



US 20130040542A1

(19) **United States**
(12) **Patent Application Publication**
Schwappach et al.

(10) **Pub. No.: US 2013/0040542 A1**
(43) **Pub. Date: Feb. 14, 2013**

(54) **ABRASIVE ARTICLE**

61/267,031, filed on Dec. 5, 2009, provisional application No. 61/267,030, filed on Dec. 5, 2009.

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Publication Classification

(21) Appl. No.: **13/492,513**

(51) **Int. Cl.**
B24D 11/02 (2006.01)
B24D 18/00 (2006.01)
B24D 3/00 (2006.01)

(22) Filed: **Jun. 8, 2012**

(52) **U.S. Cl. 451/490; 451/539; 451/532; 451/540; 51/297**

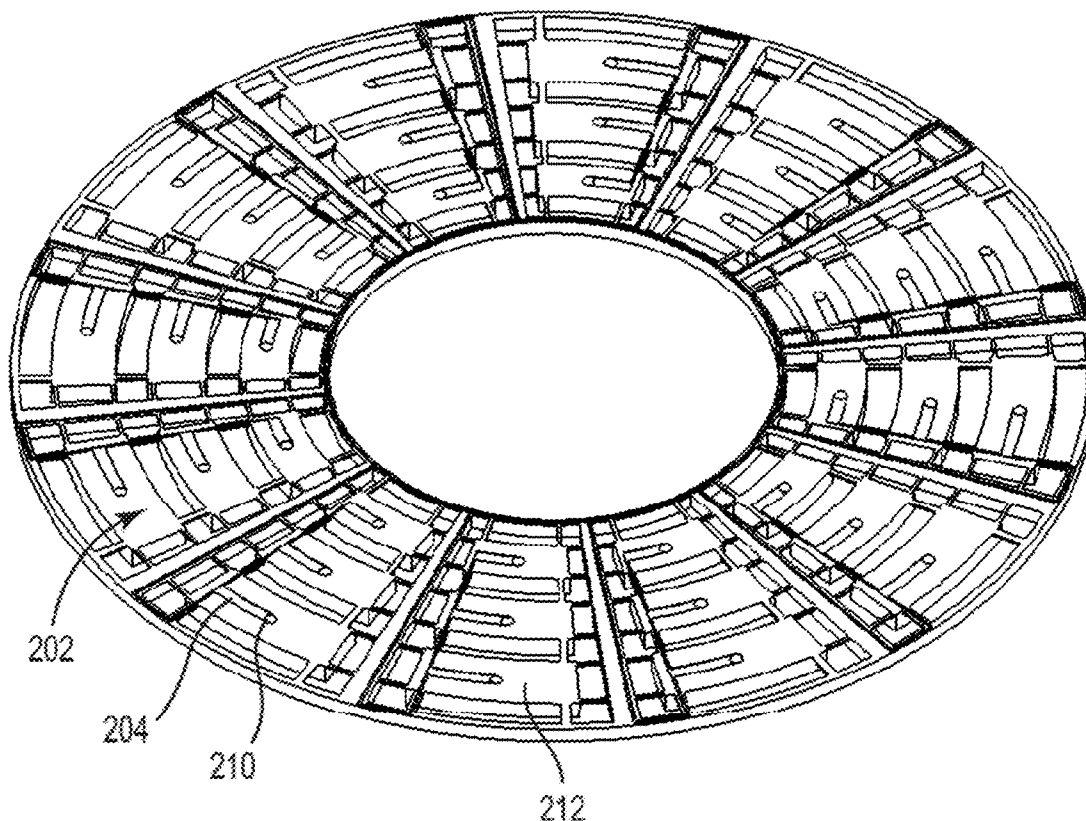
Related U.S. Application Data

(63) Continuation of application No. 12/784,908, filed on May 21, 2010, which is a continuation-in-part of application No. 12/766,473, filed on Apr. 23, 2010.

(57) **ABSTRACT**

(60) Provisional application No. 61/174,472, filed on Apr. 30, 2009, provisional application No. 61/187,658, filed on Jun. 16, 2009, provisional application No. 61/220,149, filed on Jun. 24, 2009, provisional application No. 61/221,554, filed on Jun. 30, 2009, provisional application No. 61/232,425, filed on Aug. 8, 2009, provisional application No. 61/232,525, filed on Aug. 10, 2009, provisional application No. 61/248,194, filed on Oct. 2, 2009, provisional application No.

An abrasive article including a flexible backing having opposing first and second surfaces. The first surface of the flexible backing includes abrasive features. An adhesive layer including load bearing particles and an adhesive matrix is disposed on the second surface of the flexible backing. At least a portion of the load bearing particles is substantially enveloped in the adhesive matrix and is in contact with the second surface of the polymer substrate. A rigid support is preferably attached to the adhesive layer including the load bearing particles. At least a portion of the load bearing particles is preferably in contact with the rigid support.



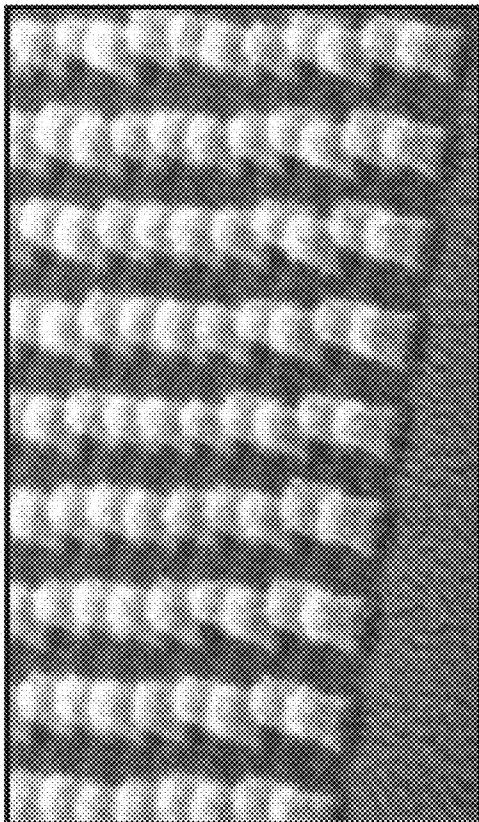


Fig. 2
(PRIOR ART)

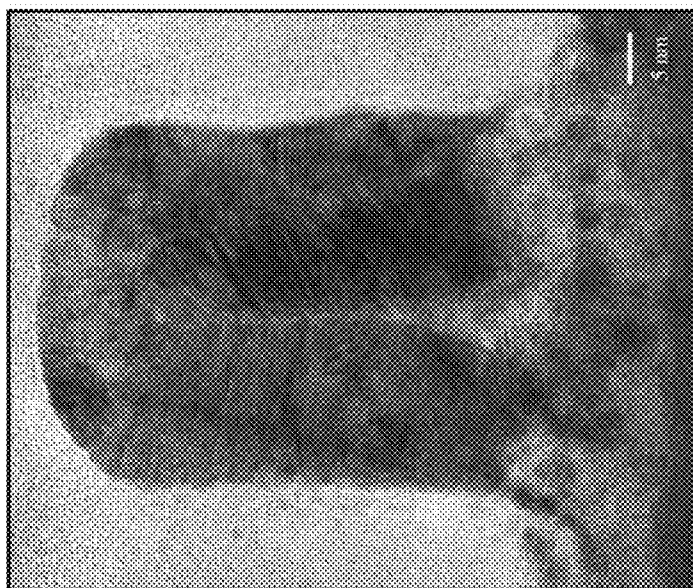
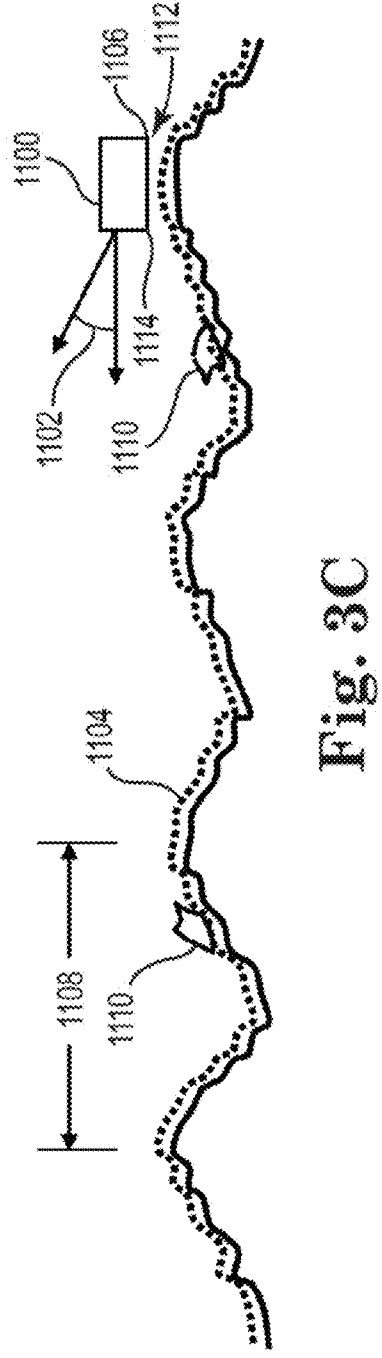
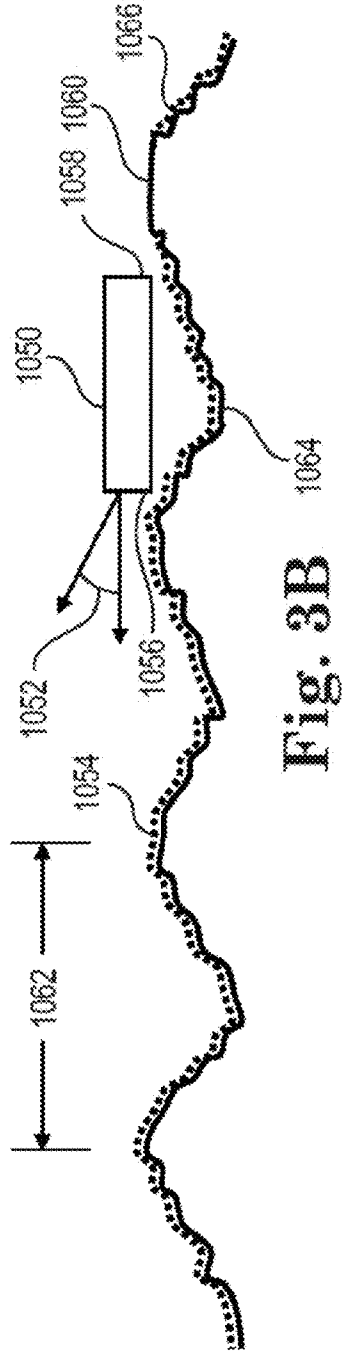
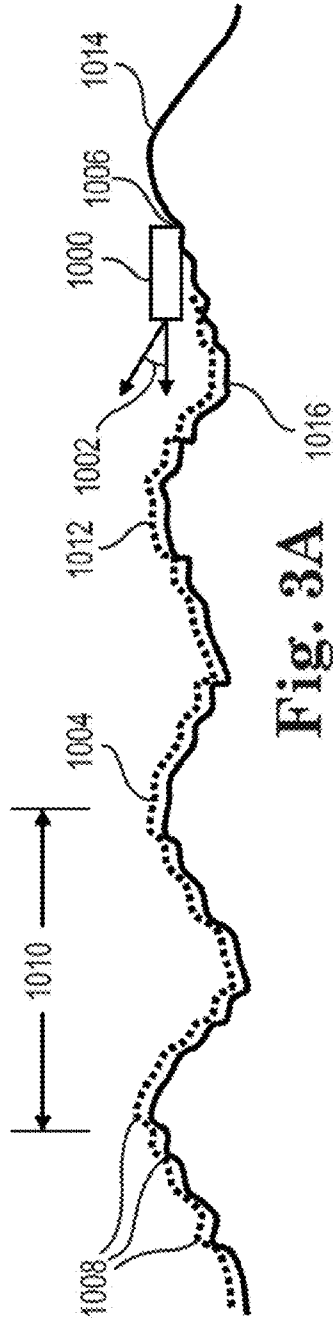


Fig. 1
(PRIOR ART)



