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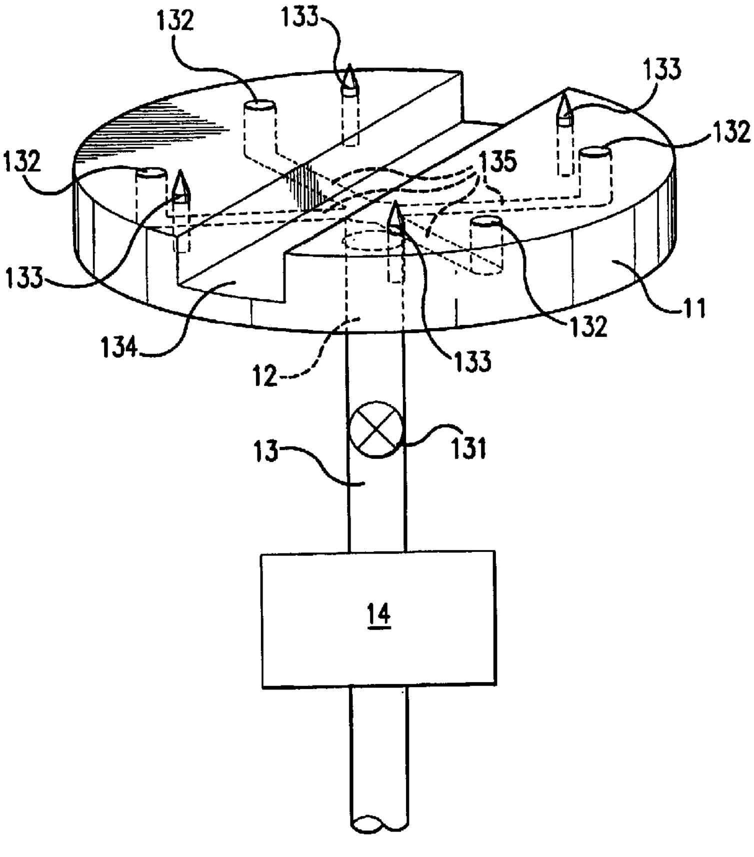
(54) Title: APPARATUS AND METHOD FOR HANDLING AND TESTING OF WAFERS



(57) Abstract: Embodiments provide an apparatus and method permitting the handling of a semiconductor wafer while maintaining the vacuum applied to the relevant wafer handling equipment continuously in an actuated state. These embodiments provide more gentle wafer handling with reduced contamination risk. One embodiment provides a passive end effector. Another embodiment provides a holder, for an object such as semiconductor wafer, that utilizes Bernoulli-type forces to retain the object against the holder.

APPARATUS AND METHOD FOR HANDLING AND TESTING OF WAFERS

Technical Field

The present invention relates to apparatus and methods for handling of semiconductor wafers, more particularly for testing purposes.

Background Art

In numerous areas of high and low technological application, fragile objects must be handled for purposes of transport and holding in place while minimizing undue risk of breakage, warpage, and contamination. Varying degrees of sophistication and innovation in, for example, vacuum, magnetic, and electrostatic fixturing have led to considerable advances in non-contact or minimal contact transport and holding devices. Contamination remains a continuing problem area.

Representative systems in the prior art for handling semiconductor wafers for testing purposes are shown in United States patents 4,695,215; 4,907,931; 5,479,108 (the "'108 Patent"); and 6,249,342. It is common to use an end effector (such as wand 62 shown in the '108 Patent) to move a wafer between a first location, such as a cassette (for example, cassette assembly 18 in the '108 Patent), and a test chuck (such as chuck 30 in the '108 Patent). To accomplish the handling of the wafer in a secure and reliable fashion, it is common to equip the end effector with a vacuum arrangement to enable the end effector to removably grasp the wafer. In a typical system, the end effector includes a series of holes (such as apertures 70 in the '108 Patent) that are coupled to a vacuum source that may be toggled between states in which it is actuated or released.

Furthermore, in semiconductor metrology, wafer substrates typically must be held in place with a high degree of precision on fixtures, particularly during measurement operations. A popular, traditional method is to clamp a wafer substrate to a chuck by means of an applied vacuum. The chuck is then rotated or moved along linear axes as needed to implement the measurement process. It is generally accepted that this approach to holding the substrate can and often does cause contamination of the surface that is clamped. The risks associated with contamination are exacerbated by recent wafer processing advances that require that the surfaces be highly polished and free of particles. Two likely causes of contamination are the generation of particles when the substrate contacts the chuck and the flow of unclean gas (usually air) generated when the vacuum is released. Because particles are detrimental to subsequent processing of wafer substrates, their generation and proliferation are objectionable and should be minimized. A typical prior art approach for conducting measurements on a wafer may involve steps such as the following:

1. insert end effector into the cassette in which the wafer is located;
2. actuate vacuum arrangement coupled to end effector to grasp the wafer;
3. move the end effector (with wafer) to an alignment station chuck and actuate alignment chuck vacuum to hold down the wafer;
4. turn off end effector vacuum;
5. remove end effector;
6. physically align wafer in alignment chuck;
7. insert end effector beneath the wafer in the alignment chuck;
8. actuate vacuum arrangement coupled to end effector to regrasp the wafer and release alignment chuck vacuum;
9. move wafer to measurement chuck;
10. actuate vacuum on measurement chuck;
11. release end effector vacuum;
12. remove end effector from measurement chuck;
13. run test on wafer on measurement chuck;
14. insert end effector beneath the wafer in the measurement chuck;
15. actuate vacuum arrangement coupled to end effector to regrasp the wafer and release measurement chuck vacuum;
16. return wafer to cassette;
17. release end effector vacuum; and
18. remove end effector from cassette.

An innovation by QC Solutions, Inc., the assignee herein, has somewhat reduced the number of steps involved in wafer testing by eliminating the need for a separate alignment chuck. This innovation provides what we call "virtual alignment" of the wafer on the measurement chuck. The virtual alignment process involves measuring, with a high degree of accuracy, the effective two-dimensional displacement of the wafer's center from the measurement chuck's rotational axis. This displacement measurement is then used to provide appropriate adjustment to the coordinates associated with measurements taken over the surface of the wafer while it sits on the measurement chuck. Using this process, the wafer can be transferred directly from the cassette to the measurement chuck without intermediate use of an alignment chuck.

The use of gas flow in object holders to generate forces essentially orthogonal to the direction of the flow (based upon the Bernoulli principle) is well known in the art. For example, U.S. Patent No. 6,095,582 to Siniaguine et al., directed to article holders and holding methods, as well as U.S. 4,903,717, U.S. 5,080,549, U.S. 5,967,578, U.S. 5,979,475, and U.S. 6,056,825 disclose such principles and fixturing.

All of the patents referenced in the present application, and the references cited in such patents, are hereby incorporated herein by reference in their entirety.

Summary of the Invention

In embodiments of the present invention we have provided an apparatus and method permitting the handling of a wafer while maintaining the vacuum applied to the relevant wafer handling equipment continuously in an actuated state. These embodiments provide more gentle wafer handling with reduced contamination risk.

In one of these embodiments, there is provided a method of handling a semiconductor wafer. The method of this embodiment includes:

placing an end effector beneath the wafer, the end effector having a retaining means for retaining the wafer;

using the end effector to move the wafer and to cause the wafer to rest on a holder;

using air flow toward an actuatable vacuum source to provide a force that retains the wafer against the holder;

removing the end effector from beneath the wafer; and

performing all of the foregoing processes while maintaining the vacuum source continuously in an actuated state so that the air flow is continuous and without changing the state of the retaining means.

In a related embodiment, the retaining means includes a plurality of contact regions mounted on the end effector and in contact with the lower surface of the wafer, for retaining the wafer thereon using gravitational force. Optionally, at each contact region the end effector includes a wedge-shaped lifter, the lifter being disposed so that a region of the periphery lies on the lifter, the wedge being thickest in a direction outward from the periphery. The end effector as described is by itself another embodiment of the invention.

In another related embodiment, the holder includes a plate with a first plate surface having a plurality of support pins protruding therefrom and in contact with the lower surface of the wafer, the plate also having a fluid outlet port in communication with the first plate surface, and wherein the vacuum source is coupled to the fluid outlet port, so that a gap is defined between the first plate surface and the lower surface of the wafer and air flow in the gap between the first plate surface and the lower surface of the wafer provides a force that retains the wafer against the holder.

