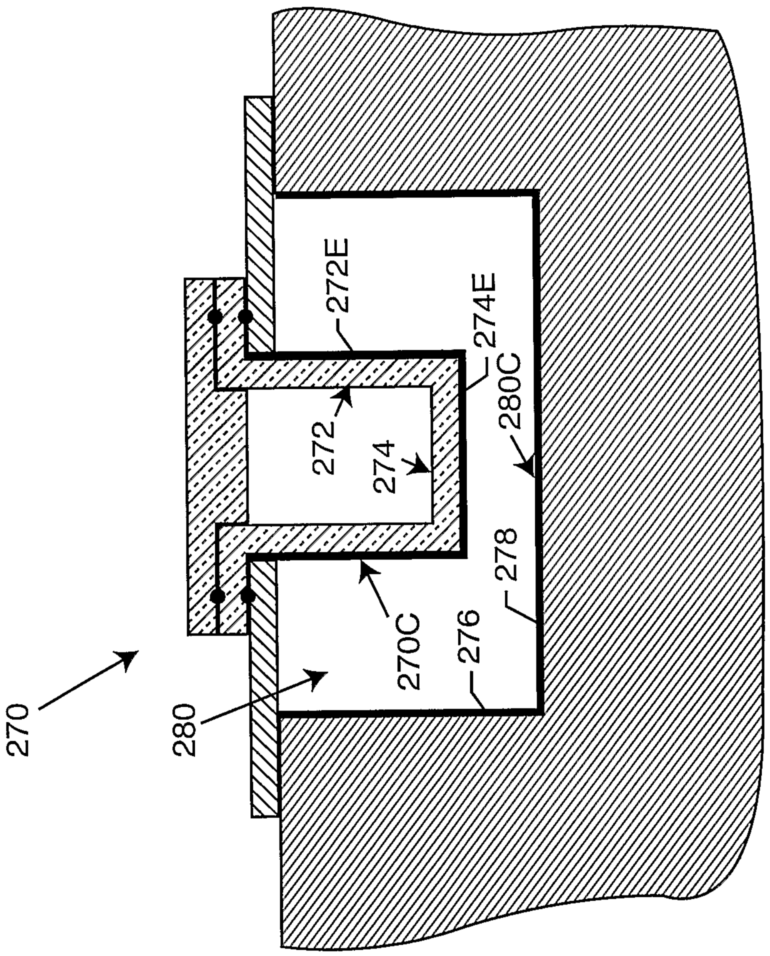


FIG. 4D

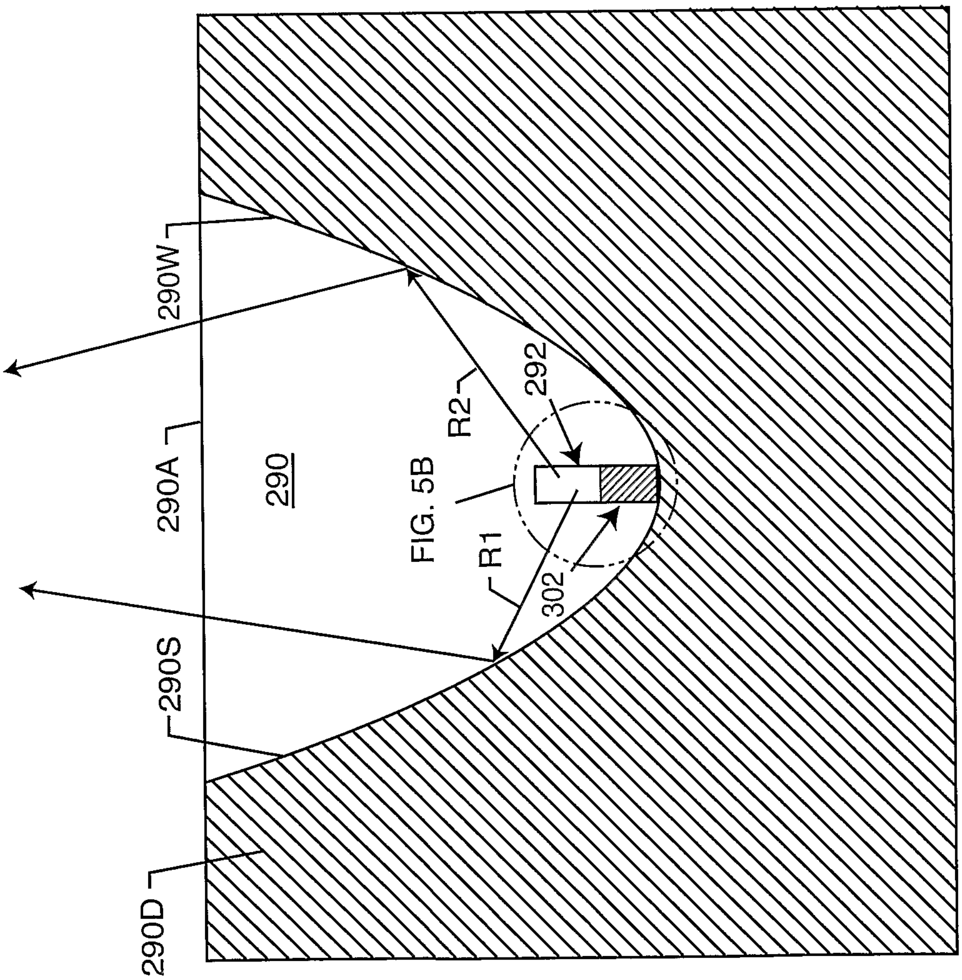


FIG. 5A

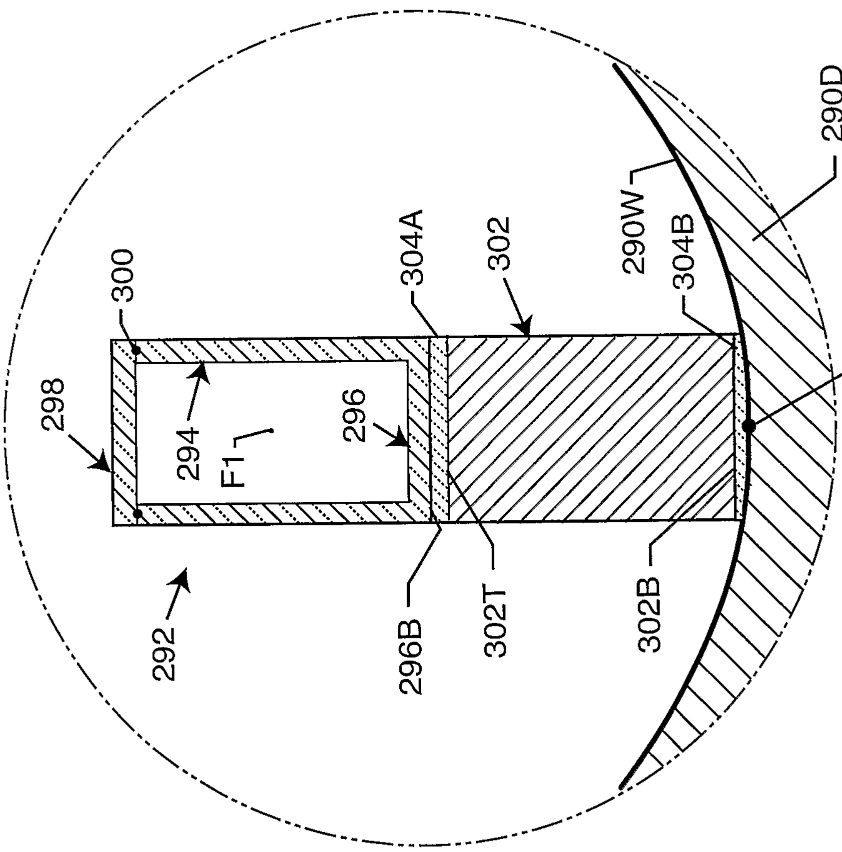

298
300
294
F1
296