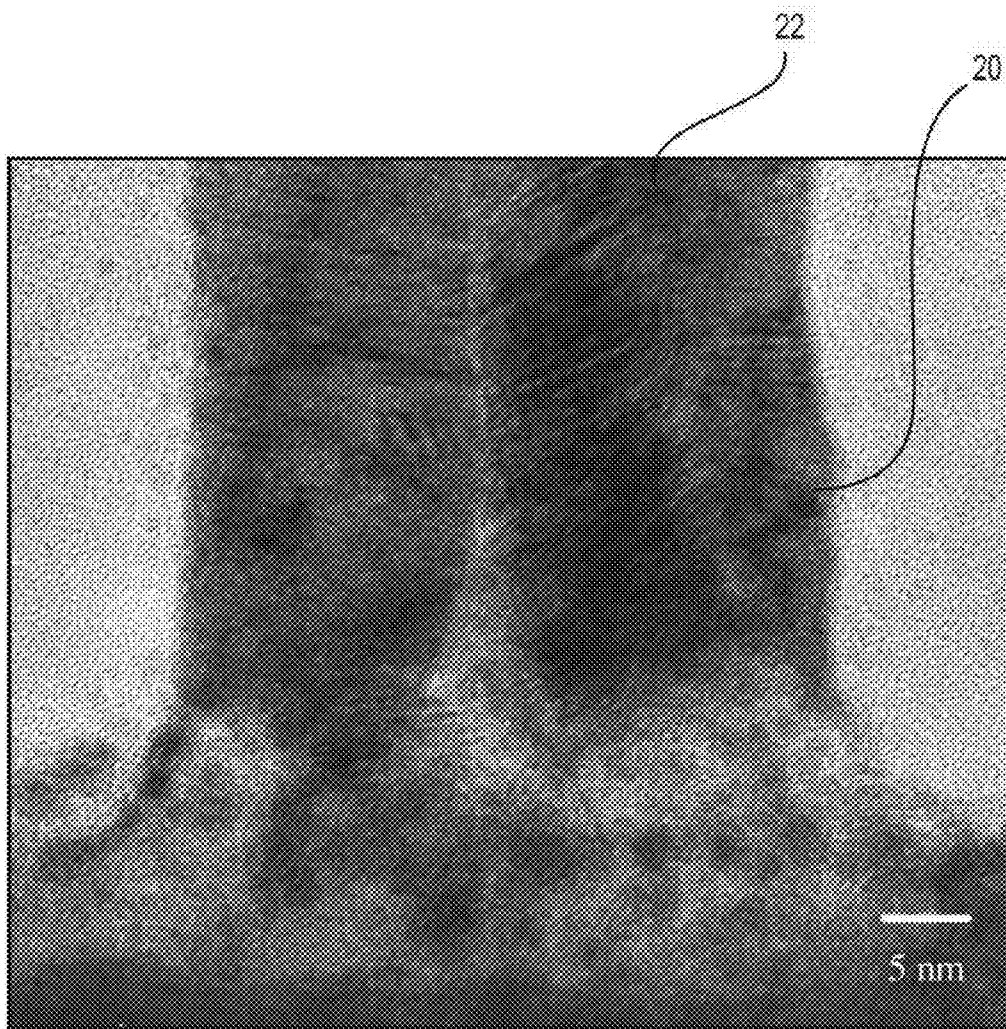


Fig. 4

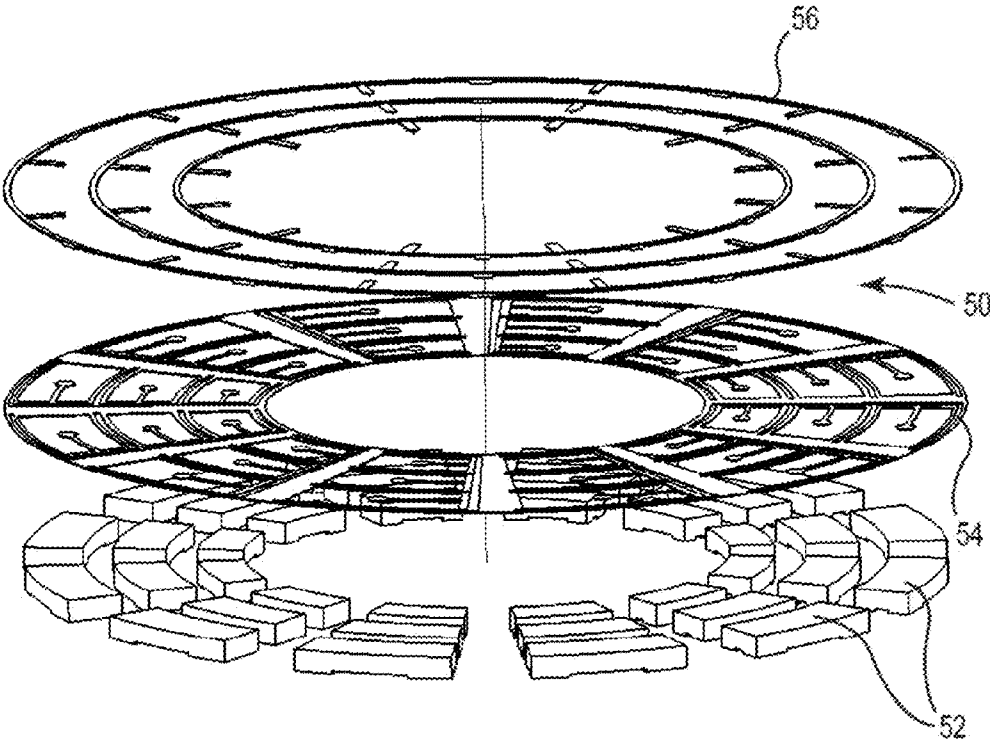


Fig. 5

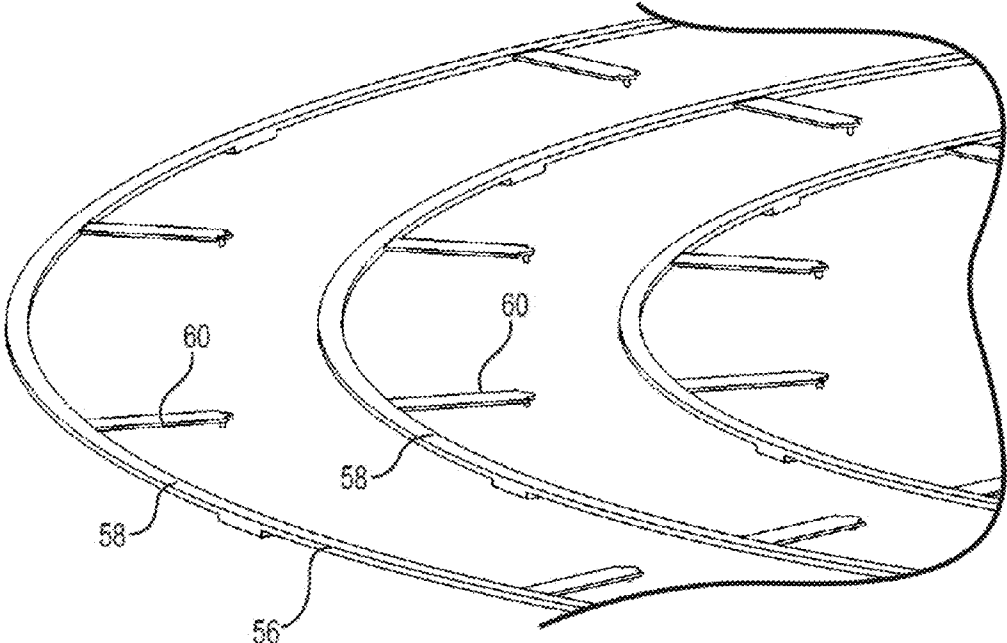


Fig. 6

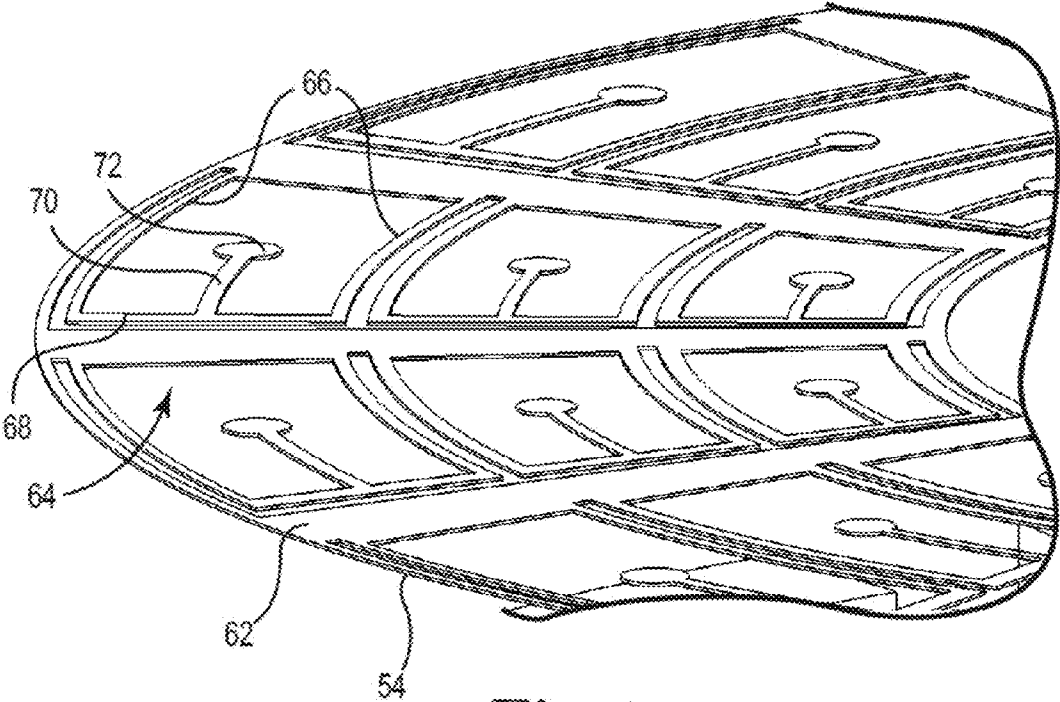


Fig. 7

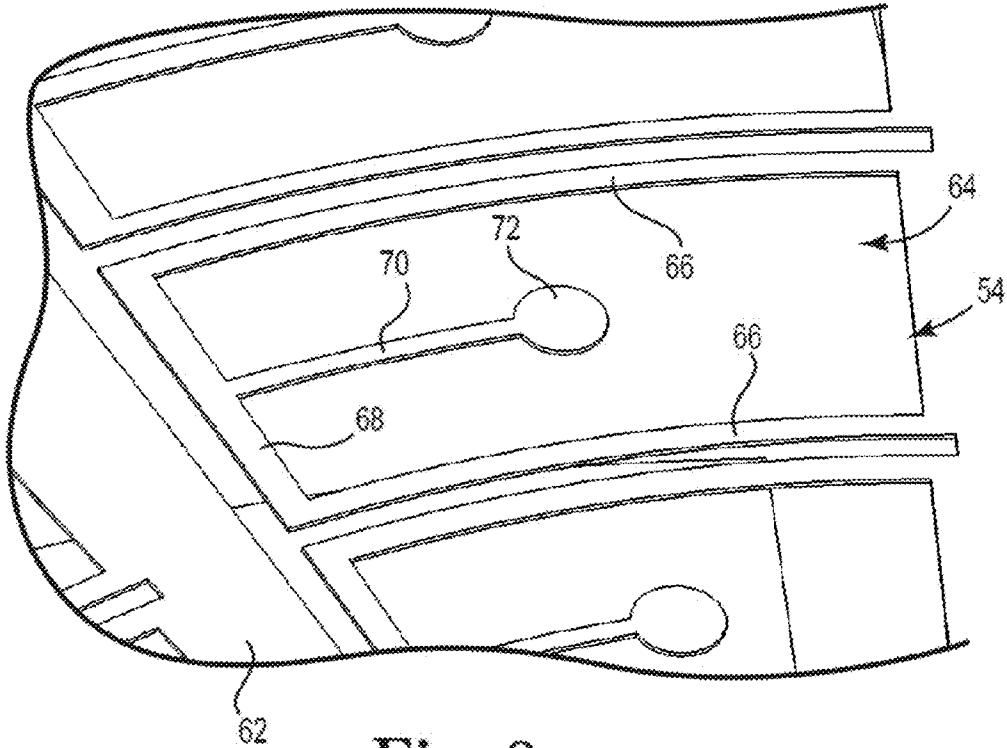


Fig. 8