In a related embodiment, there is provided a method for holding an object, such as a semiconductor wafer. The method of this embodiment includes:

providing a holder, the holder including a plate having a first plate surface, the first plate surface having a plurality of support pins protruding therefrom, the plate having a fluid outlet port in communication with the first plate surface, and wherein a vacuum source is coupled to the fluid outlet port;

resting the first object surface on the support pins so as to define a gap between the first plate surface and the first object surface, so that the fluid outlet port provides fluid communication between the gap and the vacuum source; and

using the vacuum source to move fluid from the gap so as to establish a retentive force on the object.

In related embodiments, (i) a manifold is disposed in the plate and the manifold is in communication with the outlet port; (ii) the plate has a plurality of inlet ports in communication with the manifold and having openings on the first plate surface. Optionally, each inlet port is disposed proximate to a support pin, and the plurality of inlet ports is the same as the plurality of support pins. The method may also include optionally adjusting the flow of fluid through the gap to provide a desired amount of retentive force on the object.

In further related embodiments, the fluid is a gas, such as air. While any object size can be accommodated, optionally, the object is a semiconductor wafer having a diameter that measures approximately 200 mm or 300 mm. Optionally the support pins project above the first plate surface by an amount measuring between approximately 0.1 mm and approximately 3 mm. In further related embodiments, the support pins project above the first plate surface by an amount measuring between approximately 0.3 mm and approximately 0.7 mm, and optionally approximately 0.5 mm. Also in related embodiments, the support pins contain quartz and alternatively or in addition contain an electrically conductive material. Optionally, the plate has at least one additional fluid outlet port providing fluid communication between the gap and the vacuum source; alternatively or in addition, the plate has a fluid port providing fluid communication between a volume exterior to the holder and the gap.

In other related embodiments, there is provided a holder as described in connection with the methods above.

The Bernoulli-type force generated by the fluid flow within the gap effectively holds the object upon the support pins while the pump remains activated. The fluid may be air, in which case air that is removed from the gap may be replaced from the surroundings. The object may be a semiconductor wafer to be held with minimal risk of breakage, warping and contamination. The support pins may contain quartz; the support pins may also contain an electrically conductive material.

In another holder embodiment, the plate may have at least one additional fluid outlet port providing fluid communication between the gap and the pump. In yet another holder embodiment, the plate has another fluid port providing fluid communication between a volume exterior to the holder and the gap. In this embodiment, the holder may further have a filter located between the volume and the gap.

Brief Description of the Drawings

Fig. 1 is a cross-sectional view of a holder and a held object in accordance with an embodiment of the present invention.

Fig. 2 is a schematic representation of the Bernoulli-type force, **B**, generated by the apparatus of Fig. 1.

Fig. 3 is a top view of a plate component of a holder in accordance with an embodiment of the invention.

Fig. 4a is a partial cross-section of the gap associated with a holder embodiment; Fig. 4b is a partial cross-section of the gap associated with a variation of the holder embodiment of Fig. 4a.

Fig. 5 is a cross-sectional view of another holder embodiment.

Fig. 6 is a longitudinal view of a variation of the holder embodiment of Fig. 5.

Fig. 7 is a cross-sectional view of yet another holder embodiment.

Fig. 8 is a cross-sectional view of a holder in accordance with a further embodiment of the present invention.

Fig. 9 is a view of an end effector **91** in accordance with an embodiment of the present invention shown holding a wafer.

Fig. 10 is a view providing further detail of the end effector of Fig. 9.

Fig. 11 is a view providing detail of the lifter **95** of Figs. 9 and 10.

Fig. 12 shows embodiment of a holder in accordance with the present invention in which the plate is provided with a manifold.

Fig. 13 shows an embodiment of a holder having an end effector cutout suitable for use with the end effector of Fig. 9.

Detailed Description of Specific Embodiments

A holder which, inherently, has less risk of contamination may desirably provide a very small contact area with the held object to minimize particle generation and deposition via direct contact. It should provide adequate force (and friction, in some embodiments) to retain the object on the holder during any required processing. Further, holder operation should tend to minimize the effect of any generated contamination.

Definitions. As used in this description and the accompanying claims, the following terms shall have the meanings indicated, unless the context otherwise requires:

"Fluid" is any liquid or gas which, by its flow, may generate Bernoulli-type forces essentially orthogonal to the fluid flow.

An "atmospheric" system is one that utilizes air or other gas at a pressure near atmospheric pressure as opposed to a "vacuum process" system.

A "vacuum source" is any arrangement that provides a partial vacuum suitable for causing the exhaust flow of fluid from a region to which the arrangement is coupled. Accordingly, the "vacuum source" may be implemented as a pump that is configured to exhaust fluid from the region.

A “pump” is any device that urges fluid from one location to another. Within the scope of the present disclosure, the pump element of the embodiments of the holder is designed to direct fluid toward itself rather than away from itself. In this context, any contamination associated with the introduction of an operating pump will not tend to affect the object being held. Further, existing contamination proximal to the object or its near surroundings may beneficially be pumped away from the surfaces of the object.

A “plate” is an element of the holder that has a first plate surface. Although the plate, in the various embodiments and in the applications specifically directed toward semiconductor wafer holders, is depicted to be essentially flat, it is understood by one of ordinary skill that a curved or otherwise irregular surface that may, in some geometry, be congruent with a surface of the object to be held will, also, be within the scope of the disclosure. As long as Bernoulli-type forces may be generated within a gap defined by these surfaces, it is deemed that the term “plate” and the plate element of the holder be not limited to essentially flat structures.

The “length” of a support tip protruding from a first plate surface is the distance occupied by the support tip in a direction normal to the first plate surface.

Referring now to Fig. 1, an embodiment of a holder **10** includes a plate **11** having fluid outlet port **12** in fluid communication via hose **13** with pump **14**. The object **15** to be held by holder **10** is shown with first object surface **16** touching, at positions **17**, support pins **18** that protrude from the first plate surface **19**. Although only two support pins 18 are shown in this figure, in fact three support pins are utilized in this embodiment. In other embodiments, such as the embodiment of Fig. 13, four support pins are employed; however, other numbers of support pins may suitably be used under appropriate conditions. Holder **10** may be situated in air, preferably in a clean air environment such as those commonplace in facilities where contamination-sensitive processing takes place. Object **15** may, for example, be a semiconductor wafer having essentially flat primary surfaces requiring a high degree of cleanliness on both first object surface **16** and on opposing surface **160**. First plate surface **19** and first object surface **16** define a gap **110** through which air may pass between object **15** and holder **10**. Pump **14** functions to generate air flow directed first through the gap **110** adjacent to first object surface **16**, then through hose **13** away from object **15**, through flow valve **131**, and out of gap **110**. Refer to arrows **F**. In this embodiment, air is replenished to the gap **110** from the environment. Refer to arrows **E**. Air flow adjacent to and essentially parallel to first object surface **16** within gap **110** generates, as schematically illustrated in Fig. 2, Bernoulli-type forces essentially orthogonal to the air flow direction. Refer to arrows **B** for the direction of these forces, which tend to retain object **15** in place against the support pins **18**. The flow of air through the gap **110** between the plate **11** and object **15** (due to the Bernoulli principle) develops force essentially normal to first object surface **16**. This force increases the frictional force between object **15** and holder **10**, and helps hold the object **15** in place. Fluid flow direction does not need to be reversed during the holding operation, and for this, among other reasons, the embodiment of this figure differs from conventional vacuum clamping methods. Flow valve **131** is used to adjust the air flow through the path described to produce a desired retaining force for given conditions of the gap **110** and object **15**.