292
296B
304A
302
302T
290W
304B
302B
290D
290B

FIG. 5B

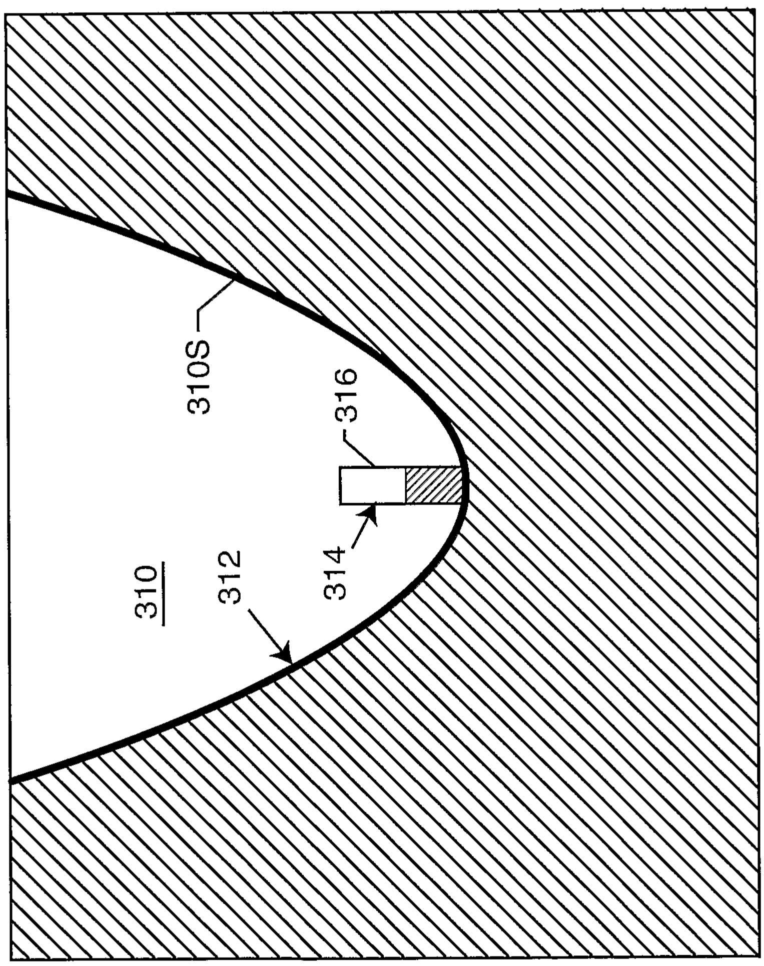


FIG. 5C

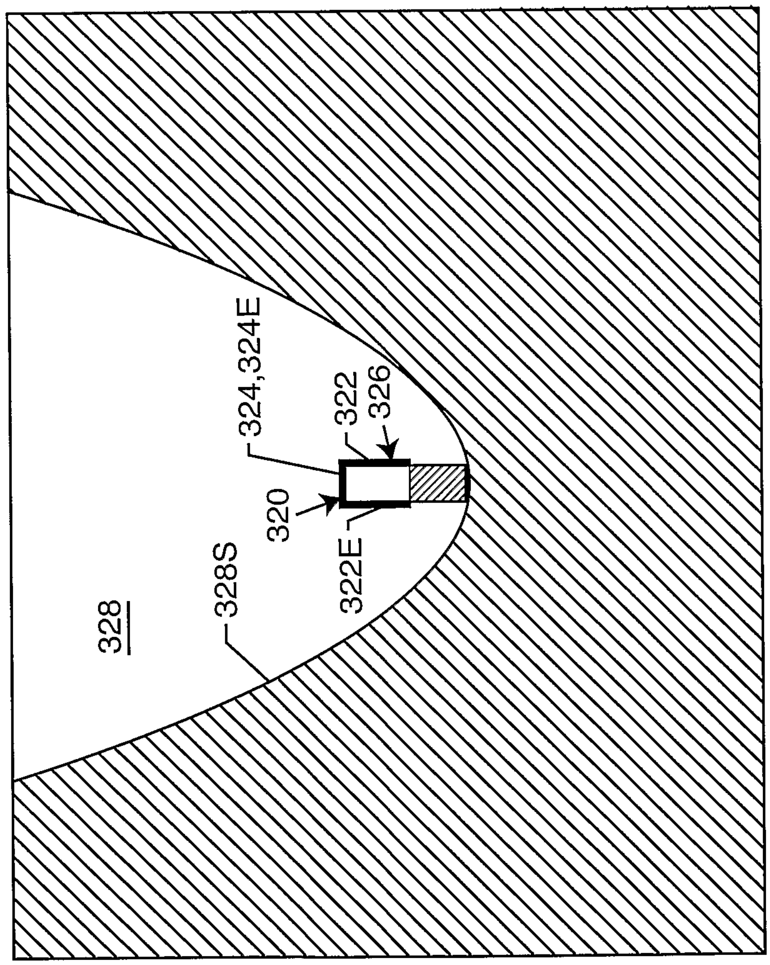


FIG. 5D