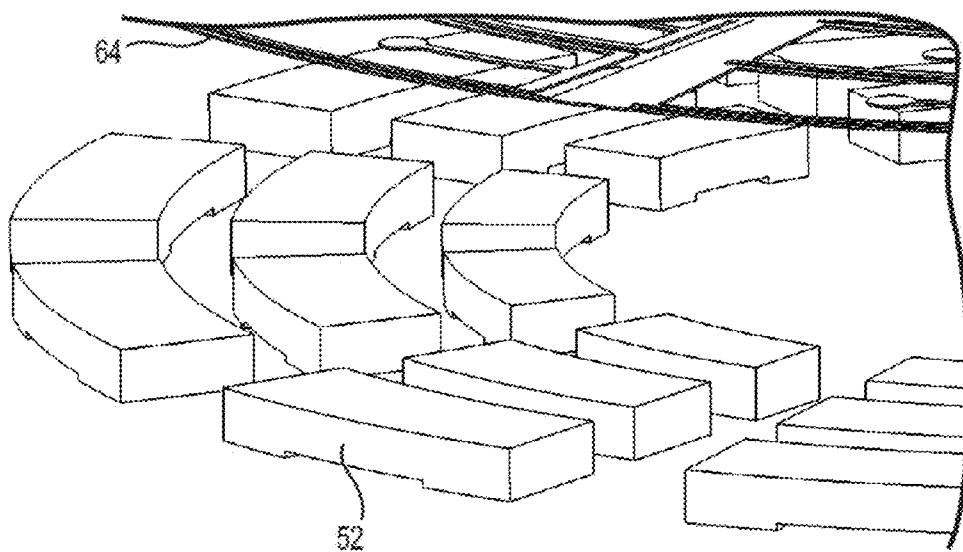


Fig. 9

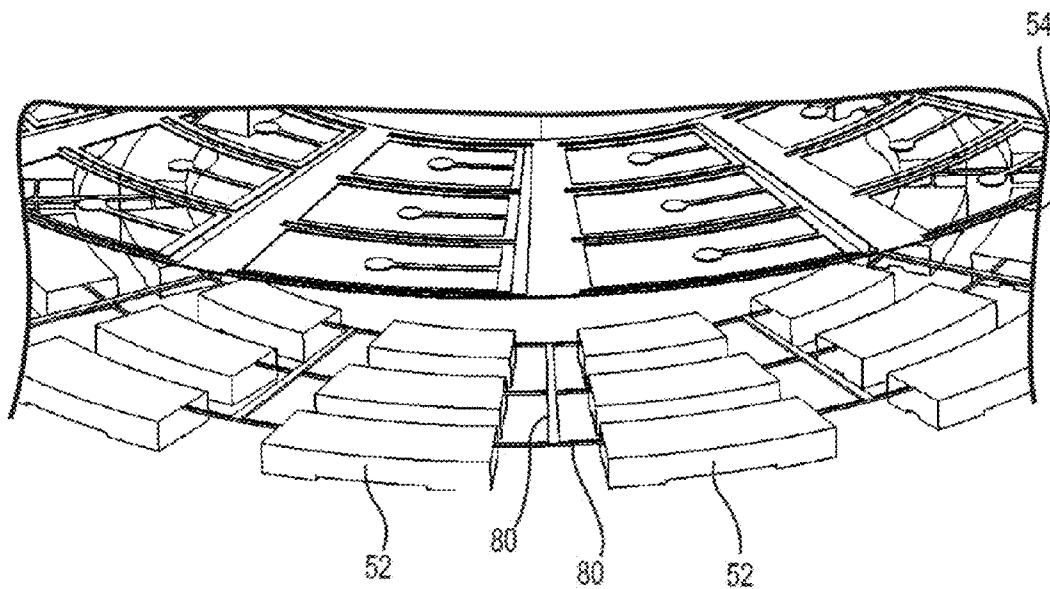


Fig. 10

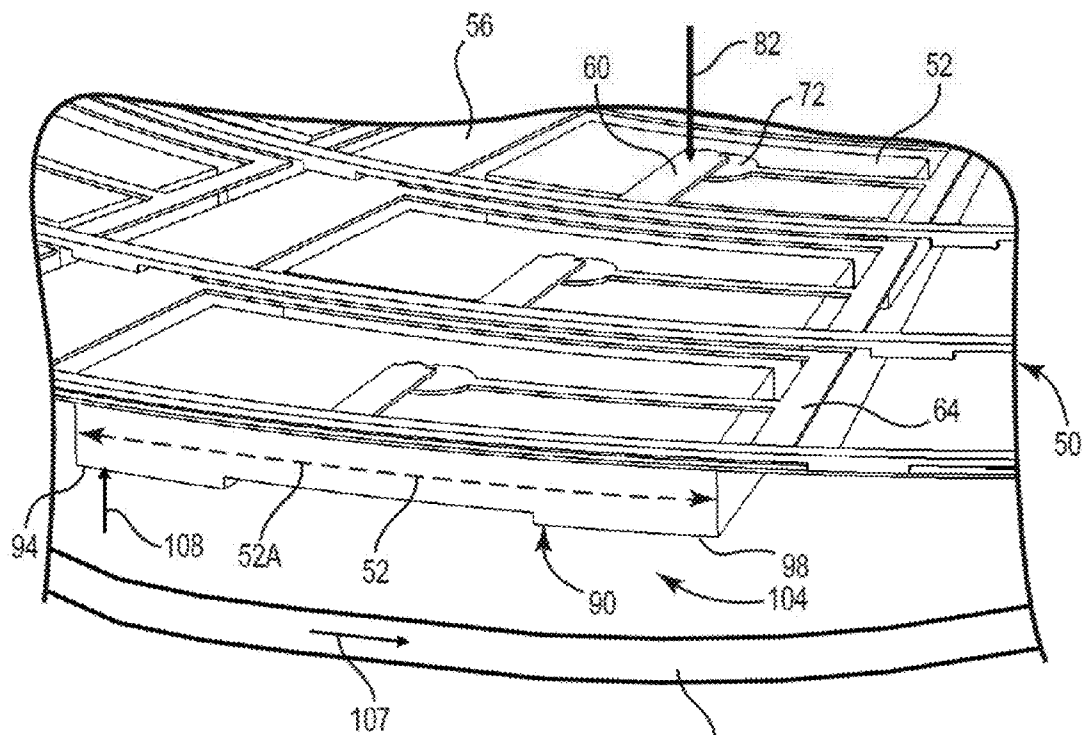


Fig. 11

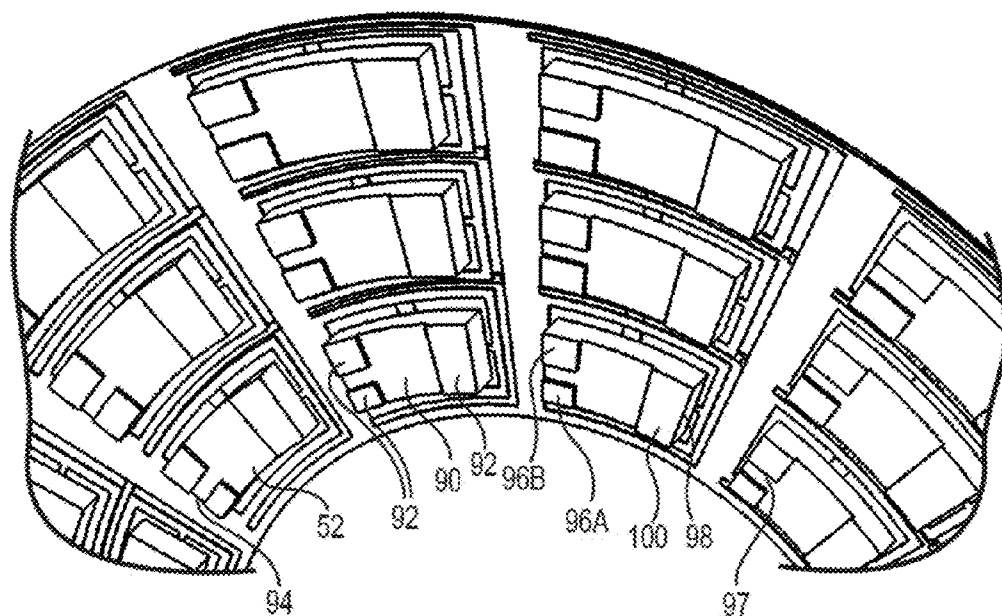


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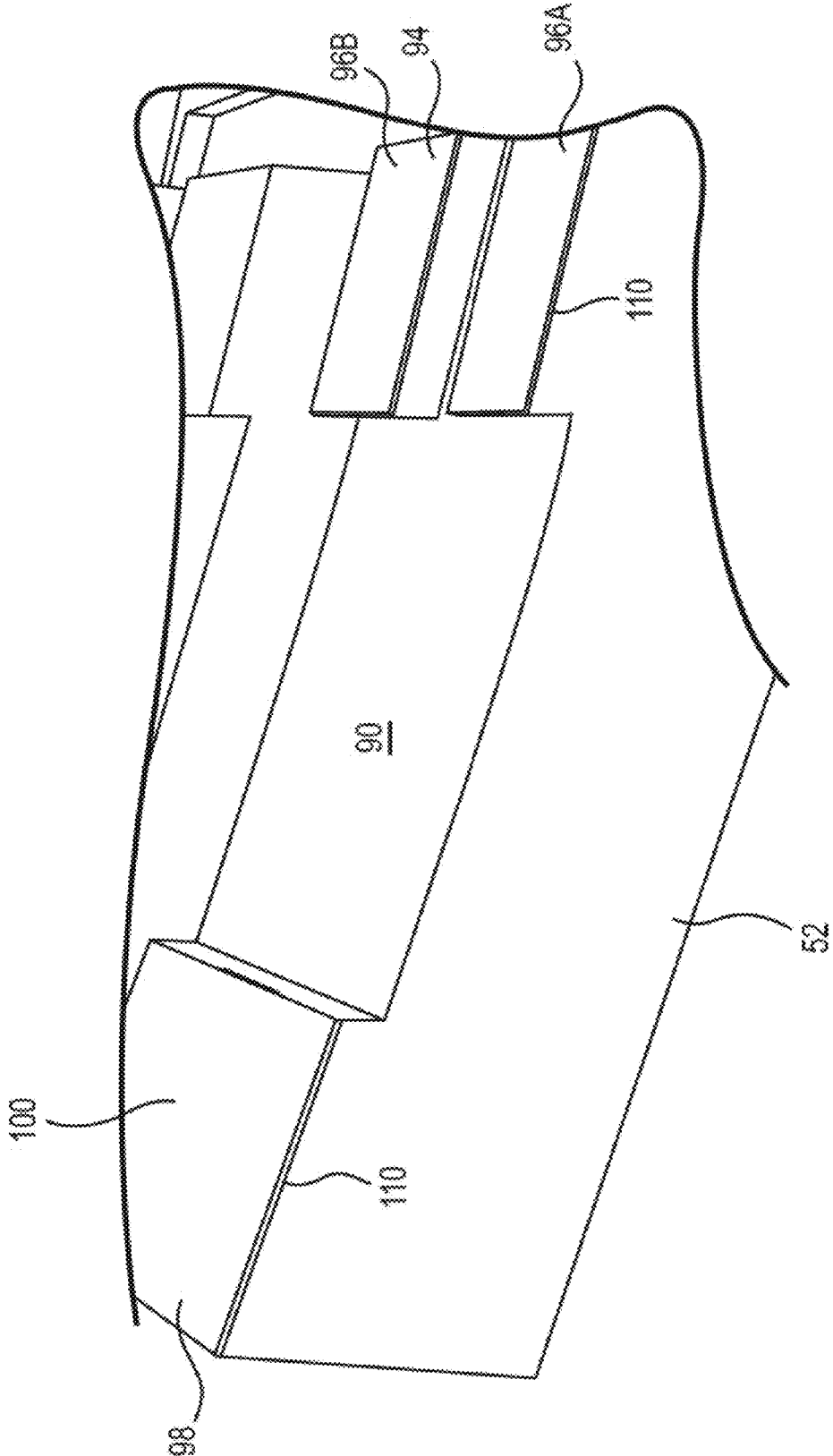