Fig. 3 is a top view of plate **11**. Plate **11** has three support pins **18** protruding from first plate surface **19**. Three support pins **18** tend to maintain an approximately constant gap **110** dimension over the first plate surface **19**. In this embodiment, fluid outlet port **12** is centrally disposed in plate **11**. As stated above, object **15** is depicted as a disk but is in no way limited to that shape. No fluid (air) flow is generated adjacent the opposing surface **160** of the object. Flow generated adjacent first object surface **16** will tend to sweep any loosely held contamination away from the surface **16** rather than, in prior art Bernoulli-type systems, towards surface **16**. Most generally, contamination will move away from object **15** and out of holder **10**. By way of example, it is common in "atmospheric" semiconductor equipment, to maintain the air in the vicinity of the wafers in a very clean state. It is, therefore, convenient to use this ambient air as the source of clean air because of the complexities involved in providing clean air or gas through a plumbing system. The flow of clean air past the under side of a wafer (surface **16)** minimizes or eliminates deposition of new particles and may possibly remove some pre-existing particles. Support pins **18** may be suitably fabricated from a range of materials. In one embodiment, the material for the support pins may be harder than the object support; hence in the case where the object is a semiconductor wafer, the pins may be made of quartz. In addition the support pins may be optionally electrically conductive, to provide an electrical path between the object 15 and the holder. In one implementation, a layer of indium-tin oxide may be formed on the selected hard material. Alternatively, the support pins 18 may be fabricated from a material that is softer than object **15**, and where the object is a semiconductor wafer, the support pins may be made of polyetheretherketone (available from Victrex plc, Thornton Cleveleys, Lancashire, UK under the trademark PEEK). Again the support pins may be made electrically conductive. In yet another embodiment, the support pins may be made of the same material as the object. The support pins, which touch surface **16** during operation of holder **10**, may also contain electrically conductive material depending upon the application of holder **10**. The support pins may be appropriately rounded to minimize contact area with surface **16** while maintaining an acceptable level of localized deformation of both surface **16** and support pins **18** caused by the holding Bernoulli-type forces. The object **15** does not touch first plate surface **19** and is touched only at points **17** during operation. Fluid flow is continuous and is not directed toward the object **15**. Plate **11** may be constructed out of a suitable conductive or non-conductive material. In the semiconductor industry, aluminum or structural ceramic are common materials for this purpose.

As an example, the amount of retentive force generated by a holder embodiment of the present invention has been determined in accordance with a procedure as herein described. A conventional chuck (plate **11**) was modified by adding 3 holes equally spaced on a 5.563 in. (141mm) diameter bolt circle. Three quartz pins (support pins **18**) were added with a nominal 0.0185 in. (0.47mm) projection above the surface of the chuck. A chuck insert was added to fill an end-effector cutout disposed in the chuck. Air was drawn through the center of the chuck (fluid outlet port **12**) using a pump and flow was adjusted by means of a valve in series with the pump, and measured by a 0-4 SCFM rotameter. The pump used to draw the air was a Gast (Model 2Z866) diaphragm vacuum/air pump. A 200mm silicon wafer (object **15**), polished on one side, was placed (centered) on the chuck. The wafer used weighed 53g and was approximately 725 micrometers thick.

The lateral force needed to move the wafer sitting on the pins of this horizontally oriented chuck was measured under various conditions and tabulated here:

Condition	**Retentive lateral force (grams)**	
	@ 0 SCFM just friction and gravity	@ 1 SCFM
Polished Side Down	9.5	51.3
Unpolished Side Down	13.5	93.3

It should be noted that the pins may, in various embodiments in practice, extend away from surface **19** by as little as about 0.1 mm or as much as about 3mm for a 200mm or 300 mm semiconductor wafer object to be held.

Fig. 4a illustrates, in an embodiment, object **15** extending radially beyond the radial extent of plate **11**; Fig. 4b illustrates plate **11** extending radially beyond the radial extent of object **15**. As long as fluid may flow in the direction of arrow **E** both of these embodiments will result, in operation, in a Bernoulli-type holder described above.

Fig. 5 depicts a further embodiment of a holder **50** having two fluid outlet ports **51** and **52** disposed in plate **11**. Fig. 6 is a longitudinal view of the embodiment of Fig. 5 (two outlet ports). It also, for use in conjunction with a robotic end-effector, illustrates plate **11** having an end-effector cutout section **60**. Fig. 7 is a cross-sectional view of a holder embodiment with two fluid outlet ports **71** and **72** and a centrally disposed fluid inlet port **70** disposed in plate **11** to provide more air into the gap. Air flow into port **70** occurs by the same mechanism as other air flow entry (via flow in direction of arrow **E**) replacing air that has been urged out of the gap by pump **14**. Pump **14** is not directly forcing fluid toward object **15**, unlike prior art system. Fig. 8 is a cross-sectional view of yet another holder embodiment having a single fluid outlet port **81**, a fluid inlet port **82**, and an in-line air filter **80** to help insure the cleanest of air within gap **110**. Plate **811** is shown as having an optional shoulder **812** that may afford, if necessary, proper balancing of flow within gap **110** to provide appropriate holding force across object **15**.

Although support pins **18** are shown as separate pins placed into holes provided by plate **11**, such support pins **18** may also be integrally or otherwise formed as part of plate **11**.

Fig. 12 shows another embodiment of a holder in accordance with the present invention in which the plate **11** is provided with a manifold. In this embodiment, the plate **11** is provided with a manifold **121** in communication with outlet port **12** and a plurality of inlet ports, here identified as inlet port **122** and **123**. In this embodiment, support pins **121** are disposed in holes that run through the entire thickness of plate **11** and rest on a table **124**, to which the plate **11** is bolted. The benefit of using support pins that rest on the table is that the table is made exceptionally flat, and the support pins can be made of a uniform length, so that they project a uniform amount above the plate **11**, when the plate **11** is of uniform thickness; in this fashion a uniform gap **110** may be created between the upper surface **19** of the plate **11** and the lower surface **16** of the object **15**.

Fig. 9 is a view of an end effector **91** in accordance with an embodiment of the present invention shown holding a semiconductor wafer **15**. Fig. 10 is a view providing further detail of the end effector of Fig. 9, and Fig. 11 is a view providing detail of the lifter **95** of Figs. 9 and 10. As shown in these figures, the end effector **91** has a body that includes a base **92** and a wand **93** extending therefrom. The body may desirably be made of ceramic or other suitable rigid material. The end effector has a plurality of contact regions where it comes in contact with the wafer **15**. At each contact region there is located a wedge-shaped lifter **95**. The lifter may be made of a suitable material, such PTFE (available from E.I. du Pont de Nemours and Company ("Dupont") Wilmington, Delaware, under the trademark TEFLON), polyacetal resin (also available from Dupont, under the trademark DELRIN) or other materials such as perfluoroelastomer (available from DuPont Dow Elastomers L.L.C., Wilmington, DE under the trademark KALREZ) and polyetheretherketone (available from Victrex plc, Thornton Cleveleys, Lancashire, UK, under the trademark PEEK). Each lifter **95** is disposed so that a region of the periphery of the wafer **15** lies on the lifter. The wedge of each lifter **95** is thickest in a direction outward from the periphery. In other words, the thickest part **111** of the wedge of the lifter lies outside the periphery of the wafer **15**. With this configuration of the end effector, gravitational force is used to retain the wafer on the end effector, and the wedge-shaped lifters keep the wafer in a well where the gravitational potential is at a local minimum. In particular, the materials we have identified above are somewhat softer than the wafer they support, and frictional forces between the wafer and the lifter (which are present in part due to gravity) help to retain the wafer in position relative to the body of the end effector. While we have illustrated the use of separate wedge-shaped lifters, a gravitational well for retaining the wafer can be achieved by providing, for example, an end effector body into which the lifters are fully integrated and formed of the same material as the body. Alternatively, the lifters may be partially integrated, so that the wedge shape is achieved by the end effector body, but a different material, such as PTFE, is placed on top at each contact region. Typical dimensions of the lifter when implemented as a separate member are approximately 1 cm wide along a line perpendicular to the radius of the wafer, approximately 1/2 cm along a radial line, and approximately 2 mm at the thicker end of the wedge. The slope of the wedge may be usefully arranged at approximately 15 degrees.

Using an end effector of the type described in connection with Figs. 9-11, a wafer may be moved on and off a chuck configured as a holder in the manner of Fig. 1 while the pump is run continuously to provide a force for retaining the wafer on the holder. The end effector needs no vacuum to retain the wafer while moving it, and the end effector can still place the wafer on the chuck and lift the wafer off the chuck while the pump is running. Alternatively or in addition, the end effector may be provided with means for retaining the wafer that does not depend on gravity. For example, the end effector may be provided with its own-Bernoulli-type retaining arrangement in a manner analogous to that shown in connection with Fig. 1 to provide a retaining force in addition to that of gravity.

Fig. 13 shows an embodiment of a holder having an end effector cutout suitable for use with the end effector of Fig. 9. To facilitate insertion and removal of the end effector **91**, the end effector cutout **134** here straddles an entire diameter of the plate **11**. Four support pins **133** are disposed symmetrically around the plate **11** in a manner leaving the cutout **134** unobstructed. As in the case of Fig. 12, a manifold **135** disposed in the plate **11** is in communication with a plurality of inlet ports **132** and a centrally disposed outlet port **12**. Each inlet port **132** is disposed proximate to a support pin **133**.

