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(54) **A carrier head with a layer of conformable material for a chemical mechanical polishing system**

(57) The disclosure relates to a carrier head (100) for a chemical mechanical polishing apparatus. A layer of conformable material (308) is disposed in a recess of the carrier head to provide a mounting surface for a substrate (10). The conformable material may be elastic and undergo normal strain in response to an applied load. The carrier head may also include a support fixture (352) detachably connected to a backing fixture (350), a retaining ring (362) connected directly to the conformable material, and a shield ring (360) which projects over a portion of the layer of conformable material.

FIG. 1

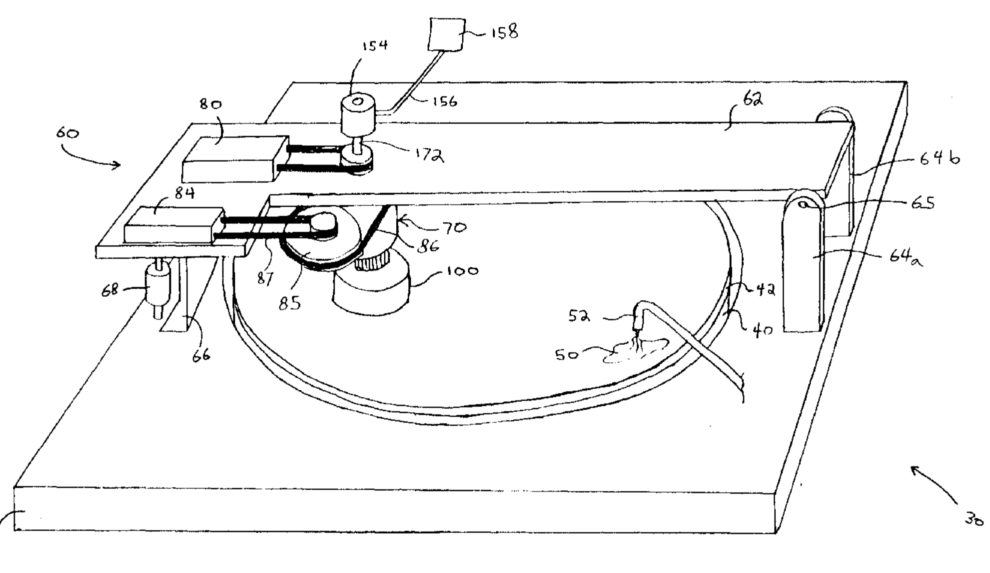

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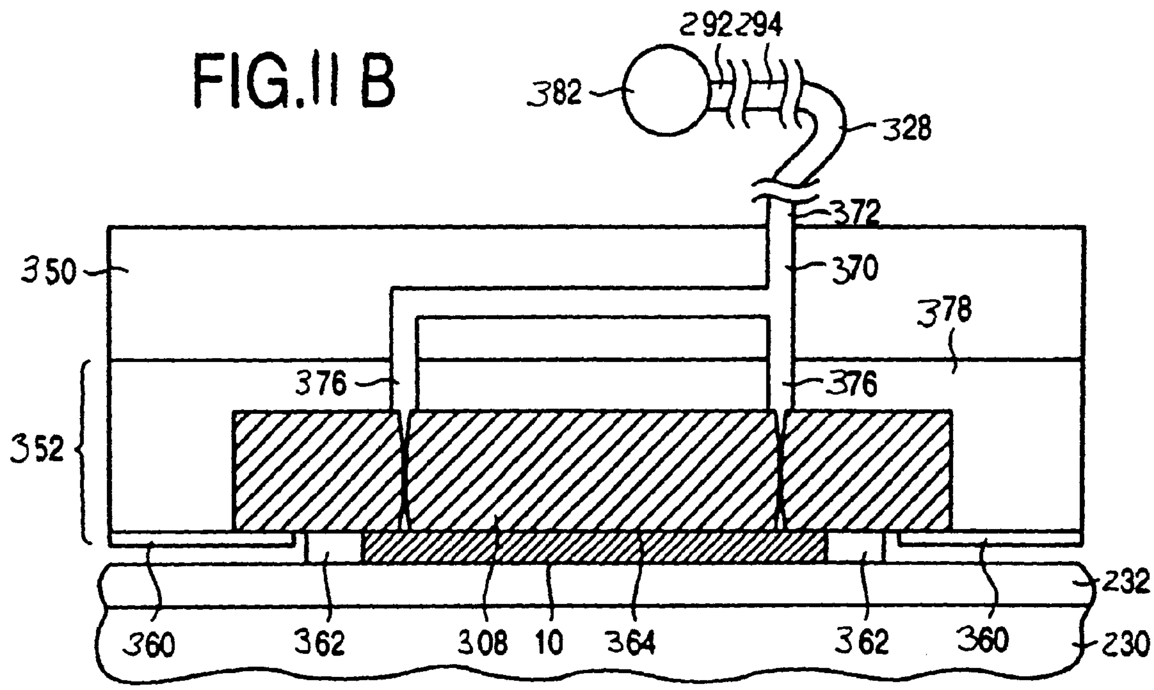
FIG.11 B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352
232
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10
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230

Description

The present invention relates generally to chemical mechanical polishing of substrates, and more particularly to a carrier head for a chemical mechanical polishing system. Reference should be made to the Applicants' US Patent Specification No. 5 643 053.

Integrated circuits are typically formed on substrates, particularly silicon wafers, by the sequential deposition of conductive, semiconductive or insulative layers. After each layer is deposited, the layer is etched to create circuitry features. As a series of layers are sequentially deposited and etched, the outer or uppermost surface of the substrate, i.e., the exposed surface of the substrate, becomes increasingly more non-planar. This non-planar outer surface presents a problem for the integrated circuit manufacturer. If the outer surface of the substrate is non-planar, then a photoresist layer placed thereon is also non-planar. A photoresist layer is typically patterned by a photolithographic apparatus that focuses a light image onto the photoresist. If the outer surface of the substrate is sufficiently non-planar, then the maximum height difference between the peaks and valleys of the outer surface may exceed the depth of focus of the imaging apparatus, and it will be impossible to properly focus the light image onto the outer substrate surface.

It may be prohibitively expensive to design new photolithographic devices having an improved depth of focus. In addition, as the feature size used in integrated circuits becomes smaller, shorter wavelengths of light must be used, resulting in further reduction of the available depth of focus. Therefore, there is a need to periodically planarize the substrate surface to provide a substantially planar layer surface.

Chemical mechanical polishing (CMP) is one accepted method of planarization. This planarization method typically requires that the substrate be mounted to a carrier or polishing head. The exposed surface of the substrate is then placed against a rotating polishing pad: The carrier provides a controllable load, i.e., pressure, on the substrate to push it against the polishing pad. In addition, the carrier may rotate to provide additional motion between the substrate and polishing pad. A polishing slurry, including an abrasive and at least one chemically-reactive agent, is distributed over the polishing pad to provide an abrasive chemical solution at the interface between the pad and substrate. A CMP process is fairly complex, and differs from simple wet sanding. In a CMP process the reactive agent in the slurry reacts with the outer surface of the substrate to form reactive sites. The interaction of the polishing pad and abrasive particles with the reactive sites results in polishing.

An effective CMP process has a high polishing rate and generates a substrate surface which is finished (lacks small-scale roughness) and flat (lacks large-scale topography). The polishing rate, finish and flatness are determined by the pad and slurry combination, the relative speed between the substrate and pad, and the force pressing the substrate against the pad. Because inadequate flatness and finish can create defective substrates, the selection of a polishing pad and slurry combination is usually dictated by the required finish and flatness. Given these constraints, the polishing rate sets the maximum throughput of the polishing apparatus.

The polishing rate depends upon the force pressing the substrate against the pad. Specifically, the greater this force, the higher the polishing rate. If the carrier head applies a non-uniform load, i.e., if the carrier applies more force to one region of the substrate than to another, then the high pressure regions will be polished faster than the lower pressure regions. Therefore, a non-uniform load may result in non-uniform polishing of the substrate.

An additional consideration in the production of integrated circuits is process and product stability. To achieve a high yield, i.e., a low defect rate, each successive substrate should be polished under substantially similar conditions. Each substrate should be polished by approximately the same amount so that each integrated circuit is substantially identical.

In view of the foregoing, there is a need for a chemical mechanical polishing apparatus which optimizes polishing throughput, while providing the desired flatness and finish. Specifically, the chemical mechanical polishing apparatus should have a carrier head which applies a substantially uniform load to the substrate.

In one aspect, the invention is directed to a carrier for positioning a substrate on a polishing surface in a chemical mechanical polishing apparatus. The carrier comprises a housing and a containment assembly connected to the housing to hold a layer of conformable material. The layer of conformable material provides a mounting surface for a substrate.

Implementations of the invention may include the following. The containment assembly may include a flexible membrane defining an enclosed volume, with the conformable material disposed within the enclosed volume. The flexible membrane may be attached to a backing member, and a flexible connector may connect the backing member to the housing. The flexible connecter may form a pressure chamber between the housing and the backing member. The flexible membrane may include a first flexible membrane portion defining a first enclosed volume and a second flexible membrane portion defining a second enclosed volume, and the conformable material may include a first conformable material having a first viscosity disposed in the first enclosed volume and a second conformable material having a second viscosity disposed in the second enclosed volume. The conformable material may be a viscoelastic material such as silicone, gelatin, or urethane. The conformable material may have a durometer measurement, such as between about twenty-five and thirty-five, selected to provide both elasticity and normal strain in response to an applied load. The containment assembly may include a base member with a recess, and the layer of conformable material may be disposed in the recess to provide the mounting surface. The base member may be detachably connected to the carrier head. A retaining ring having approximately the same thickness as the substrate may be connected to the mounting surface. A shield which is thinner than the retaining ring may be connected to the base member and project over a portion of the layer of conformable material to surround the retaining ring. The shield may be positioned to prevent the conformable material from extruding when the substrate is pressed against the polishing surface. The carrier may further comprise a chucking mechanism to attach the substrate to the mounting surface. The chucking mechanism may include a passageway formed through the layer of conformable material to the mounting surface, and a pump may be connected to the passageway to suction the substrate to the mounting surface. The passageway may have a diameter such that the passageway does not collapse if the pump applies suction to the passageway. The chucking mechanism may include a pocket between the substrate and the layer of conformable material to suction the substrate to the mounting surface.

Advantages of the invention include the following. The carrier provides uniform loading of the backside of the substrate to evenly polish the substrate. The conformable material deforms and redistributes its mass if the polishing pad is tilted, the substrate is warped, or there are irregularities on the backside of the substrate or the underside of the rigid surface. The conformable layer is chemically inert vis-a-vis the polishing process. The carrier head is also able to vacuum chuck the substrate to lift the substrate off the polishing pad.

Additional advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The advantages of the invention may be realized by means of the instrumentalities and combinations particularly pointed out in the claims.

The accompanying drawings, which are incorporated in and constitute a part of the specification, schematically illustrate the present invention, and together with the general description given above and the detailed description given below, serve to explain the principles of the invention.

FIG. 1 is a schematic perspective view of a chemical mechanical polishing apparatus.

FIG. 2 is a cross-sectional view of the support assembly, carrier head and polishing pad of the chemical mechanical apparatus of FIG. 1.

FIG. 3A is a schematic cross-sectional view of the carrier head and polishing pad of the chemical mechanical apparatus of FIG. 1.

FIG. 3B is a schematic cross-sectional view of an alternate carrier head.

FIG. 4 is a schematic cross-sectional view of a carrier head having multiple enclosed volumes filled with a conformable material.

FIG. 5 is a schematic cross-sectional view of a carrier head having a loading mechanism.

FIG. 6 is an exploded perspective view of a chemical mechanical polishing apparatus.

FIG. 7 is a schematic top view of a carousel, with the upper housing removed.

FIG. 8 is a cross-sectional view of the carousel of FIG. 7 along line 8-8.

FIG. 9A is a schematic cross-sectional view of a carrier head including bellows and a layer of conformable material in accordance with the present invention.

FIG. 9B is a view of the carrier head of FIG. 9A in which the bellows are replaced by a flexible membrane.

FIG. 10 is an exaggerated cross-sectional view of a substrate in contact with the layer of conformable material of the carrier head of FIG. 9A or FIG. 9B.

FIG. 11A is a schematic cross-sectional view of a carrier head according to the present invention illustrating vacuum chucking lines in the layer of conformable material.

FIG. 11B is a view of the carrier head of FIG. IIA in which the vacuum chucking lines are closed by application of a load to the carrier head.

FIG. 12A is a schematic cross-sectional view of a carrier head according to the present invention incorporating a vertically-movable cylinder for forming a vacuum pocket.

FIG. 12B is view of the carrier head of FIG. 12A in which the vertically-movable cylinder has been positioned to form a vacuum pocket.

FIG. 13 is a schematic cross-section view of another embodiment of a carrier head according to the present invention.

Referring to FIGS. 1 and 2, a chemical mechanical polishing (CMP) apparatus 30 generally includes a base 32 which supports a rotatable platen 40 and a polishing pad 42. The CMP apparatus 30 further includes a carrier or carrier head 100 which receives a substrate 10 and positions the substrate on the polishing pad. A support assembly 60 connects carrier head 100 to base 32. The carrier head is positioned against the surface of the polishing pad by support assembly 60.

If substrate 10 is an eight-inch (200 mm) diameter disk, then platen 40 and polishing pad 42 will be about twenty inches in diameter. Platen 40 is preferably a rotatable aluminum or stainless steel plate connected by a drive shaft (not shown) to a drive mechanism (also not shown). The drive shaft may also be stainless steel. The drive mechanism, such as a motor and gear assembly, is positioned inside the base to rotate the platen and the polishing pad. The platen may be supported on the base by bearings, or the drive mechanism may support the platen. For most polishing processes, the drive mechanism rotates platen 40 at thirty to two-hundred revolutions per minute, although lower or higher rotational speeds may be used.