Fig. 13

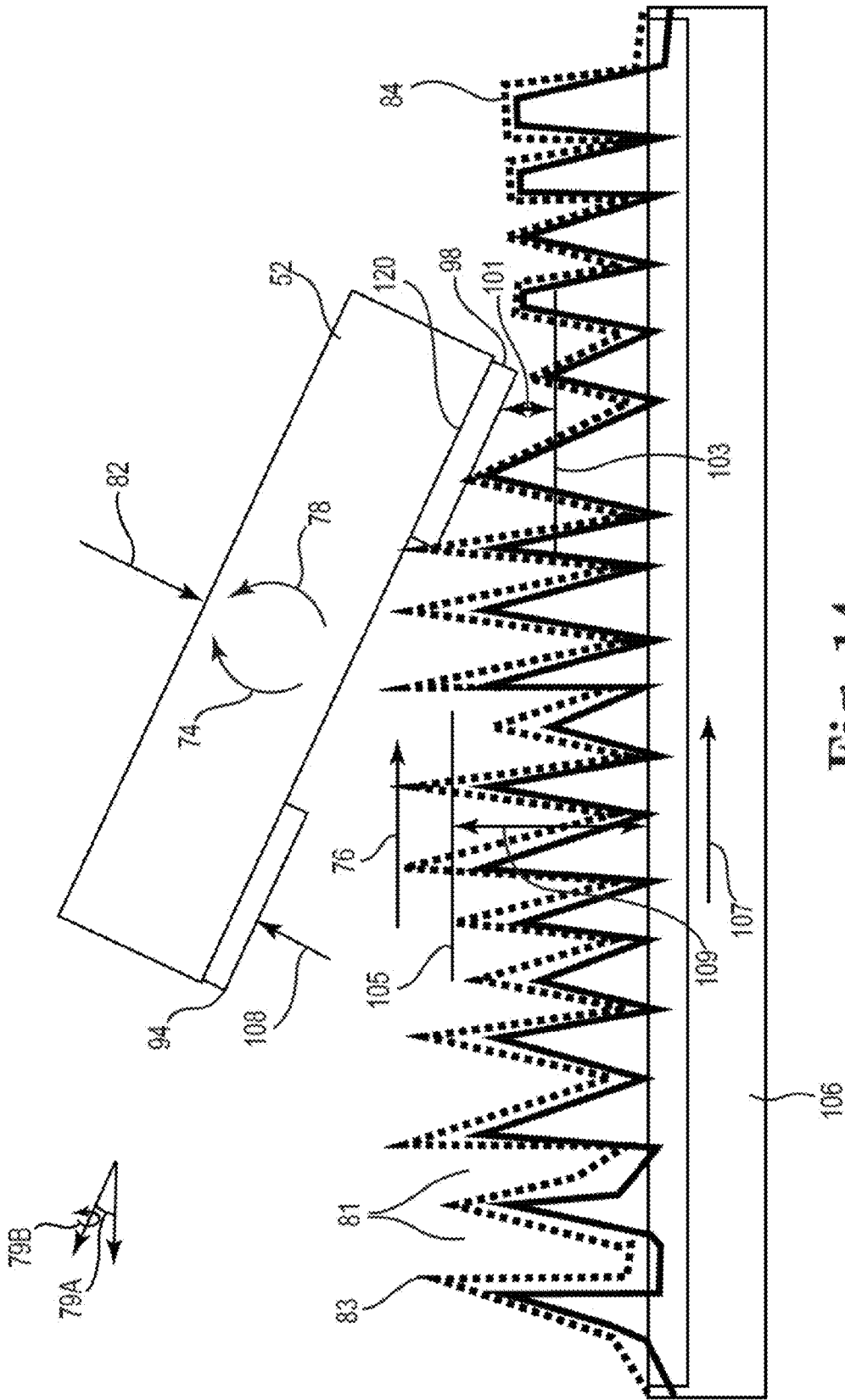


Fig. 14

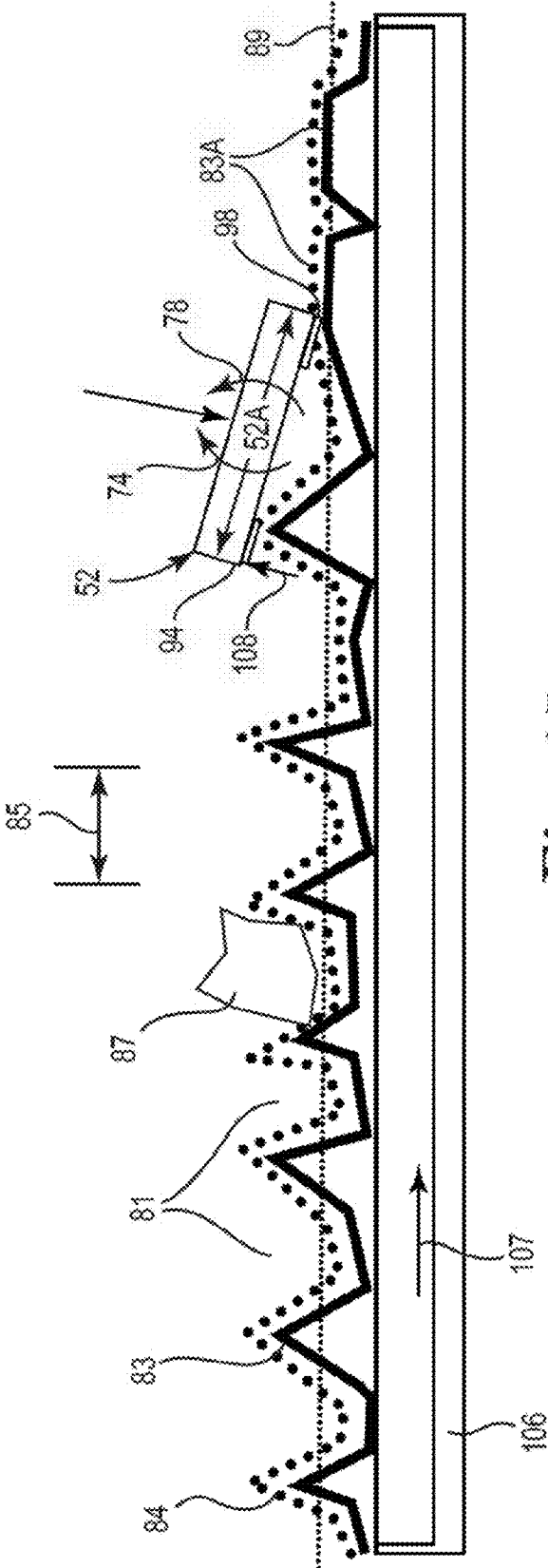


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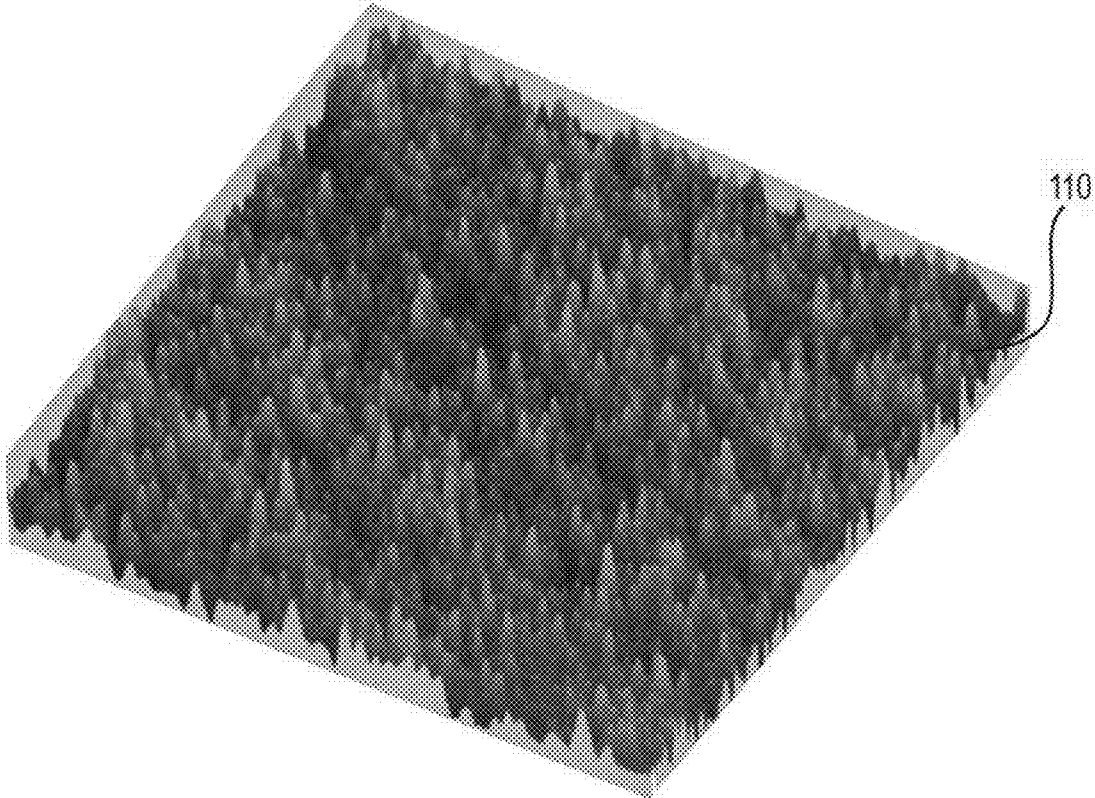