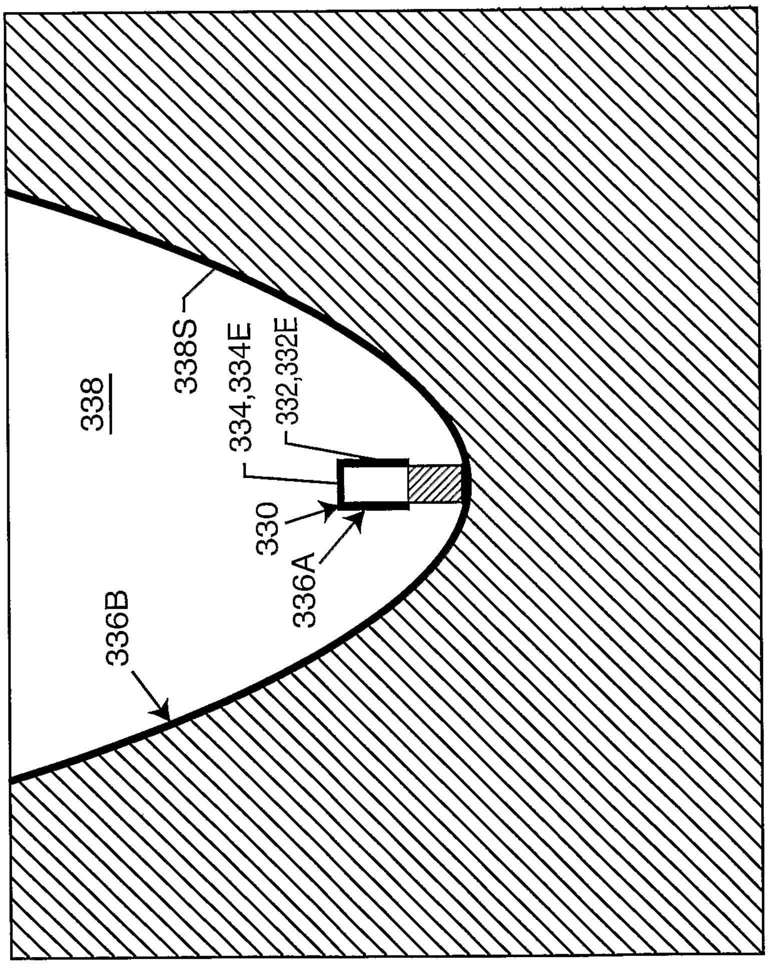


FIG. 5E

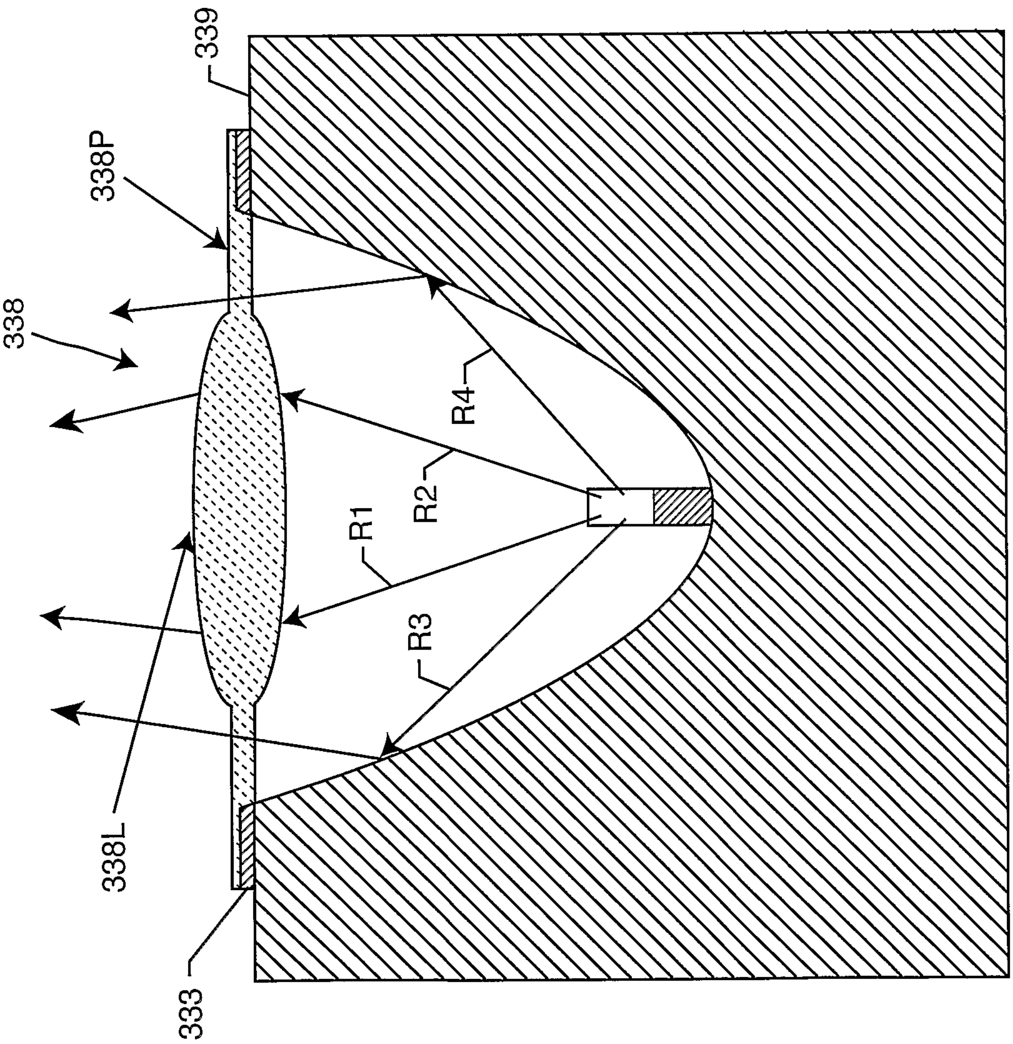


FIG. 5F

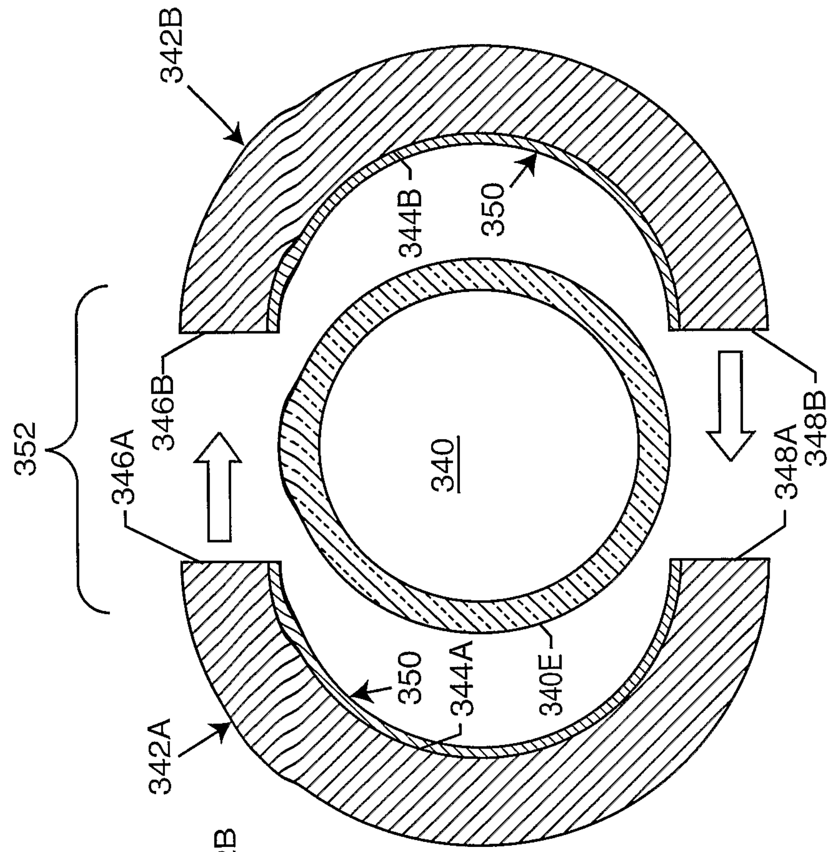

342B
350
344B
352
346B
346A