Referring to FIG. 3A, polishing pad 42 may be a hard composite material having a roughened polishing surface 44. The polishing pad 42 may be attached to platen 40 by a pressure-sensitive adhesive layer 49. Polishing pad 42 may have a fifty mil thick hard upper layer 46 and a fifty mil thick softer lower layer 48. Upper layer 46 is preferably a material composed of polyurethane mixed with other fillers. Lower layer 48 is preferably a material composed of compressed felt fibers leached with urethane. A common two-layer polishing pad, with the upper layer composed of IC-1000 and the lower layer composed of SUBA-4, is available from Rodel, Inc., Newark, Delaware (IC-1000 and SUBA-4 are product names of Rodel, Inc.).

Referring to FIG. 1, a slurry 50 containing a reactive agent (e.g., deionized water for oxide polishing), abrasive particles (e.g., silicon dioxide for oxide polishing) and a chemically reactive catalyzer (e.g., potassium hydroxide for oxide polishing) is supplied to the surface of polishing pad 42. A slurry supply tube or port 52 distributes or otherwise meters the slurry onto the polishing pad. The slurry may also be pumped through passages (not shown) in platen 40 and polishing pad 42 to the underside of substrate 10.

To properly position the carrier head with respect to the polishing pad, support assembly 60 includes a crossbar 62 that extends over the polishing pad. Crossbar 62 is positioned above the polishing pad by a pair of opposed upright members 64a, 64b and 66, and a biasing piston 68. One end of crossbar 62 is connected to upright members 64a and 64b by means of a hinge 65. The other end of crossbar 62 is connected to the biasing piston 68. The biasing piston may lower and raise crossbar 62 in order to control the vertical position of the carrier head. The second upright member 66 is positioned adjacent to the biasing piston 68 to provide a vertical stop which limits the downward motion of the crossbar.

To place a substrate on carrier head 100, the crossbar is disconnected from the biasing piston, and the crossbar is rotated about hinge 65 to lift carrier head 100 off the polishing pad. The substrate is then placed in the carrier head, and the carrier head is lowered to place substrate 10 against polishing surface 44 (see FIG. 3A).

Support assembly 60 includes a transfer case 70 which is suspended from crossbar 62 to controllably orbit and rotate the substrate about the polishing pad. The transfer case 70 includes a drive shaft 72 and a housing 74. The housing 74 includes a fixed inner hub 76 and an outer hub 78. The fixed inner hub 76 is rigidly secured to the underside of crossbar 62, for example by a plurality of bolts (not shown). The rotatable outer hub 78 is journalled to fixed inner hub 76 by upper and lower tapered bearings 77. These bearings provide vertical support to rotatable outer hub 78, while allowing it to rotate with respect to the fixed inner hub. The drive shaft 72 extends through fixed inner hub 76 and is also vertically supported by tapered bearings 79 which allow the drive shaft 72 to rotate with respect to the fixed inner hub 76.

As discussed in aforementioned U.S. Patent Application Serial No. 08/173,846, a first motor and gear assembly 80 is connected to drive shaft 72 to control the orbital motion of the carrier head, and a second motor and gear assembly 84 is connected by means of a pulley 85 and drive belts 86 and 87 to rotatable outer hub 78 to control the rotational motion of the carrier head. One end of a horizontal cross arm 88 is connected to the lower end of drive shaft 72. The other end of crossarm 88 is connected to the top of a secondary vertical drive shaft 90. The bottom of secondary drive shaft 90 fits into a cylindrical depression 112 in the carrier head. Thus, when drive shaft 72 rotates, it sweeps secondary drive shaft 90 and carrier head 100 in an orbital path.

Support assembly 60 also includes a rotational compensation assembly to control the rotational speed of carrier head 100. The compensation assembly includes a ring gear 94 which is connected to the bottom of rotatable outer hub 78 of housing 74, and a pinion gear 96 connected to secondary drive shaft 90 immediately below cross arm 88. Ring gear 94 has an inner toothed surface, and the pinion gear 96 includes an outer toothed surface which engages the inner toothed surface of ring gear 94. As cross arm 88 pivots, it sweeps pinion gear 96 around the inner periphery of ring gear 94. A pair of dowel pins 98 extend from the pinion gear 96 into a pair of mating dowel pin holes 114 in the carrier head to rotationally fix the pinion gear with respect to the carrier head. Thus, the rotational motion of rotatable outer hub 78 is transferred to carrier head 100 through ring gear 94, pinion gear 96, and pins 98.

The compensation assembly allows the user of CMP apparatus 30 to vary both the rotational and orbital components of motion of the carrier head, and thereby control the rotation and orbit of substrate 10. By rotating rotatable outer hub 78 while simultaneously rotating drive shaft 72, the effective rotational motion of carrier head 100 may be controlled. Carrier head 100 and substrate 10 may be caused to rotate, orbit, or rotate and orbit. The carrier head rotates or orbits at about thirty to two-hundred revolutions per minute (rpm).

As the substrate orbits, the polishing pad may be rotated. Preferably, the orbital radius is no greater than one inch, and the polishing pad rotates at a relatively slow speed, e.g., less than ten rpm and more preferably at less than five rpm. The orbit of the substrate and the rotation of the polishing pad combine to provide a nominal speed at the surface of the substrate of 1800 to 4800 centimeters per minute.

A substrate is typically subjected to multiple polishing steps including a main polishing step and a final polishing step. For the main polishing step, carrier head 100 applies a force of approximately four to ten pounds per square inch (psi) to substrate 10, although carrier head 100 may apply more or less force. For a final polishing step, carrier head 100 may apply about three psi.

Generally, carrier head 100 transfers torque from the drive shaft to the substrate, uniformly loads the substrate against the polishing surface and prevents the substrate from slipping out from beneath the carrier head during polishing operations.

As shown in more detail in FIG. 3A, carrier head 100 includes three major assemblies: a housing assembly 102, a substrate loading assembly 104, and a retaining ring assembly 106.

The housing assembly 102 is generally circular so as to match the circular configuration of the substrate to be polished. The housing assembly 102 may be machined aluminum. The top surface of housing assembly 102 includes a cylindrical hub 110 having cylindrical recess 112 for receiving secondary drive shaft 90. At least one passageway 116 connects recess 112 to the bottom of housing assembly 102.

As shown in FIG. 2, drive shaft 72 includes one or more channels 150 and secondary drive shaft 90 includes one or more channels 152, to provide fluid or electrical connections to the carrier head. A rotary coupling 154 at the top of drive shaft 72 couples channel(s) 150 to one or more fluid or electrical lines 156. For instance, one of lines 156 may be a conformable material supply line as described below. Another rotary coupling (not shown) in cross arm 88 connects channel(s) 150 in drive shaft 72 to channel(s) 152 in secondary drive shaft 90. As shown, passageway 116 passes through housing assembly 102 to connect to channel 152 to substrate loading assembly 104.

As the polishing pad rotates, it tends to pull the substrate out from beneath the carrier head. Therefore, carrier head 100 includes a retaining ring assembly 106 which projects downwardly from housing assembly 102 and extends circumferentially around the outer perimeter of the substrate. The retaining ring assembly 106 may be attached with a key-and-keyway assembly 120 to housing assembly 102 so that the retaining ring assembly rests on the polishing pad and is free to adjust to variations in the height of the polishing surface 44. An inner edge 122 of retaining ring assembly 106 captures the substrate so that the polishing pad cannot pull the substrate from beneath the carrier head. Retaining ring assembly 106 may be made of a rigid plastic material.

Substrate loading assembly 104 is located beneath housing assembly 102 in the recess formed by retaining ring assembly 106. Substrate loading assembly 104 may include a removable carrier plate 124, a membrane 134 which defines an enclosed volume 126, and a removable carrier film 128. Enclosed volume 126 may be located in the cylindrical recess surrounded by retaining ring assembly 106.

The removable carrier plate 124 may be a circular stainless-steel disk of approximately the same diameter as the substrate. The lower surface of the carrier plate, or the lower surface of the housing if the carrier plate is not present, provides a face 130 to which membrane 134 may be adhesively attached.

The enclosed volume 126 is filled with a conformable material 132. The conformable material 132 is a non-gaseous material which undergoes viscous, elastic, or viscoelastic deformation under pressure. Preferably, conformable material 132 is a viscoelastic material, such as a silicon, a gelatin, or another substantially resilient yet viscous substance which will redistribute its mass under pressure. The pressure applied during polishing is substantially uniformly distributed across substrate 10 by means of the conformable material in enclosed volume 126.

As shown in FIG. 3A, membrane 134 defines enclosed volume 126. The membrane is comprised of a flexible, stretchable and compressible material such as rubber. Membrane 134 may entirely encapsulate conformable material 132. An upper surface 136 of membrane 134 is placed against face 130. Alternately, as shown in FIG. 3B, the enclosed volume may be formed by extending the membrane across the recess beneath face 130 and filling the enclosed volume with conformable material 132.

Carrier film 128 may be attached to a lower surface 138 of membrane 134. Carrier film 128 is formed of a thin circular layer of a porous material such as urethane. Carrier film 128, if used, is sufficiently thin and flexible that it substantially conforms to the surface of substrate 10. Carrier film 128 provides a mounting surface 142 to which substrate 10 is releasably adhered by surface tension. Alternately, if the carrier film is not used, the lower surface of membrane 134 may be porous to accomplish the same thing (see FIG. 5). Carrier film 128 is sufficiently thin and flexible so that it substantially conforms to the surface of substrate 10.

The space defined by retaining ring assembly 106 and mounting surface 142 provides a substrate receiving recess 140. The substrate is placed against mounting surface 142, causing conformable material 132 and carrier film 128, if present, to deform to contact the substrate across its entire backside. Carrier head 100 is then lowered to bring the substrate into contact with polishing surface 44. The load applied to the substrate is transferred through conformable material 132.

The polishing surface 44 may be non-planar; e.g., it may have sloping contours. Carrier plate 124 and the underside or surface 141 of housing assembly 102 may also be non-planar. The polishing pad may be tilted relative to the carrier head. In addition, the backside of substrate 10 may have surface irregularities. The substrate could also be warped. The conformable material 132 ensures a uniform distribution of the carrier load on the substrate for both large scale effects (e.g., a tilted polishing pad) and small scale effects (e.g., surface irregularities on the backside of the substrate). Conformable material 132 conforms to the substrate surface as well as to face 130. That is, the conformable material inside membrane 134 redistributes its mass to conform to surface irregularities on the backside of the substrate and face 130. Because the conformable material contacts substrate across its entire back surface, and because the conformable material has a uniform density, it ensures a uniform load across the backside of the substrate. In addition, conformable material 132 may flow and deform. This permits the substrate to tilt with respect to housing assembly 102 to follow the contours of the polishing pad. In summary, the conformable material ensures that carrier head 100 uniformly loads the substrate against the polishing surface 44.

When carrier head 100 rotates at high speeds, centrifugal force will tend to push the conformable material in the enclosed volume outwardly toward the edge of the carrier head. This tends to increase the density of the conformable material near the perimeter of enclosed volume. Consequently, the conformable material near the edge of the enclosed volume will tend to become less compressible than the center, and a non-uniform load may be applied to the substrate.

To prevent this non-uniform load, enclosed volume 126 is connected by passageway 116, channels 150 and 152, and conformable material supply line 156 to a supply 158. Supply 158 can provide conformable material at a constant pressure to enclosed volume 126. Consequently, when carrier head 100 rotates and conformable material 132 is forced toward the edge of the enclosed volume, supply 158 provides additional conformable material to the center of the enclosed volume and maintains the conformable material at a substantially uniform distribution throughout enclosed volume 126. This uniform distribution of conformable material ensures uniform polishing at the center and edges of the substrate.

Supply 158 may also be used to control the viscosity of conformable material 132. By increasing the pressure on the conformable material, the density of conformable material 132 can be increased. If the density of conformable material 132 increases, its viscosity will decrease.

The minimum pressure from supply 158 must overcome the load applied by the carrier head to the substrate; otherwise, this load will force the conformable material back through passageway 116. When the carrier head stops rotating, the conformable material is uniformly redistributed throughout membrane 134. The excess conformable material then flows back through passageways 116, 150 and 152 to supply 158.

In another implementation, conformable material 132 may be a material, such as rubber, which is sufficiently rigid that it does not flow under the influence of centrifugal forces. In this implementation, the distribution of conformable material 132 does not change significantly when carrier head 100 rotates. Thus, conformable material supply 158 is not required.

As shown in FIG. 4, substrate loading assembly 104 may include multiple compartments or enclosed volumes 160 and 162. The enclosed volumes 160 and 162 are defined by two or more membrane portions. The membrane portions may be separate, discrete membranes, or they may be different portions of a single membrane. Enclosed volume 160 may be a circular disk, located above the center of mounting surface 142, and enclosed volume 162 may be an annular ring surrounding enclosed volume 160. The enclosed volumes 160 and 162 contain conformable materials 164 and 166, respectively. Conformable materials 164 and 166 have different viscosities. By selecting the relative viscosities of conformable materials 164 and 166, over-polishing of the substrate edge may be avoided and more uniform polishing of the substrate may be achieved. Each enclosed volume may be connected by a passageway 168 to a supply (not shown).

Referring to FIG. 5, carrier head 100 may be held in a vertically-fixed position by support assembly 60 (see FIG. 3A), and a force may be applied to substrate 10 by the carrier head. In this embodiment, the loading assembly 104 includes a flexible connector, such as a bellows 170. The bellows 170 connects a substrate backing member 174 to a bottom surface 173 of housing assembly 102. The bellows 170 is expandable so that substrate backing member 174 can move vertically relative to housing assembly 102. The interior of bellows 170 forms a pressure chamber 176. Pressure chamber 176 can be pressurized negatively or positively by a pressure or vacuum source (not shown) which is connected to pressure chamber 176 by a conduit 178. Membrane 134 is attached to the bottom face of substrate backing member 174. By pressurizing chamber 176, a force is exerted on conformable material 132 to press the substrate against the polishing pad. Thus, flexible connector 170 acts as a loading mechanism, and replaces the biasing piston 68.