Although the invention has been described with reference to several embodiments, it will be understood by one of ordinary skill in the art that various modifications can be made without departing from the spirit and the scope of the invention as defined by the following claims.

What is claimed is:

1. A method for holding an object, the object having a first object surface, the method comprising:

providing a holder, the holder including a plate with a first plate surface having a plurality of support pins protruding therefrom, the plate also having a fluid outlet port in communication with the first plate surface, and wherein a vacuum source is coupled to the fluid outlet port;

resting the first object surface on the support pins so as to define a gap between the first plate surface and the first object surface, so that the fluid outlet port provides fluid communication between the gap and the vacuum source; and

using the vacuum source to move fluid through the gap so as to establish a retentive force on the object.

2. A method according to claim 1, wherein the fluid is a gas.

3. A method according to claim 2, wherein the fluid is air.

4. A method according to claim 1, wherein the object is a semiconductor wafer having a diameter that measures approximately 200 mm and wherein the support pins project above the first plate surface by an amount measuring between approximately 0.1 mm and approximately 3 mm.

5. A method according to claim 4, wherein the support pins project above the first plate surface by a amount measuring between approximately 0.3 mm and approximately 0.7 mm.

6. A method according to claim 5, wherein the support pins project above the first plate surface by a amount measuring approximately 0.5 mm.

7. A method according to claim 1, wherein the support pins contain a material harder than the object.

8. A method according to claim 7, wherein the material is quartz.

9. A method according to claim 1, wherein the support pins contain a material softer than the object.

10. A method according to claim 9, wherein the material is polyetheretherketone.

11. A method according to claim 7, wherein the support pins contain an electrically conductive material.

12. A method according to claim 1, wherein the plate has at least one additional fluid

outlet port providing fluid communication between the gap and the vacuum source.

13. A method according to claim 1, wherein the plate has a fluid port providing fluid communication between a volume exterior to the holder and the gap.

14. A method according to claim 1, wherein: (i) a manifold is disposed in the plate and the manifold is in communication with the outlet port; (ii) the plate has a plurality of inlet ports in communication with the manifold and having openings on the first plate surface.

15. A method according to claim 14, wherein each inlet port is disposed proximate to a support pin.

16. A method according to claim 15, wherein the plurality of inlet ports is the same as the plurality of support pins.

17. A method according to claim 1, further comprising:

adjusting the flow of fluid through the gap to provide a desired amount of retentive force on the object.

18. A holder for holding an object, in combination with the object, the object having a first object surface, the holder comprising:

a plate having a first plate surface, the first plate surface having a plurality of support pins protruding therefrom so that when the first object surface is rested on the support pins there is defined a gap between the first plate surface and the first object surface;

a fluid outlet port, in fluid communication with the first plate surface, for being coupled to a vacuum source, so that, when the first object surface is rested on the support pins, the fluid outlet port provides fluid communication between the gap and the vacuum source, the vacuum source moving fluid through the gap so as to establish a retentive force on the object.

19. A holder according to claim 18, wherein the fluid is a gas.

20. A holder according to claim 19, wherein the fluid is air.

21. A holder according to claim 18, wherein the object is a semiconductor wafer having a diameter that measures approximately 200 mm and wherein the support pins project above the first plate surface by an amount measuring between approximately 0.1 mm and approximately 3 mm.

22. A holder according to claim 21, wherein the support pins project above the first

plate surface by an amount measuring between approximately 0.3 mm and approximately 0.7 mm.

23. A holder according to claim 22, wherein the support pins project above the first plate surface by an amount measuring approximately 0.5 mm.

24. A holder according to claim 18, wherein the support pins contain quartz.

25. A holder according to claim 18, wherein the support pins contain polyetheretherketone.

26. A holder according to claim 18, wherein the support pins contain an electrically conductive material.

27. A holder according to claim 18, wherein the plate has at least one additional fluid outlet port providing fluid communication between the gap and the vacuum source.

28. A holder according to claim 18, wherein the plate has a fluid port providing fluid communication between a volume exterior to the holder and the gap.

29. A holder according to claim 28, further comprising a filter located between the volume and the gap.

30. A holder according to claim 18, further comprising:

a flow valve disposed between the vacuum source and the outlet port to permit adjustment of flow of fluid through the gap and therefore of the retentive force on the object.

31. A holder according to claim 18, wherein: (i) a manifold is disposed in the plate and the manifold is in communication with the outlet port; (ii) the plate has a plurality of inlet ports in communication with the manifold and having openings on the first plate surface.

32. A holder according to claim 31, wherein each inlet port is disposed proximate to a support pin.

33. A holder according to claim 32, wherein the plurality of inlet ports is the same as the plurality of support pins.

34. A method of handling a semiconductor wafer, the method comprising:

placing an end effector beneath the wafer, the end effector having a retaining means for retaining the wafer;

using the end effector to move the wafer and to cause the wafer to rest on a holder;

using air flow toward an actuatable vacuum source to provide a force that retains the wafer against the holder;

removing the end effector from beneath the wafer; and

performing all of the foregoing processes while maintaining the vacuum source continuously in an actuated state so that the air flow is continuous and without changing the state of the retaining means.

35. A method according to claim 34, wherein the wafer has a lower surface and the retaining means includes a plurality of contact regions mounted on the end effector and in contact with the lower surface of the wafer, for retaining the wafer thereon using gravitational force.

36. A method according to claim 35, wherein the wafer has a periphery and at each contact region the end effector includes a wedge-shaped lifter, the lifter being disposed so that a region of the periphery lies on the lifter, the wedge being thickest in a direction outward from the periphery.

37. A method according to claim 34, wherein:

the wafer has a lower surface; and

the holder includes a plate with a first plate surface having a plurality of support pins protruding therefrom and in contact with the lower surface of the wafer, the plate also having a fluid outlet port in communication with the first plate surface, and wherein the vacuum source is coupled to the fluid outlet port,

so that a gap is defined between the first plate surface and the lower surface of the wafer and air flow in the gap between the first plate surface and the lower surface of the wafer provides a force that retains the wafer against the holder.

38. A method according to claim 35, wherein:

the wafer has a lower surface; and

the holder includes a plate with a first plate surface having a plurality of support pins protruding therefrom and in contact with the lower surface of the wafer, the plate also having a fluid outlet port in communication with the first plate surface, and wherein the vacuum source is coupled to the fluid outlet port,

so that a gap is defined between the first plate surface and the lower surface of the wafer and air flow in the gap between the first plate surface and the lower surface of the wafer provides a force that retains the wafer against the holder.

39. A method of handling a semiconductor wafer, the wafer having a lower surface, the method comprising:

placing beneath the wafer an end effector, the end effector having plurality of contact regions in contact with the lower surface of the wafer for retaining the wafer thereon using gravitational force;

using the end effector to move the wafer and to cause the wafer to rest on a holder, the holder including a plate with a first plate surface having a plurality of support pins protruding therefrom and in contact with the lower surface of the wafer, so that a gap is defined between the first plate surface and the lower surface of the wafer;

using air flow toward an actuatable vacuum source to maintain fluid flow in the gap between the first plate surface and the lower surface of the wafer to provide a force that retains the wafer against the holder;

removing the end effector from beneath the wafer; and

performing all of the foregoing processes while maintaining the vacuum source continuously in an actuated state so that the air flow is continuous.

40. An end effector for moving a semiconductor wafer, the wafer having a lower surface and a periphery, the end effector comprising:

a base and a wand extending therefrom, the base and the wand collectively having a plurality of contact regions for contacting the lower surface of the wafer, at each contact region there being located a wedge-shaped lifter, the lifter being disposed so that a region of the periphery lies on the lifter, the wedge being thickest in a direction outward from the periphery, so that the wafer is retained thereon using gravitational force.