340
348A
348B
342A
350
344A
340E

FIG. 6B

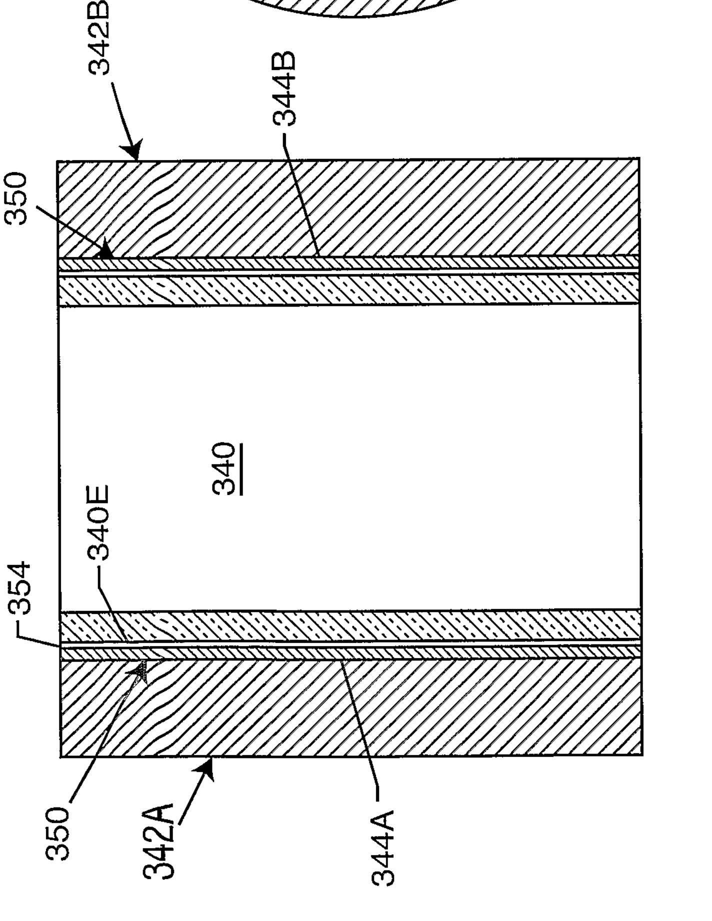
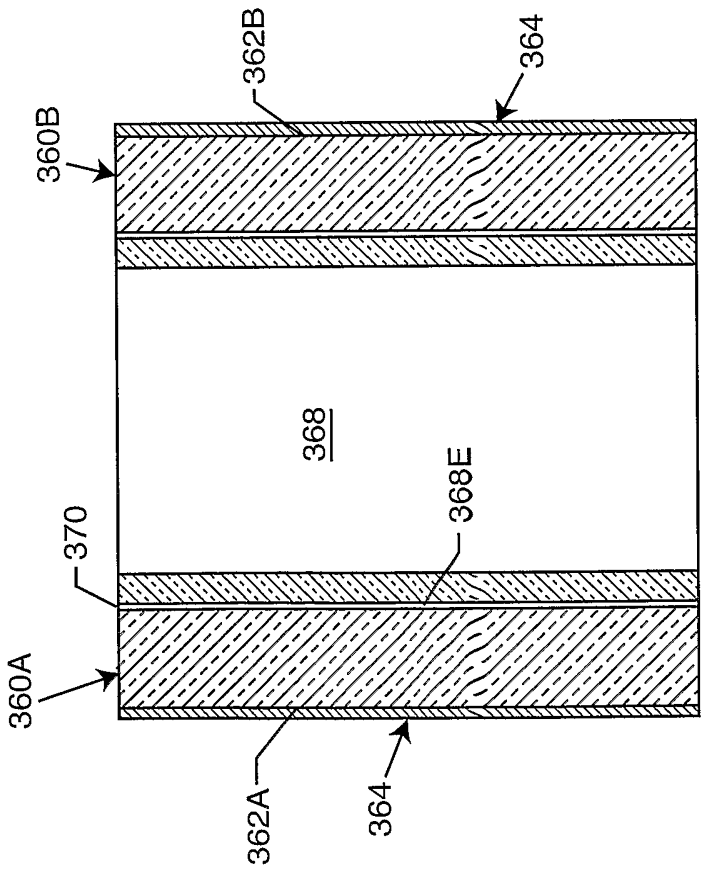
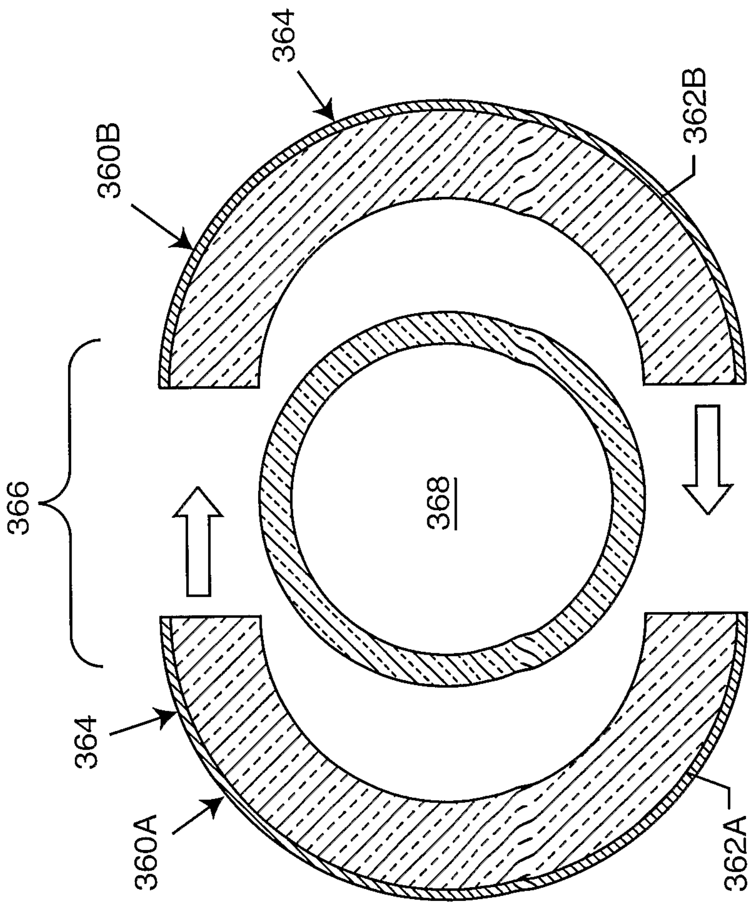