Enclosed volume 126 may be connected to a supply as shown in the embodiment of FIG. 2. A flexible conduit 182, which may be a plastic tubing, connects a passageway 180 in substrate backing member 174 to passageway 116 in housing assembly 102 for this purpose. The points at which flexible conduit 182 is connected to passageways 180 and 116 may be sealed by appropriate fittings to prevent conformable material 132 from leaking into pressure chamber 176.

Referring to FIG. 6, in another embodiment, one or more substrates 10 are polished by a chemical mechanical polishing (CMP) apparatus 220. A complete description of CMP apparatus 220 may be found in EP-A-0774323, the entire disclosure of which is hereby incorporated by reference.

The CMP apparatus 220 includes a lower machine base 222 with a table top 223 mounted thereon and removable upper outer cover (not shown). Table top 223 supports a series of polishing stations 225a, 225b and 225c, and a transfer station 227. Transfer station 227 forms a generally square arrangement with the three polishing stations 225a, 225b and 225c. Transfer station 227 serves multiple functions of receiving individual substrates 10 from a loading apparatus (not shown), washing the substrates, loading the substrates into carrier heads (to be described below), receiving the substrates from the carrier heads, washing the substrates again, and finally transferring the substrates back to the loading apparatus.

Each polishing station 225a-225c includes a rotatable platen 230 on which is placed a polishing pad 232. If substrate 10 is an eight-inch (200 mm) diameter disk, then platen 230 and polishing pad 232 will be about twenty inches in diameter. Platen 230 is preferably a rotatable aluminum or stainless steel plate connected by stainless steel platen drive shaft (not shown) to a platen drive motor (not shown). For most polishing processes, the drive motor rotates platen 230 at thirty to two-hundred revolutions per minute, although lower or higher rotational speeds may be used.

Referring to FIG. 10, polishing pad 232 is a composite material with a roughened polishing surface 234. Polishing pad 232 may be attached to platen 230 by a pressure-sensitive adhesive layer 239. Polishing pad 232 may have a fifty mil thick hard upper layer 236 and a fifty mil thick softer lower layer 238. Upper layer 236 is preferably a material composed of polyurethane mixed with other fillers. Lower layer 238 is preferably a material composed of compressed felt fibers leached with urethane. A common two-layer polishing pad, with the upper layer composed of IC-1000 and the lower layer composed of SUBA-4, is available from Rodel, Inc., located in Newark, Delaware (IC-1000 and SUBA-4 are product names of Rodel, Inc.).

Returning to FIG. 6, each polishing station 225a-225c may further include an associated pad conditioner apparatus 240. Each pad conditioner apparatus 240 has a rotatable arm 242 holding an independently rotating conditioner head 244 and an associated washing basin 246. The conditioner apparatus maintains the condition of the polishing pad so it will effectively polish any substrate pressed against it while it is rotating.

A slurry 250 containing a reactive agent (e.g., deionized water for oxide polishing), abrasive particles (e.g., silicon dioxide for oxide polishing) and a chemically reactive catalyzer (e.g., potassium hydroxide for oxide polishing), is supplied to the surface of polishing pad 232 by a slurry supply tube 252. Sufficient slurry is provided to cover and wet the entire polishing pad 232. Two or more intermediate washing stations 255a and 255b are positioned between neighboring polishing stations 225a, 225b and 225c. The washing stations rinse the substrates as they pass from one polishing station to another.

A rotatable multi-head carousel 260 is positioned above lower machine base 222. Carousel 260 is supported by a center post 262 and rotated thereon about a carousel axis 264 by a carousel motor assembly located within base 222. Center post 262 supports a carousel support plate 266 and a cover 268. Multi-head carousel 260 includes four carrier head systems 270a, 270b, 270c, and 270d. Three of the carrier head systems receive and hold substrates, and polish them by pressing them against the polishing pad 232 on platen 230 of polishing stations 225a-225c. One of the carrier head systems receives a substrate from and delivers the substrate to transfer station 227.

The four carrier head systems 270a-270d are mounted on carousel support plate 266 at equal angular intervals about carousel axis 264. Center post 262 allows the carousel motor to rotate the carousel support plate 266 and to orbit the carrier head systems 270a-270d, and the substrates attached thereto, about carousel axis 264.

Each carrier head system 270a-270d includes a polishing or carrier head 300. Each carrier head 300 independently rotates about its own axis, and independently laterally oscillates in a radial slot 272 formed in carousel support plate 266. A carrier drive shaft 274 connects a carrier head rotation motor 276 to carrier head 300 (shown by the removal of one-quarter of cover 268). There is one carrier drive shaft and motor for each head.

Referring to FIG. 7, in which cover 268 of carousel 260 has been removed, carousel support plate 266 supports the four carrier head systems 270a-270d. Carousel support plate includes four radial slots 272, generally extending radially and oriented 90° apart. Radial slots 272 may either be close-ended (as shown) or open-ended. The top of support plate supports four slotted carrier head support slides 280. Each slide 280 aligns along one of the radial slots 272 and moves freely along a radial path with respect to carousel support plate 266. Two linear bearing assemblies bracket each radial slot 272 to support each slide 280.

As shown in FIGS. 7 and 8, each linear bearing assembly includes a rail 282 fixed to carousel support plate 266, and two hands 283 (only one of which is illustrated in FIG. 8) fixed to slide 280 to grasp the rail. Two bearings 284 separate each hand 283 from rail 282 to provide free and smooth movement therebetween. Thus, the linear bearing assemblies permit the slides 280 to move freely along radial slots 272.

A bearing stop 285 anchored to the outer end one of the rails 282 prevents slide 280 from accidentally coming off the end of the rails. One of the arms of each slide 280 contains an unillustrated threaded receiving cavity or nut fixed to the slide near its distal end. The threaded cavity or nut receives a worm-gear lead screw 286 driven by a slide radial oscillator motor 287 mounted on carousel support plate 266. When motor 287 turns lead screw 286, slide 280 moves radially. The four motors 287 are independently operable to independently move the four slides along the radial slots 272 in carousel support plate 266.

A carrier head assembly or system, each including a carrier head 300, a carrier drive shaft 274, a carrier motor 276, and a surrounding non-rotating shaft housing 278, is fixed to each of the four slides. Drive shaft housing 278 holds drive shaft 274 by paired sets of lower ring bearings 288 and a set of upper ring bearings 289. Each carrier head assembly can be assembled away from polishing apparatus 220, slid in its untightened state into radial slot 272 in carousel support plate 266 and between the arms of slide 280, and there tightened to grasp the slide.

A rotary coupling 290 at the top of drive motor 286 couples two or more fluid or electrical lines 292 into two or more channels 294 in drive shaft 274. Channels 294 are used, as described in more detail below, to pneumatically power carrier head 300, to vacuum-chuck the substrate to the bottom of the carrier head and to actuate a retaining ring against the polishing pad.

During actual polishing, three of the carrier heads, e.g., those of carrier head systems 270a-70c, are positioned at and above respective polishing stations 225a-225c. Carrier head 300 lowers a substrate into contact with polishing pad 232, and slurry 250 acts as the media for chemical mechanical polishing of the substrate or wafer. The carrier head 300 uniformly loads the substrate against the polishing pad.

The substrate is typically subjected to multiple polishing steps, including a main polishing step and a final polishing step. For the main polishing step, usually performed at station 225a, carrier head 300 applies a force of approximately four to ten pounds per square inch (psi) to substrate 10. At subsequent stations, carried head 300 may apply more or less force. For example, for a final polishing step, usually performed at station 225c, carrier head 300 may apply a force of about three psi. Carrier motor 76 rotates carrier head 300 at about thirty to two-hundred revolutions per minute. Platen 230 and carrier head 300 may rotate at substantially the same rate.

Generally, carrier head 300 holds the substrate against the polishing pad and evenly distributes a downward pressure across the back surface of the substrate. The carrier head also transfers torque from the drive shaft to the substrate and ensures that the substrate does not slip from beneath the carrier head during polishing.

Referring to FIG. 9A, carrier head 300 includes a housing assembly 302, a loading mechanism 304 and a base assembly 306. The drive shaft 274 is connected to housing assembly 302. Loading mechanism 304 connects housing assembly 302 to base assembly 306. The loading mechanism applied a load, i.e., a downward pressure, to base assembly 306. The base assembly 306 transfers the downward pressure from loading mechanism 304 to substrate 10 to push the substrate against the polishing pad. Base assembly 306 includes a conformable layer 308 to evenly distribute the downward pressure across the back surface of the substrate. Each of these components will be described in greater detail below.

Housing assembly 302 may be formed of aluminum or stainless steel. The housing assembly is generally circular in shape to correspond the circular configuration of the substrate to be polished. The top surface of the housing assembly may include a cylindrical hub 320 having a threaded neck 322. To connect drive shaft 274 to carrier head 300, two dowel pins 324 may be inserted into matching dowel pin holes in hub 320 and a flange 296. Then, a threaded perimeter nut 298 is screwed onto threaded neck 322 to firmly attach carrier head 300 to drive shaft 274. When drive shaft 274 rotates, dowel pins 324 transfer torque to housing assembly 302 to rotate the carrier head about the same axis as the drive shaft.

At least two conduits 326 and 328 extend through hub 320. There may be one conduit for each channel 294 in drive shaft 274. When carrier head 300 is attached to drive shaft 274, the dowel pins align the carrier head so that conduits 326 and 328 connect to channels 294. O-rings (not shown) may be positioned in hub 320 surrounding each conduit 326 and 328 to form a fluid-tight seal between the conduits to the channels.

Loading mechanism 304 forms a vertically-movable seal between housing assembly 302 and base assembly 306 and defines a pressure chamber 330. A gas, such as air, is pumped into and out of pressure chamber 330 through conduit 326 to control the load applied to base assembly 306. When air is pumped into pressure chamber 330, base assembly 306 is forced downwardly to bring substrate 10 into contact with polishing pad 232. When air is pumped out of pressure chamber 330, base assembly is lifted upwardly to remove the substrate from polishing pad 232.

Loading mechanism 304 may include a cylindrical bellows 332 which is bolted or fixed to housing assembly 302 and base assembly 306 to form pressure chamber 330. Bellows 332 may be a stainless steel cylinder which expands or contracts depending upon whether a gas is supplied to or removed from pressure chamber 330. Bellows 332 may include upper and lower support plates 334 and 336 which are bolted or otherwise secured to housing assembly 302 and a base assembly 306, respectively. A cylindrical seal 338 may fit into a circumferential groove 312 on rim 310 of housing 302 and in a circumferential groove 339 in an upwardly-extending wall portion 318 of, base assembly 306. The seal 338 surrounds and protects bellows 332 from the corrosive effects of slurry 250. When housing assembly 302 is rotated, bellows 332 transfers torque from the housing assembly to the base assembly, causing it to also rotate. However, because the bellows are flexible, base assembly 306 can pivot with respect to the housing assembly about an axis parallel to the surface of the polishing pad to remain substantially parallel to the polishing pad surface.

Base assembly 306 includes a rigid backing fixture or plate 350 and a detachable module 352 which is attached to the underside of backing plate 350. Backing plate 350 may be generally disk-shaped to match the configuration of substrate 30, and may be formed of a metal such as aluminum or stainless steel. Module 352 includes a rigid support fixture or cup 354, conformable layer 308, an annular shield ring 360, and an annular retaining ring 362. Each of these elements will be discussed in detail below.

Module 352 may be removably attached to backing plate 350 by various attachment mechanisms, such as bolts, screws, key and key slot combination, vacuum chucking, or magnets. As such, module 352 can be detached and replaced if it is damaged or worn out. In addition, it may be replaced to change the polishing parameters. For example, different modules may incorporate conformable layers with different durometer measurements. The different modules may also have different retaining ring widths or retaining ring heights. The height and width of the retaining ring affects the polishing rate near the edge of the substrate. These module features can be selected to provide an optimal polishing performance.

Cup 354 may be formed of aluminum or stainless steel and may have an outer lip or rim 356 which projects downwardly to surround a recess. The conformable layer 308 is disposed within the recess so that the bottom surface of the conformable layer is substantially flush with the bottom surface of rim 356. The recess may be approximately one-eighth to one-quarter inch deep.

The conformable layer 308 is made of a visco-elastic material that has a substantially homogeneous density. Conformable layer 308 is elastic; i.e., it will return to its original shape when an applied load is removed. Conformable layer 308 is slightly compressible. In addition, conformable layer 308 undergoes normal strain; i.e., it will redistribute its mass in directions normal to an applied load. The durometer measurement of the conformable layer must be carefully selected. If the durometer measurement is too low, the material will lack elasticity. On the other hand, if the durometer measurement is too high, the material will not undergo normal strain. Conformable layer 308 may have a durometer measurement of between approximately fifteen to twenty-five on the Shore scale. Preferably, conformable layer 308 has a durometer measurement of about twenty-one on the Shore scale. The conformable material may have an adhesive surface so that it adheres to the walls of cup 354. In addition, it should be resistant to heat and be chemically inert vis-a-vis the polishing process. An appropriate conformable material is a urethane material available from Pittsburgh Plastics of Zelienopal, Pennsylvania. Module 352 may be manufactured by pouring liquid urethane into cup 354 and curing it to form layer 309.

Referring to FIG. 10, conformable layer 308 permits substrate 10 to shift or pivot to accommodate changes in the surface of the polishing pad. Conformable layer 308 deforms to match the back side of substrate 10 and evenly distribute the load from loading mechanism 304 to the substrate. For example, if substrate 10 is warped, conformable layer 308 will, in effect, conform to the contours of the warped substrate.

A thin sheet 358 of a low-friction material may be laminated to the outer surface of conformable layer 308 to provide a low-friction substrate mounting surface 364. The sheet 358 may be a seven mil thick film of urethane having a durometer measurement of approximately eighty-three on the Shore scale. Sheet 358 permits the conformable material layer 308 to closely conform to the back side of substrate 10 but prevents the substrate from adhering to the conformable material. Sheet 358 is sufficiently thin that substrate 10 may be considered to be in direct contact with conformable layer 308.