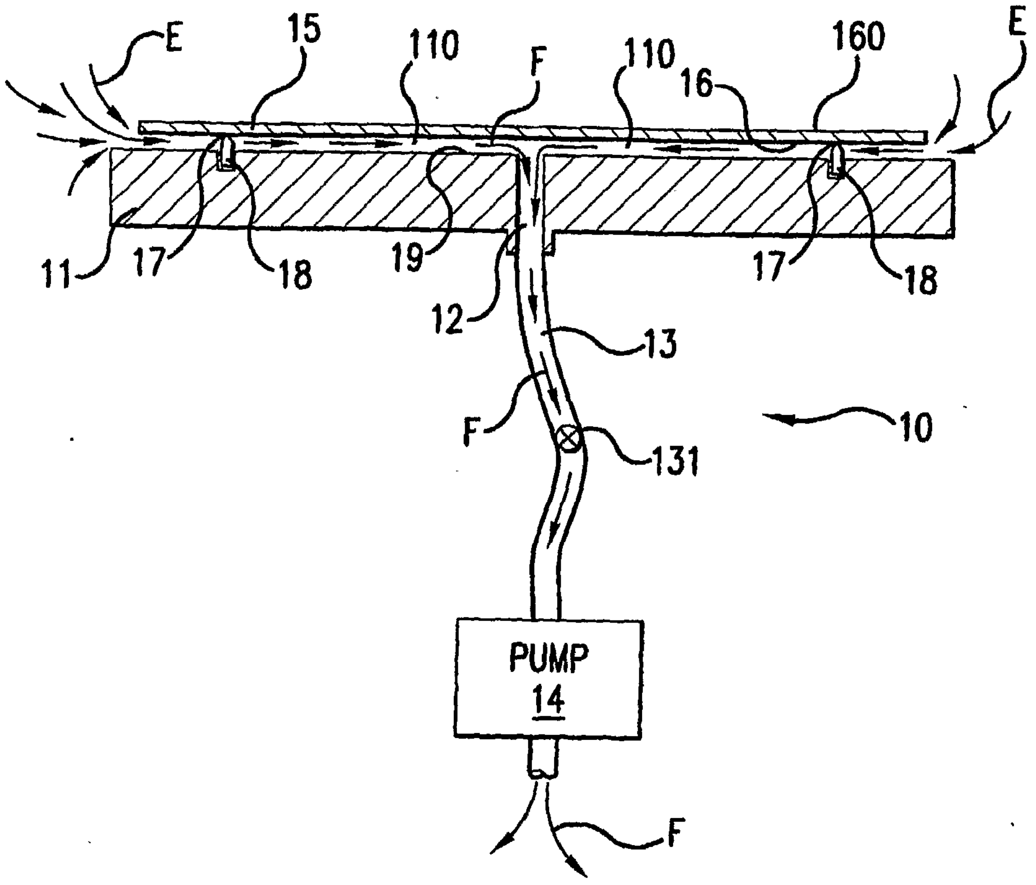


FIG.1

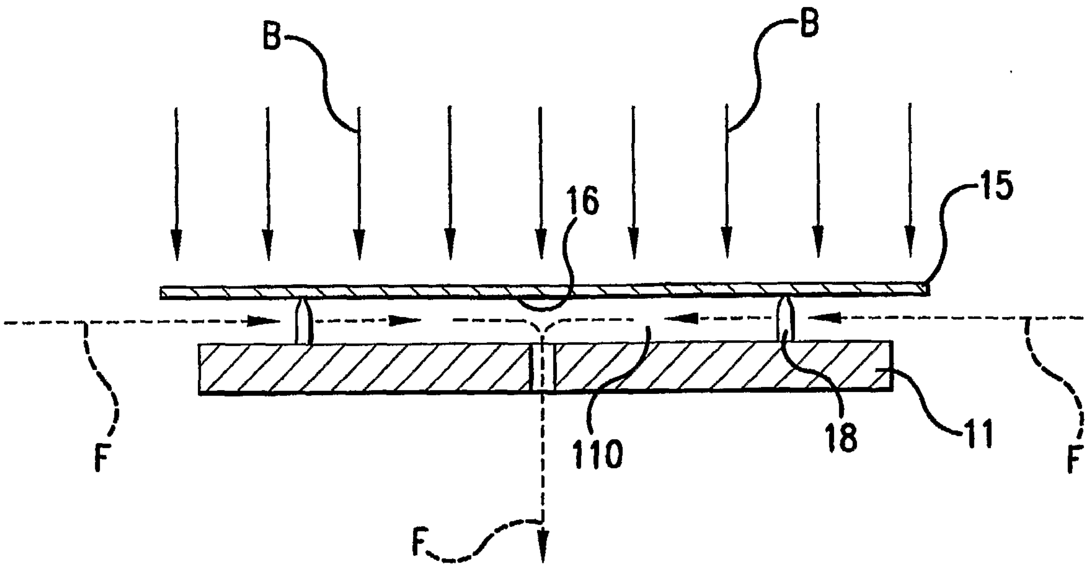


FIG.2

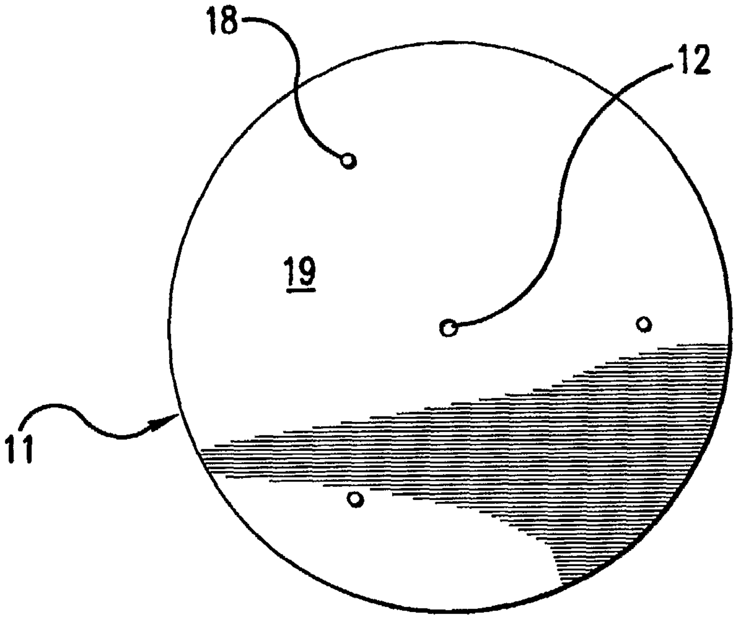


FIG.3

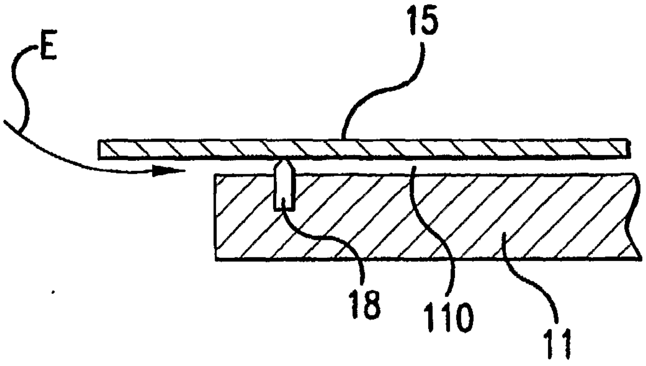