342B
344B
350
340
340E
354
350
342A
344A

FIG. 6A


360B
362B
364
370
368
368E
360A
362A
364
FIG. 7A


364
360B
362B
366
368
364
360A
362A
FIG. 7B

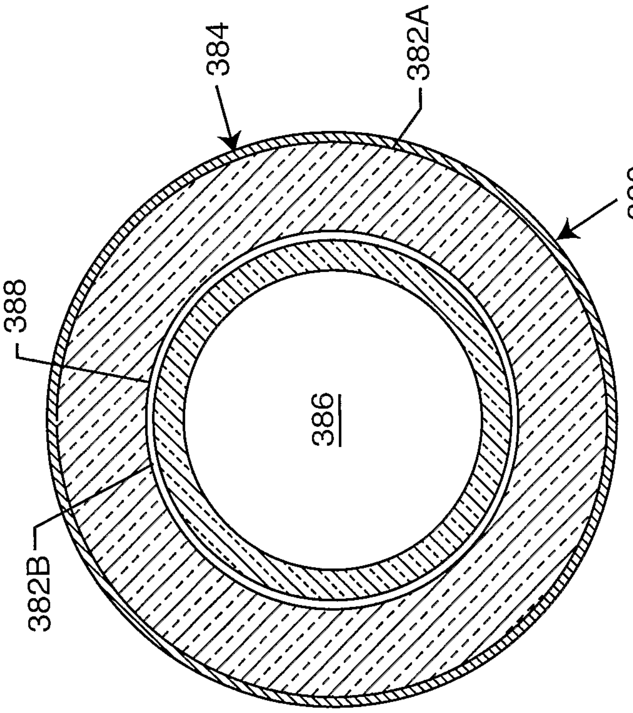

384
382A
380
388
386
382B

FIG. 8B

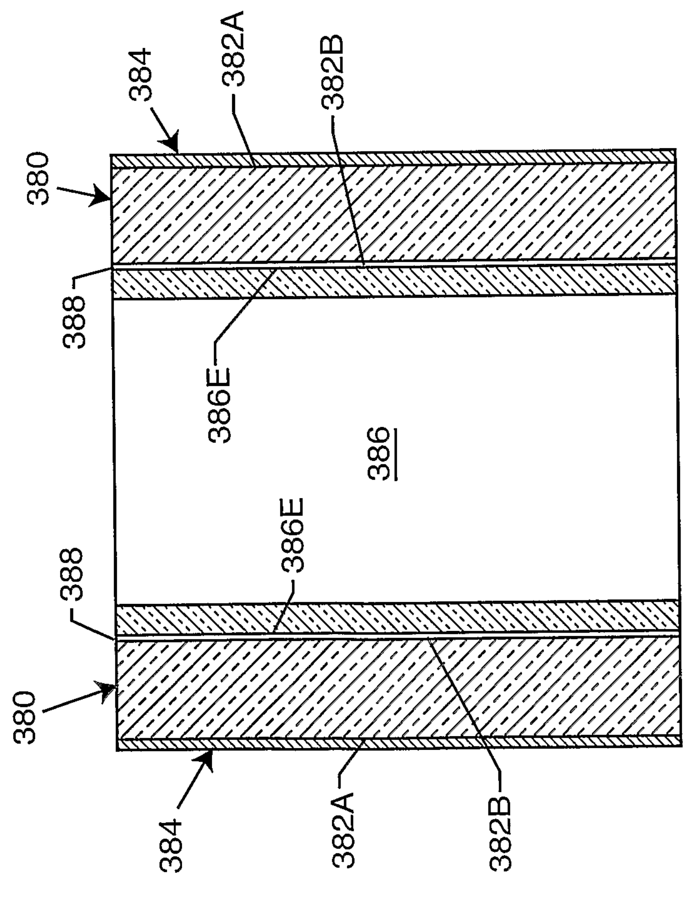

384
382A
382B
380
388
386E
386
388
386E
380
384
382A
382B

FIG. 8A

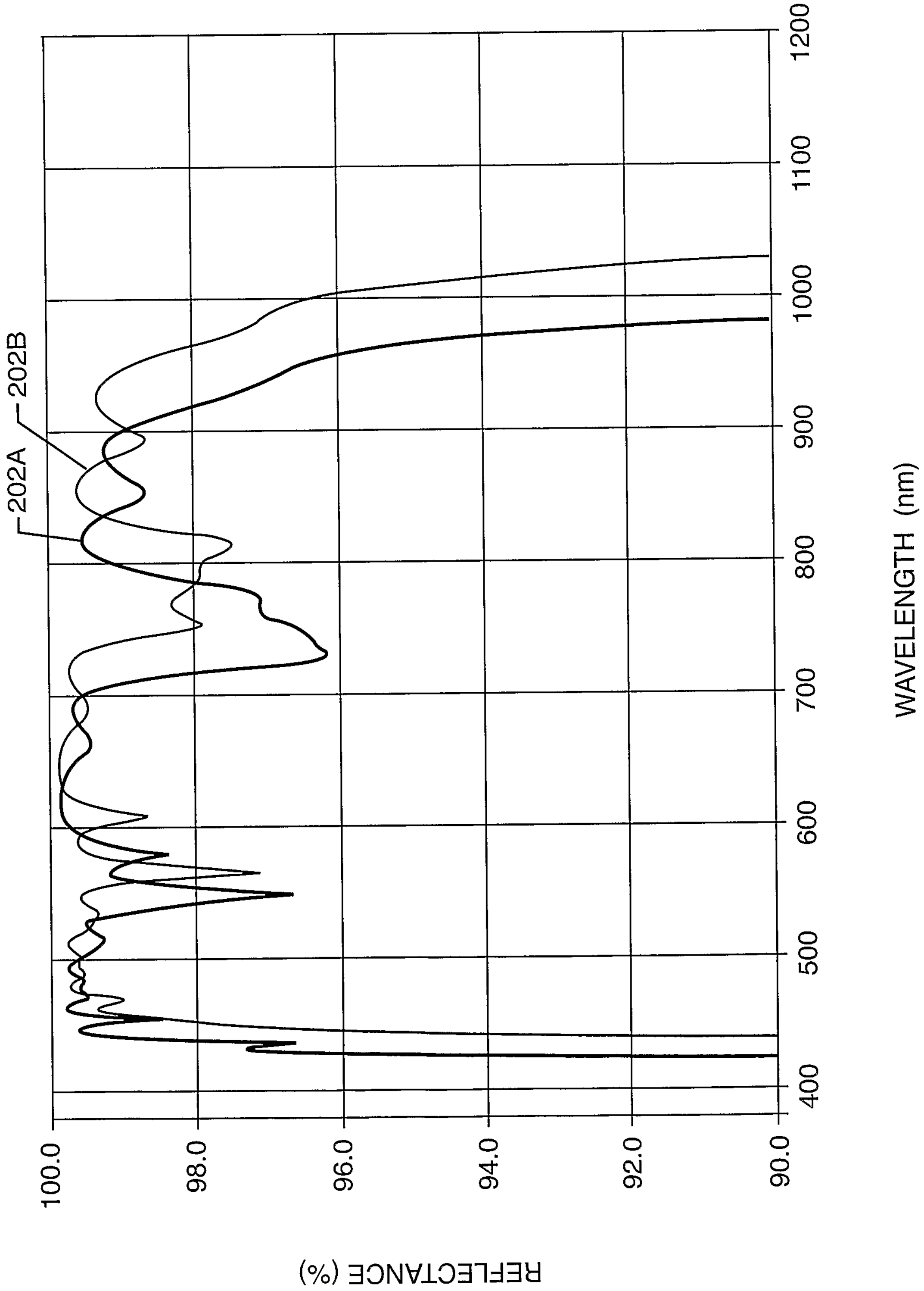

REFLECTANCE (%)
100.0
98.0
96.0
94.0
92.0
90.0