Referring to FIG. 9A, module 352, as previously noted, also includes shield ring 360 and retaining ring 362. Shield ring 360 is formed of a rigid material such as aluminum or stainless steel and is positioned below conformable layer 308 to be substantially flush with the bottom surface of rim 356 and the conformable layer. Shield ring 360 holds conformable layer 308 with the recess of cup 354 when a load is applied to substrate 10. Shield ring 360 may be appropriately secured to rim 356 such as by screws or bolts (not shown).

Retaining ring 362 is an annular rigid ring, positioned within the circumference of shield ring 360. Retaining ring 362 may be adhesively attached directly to conformable layer 308. Retaining ring 362 may be formed of a hard plastic or ceramic material. Retaining ring 362 is separated from shield ring 360 by a small gap "r" so that the retaining ring may shift or pivot to accommodate variations in the vertical height of the surface of polishing pad 232. In operation, substrate 10 fits into a circular recess defined by retaining ring 362 and abuts mounting surface 364 of the conformable layer. Retaining ring 362 and substrate 10 have substantially the same thickness, so that retaining ring 362 also contacts polishing pad 232. The shear force created by the relative velocity between substrate 10 and polishing pad 232 tends to push the substrate from beneath carrier head 300. Retaining ring 362 prevents substrate 10 from moving from beneath base assembly 306.

Referring to FIG. 9B, in another embodiment, in which similar parts are referred to with primed numbers, loading mechanism 304' may include a flexible membrane 340 instead of a bellows. Flexible membrane 340 may be an annular sheet of silicone approximately sixty mils thick, with inner and outer edges 342 and 344. The inner edge 342 is clamped between an inner clamp ring 346 and base assembly 306', whereas outer edge 344 is clamped between an outer clamp ring 348 and housing assembly 302'. The clamp rings attach the flexible membrane to the housing assembly and the base assembly to form pressure chamber 330'. Flexible membrane 340 acts as a diaphragm which rolls or unrolls, depending upon the vertical distance across pressure chamber 330'.

Housing assembly 302' includes two opposing flanges 314 which project downwardly from rim 310. Each flange 314 may have a rectangular slot 315. A torque pin 316 extends through each rectangular slot 315 and is secured in a receiving recess 317 in upward-extending wall portion 318' of backing plate 350 of base assembly 306'. The width of rectangular slot 315 is comparable to the width of torque pin 316 so that the pin cannot move horizontally in the slot. When drive shaft

274 rotates housing assembly 302', torque pins 316 transfer torque from the housing assembly to the base assembly. The height of rectangular slot 315 is greater than the height of torque pin 316 so that the pin can move vertically in the slot. Thus, base assembly 306' must rotate with housing assembly 302', but it is free to move vertically with respect to the housing assembly.

As discussed above, carrier head 300 may lift substrate 10 away from polishing pad 232 in order to move the substrate from one polishing station to another. In addition, the substrate may be ejected from carrier head 300 to return the substrate to transfer station 227 (see FIG. 6). Specifically, carrier head 300 may vacuum-chuck or pressure-eject the substrate to or from mounting surface 364, as explained in more detail below.

The carrier head includes several fluid lines which permit a gas, such as air, to flow into and out of base assembly 306 to vacuum-chuck or pressure-eject the substrate. Because base assembly 306 and housing assembly 302 can move vertically relative to each other, flexible fluid conduits are used to link conduit 328 to a passageway 370 in backing plate 350. As shown in FIG. 9A, the flexible fluid conduit may be a metal bellows 372. The metal bellows can expand and contract to match the distance across chamber 330. Alternately, as shown in FIG. 9B, the flexible fluid conduit may be a plastic tubing 374 positioned within chamber 330'. The plastic tubing may, for example, be wrapped in a half, a three-quarter, a full turn. When base assembly 306' moves relative to the housing assembly, the tubing coils or uncoils to match the distance across chamber 330'.

Referring to FIG. 11A, in one implementation, passageway 370 is connected to one or more passages 376 of cup 354. In addition, vacuum-chucking passages 380 extend through conformable layer 308 from passages 376 in cup 354 to mounting surface 364. Each vacuum chucking passage 380 is simply a hole in the conformable layer. The-hole is large enough so that it does not collapse when a vacuum is applied but small enough so that it does collapse when a load is applied to the substrate.

A pump 382 is connected via fluid line 292, channel 294, conduit 328, conduit 372, passageway 370, passages 376, and vacuum-chucking passages 380 to mounting surface 364. If a vacuum is applied to passages 380 by pump 382, substrate 10 will be vacuum-chucked to mounting surface 364. If air is forced into passages 380 by pump 382, substrate 10 will be ejected from mounting surface 364.

Referring to FIG. 11B, when substrate 10 is positioned against polishing pad 232 and a load is applied, conformable layer 308 will be compressed and vacuum-chucking passages 380 will collapse. Thus, the passages do not significantly affect the distribution of the load across the backside of the substrate. When the load is removed, conformable layer 308 will return to its normal state and vacuum-chucking passages 380 will reopen. Each vacuum-chucking passage 380 should be between approximately one-eighth and one-quarter of an inch in diameter.

Referring to FIGS. 12A and 12B, in another implementation, substrate 10 is vacuum-chucked to carrier head 300 by the formation of a vacuum pocket. As shown in FIG. 12A, module 352 may include a vertically-movable disk 390. Conformable layer 308 may be adhesively attached to disk 390. Disk 390 has a diameter less than that of the substrate, and it may be connected to the activating mechanism of an air cylinder 392. Air cylinder 392 may be positioned in cup portion 354, and it 392 may be powered by a pump 382. The pump is connected to the air cylinder by the flexible conduit, passageway 370, and passages 376. The actuating mechanism of air cylinder 392 may move disk 390 between a first position in which the disk is flush with a bottom surface 394 of base 378 of cup 354 (see FIG. 12A) and a second position in which the disk has been drawn upwardly away from the substrate. In the second position, the portion of conformable layer 308 beneath the disk will be pulled upwardly. Since the edges of conformable layer 308 remain in contact with substrate 10, whereas the center of conformable layer 308 is drawn away from the center of substrate 10, a vacuum pocket 398 is formed between the substrate and the conformable layer. This vacuum pocket vacuum-chucks the substrate to the carrier head. A conformable layer in accordance with the present invention may be incorporated into various other carrier head designs, such as the one described in JP-A-322071, the entire disclosure of which is hereby incorporated by reference.

Referring specifically to FIG. 13, such a carrier head 400 includes a housing assembly 402, a base assembly 404 and a retaining ring assembly 406. A conformable layer 408, similar in composition and structure to the conformable layer described above, may be adhered or attached to a surface 418 of base assembly 404 to provide a substrate mounting surface 410.

The present invention has been described in terms of a preferred embodiment. The invention however, is not limited to the embodiment depicted and described. Rather, the scope of the invention is defined by the appended claims.

Claims

1. A carrier for positioning a substrate on a polishing surface in a chemical mechanical polishing apparatus, comprising:

   a housing; and
   a containment assembly connected to the housing to hold a layer of conformable material, the layer of conformable material providing a mounting surface for a substrate.

2. The carrier of claim 1 wherein the containment as-

sembly includes a flexible membrane defining an enclosed volume, and the conformable material is disposed within the enclosed volume.

3. The carrier of claim 2 wherein the flexible membrane is attached to a backing member, and wherein a flexible connector connects the backing member to the housing.

4. The carrier head of claim 3 wherein the flexible connecter forms a pressure chamber between the housing and the backing member.

5. The carrier head of claim 2 wherein the flexible membrane includes a first flexible membrane portion defining a first enclosed volume and a second flexible membrane portion defining a second enclosed volume, and the conformable material includes a first conformable material having a first viscosity disposed in the first enclosed volume and a second conformable material having a second viscosity disposed in the second enclosed volume.

6. The carrier of claim 1 wherein the conformable material is a viscoelastic material.

7. The carrier head of claim 6 wherein the conformable material is selected from the group consisting of silicone and gelatin.

8. The carrier of claim 6 the conformable material has a durometer measurement selected to provide both elasticity and normal strain in response to an applied load.

9. The carrier of claim 8 wherein the conformable material has a durometer measurement between about twenty-five and thirty-five.

10. The carrier of claim 9 wherein the conformable material is substantially pure urethane.

11. The carrier of claim 1 wherein the containment assembly includes a base member with a recess, and the layer of conformable material is disposed in the recess to provide the mounting surface.

12. The carrier of claim 11, wherein the base member is detachably connected to the carrier head.

13. The carrier of claim 11 further comprising a retaining ring connected to the mounting surface.

14. The carrier of claim 13 wherein the retaining ring has approximately the same thickness as the substrate.

15. The carrier of claim 14 further comprising a shield connected to the base member and projecting over a portion of the layer of conformable material to surround the retaining ring.

16. The carrier of claim 15 wherein the shield is thinner than the retaining ring.

17. The carrier of claim 11 further comprising a shield ring connected to the base member and projecting over a portion of the layer of conformable material.

18. The carrier of claim 17 wherein the shield is positioned to prevent the conformable material from extruding when the substrate is pressed against the polishing surface.

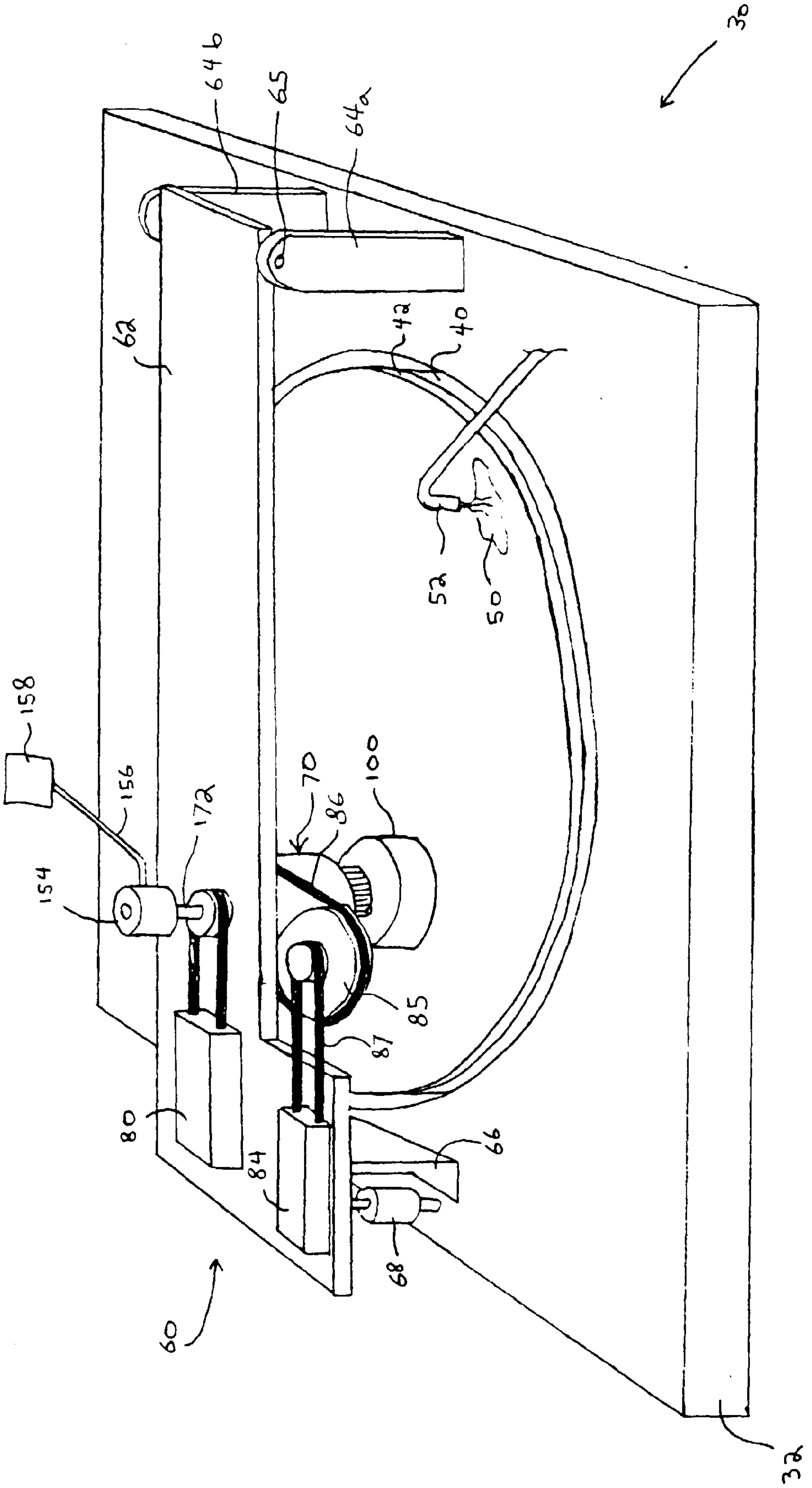
19. The carrier of claim 1 further comprising a chucking mechanism to attach the substrate to the mounting surface.

20. The carrier of claim 19 wherein the chucking mechanism includes a passageway formed through the layer of conformable material to the mounting surface, and wherein a pump is connected to the passageway to suction the substrate to the mounting surface.

21. The carrier of claim 20 wherein the passageway has a diameter such that the passageway does not collapse if the pump applies suction to the passageway.

22. The carrier of claim 21 wherein the chucking mechanism includes a pocket between the substrate and the layer of conformable material to suction the substrate to the mounting surface.