FIG.4a

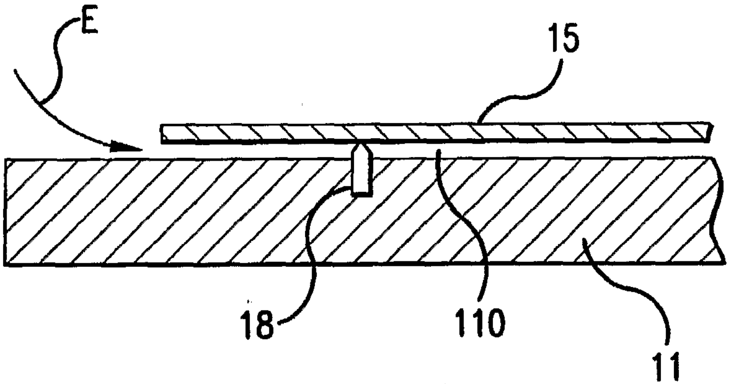


FIG.4b

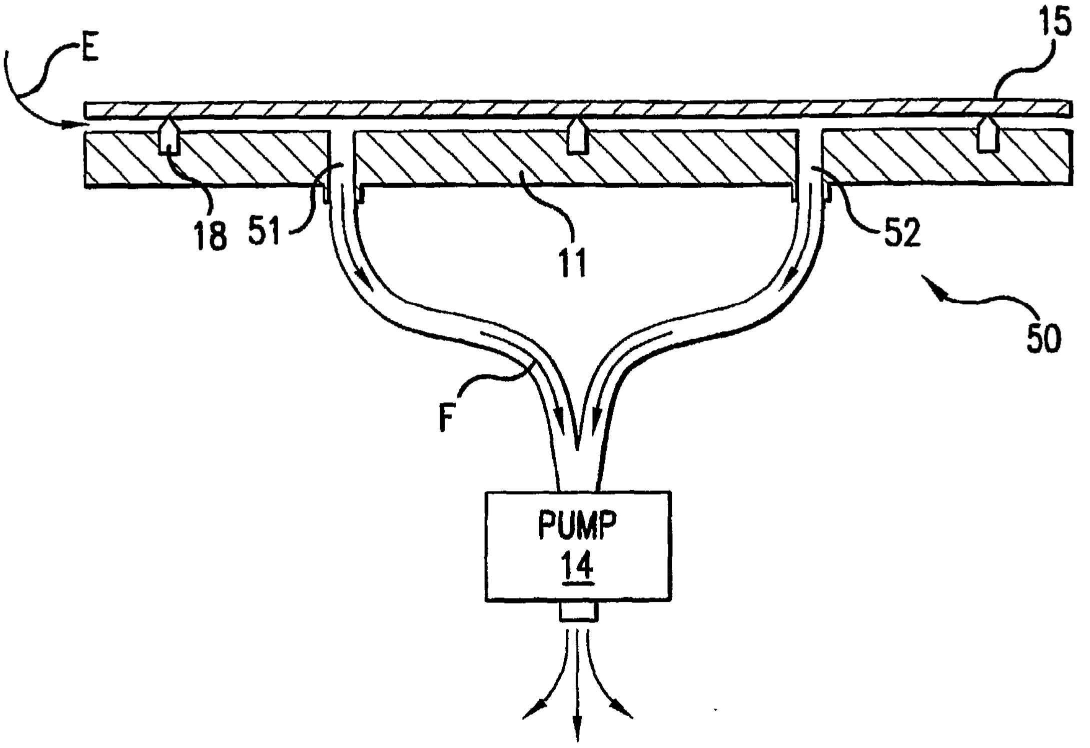


FIG.5

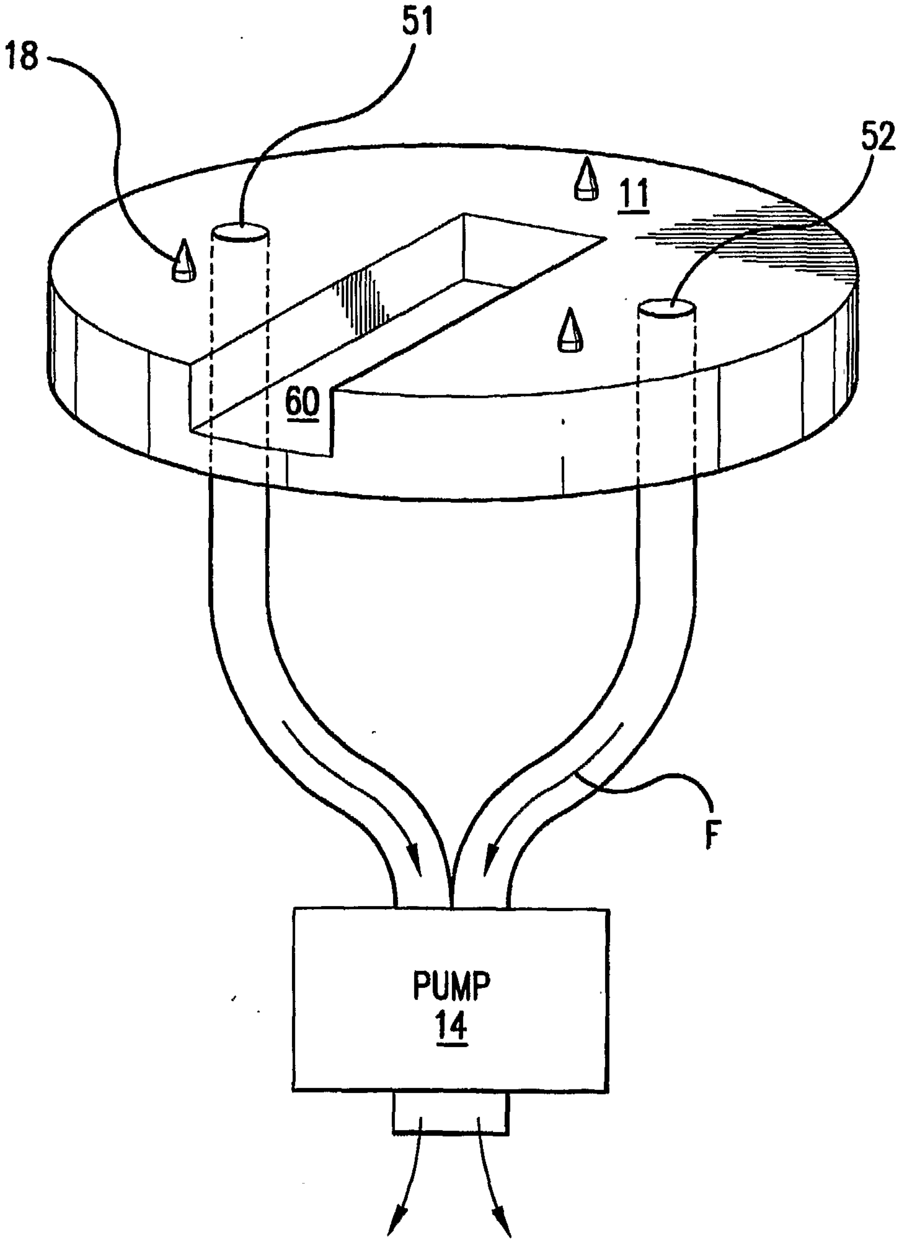


FIG.6