Fig. 16

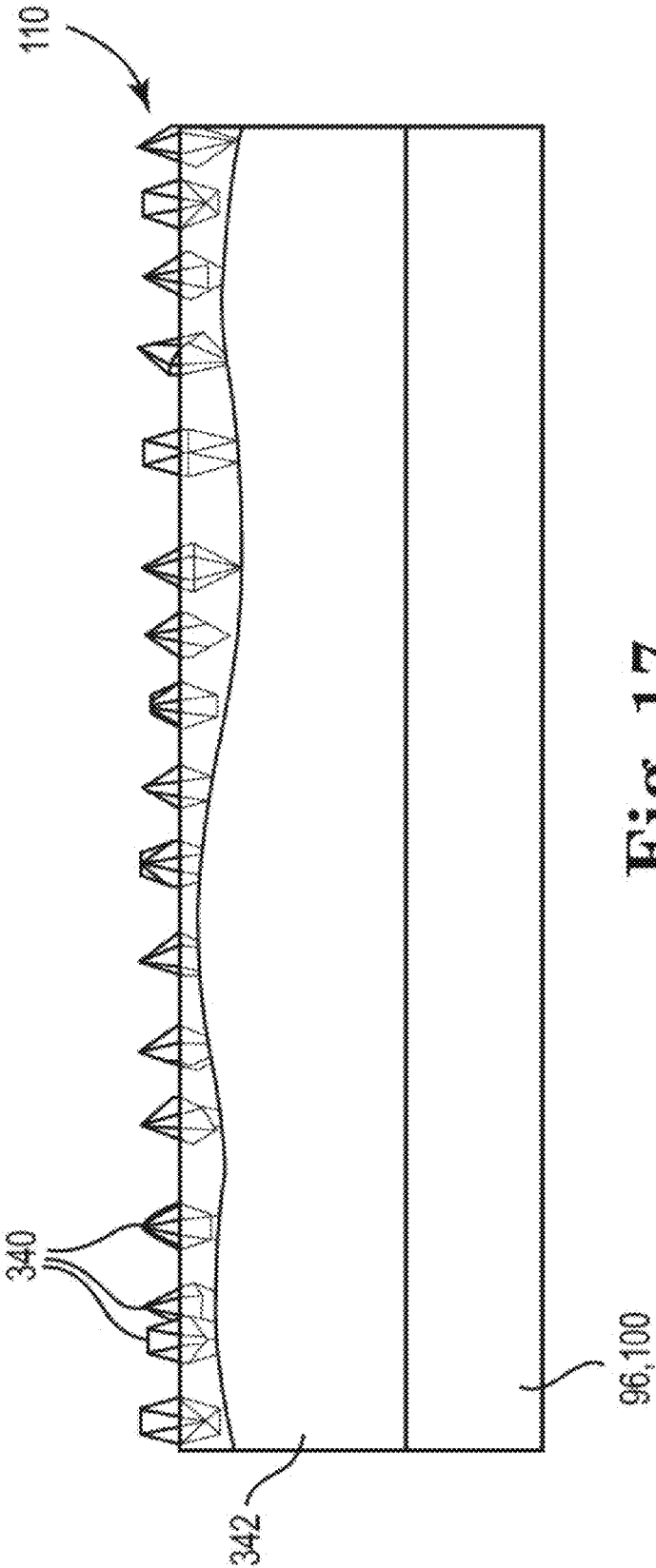


Fig. 17

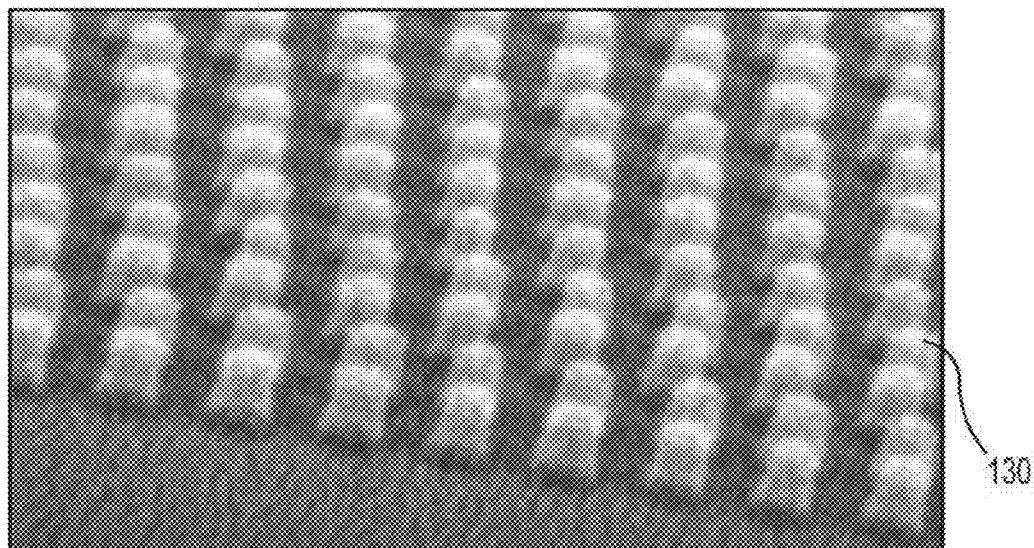


Fig. 18A

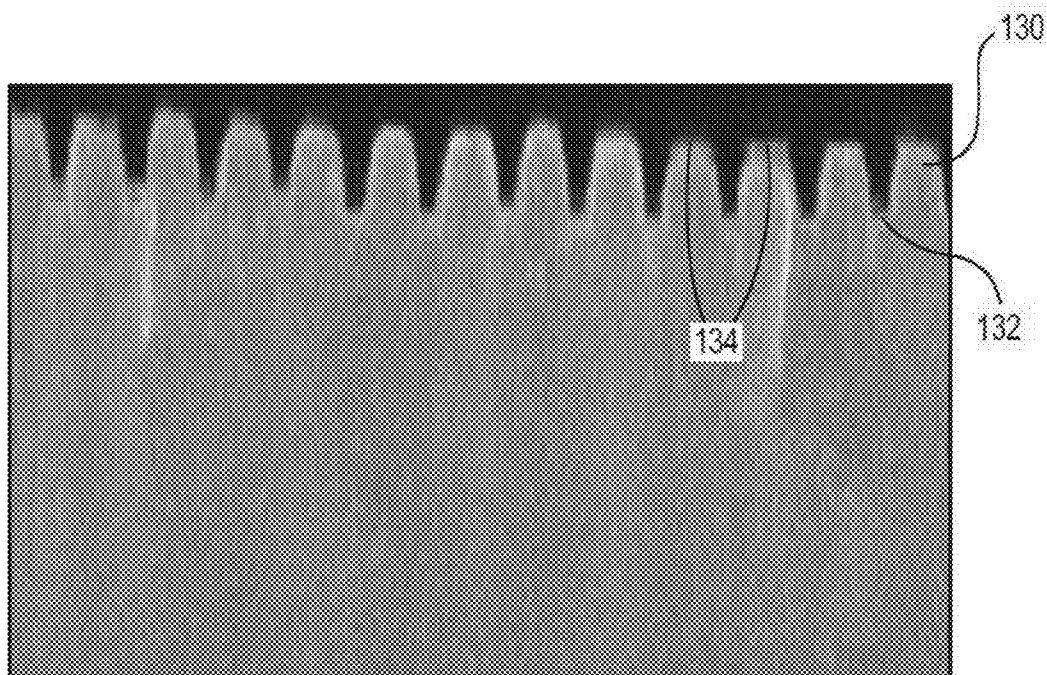


Fig. 18B

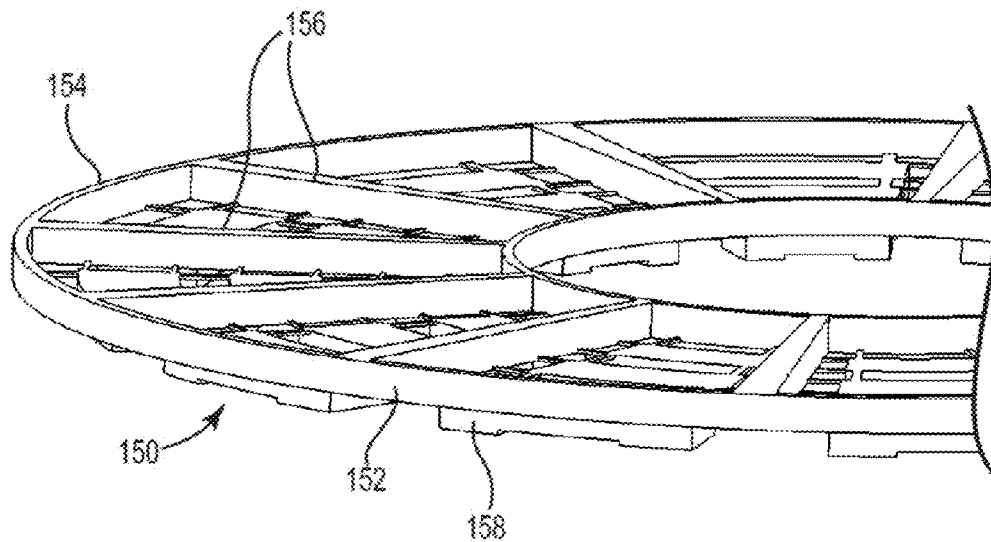


Fig. 19

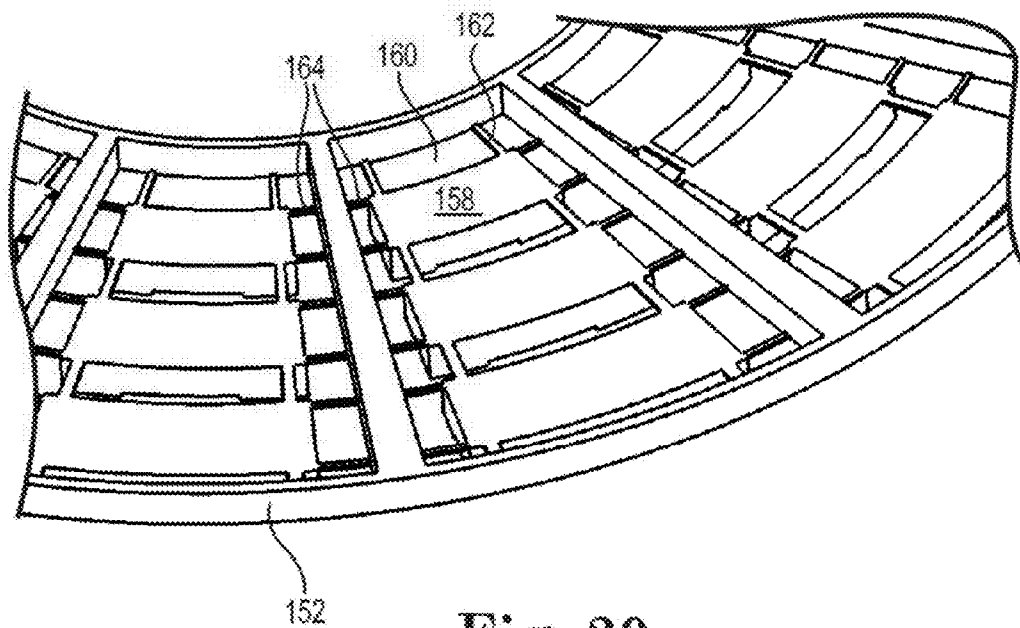


Fig. 20

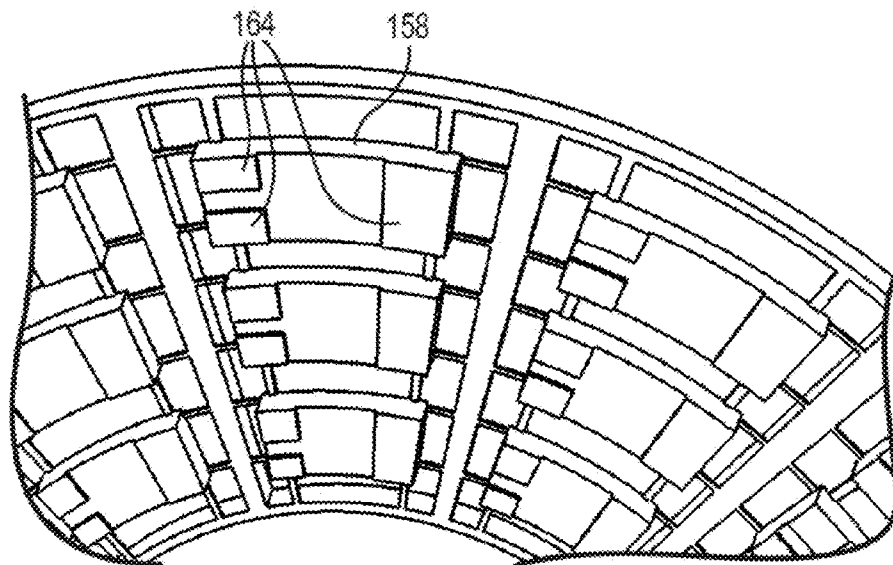


Fig. 21

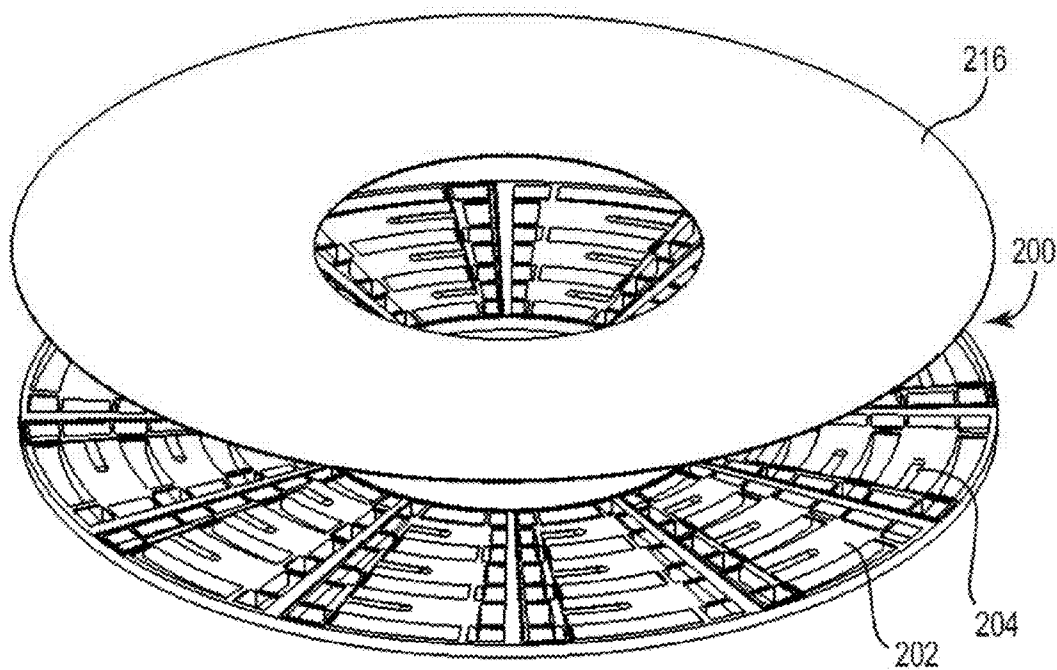


Fig. 22

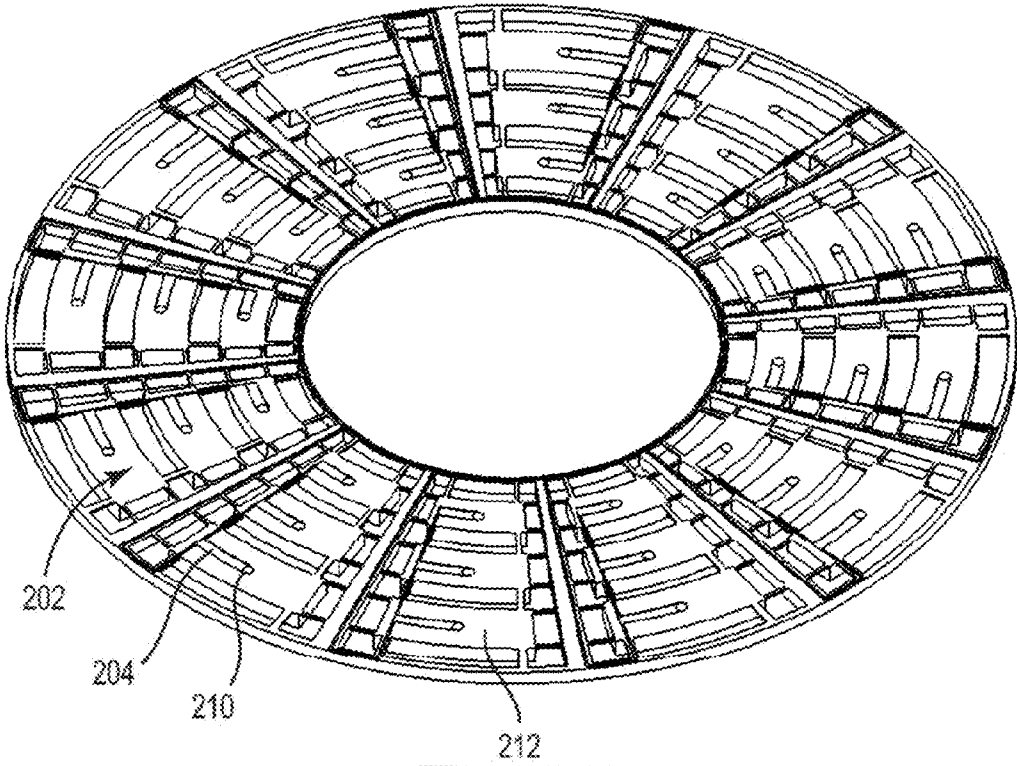


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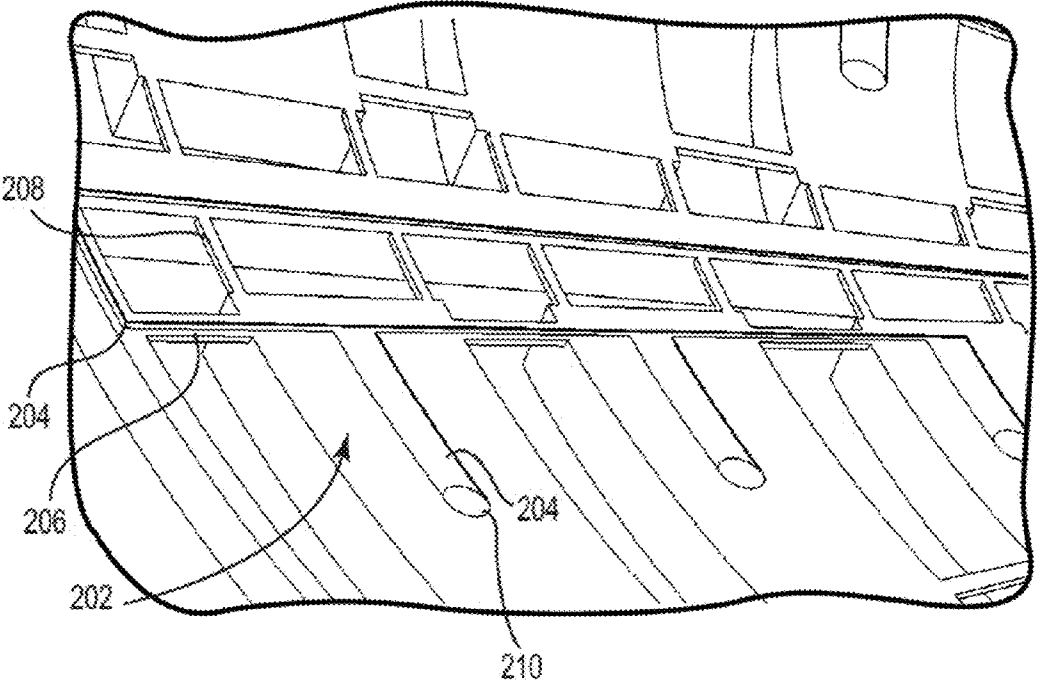


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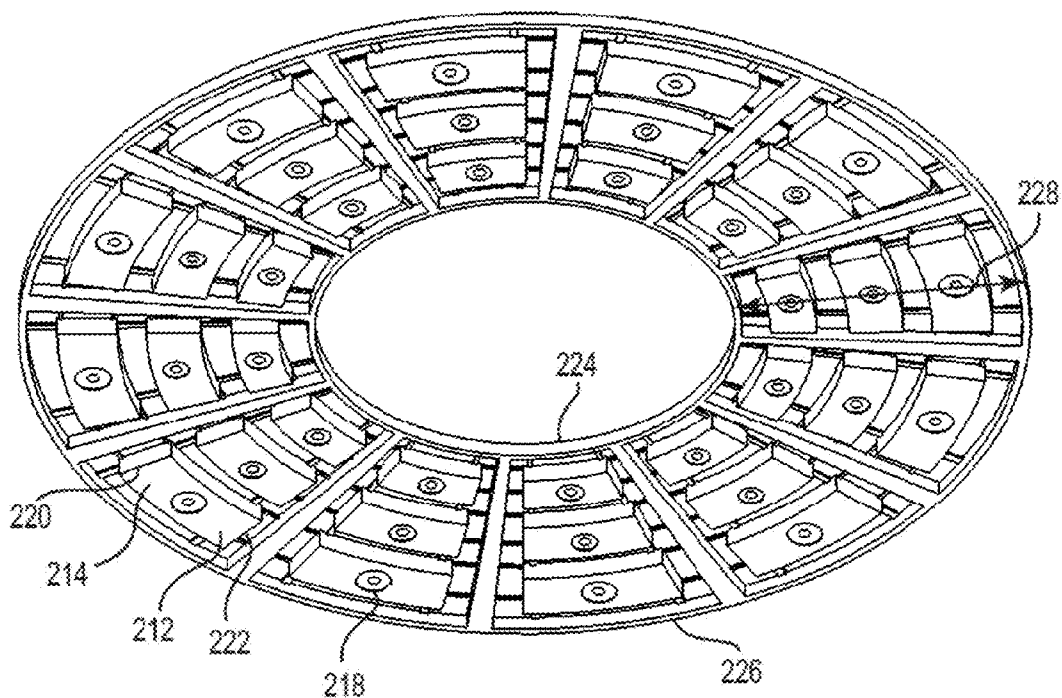