FIG. 1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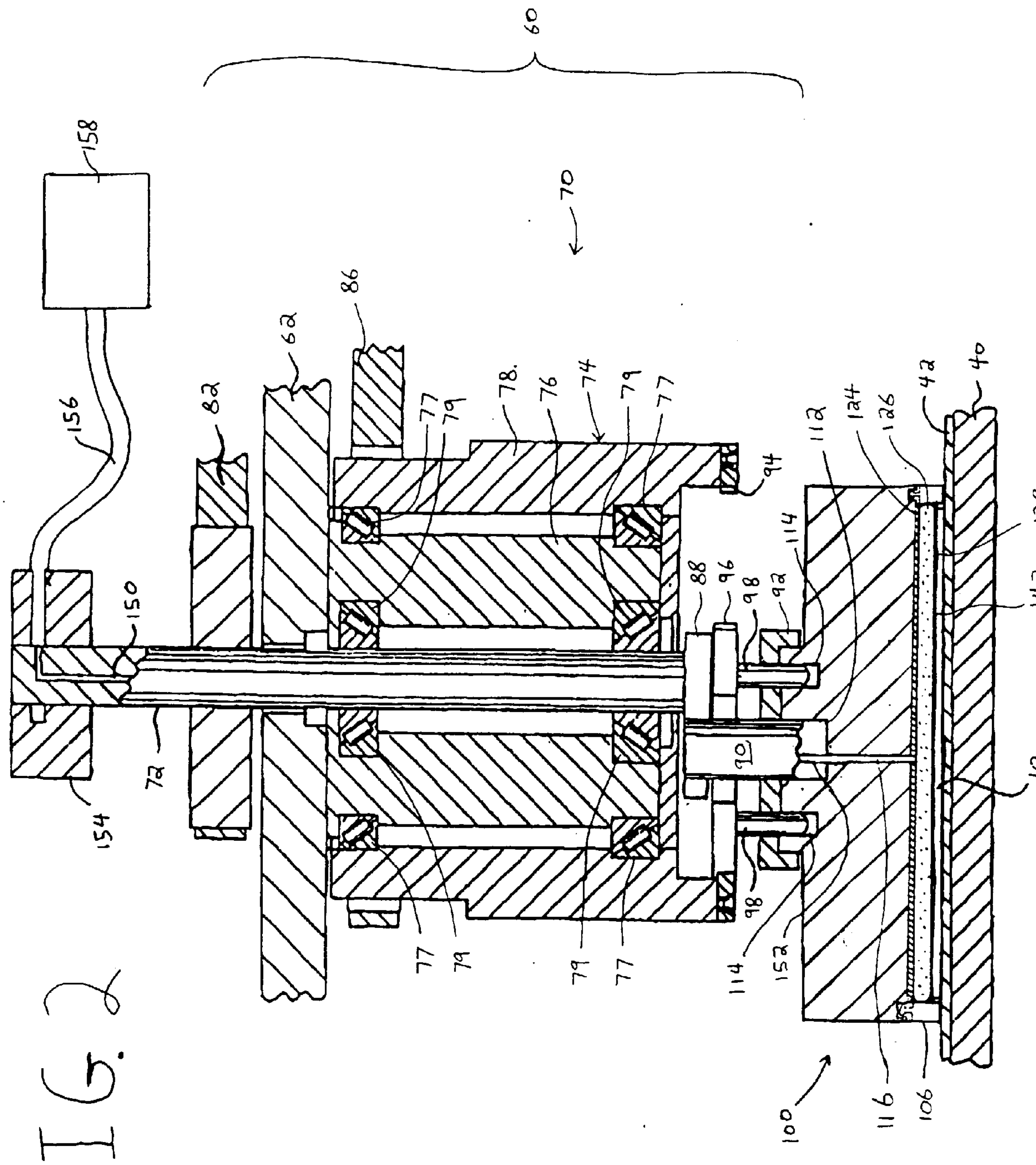
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FIG. 2

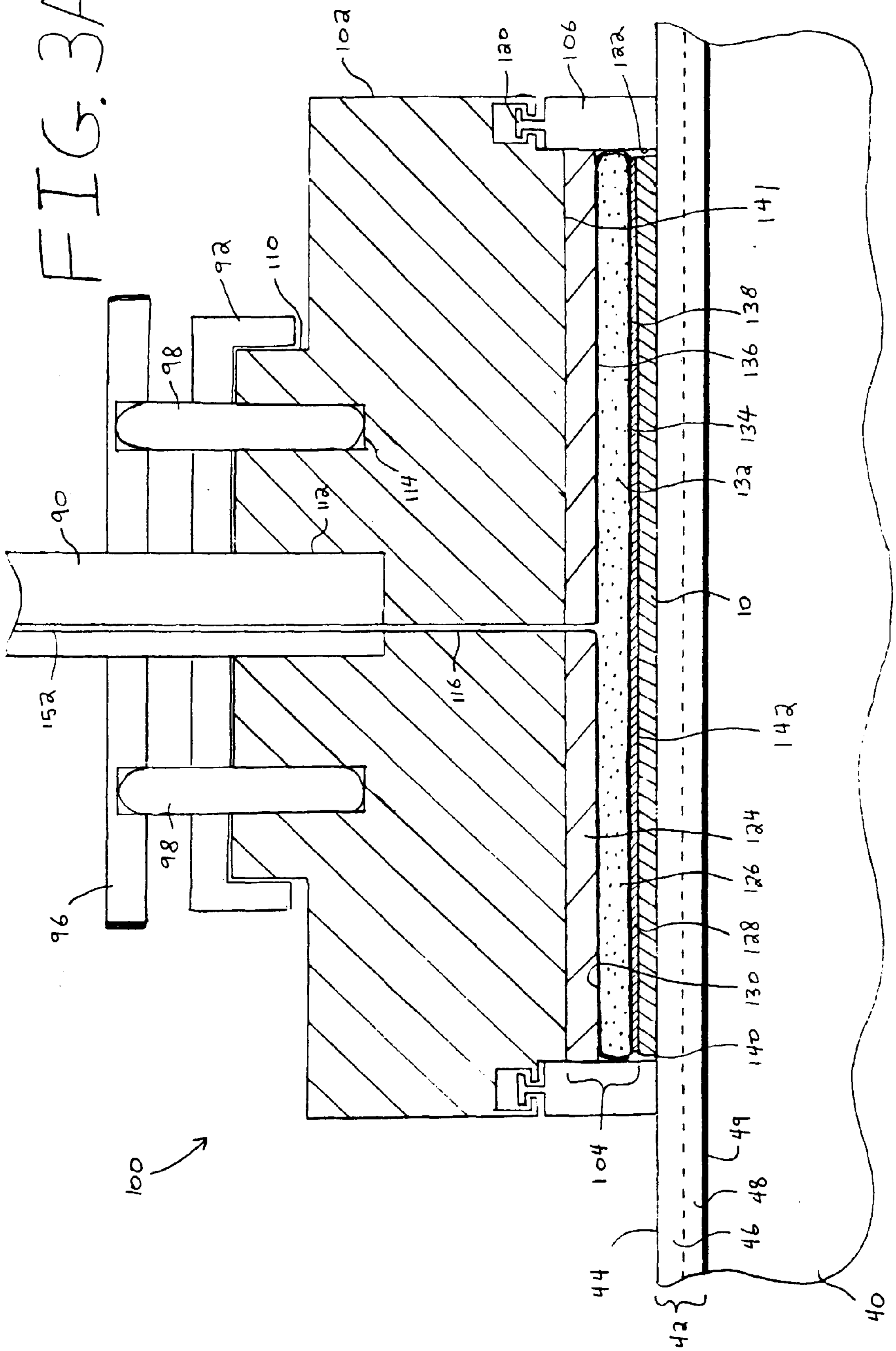
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FIG. 3A

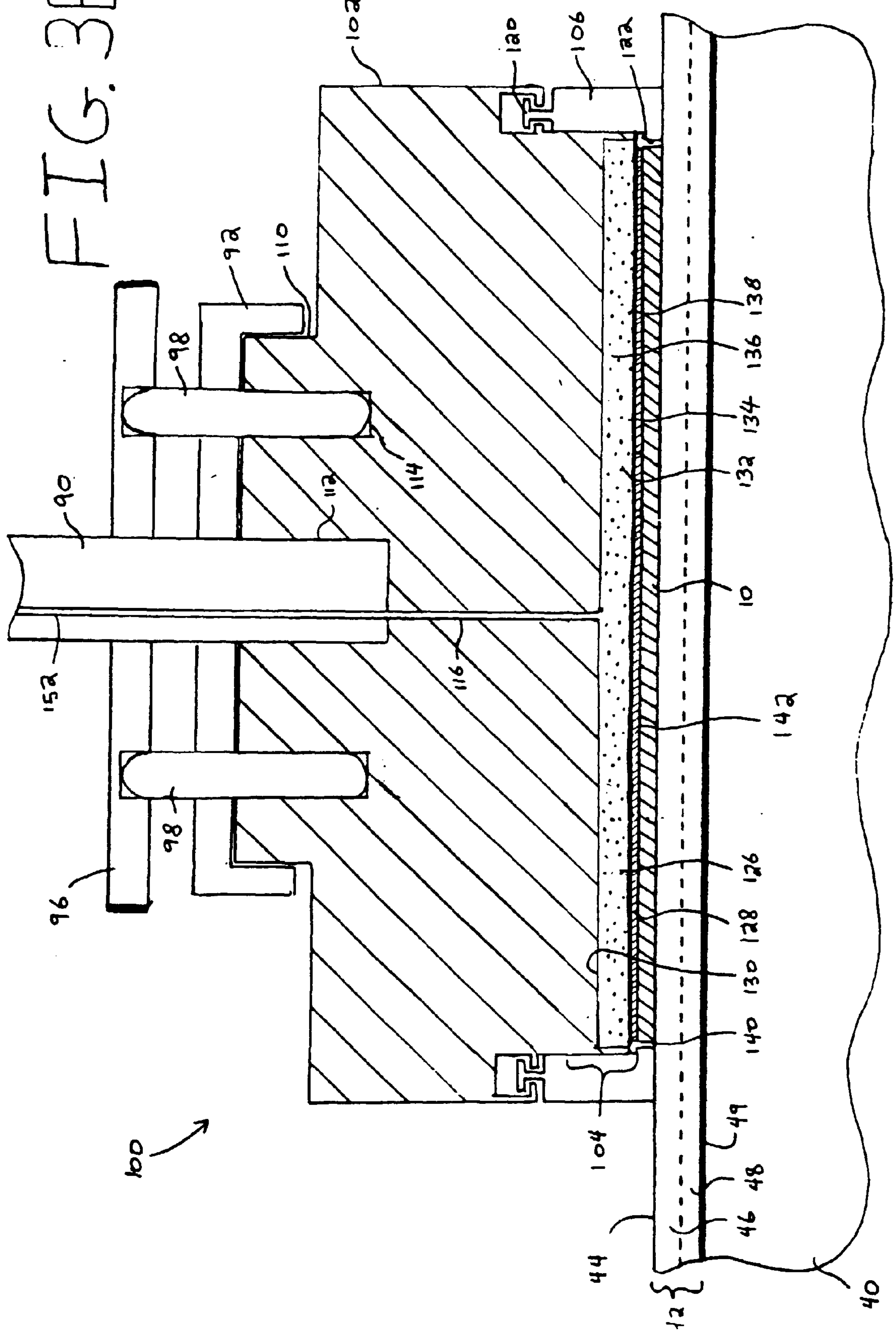
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FIG. 3B