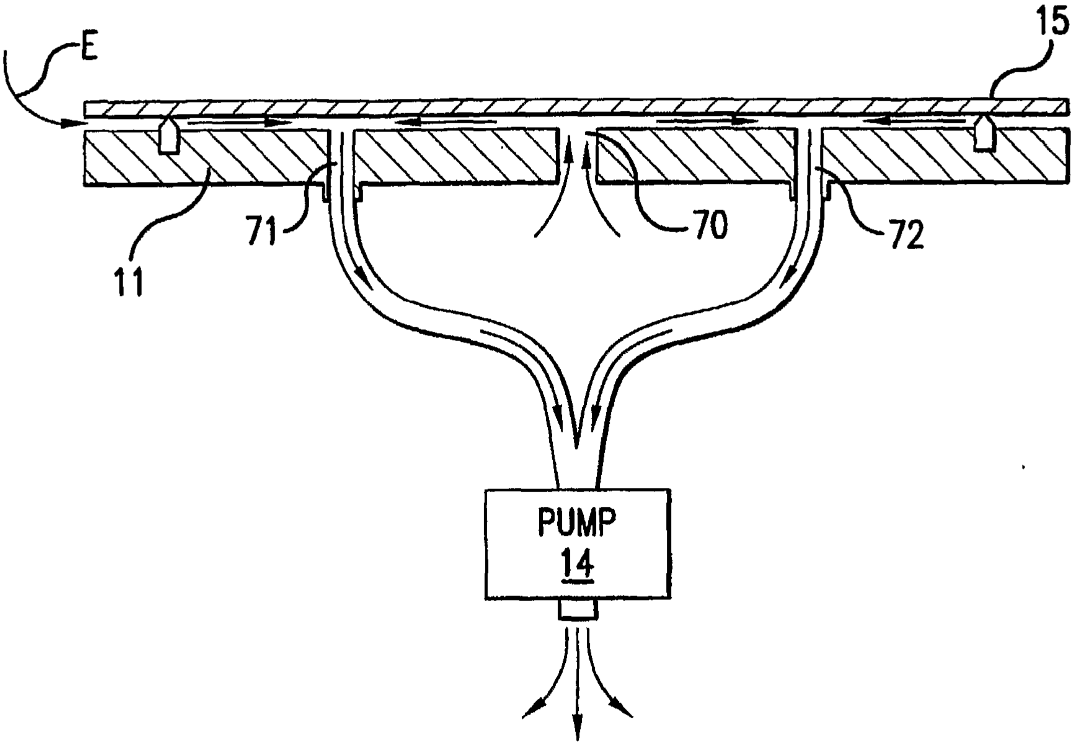


FIG.7

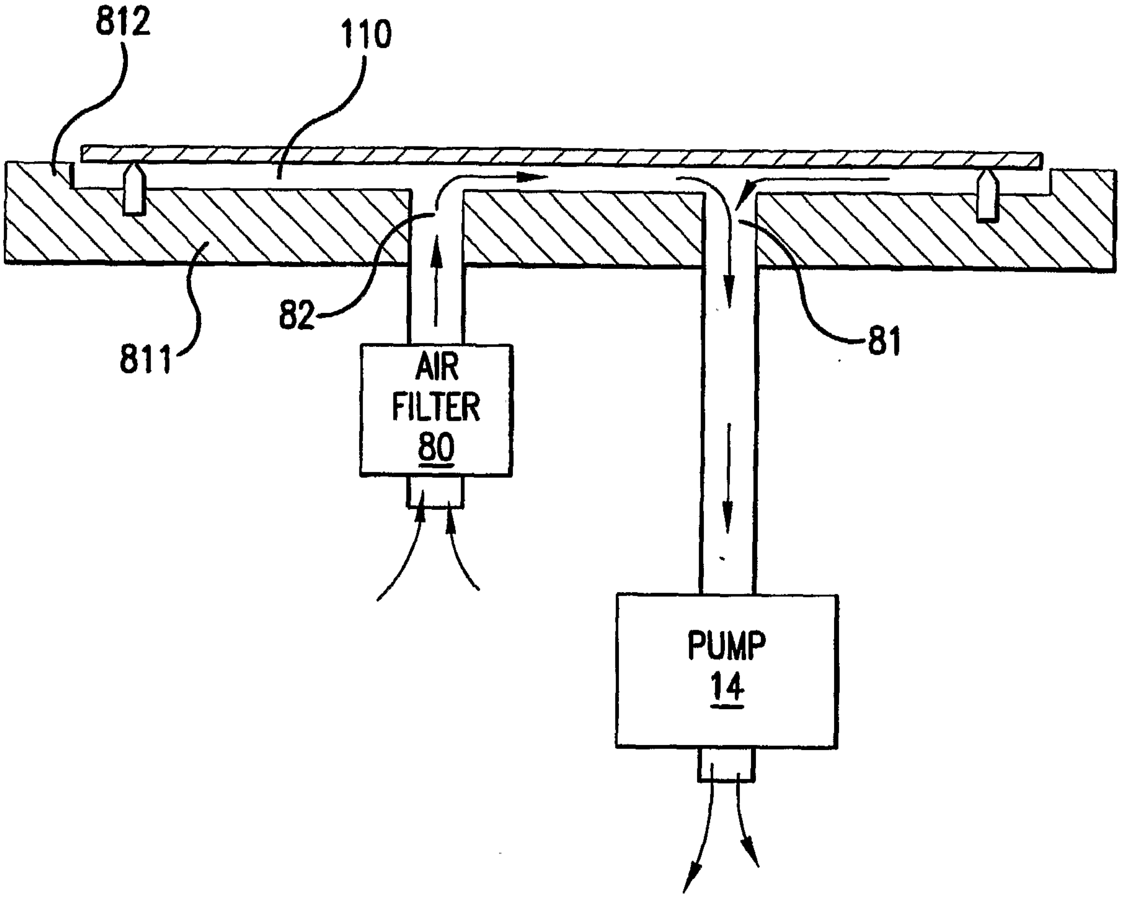


FIG.8

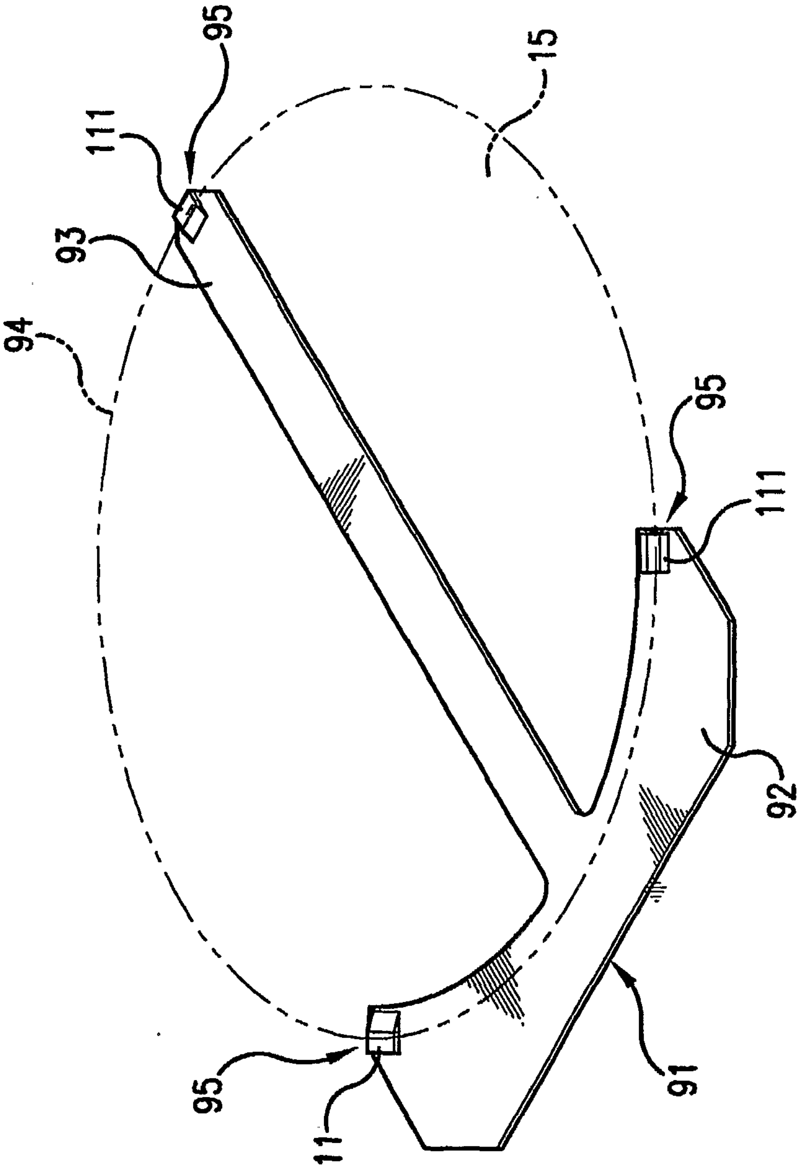


FIG.9

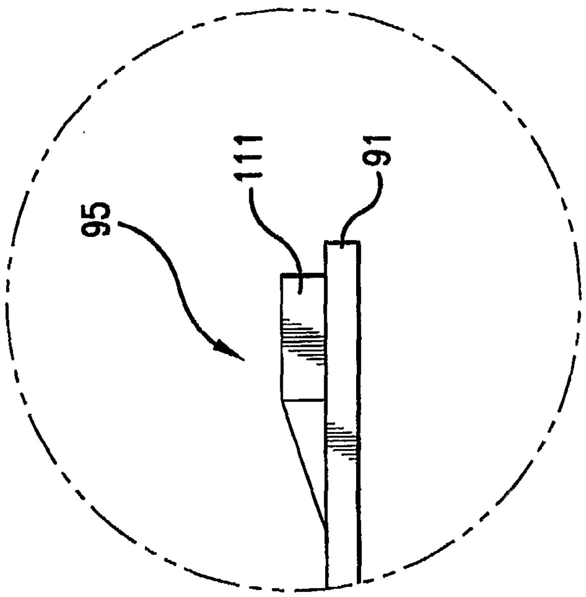