Fig. 25

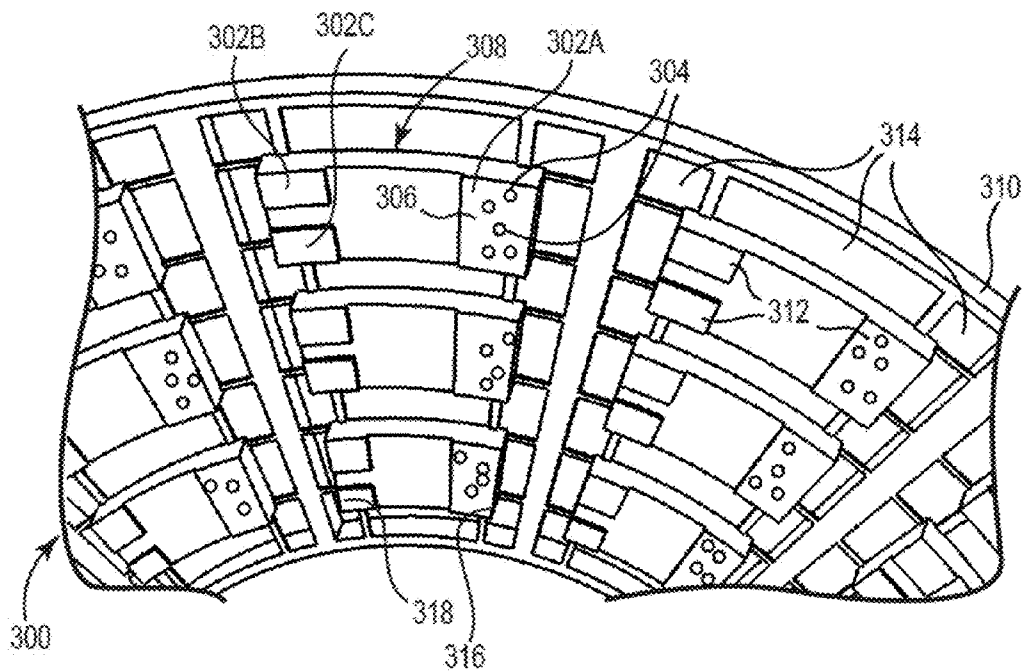


Fig. 26

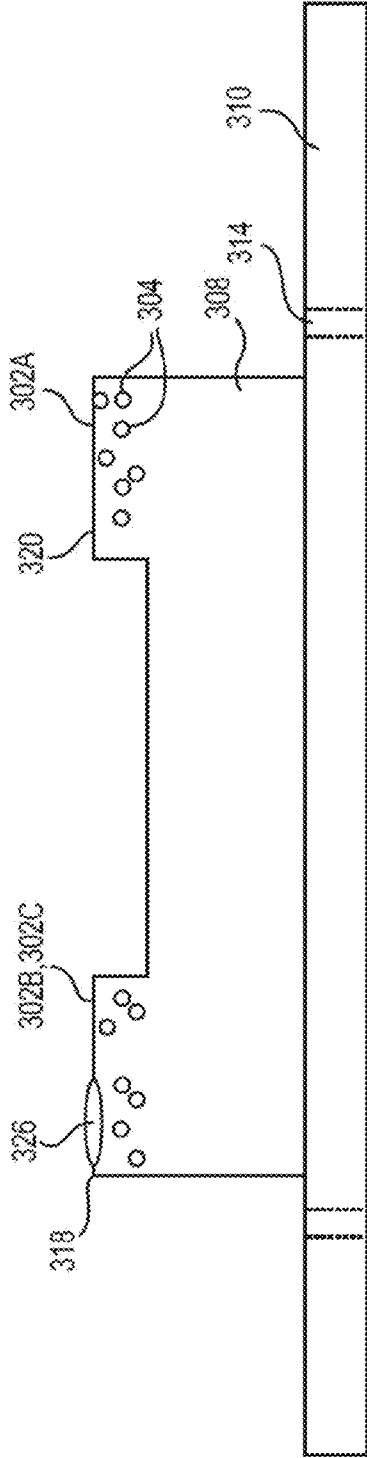


Fig. 27A

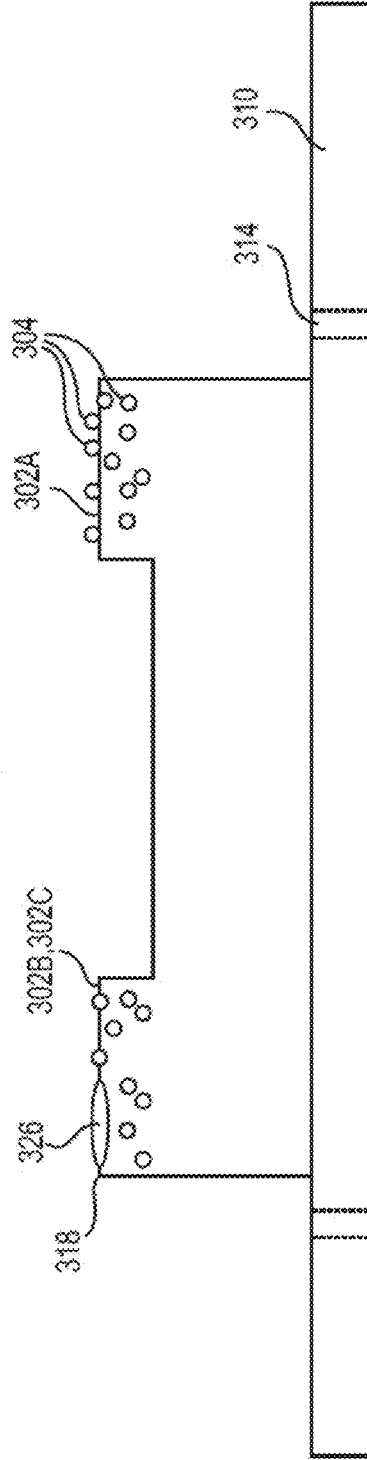


Fig. 27B

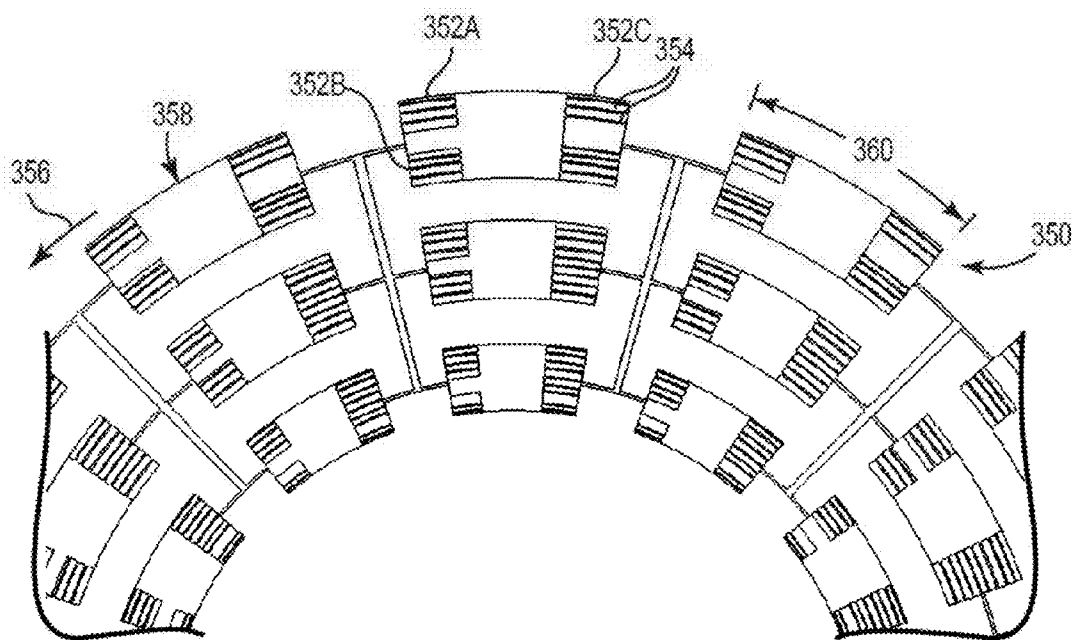


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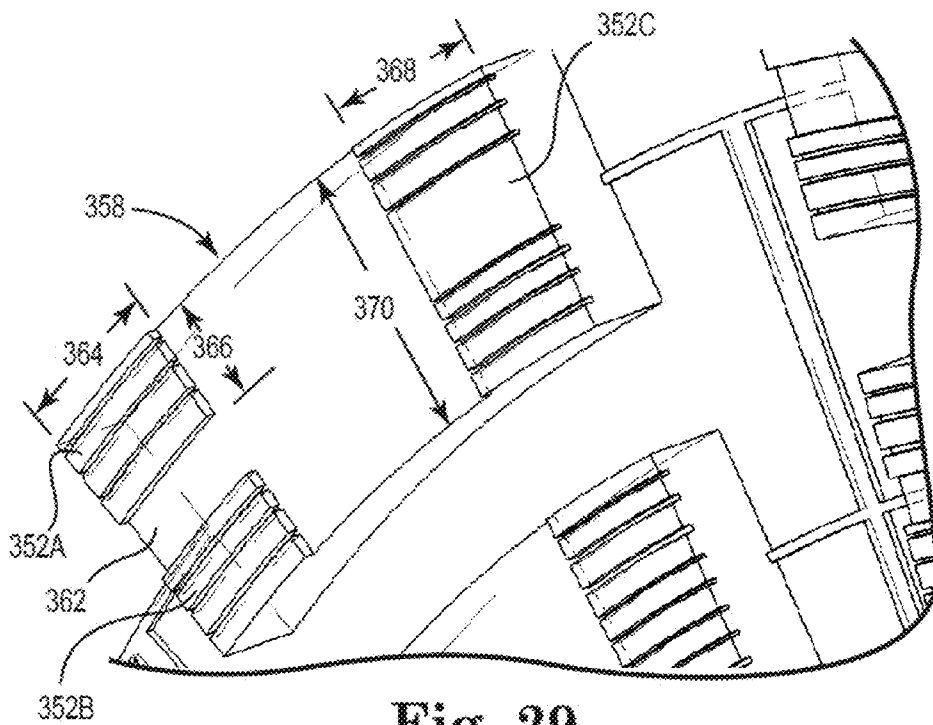


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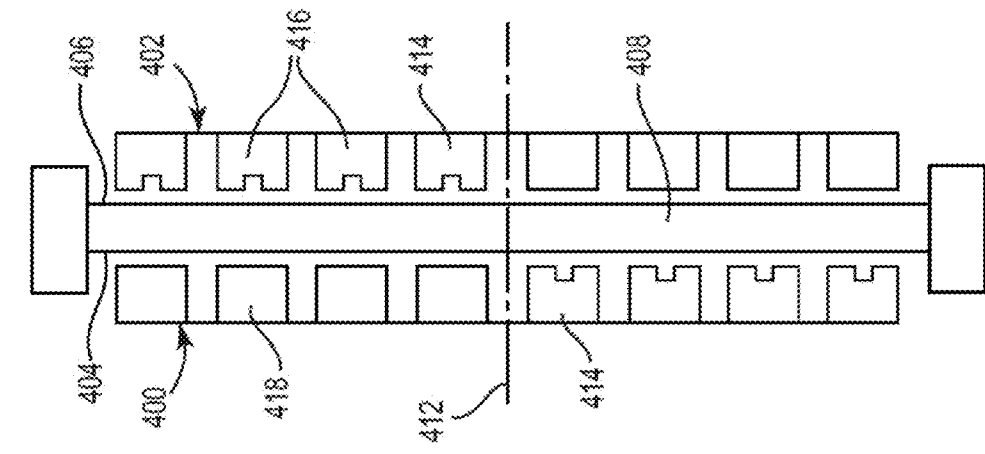


Fig. 30A

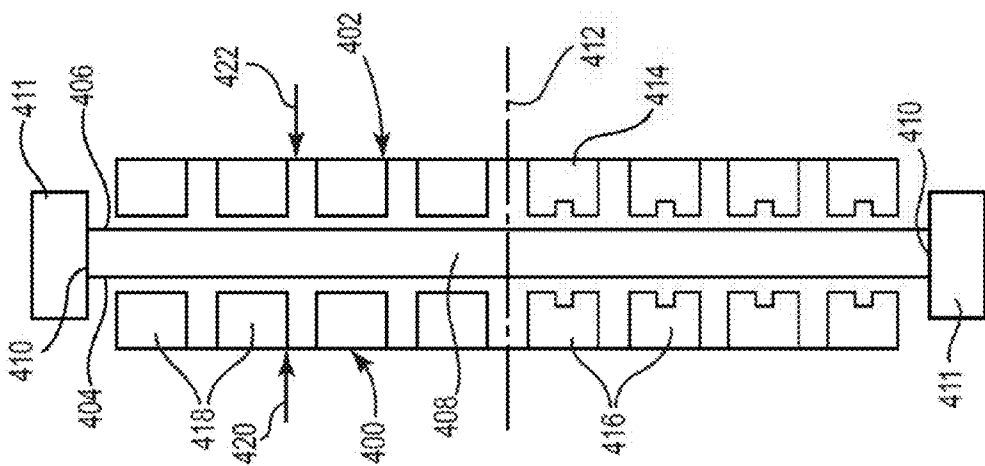


Fig. 30B

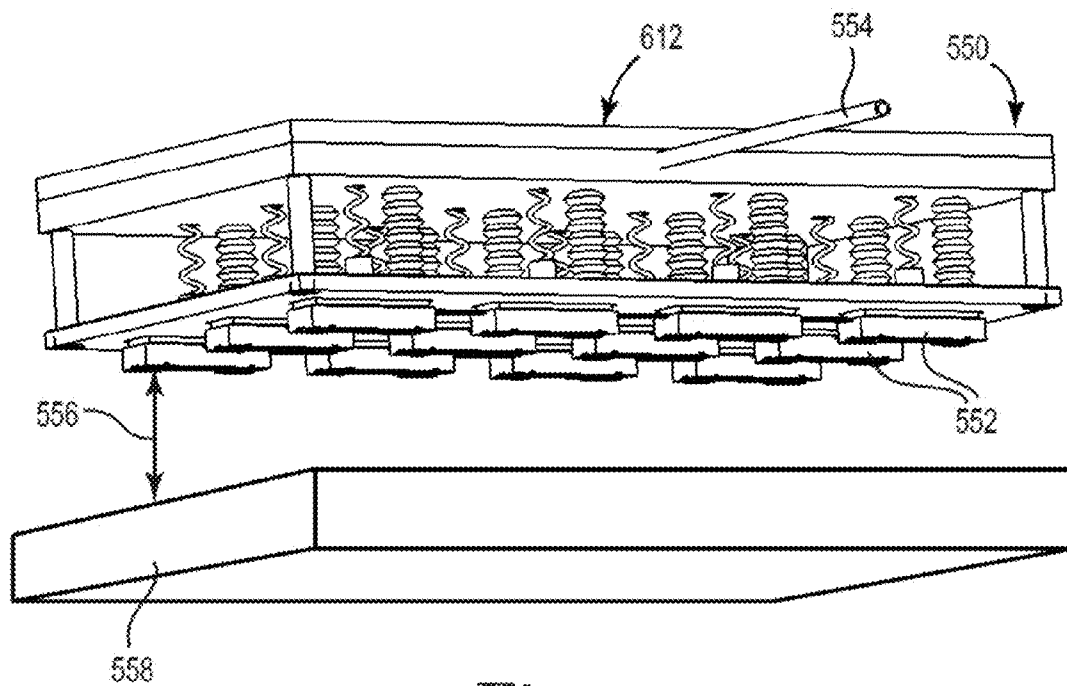


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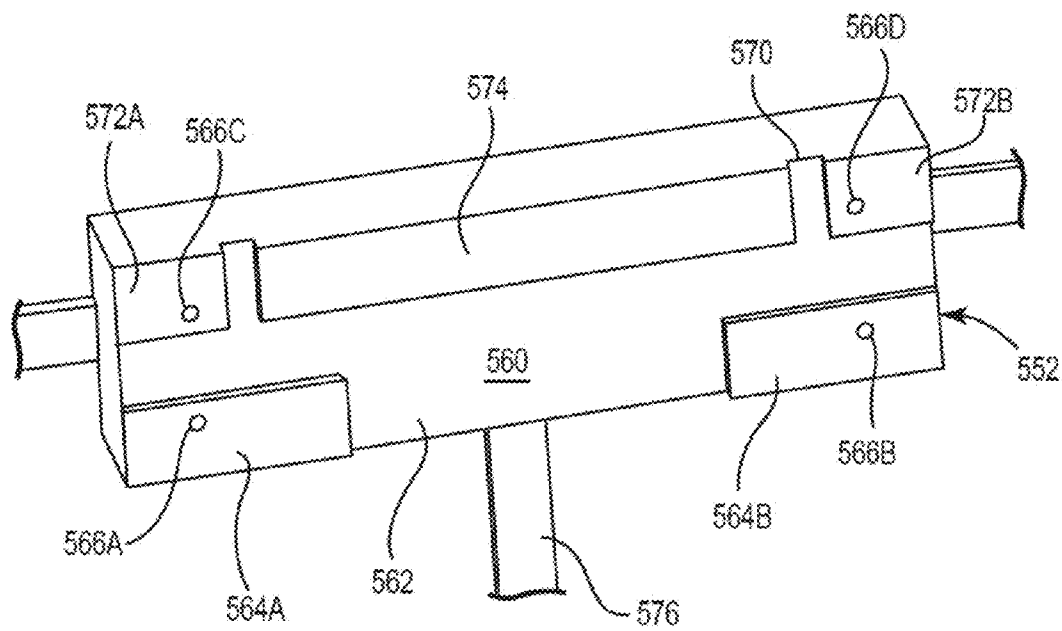