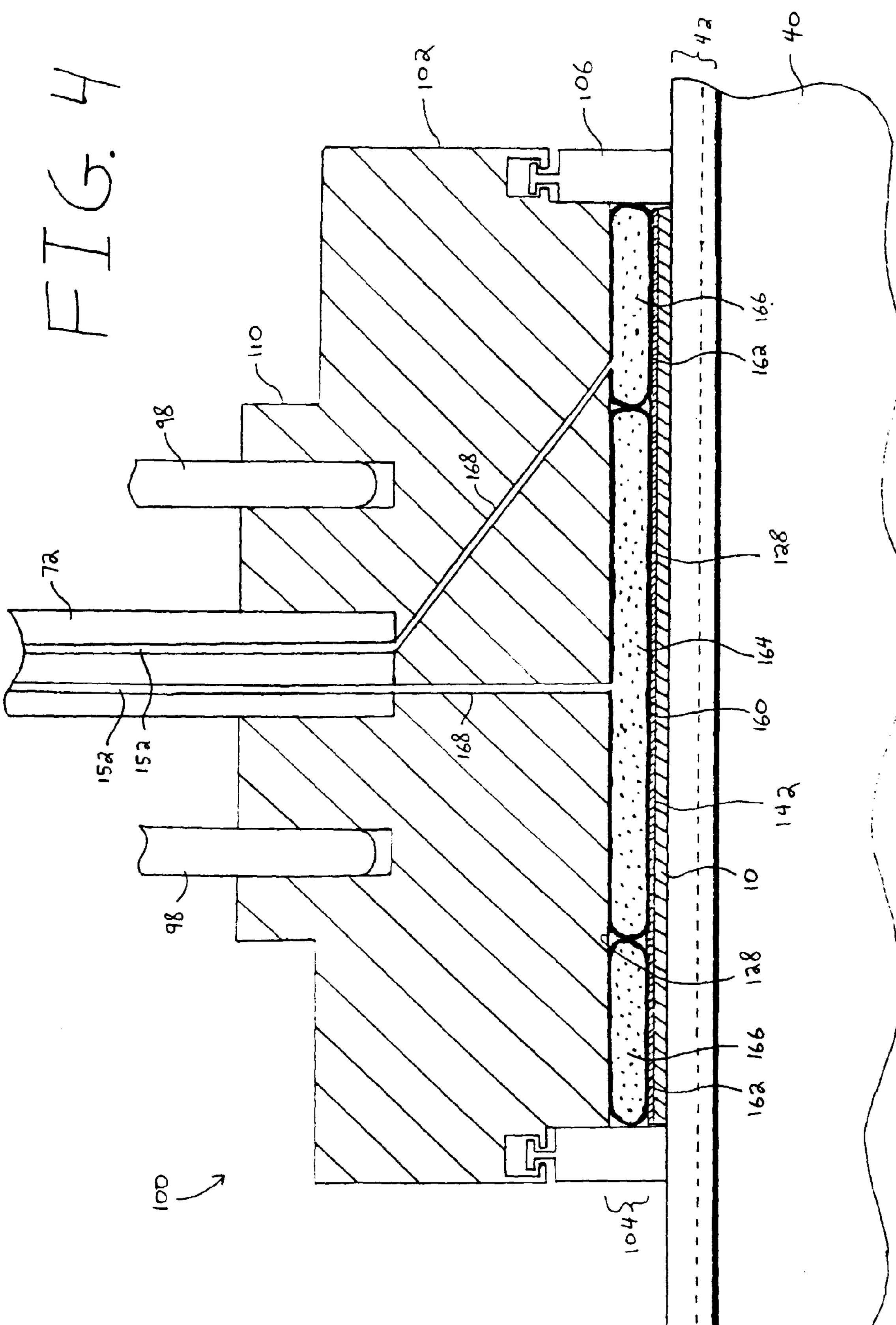

FIG. 4

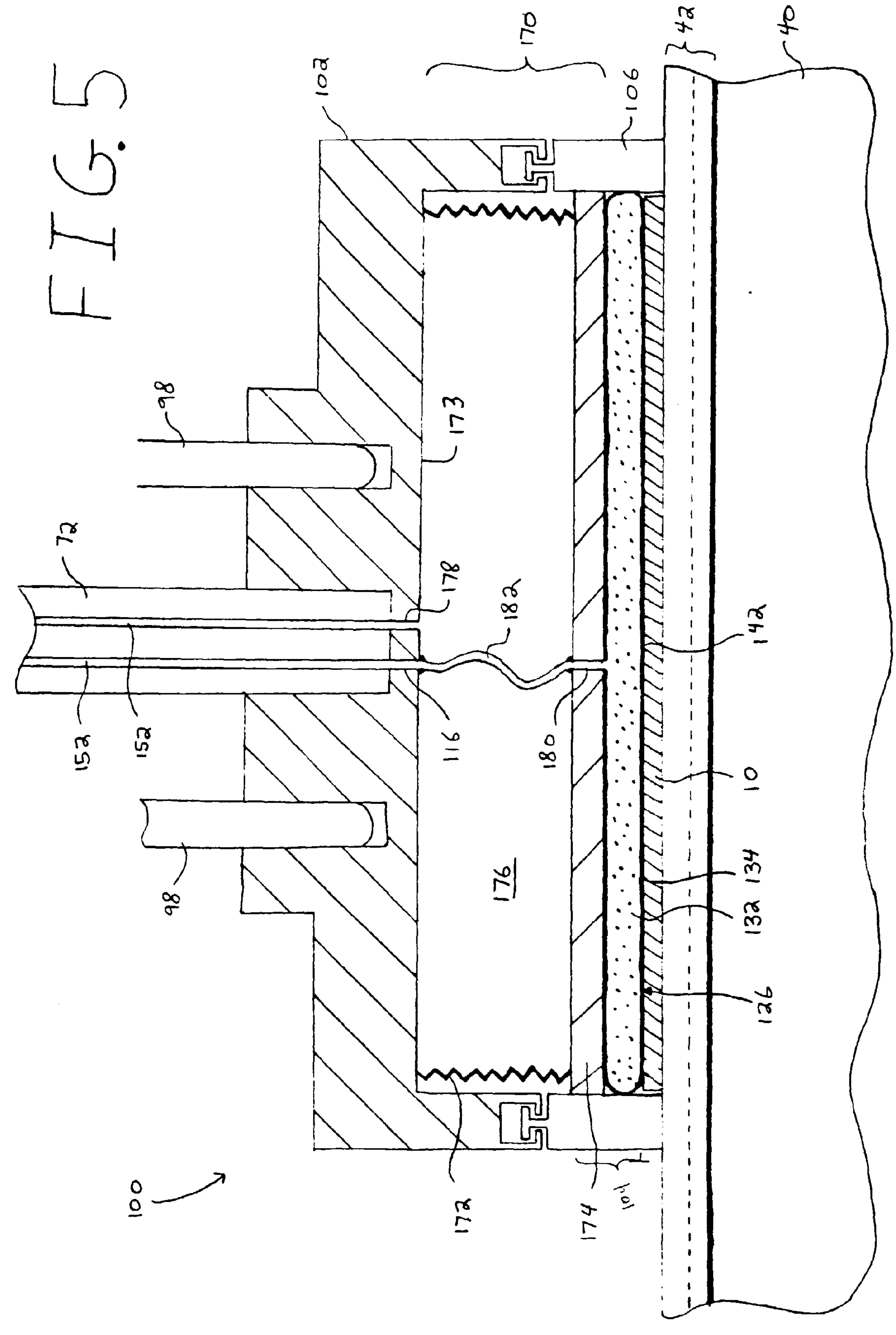
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FIG. 5

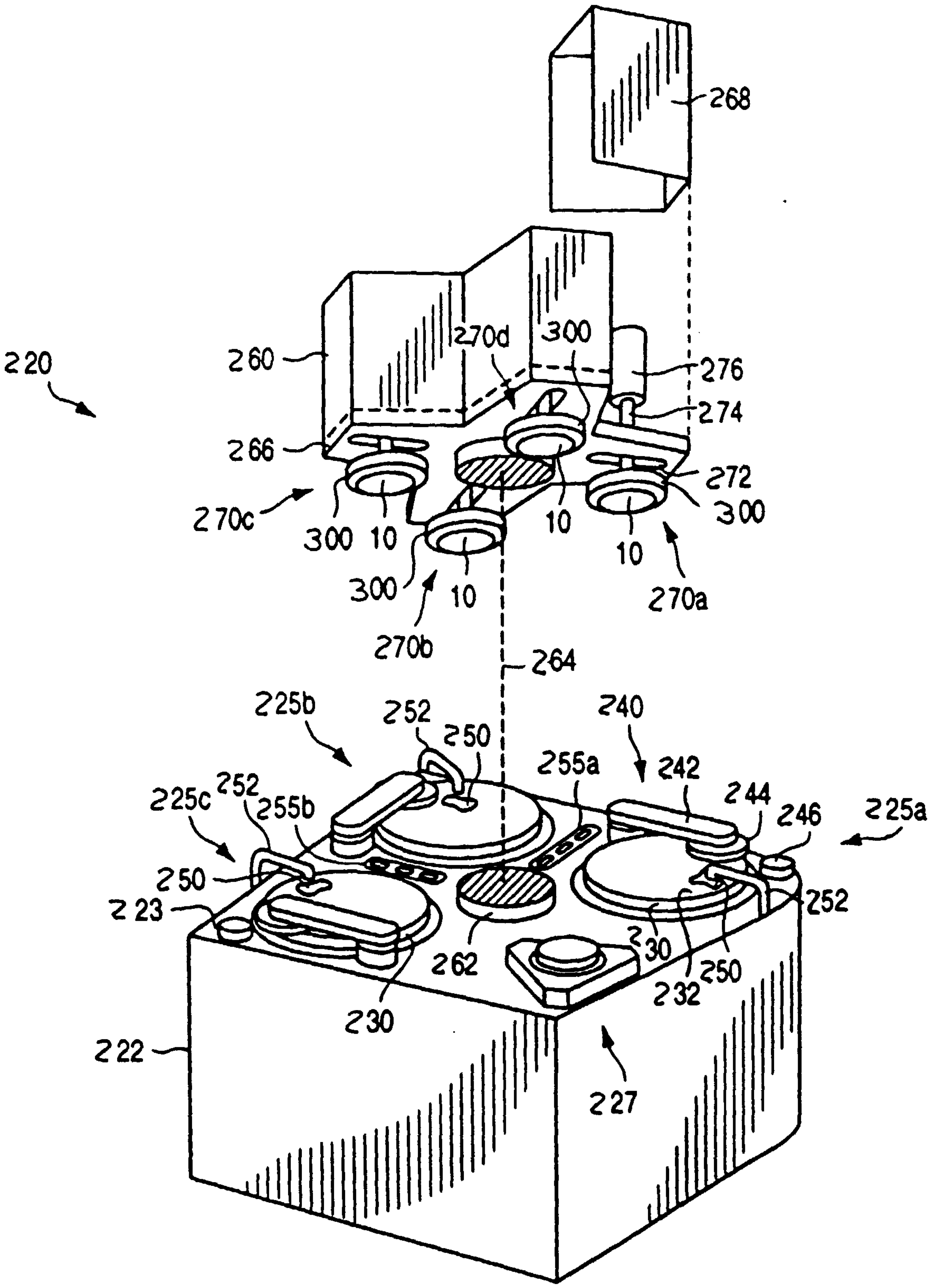
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FIG. 6

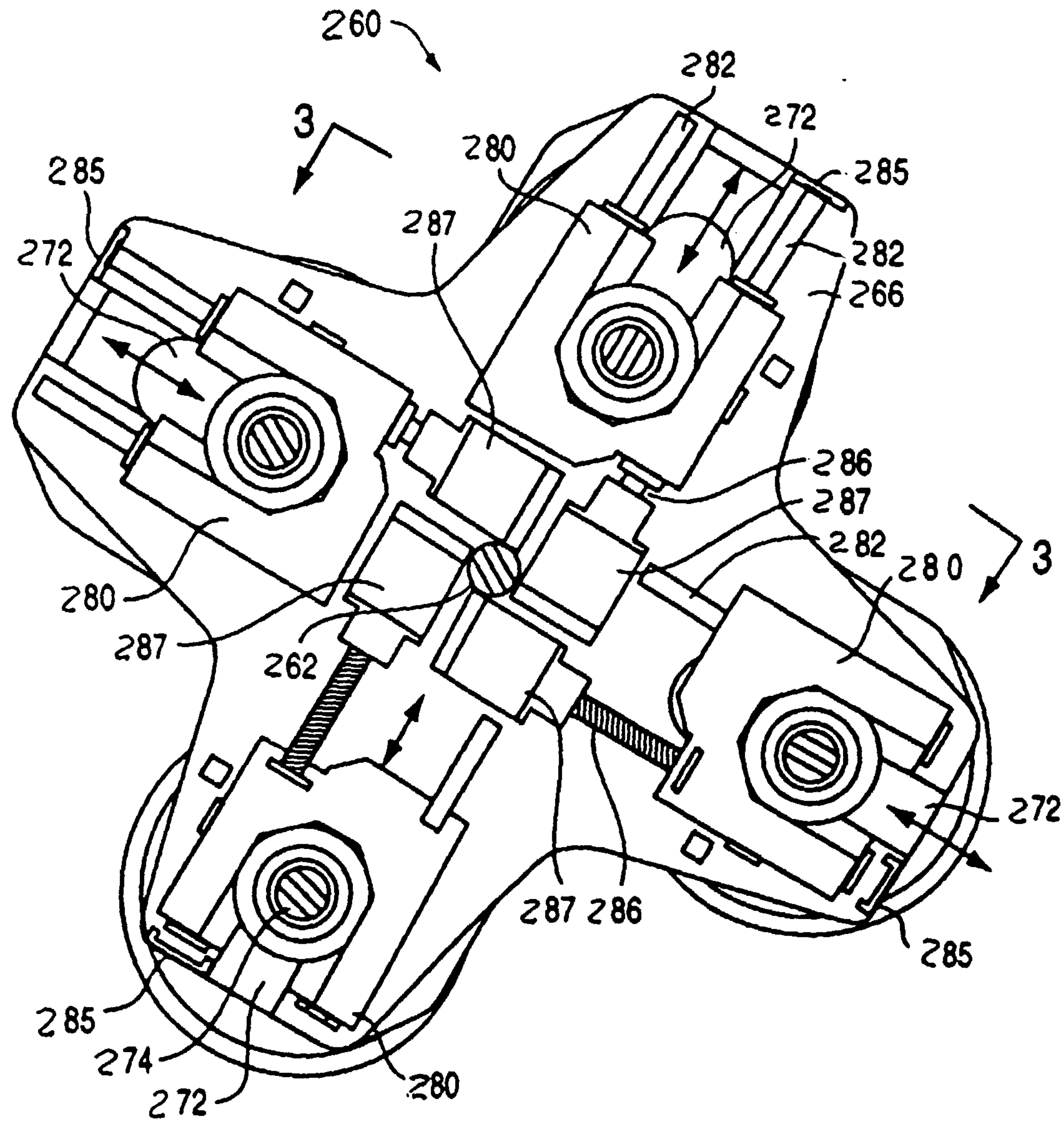
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FIG. 7