FIG.11

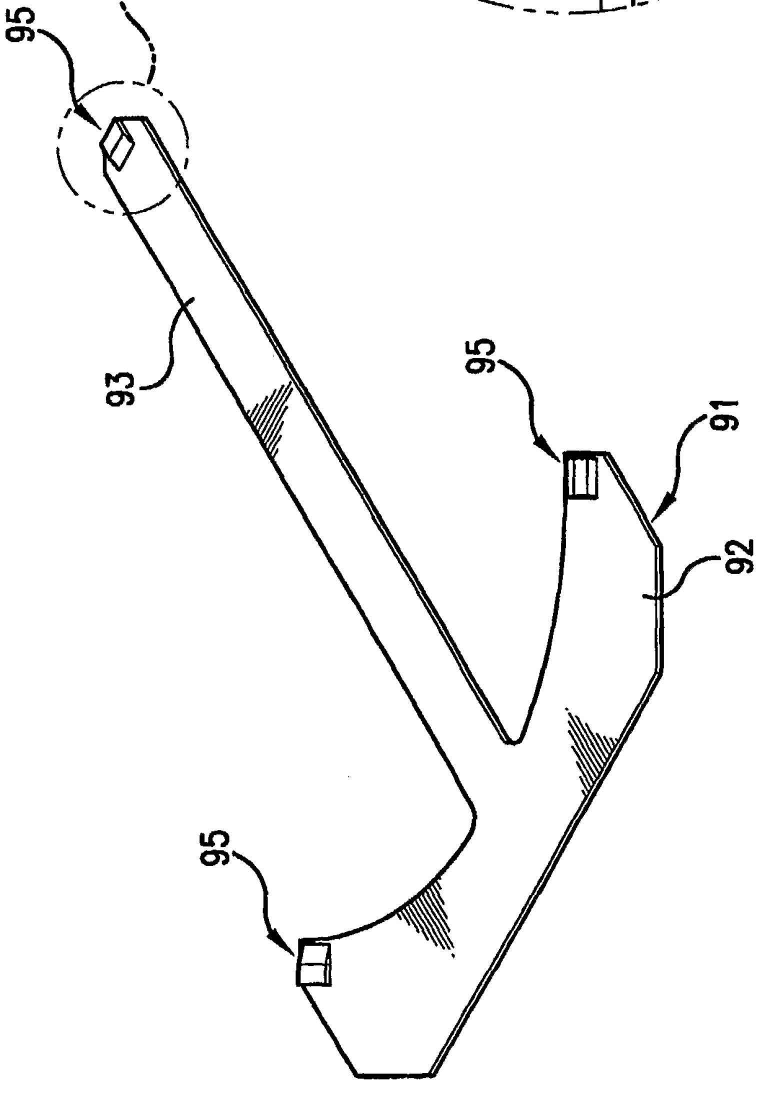


FIG.10

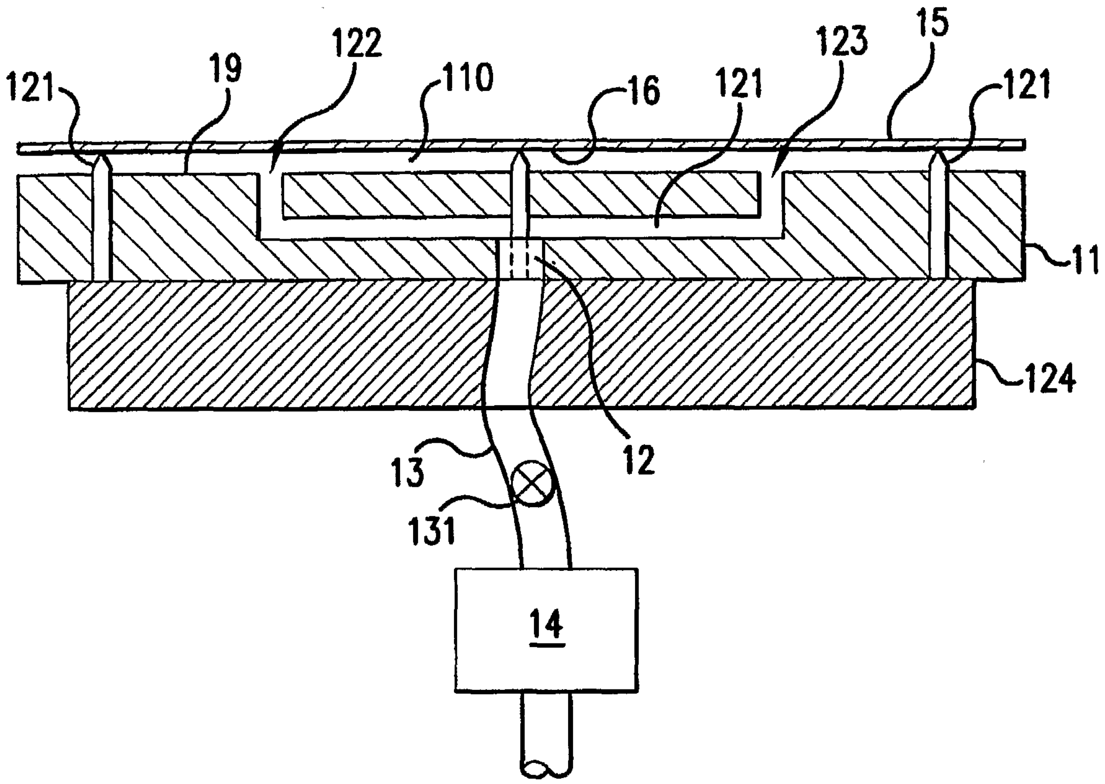


FIG.12

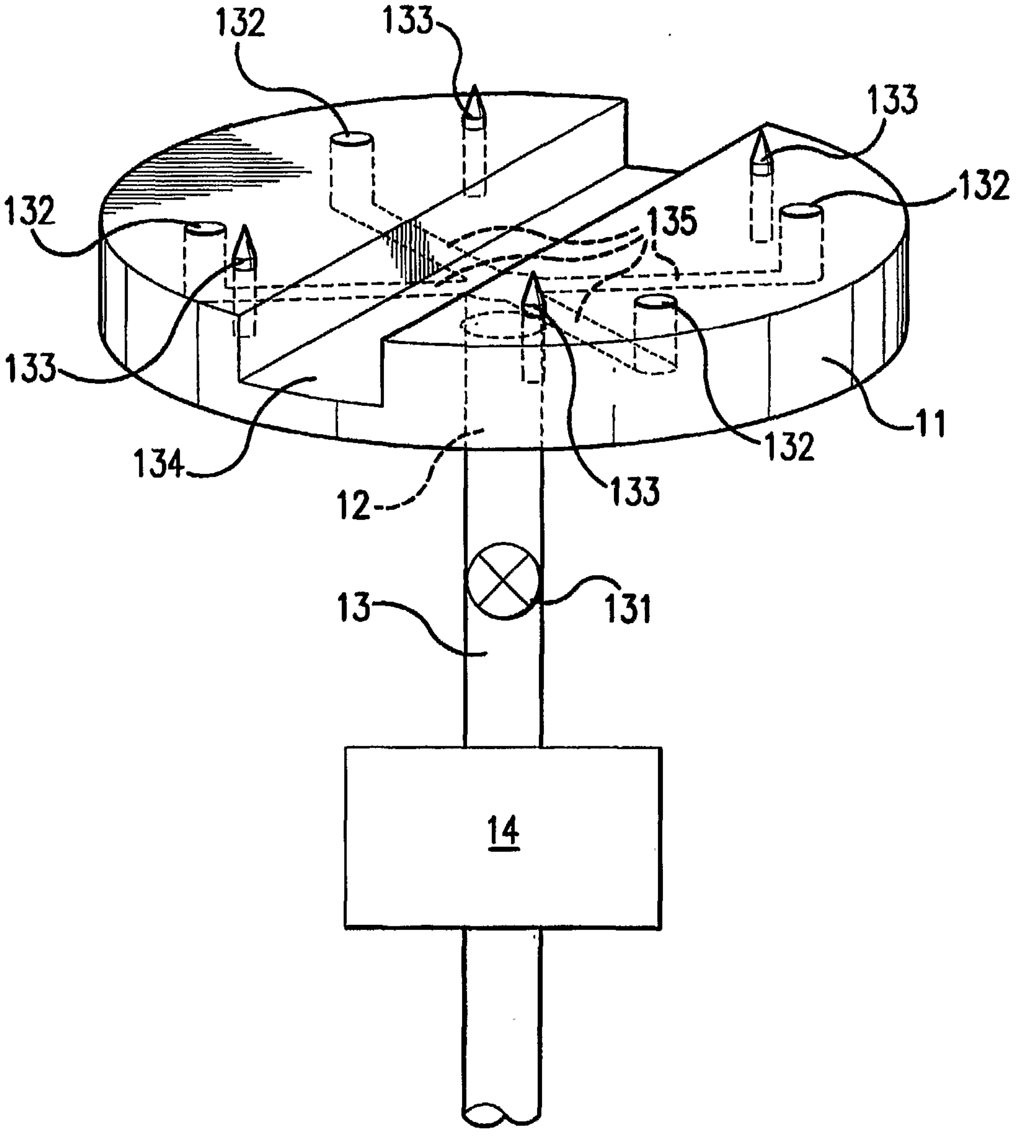


FIG.13