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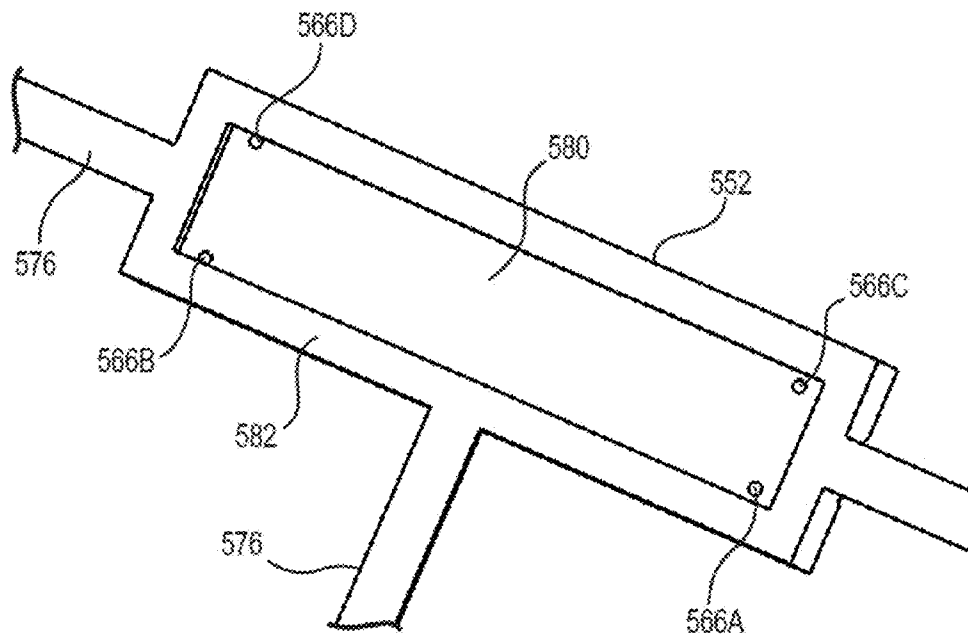


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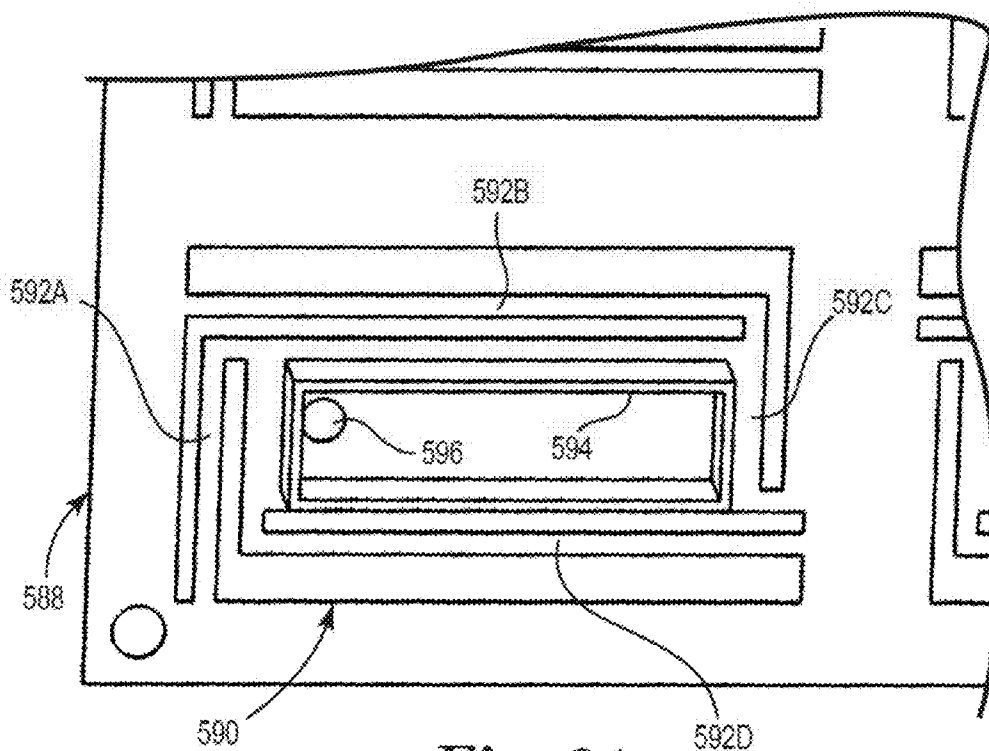


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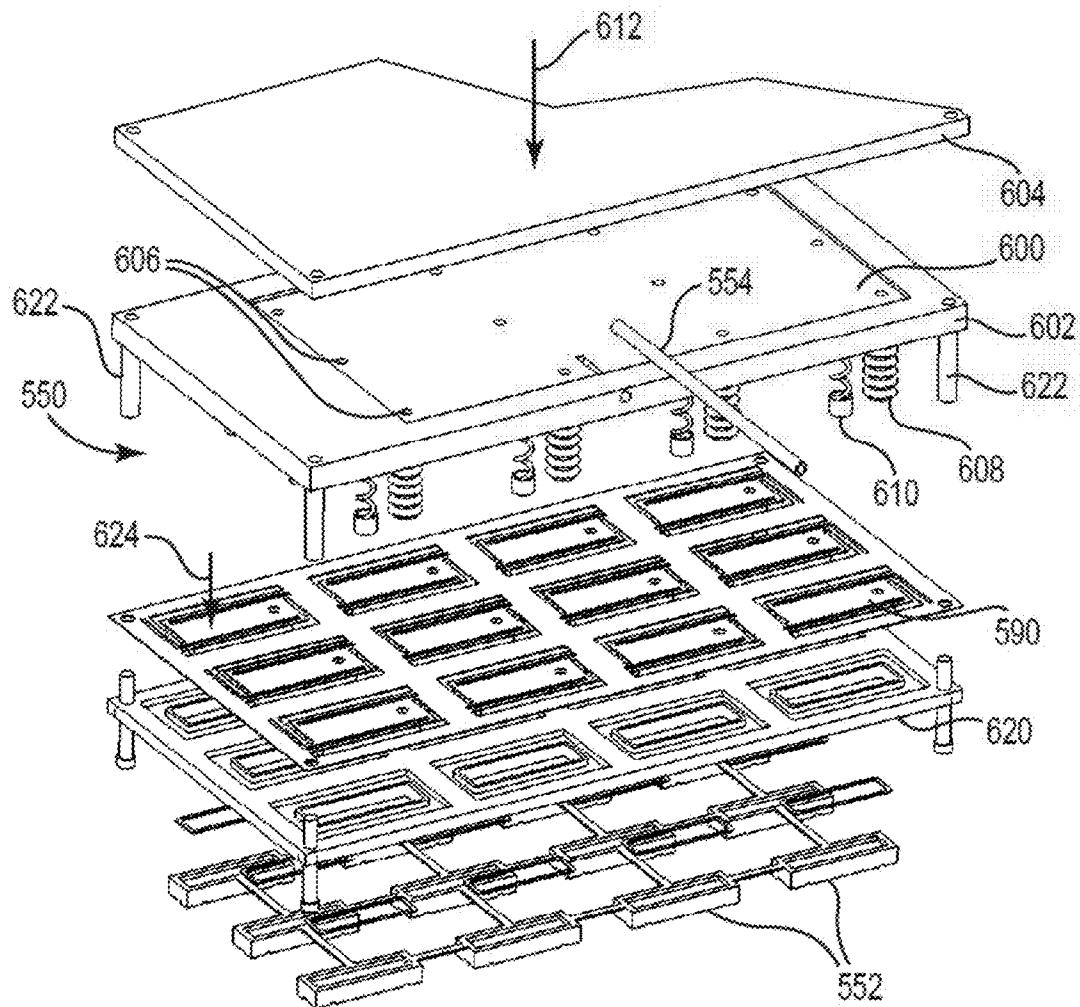


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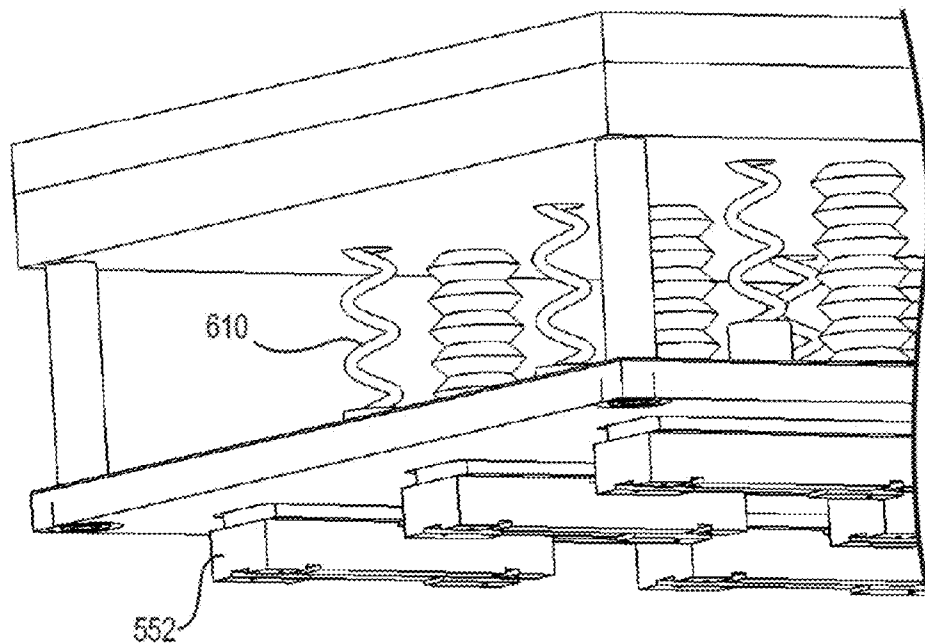


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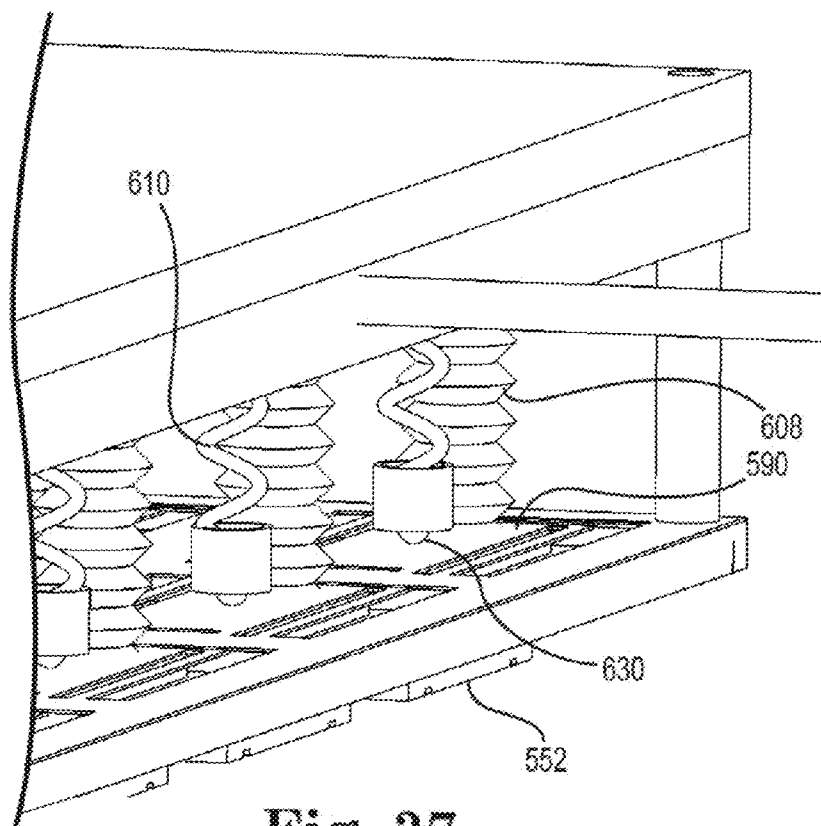


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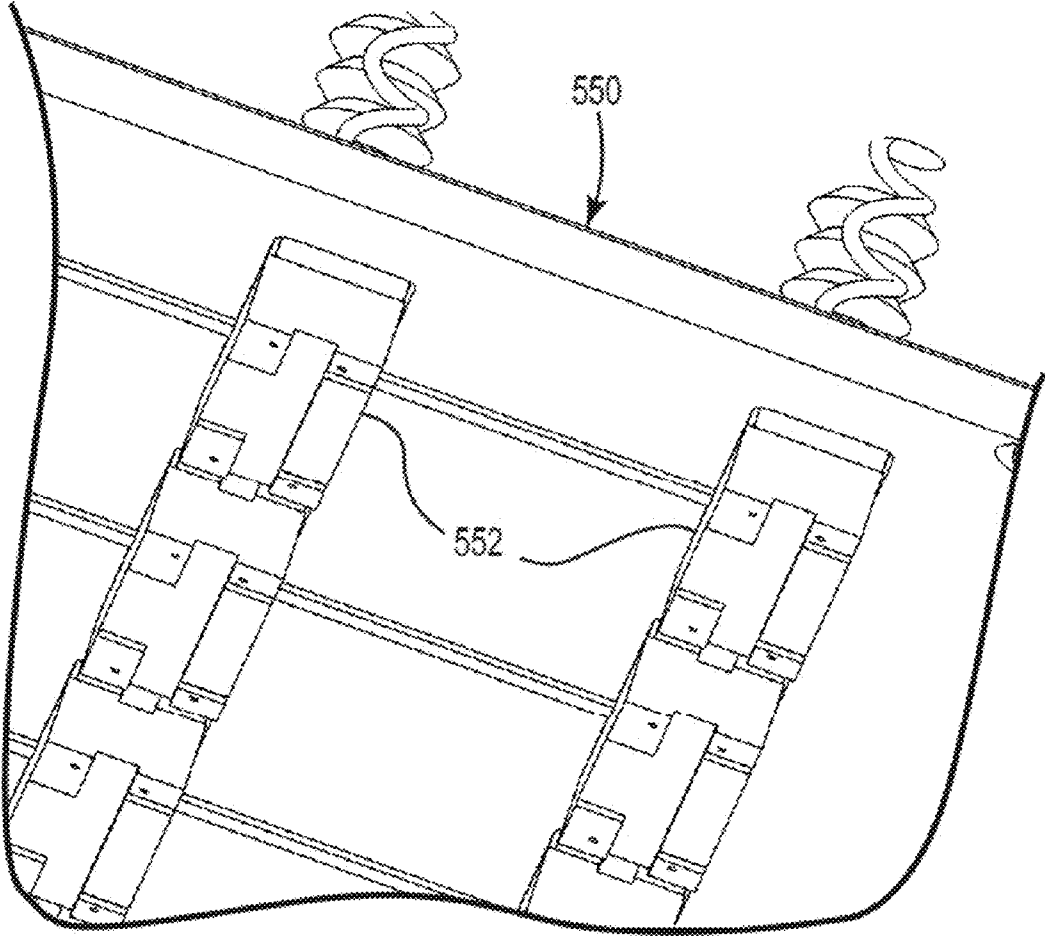