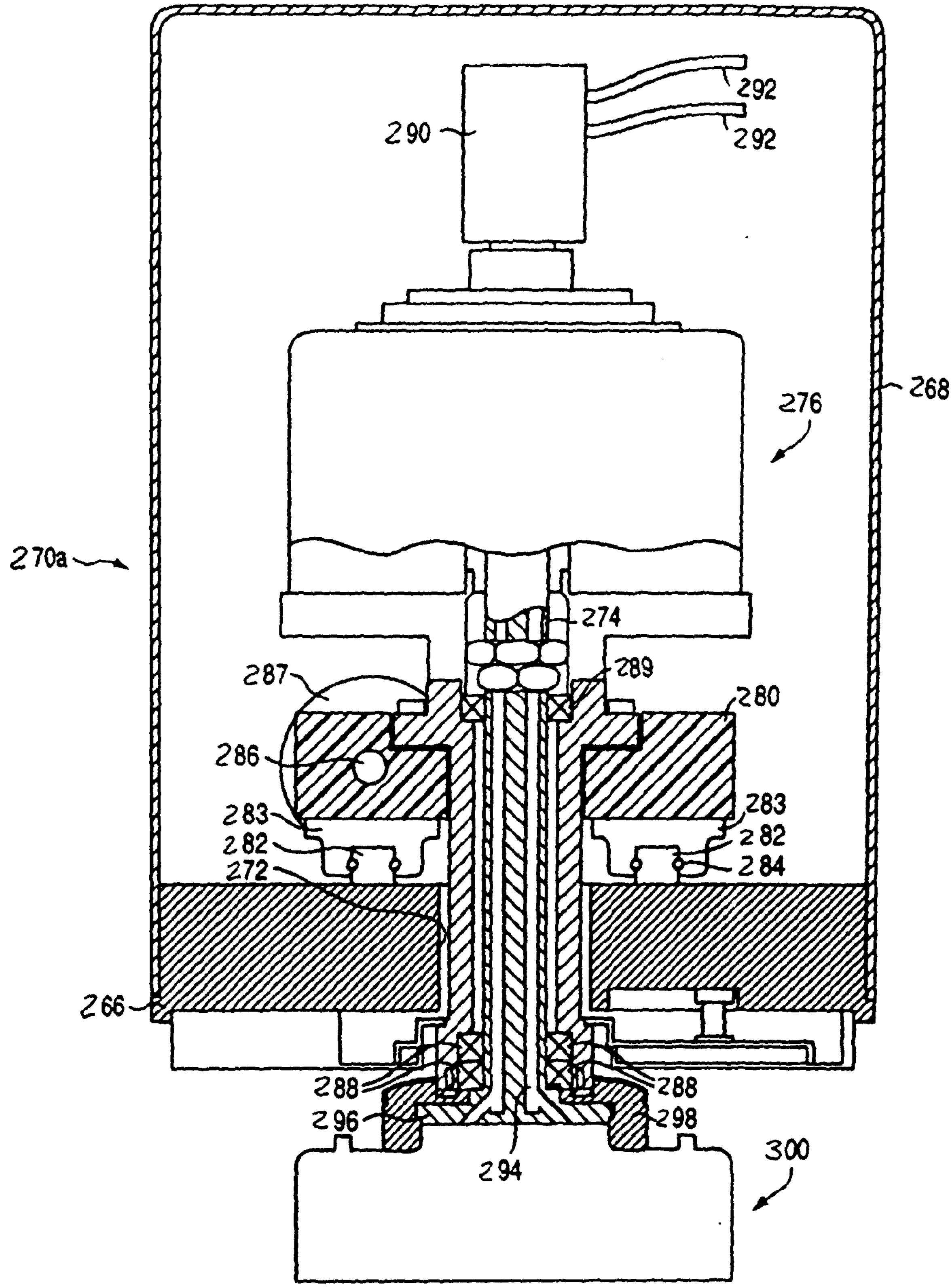
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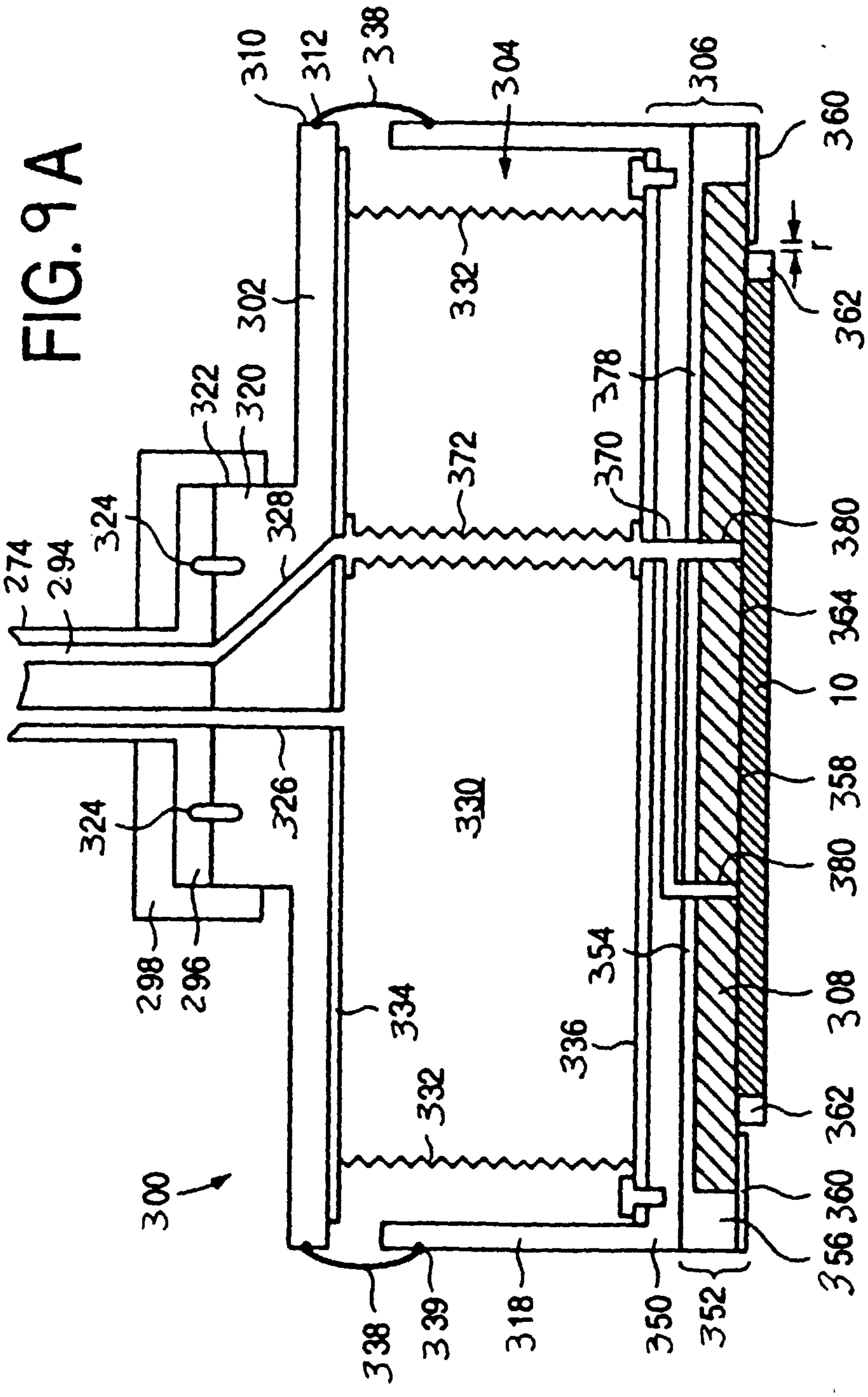
FIG.8

FIG. 9A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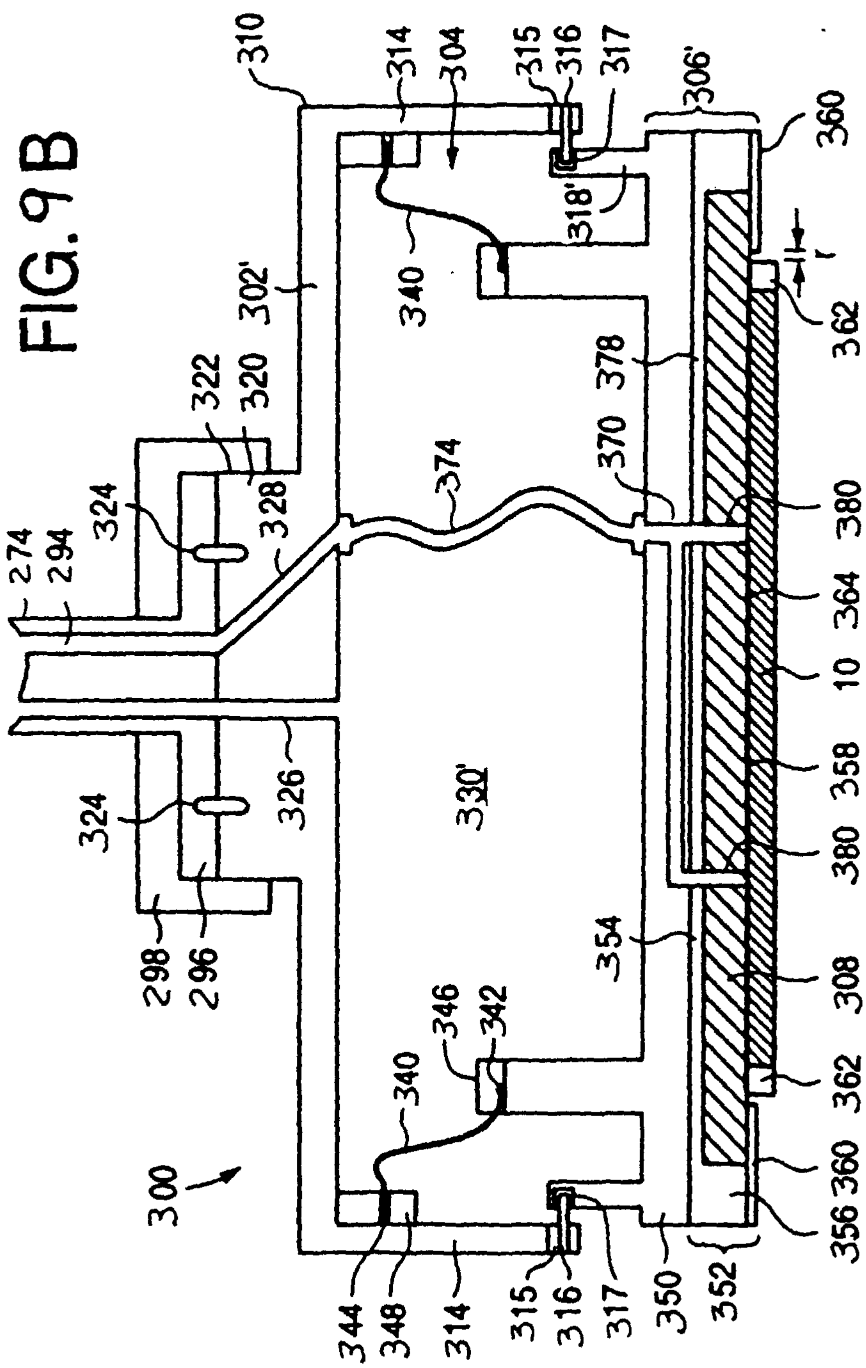
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FIG. 9B

FIG. 10

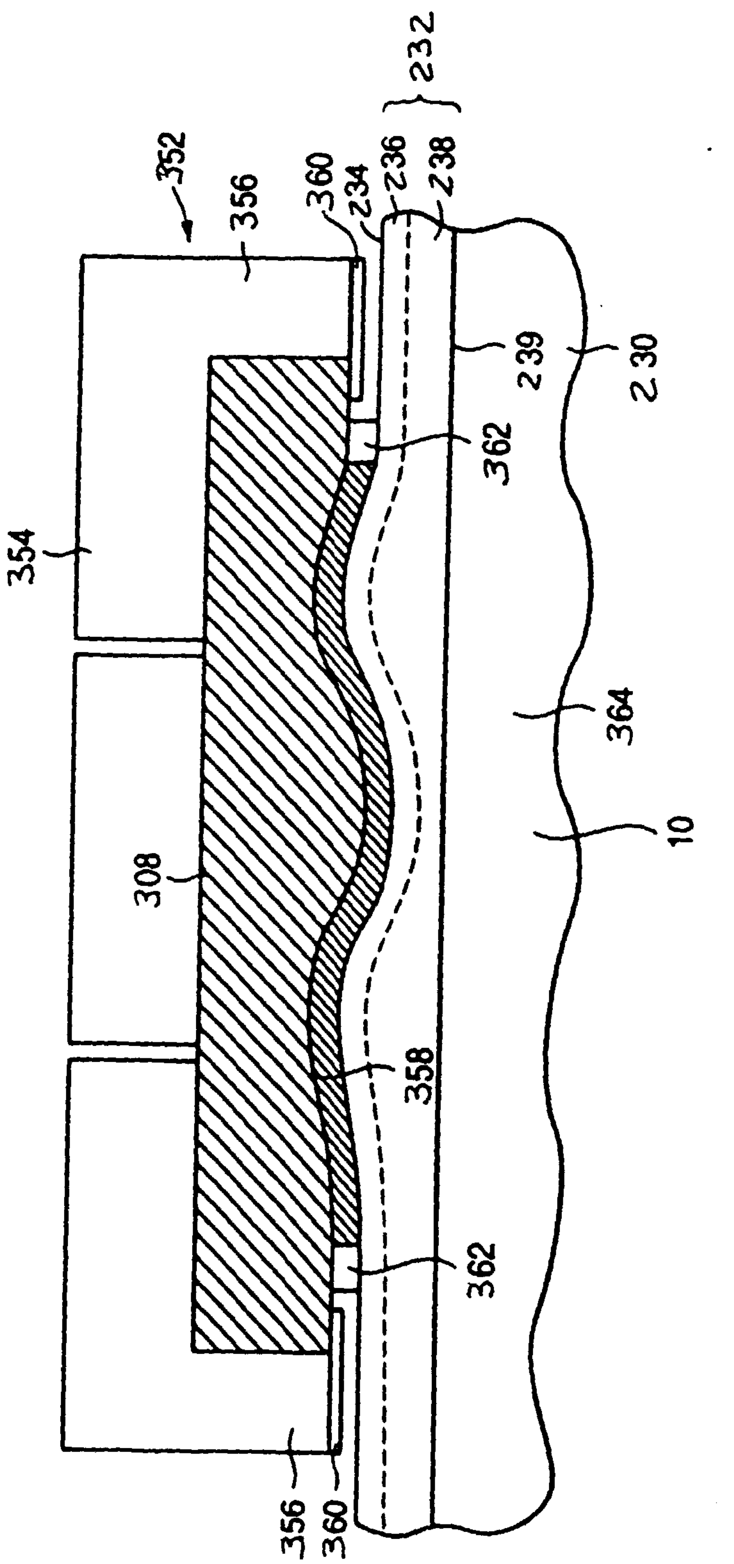
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FIG. 11A