400
500
600
700
800
900
1000
1100
1200
WAVELENGTH (nm)
202A
202B

FIG. 9

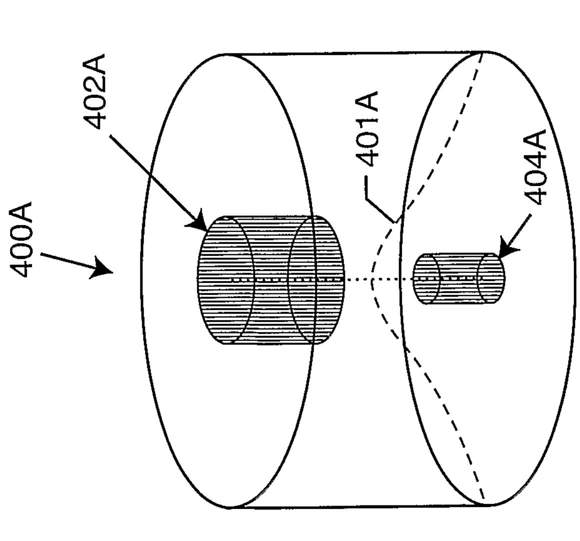


FIG. 10A

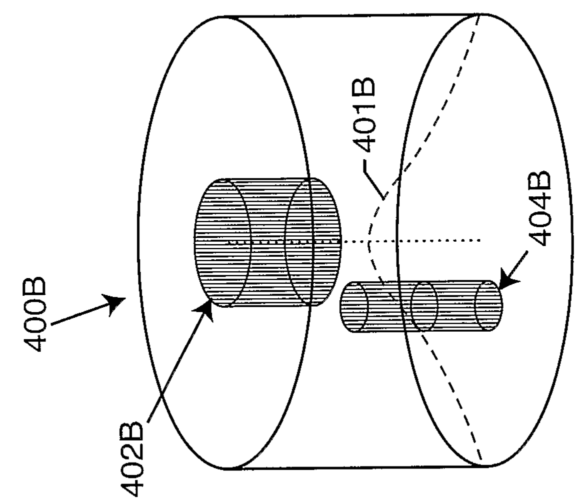


FIG. 10B

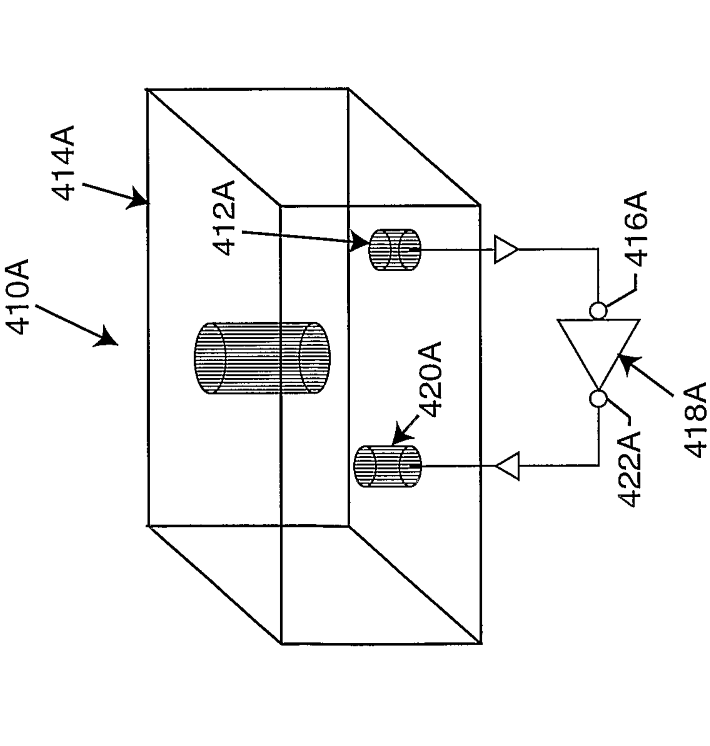


FIG. 11A

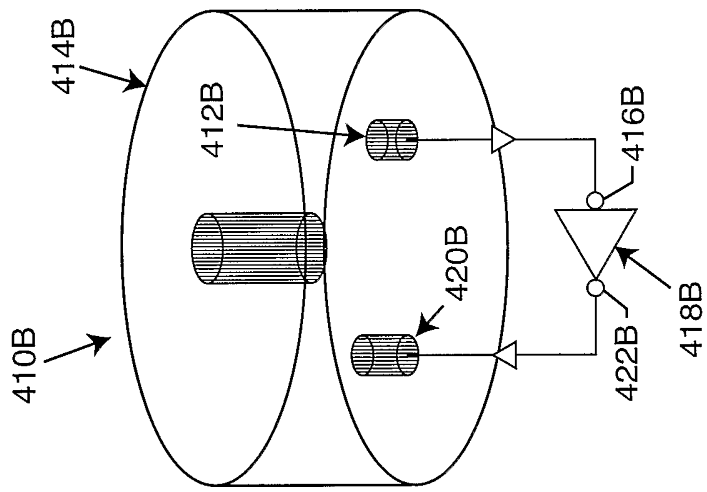


FIG. 11B

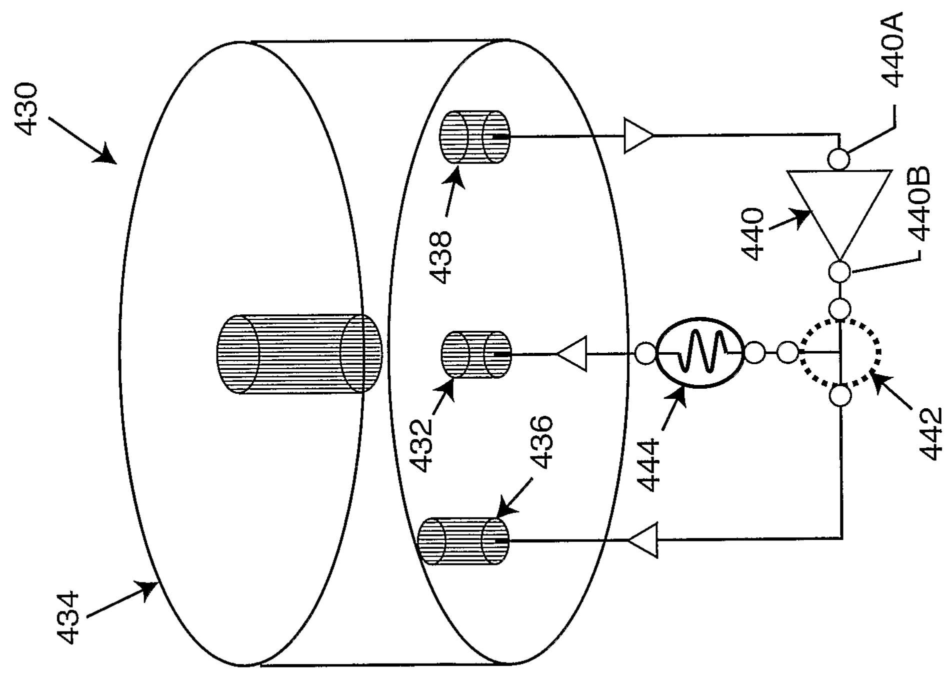


FIG. 12

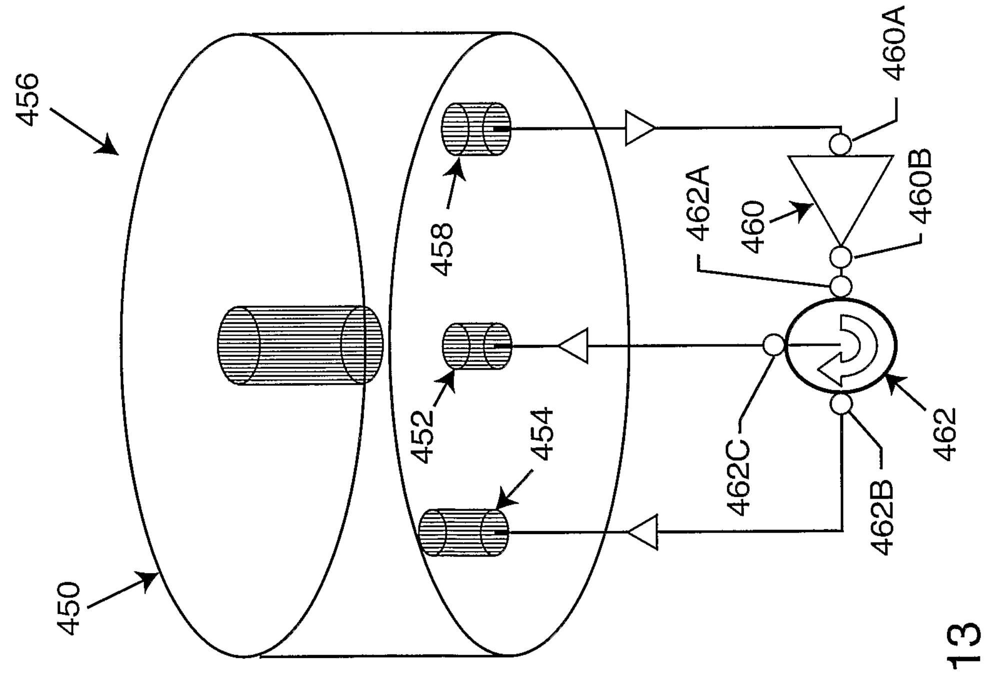


FIG. 13

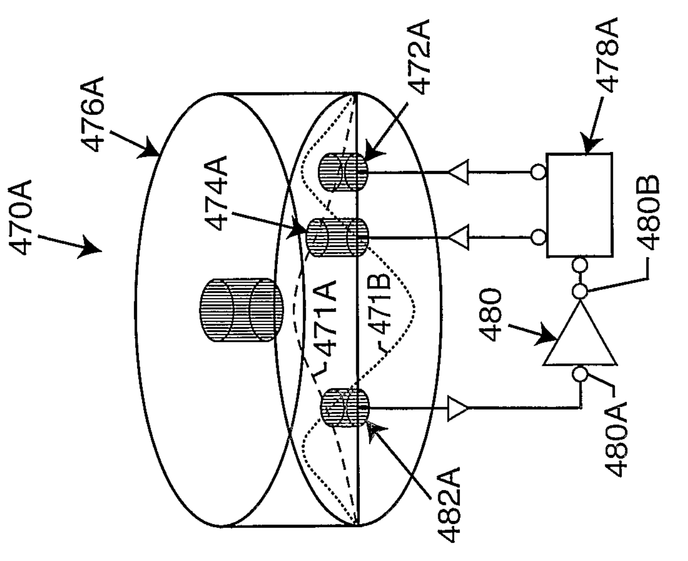