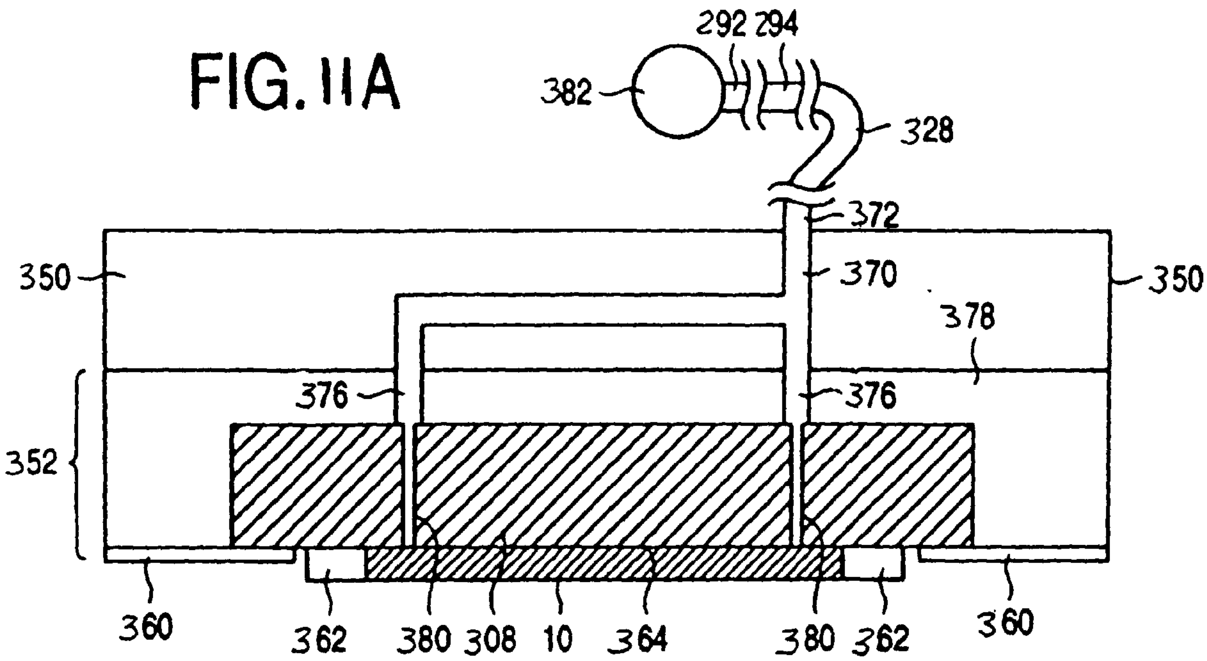


FIG. 11 B

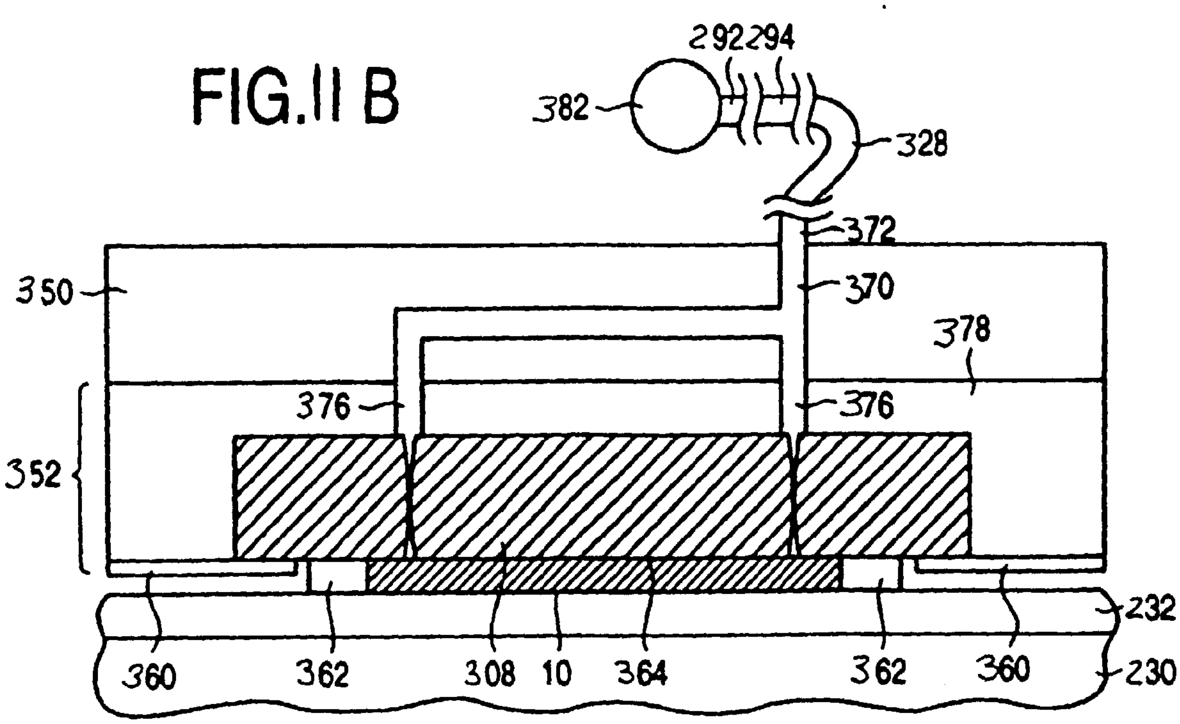


FIG.12A

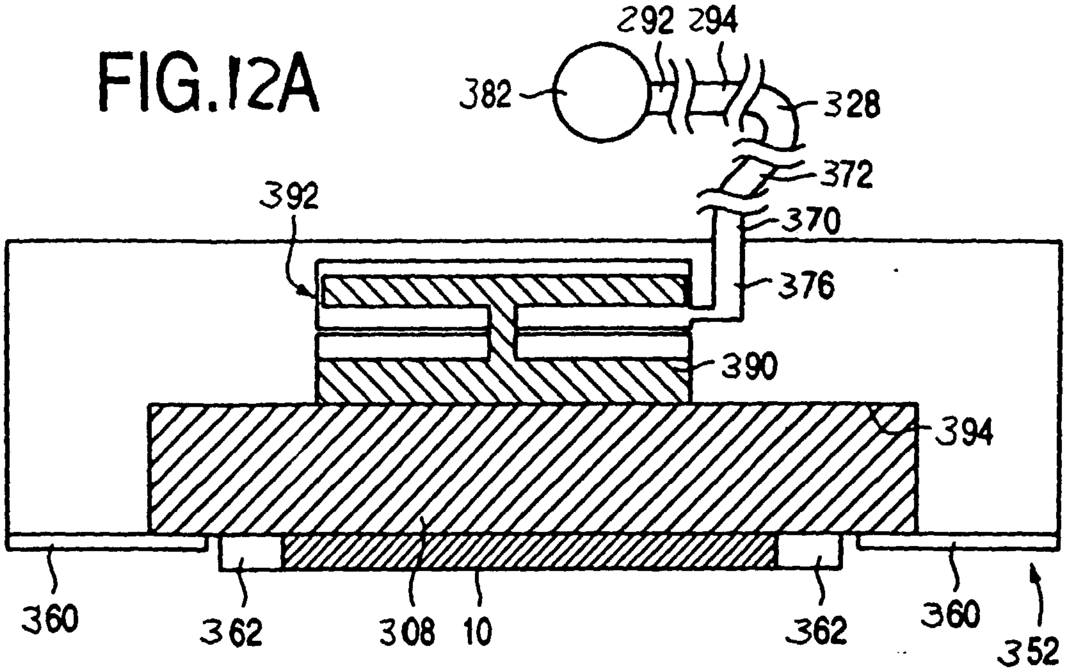
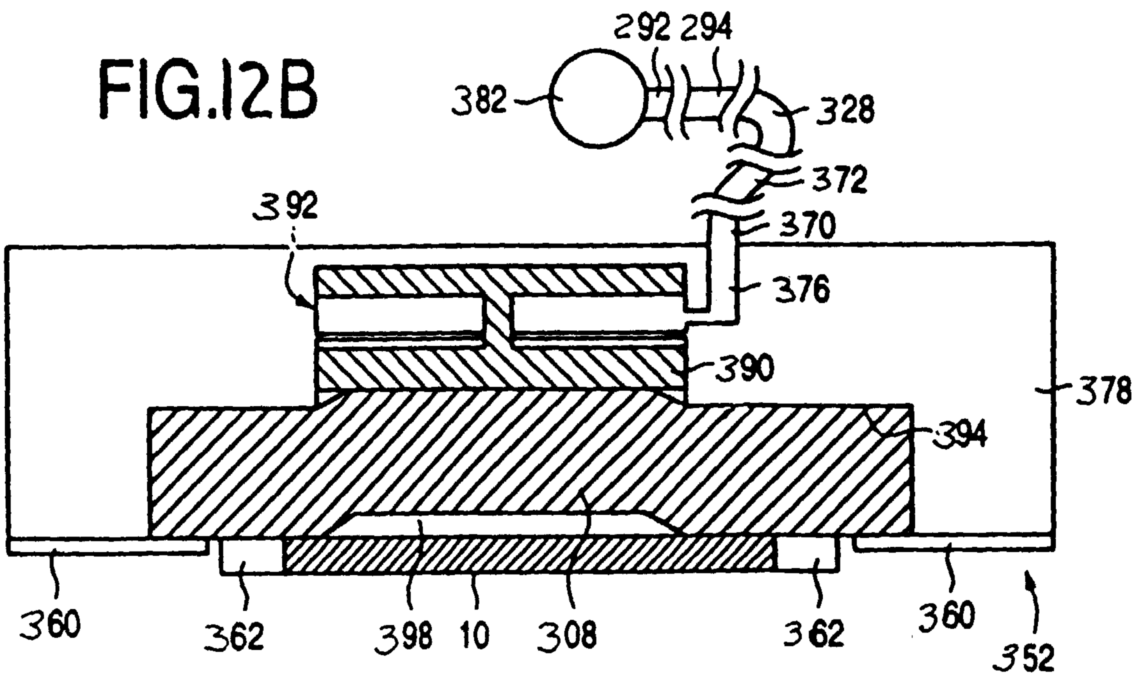


FIG.12B



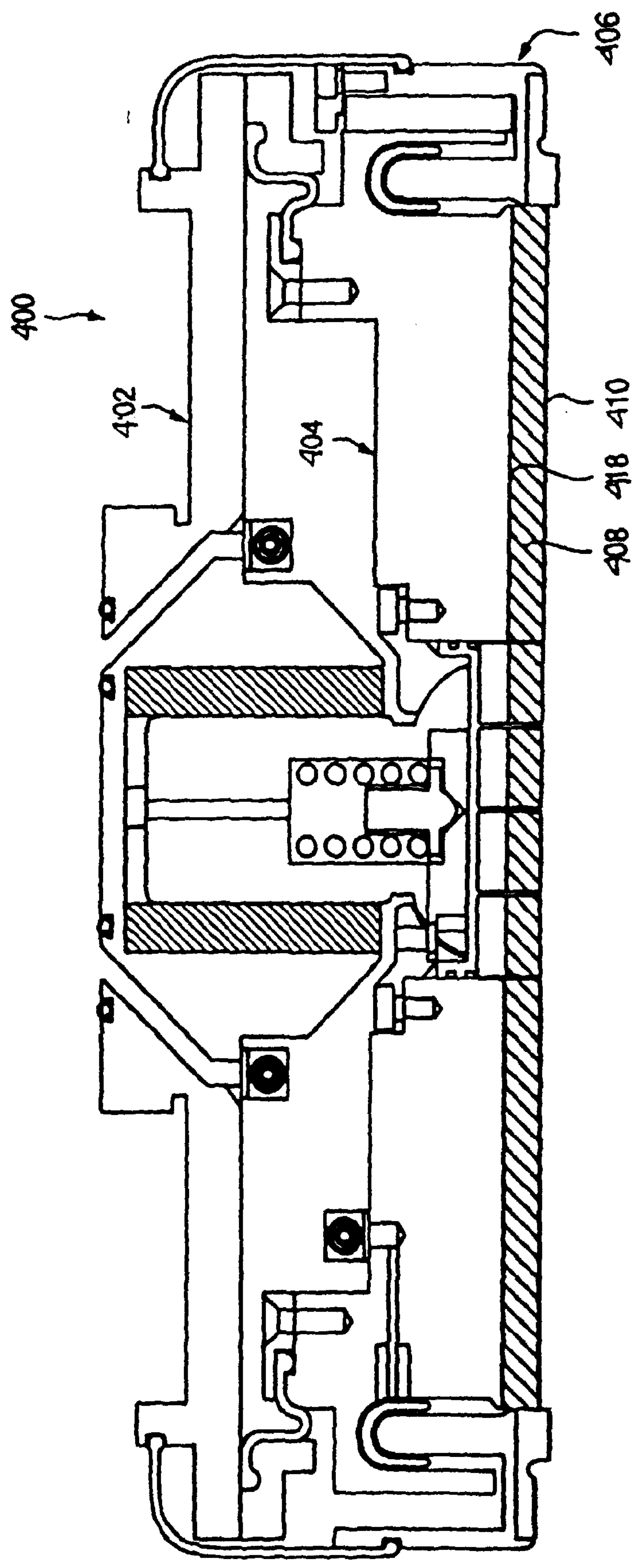


FIG.13

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 30 8022

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	US 5 193 316 A (OLMSTEAD DENNIS L) 16 March 1993 * column 2, line 1 - line 15 *	1,2,5-7	B24B37/04
A	FR 2 558 095 A (RIBARD PIERRE) 19 July 1985 * abstract; figure *	3,4	
A	US 5 449 316 A (STRASBAUGH ALAN) 12 September 1995 * column 4, line 17 - line 45; figure 5 *	11-14	
A	US 5 441 444 A (NAKAJIMA MAKOTO) 15 August 1995 * column 2, line 58 - column 3, line 2; figure 1 *	19	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
B24B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	14 January 1998	Eschbach, D

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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E : earlier patent document, but published on, or after the filing date
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