FIG. 14A

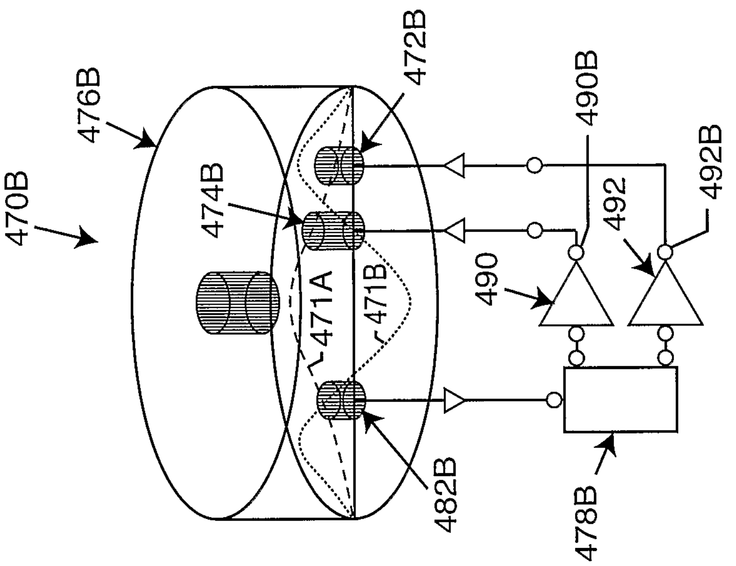


FIG. 14B

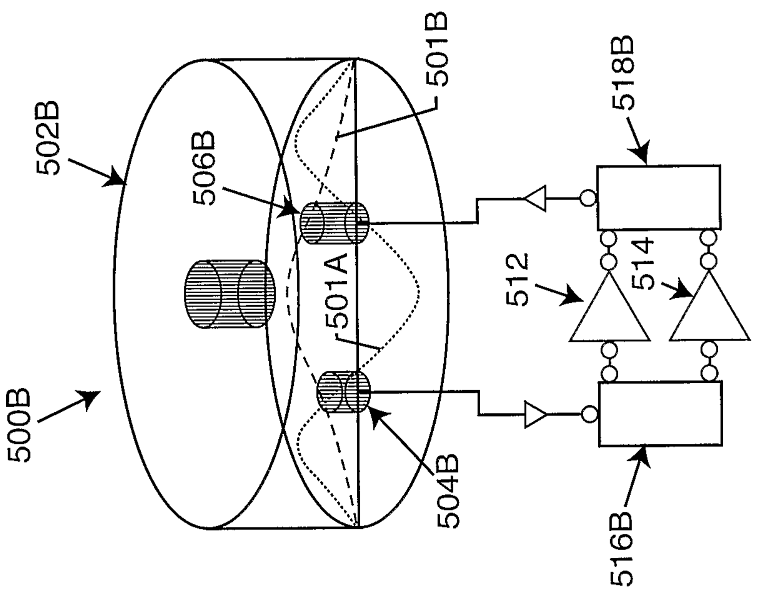


FIG. 15B

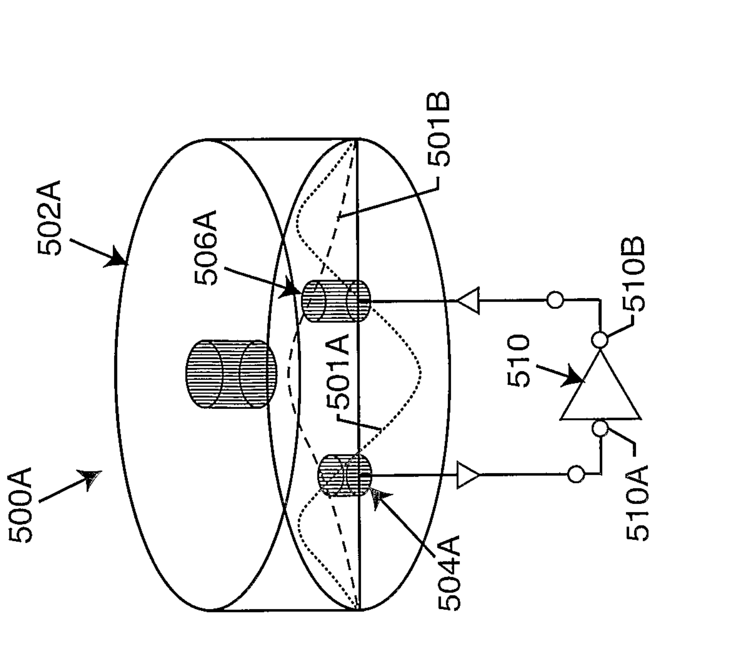


FIG. 15A

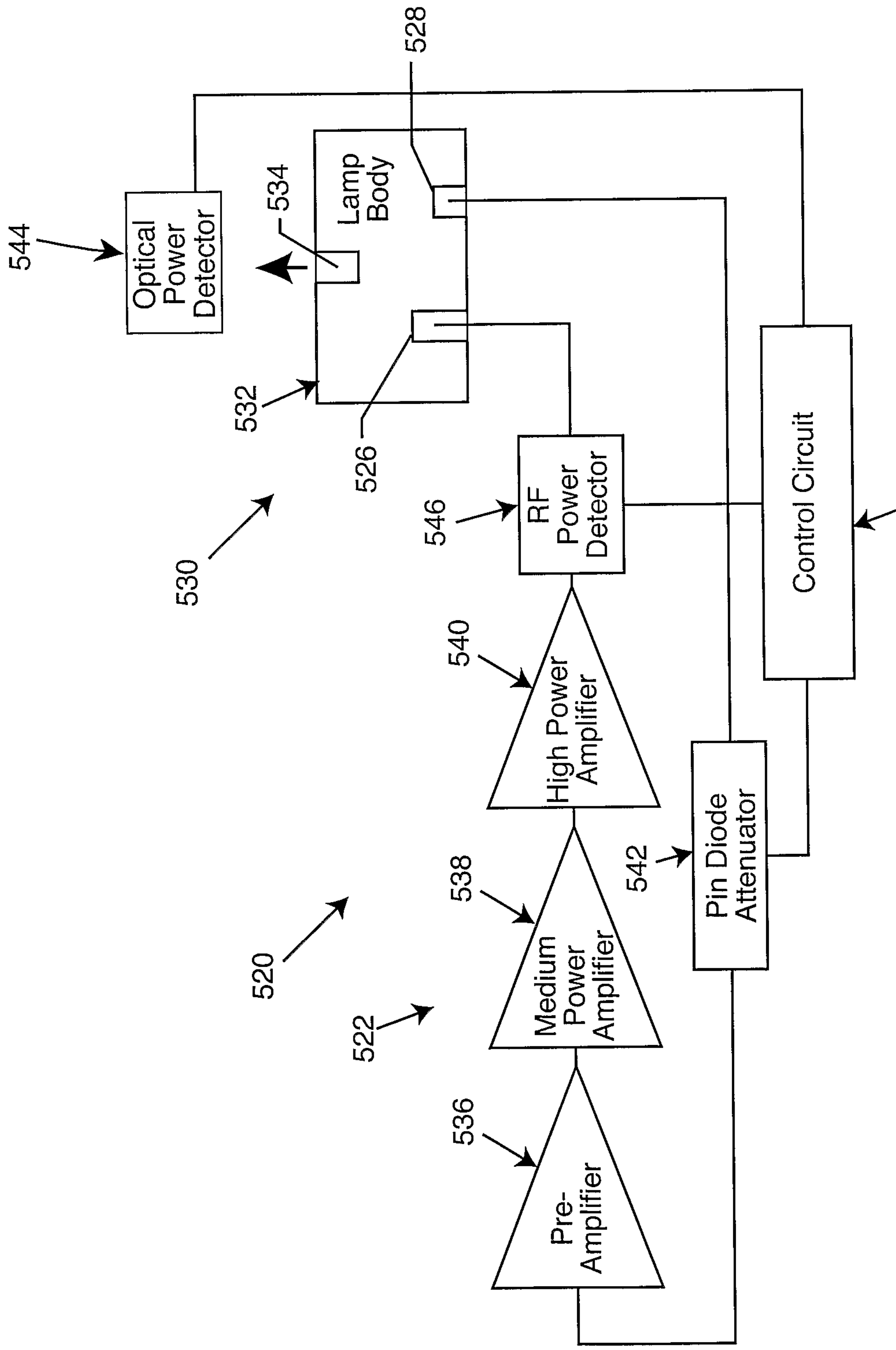

528
Lamp Body
534
544
Optical Power Detector
532
526
530
546
RF Power Detector
Control Circuit
524
540
High Power Amplifier
538
Medium Power Amplifier
542
Pin Diode Attenuator
520
522
536
Pre-Amplifier

FIG. 16

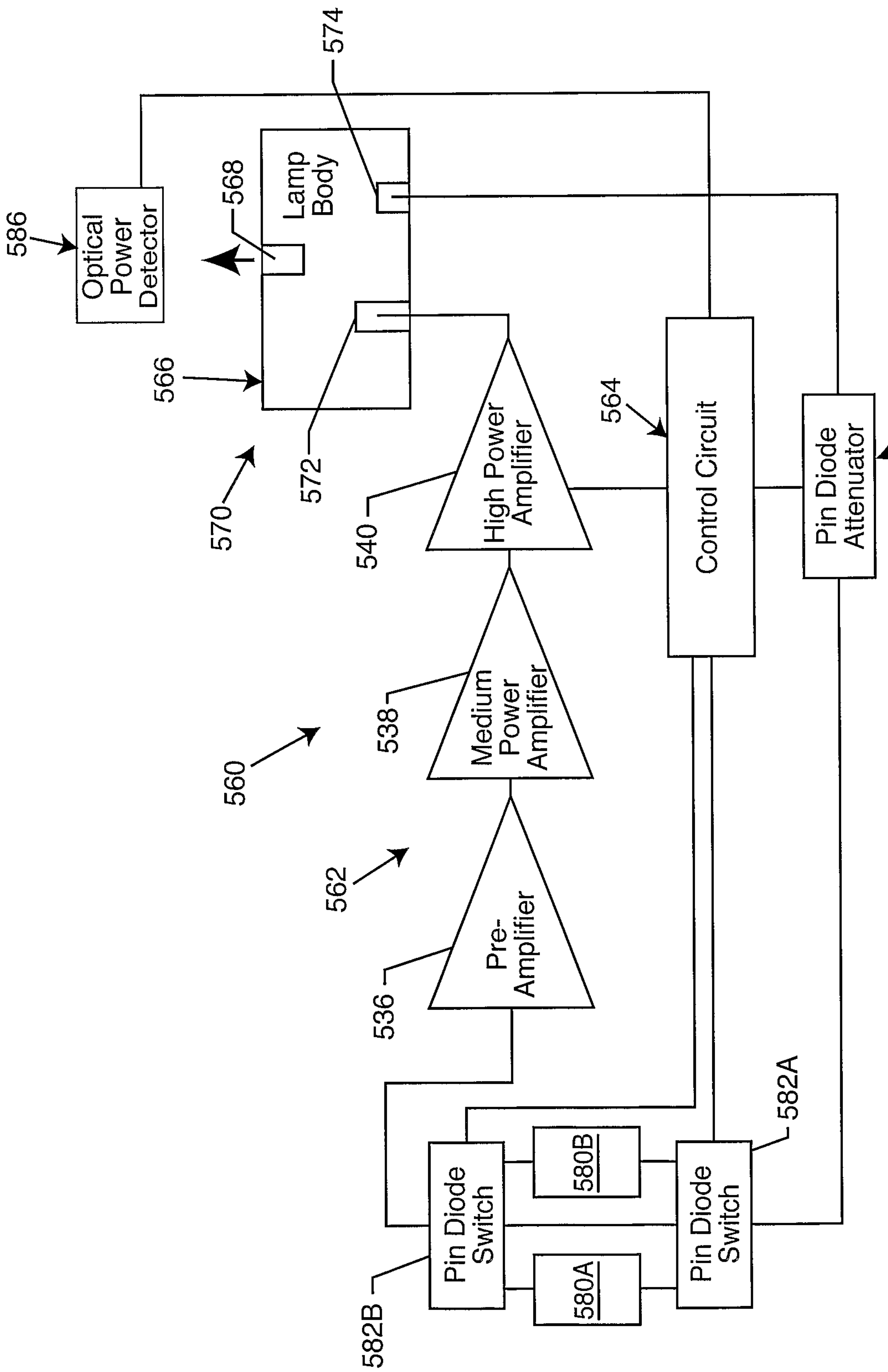

586
Optical Power Detector
568
Lamp Body
574
566
572
570
High Power Amplifier
540
564
Control Circuit
Pin Diode Attenuator
584
560
Medium Power Amplifier
538
562
Pre-Amplifier
536
582A
Pin Diode Switch
580B
580A
Pin Diode Switch
582B

FIG. 17

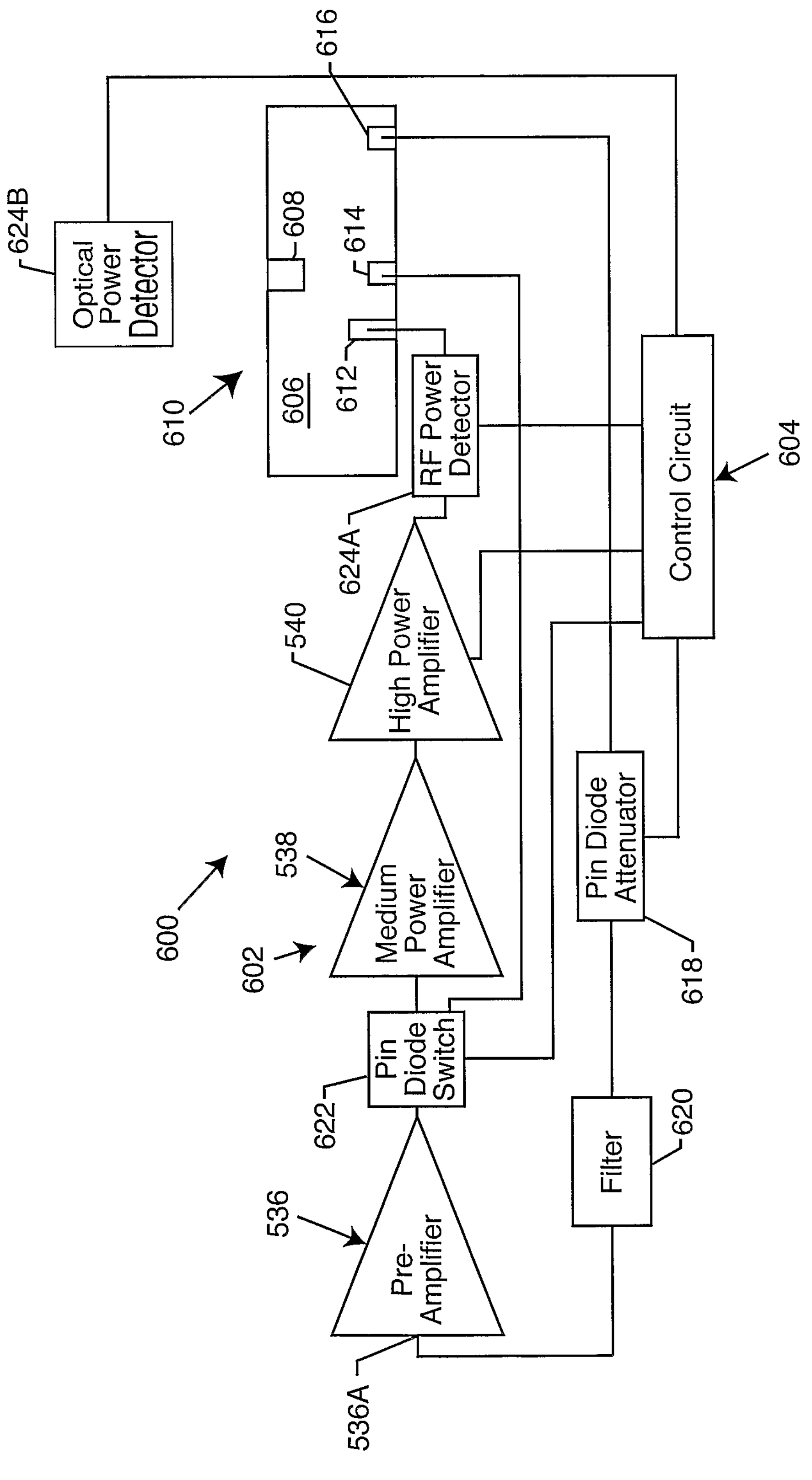

624B
Optical Power Detector
616
608
614
612
606
610
RF Power Detector
624A
Control Circuit
604
High Power Amplifier
540
Medium Power Amplifier
538
600
602
Pin Diode Switch
622
Pin Diode Attenuator
618
Filter
620
Pre-Amplifier
536
536A

FIG. 18

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2005/034446

A. CLASSIFICATION OF SUBJECT MATTER
H01J65/04 H01J61/35 H01J61/52

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01J

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 01/73806 A (DIGITAL REFLECTIONS, INC) 4 October 2001 (2001-10-04) page 9, line 8 - line 14 page 11, line 25 - line 27	1,2,4-6, 13-21, 34-42, 50-57, 62,63, 65,66
Y	WO 00/16365 A (FUSION LIGHTING, INC; KIRKPATRICK, DOUGLAS A; LENG, YONGZHANG; DOLAN,) 23 March 2000 (2000-03-23) Abstract page 4, line 3 - line 8; figure 1	1,2,5,6, 13, 34-42, 62,63

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 January 2006	08/02/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Smith, C

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2005/034446

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	WO 03/083900 A (PHILIPS INTELLECTUAL PROPERTY & STANDARDS GMBH; KONINKLIJKE PHILIPS EL) 9 October 2003 (2003-10-09) page 3, line 4 - line 9	4,50-57 50
Y	US 5 548 182 A (BUNK ET AL) 20 August 1996 (1996-08-20) column 2, line 47 - line 50 column 4, line 65 - line 67 column 5, line 6 - line 9; figure 3	13-21, 65,66
A	US 2003/178943 A1 (ESPIAU FREDERICK M ET AL) 25 September 2003 (2003-09-25) the whole document	1-66

INTERNATIONAL SEARCH REPORT	International application No. PCT/US2005/034446

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

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

1. [ ] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

see additional sheet

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers allsearchable claims.

2. [X] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search reportcovers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

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

1. claims: 1-49, 55-57, 62-66

   A lamp comprising a waveguide body comprising a material having a dielectric constant greater than 2; and a thin-film multi-layer dielectric coating.

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2. claims: 50-57, 4

   A lamp comprising a waveguide body (lamp body) and a bulb adjacent to the body; having a ceramic adhesive between the lamp body and the bulb.

   ---

3. claims: 58-61, 3

   A lamp comprising a waveguide body and a transparent bulb, whereby the waveguide body and the transparent bulb are spaced apart.

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2005/034446

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 0173806 A	04-10-2001	AU 5099301 A	08-10-2001
WO 0016365 A	23-03-2000	AU 6034999 A	03-04-2000
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		WO 0211181 A1	07-02-2002
		US 2005194619 A1	08-09-2005
		US 2004155589 A1	12-08-2004
		US 2002011802 A1	31-01-2002