Fig. 38

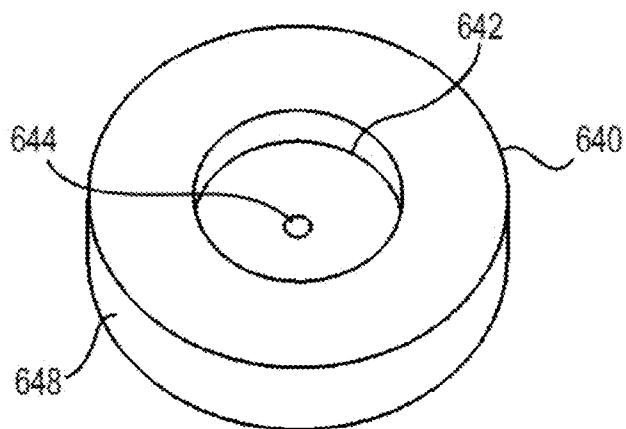


Figure 39A

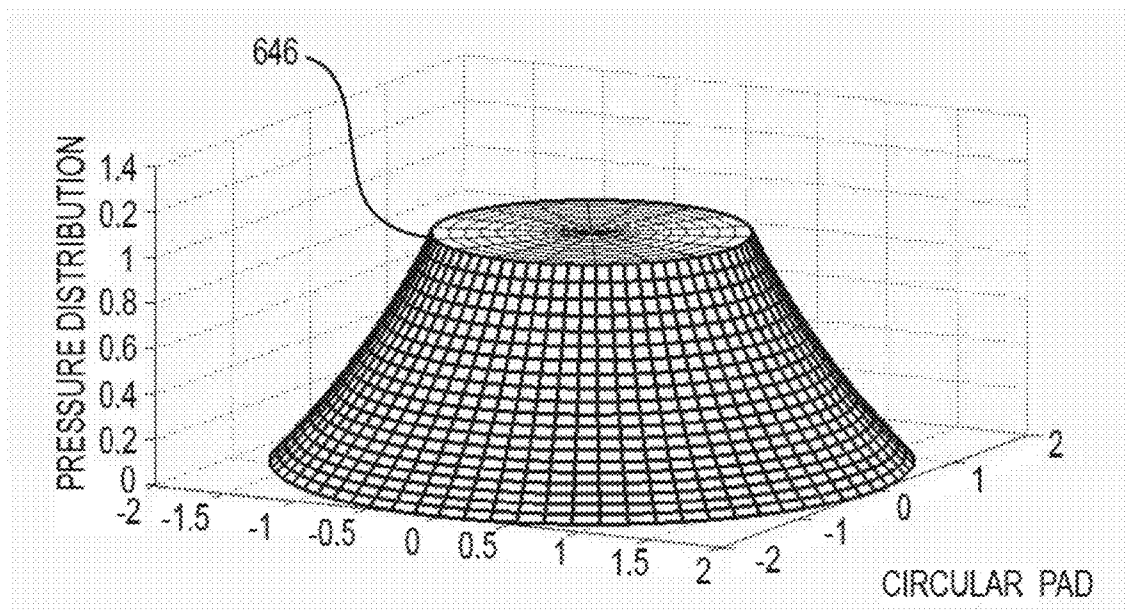


Figure 39B

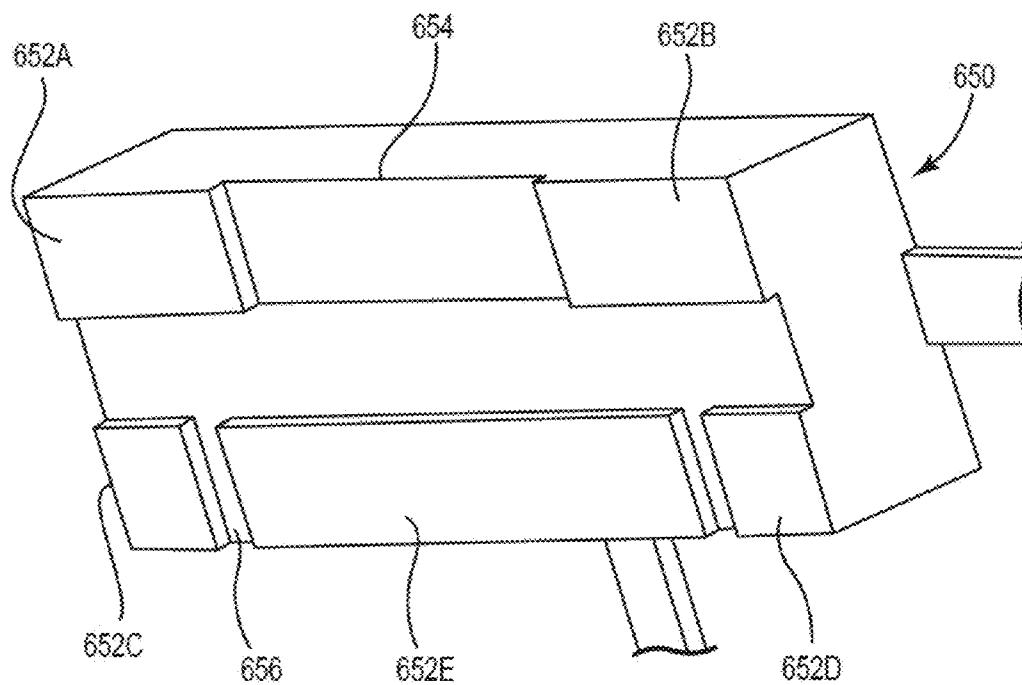


Fig. 40

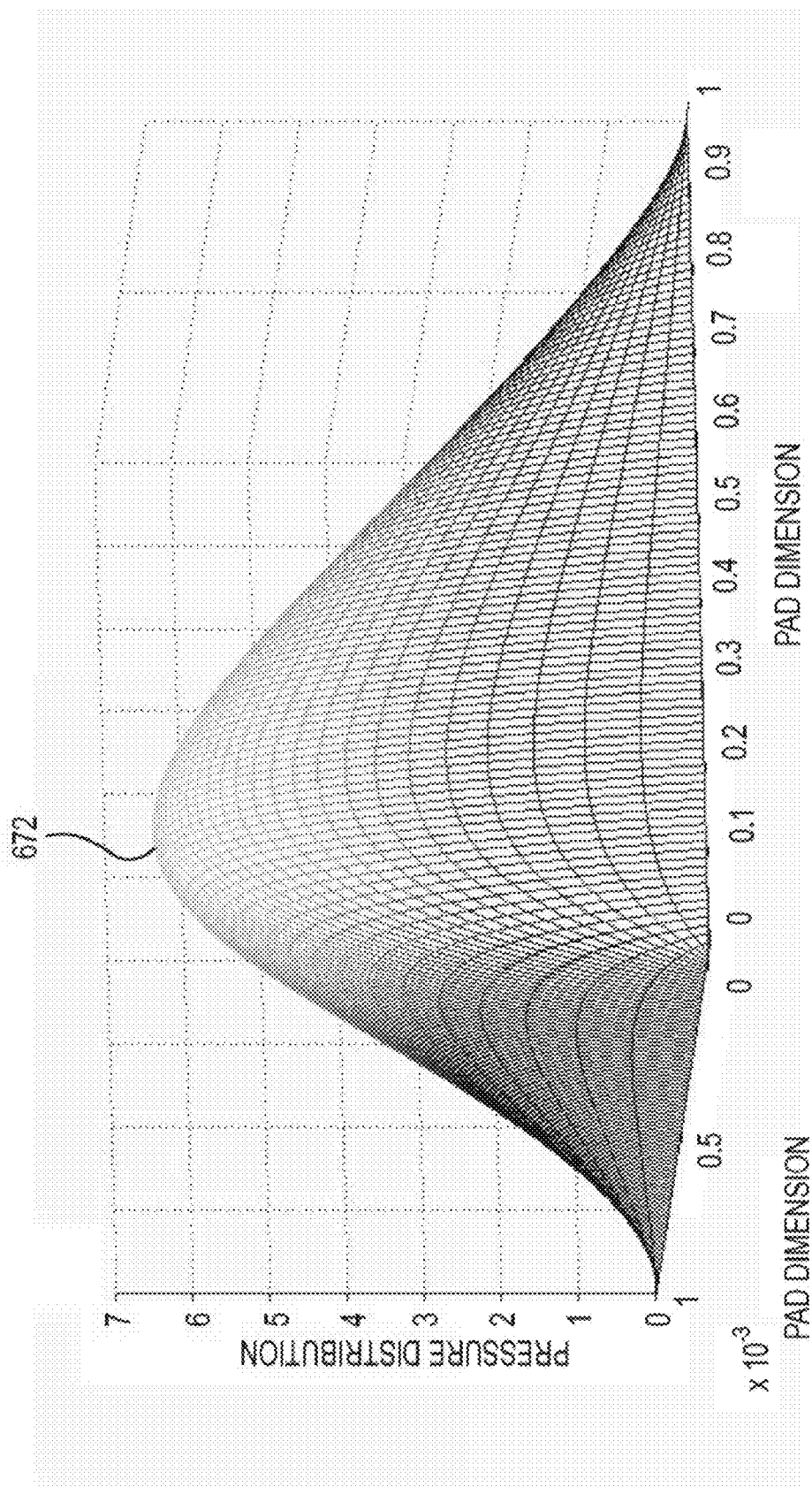


Fig. 41

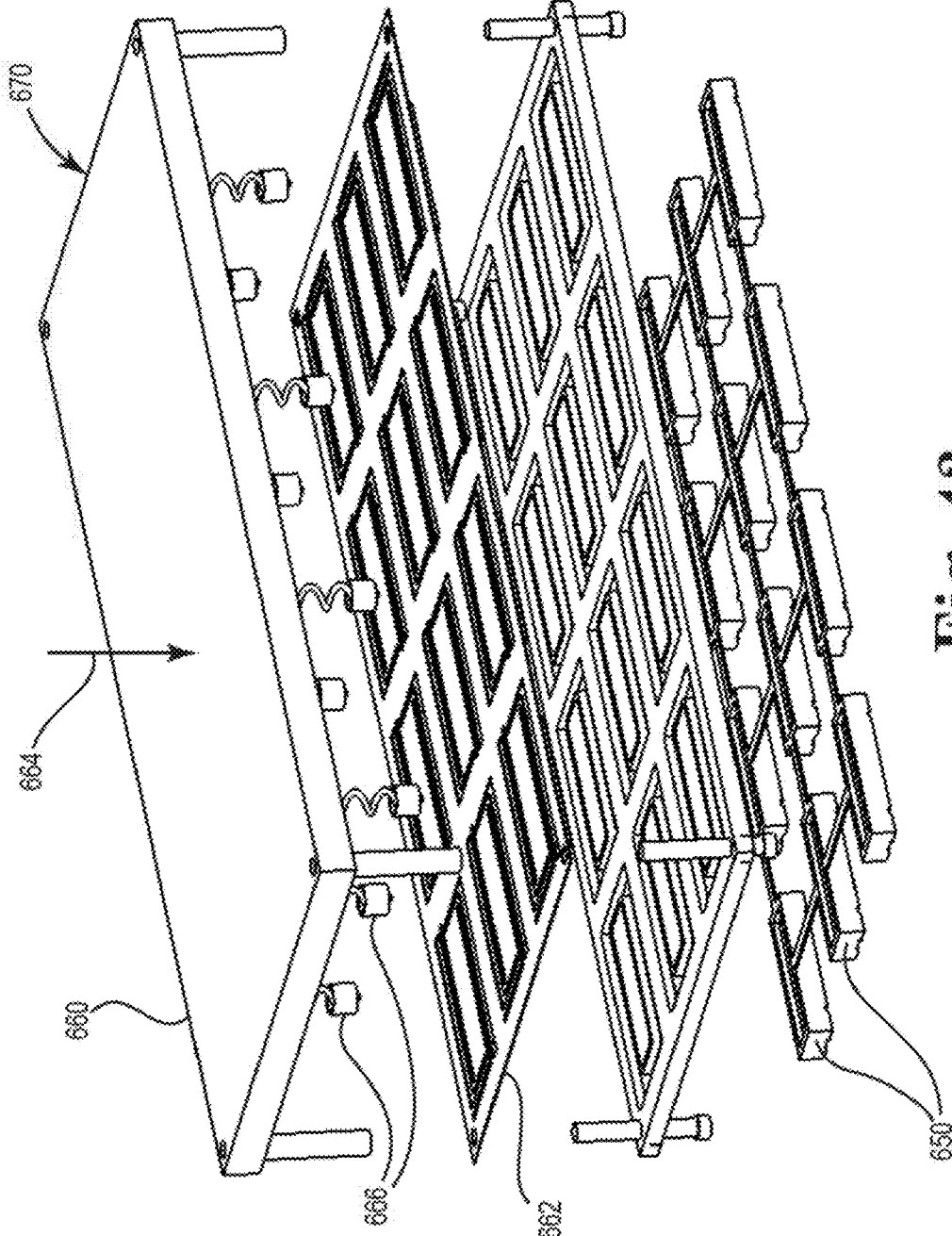


Fig. 42

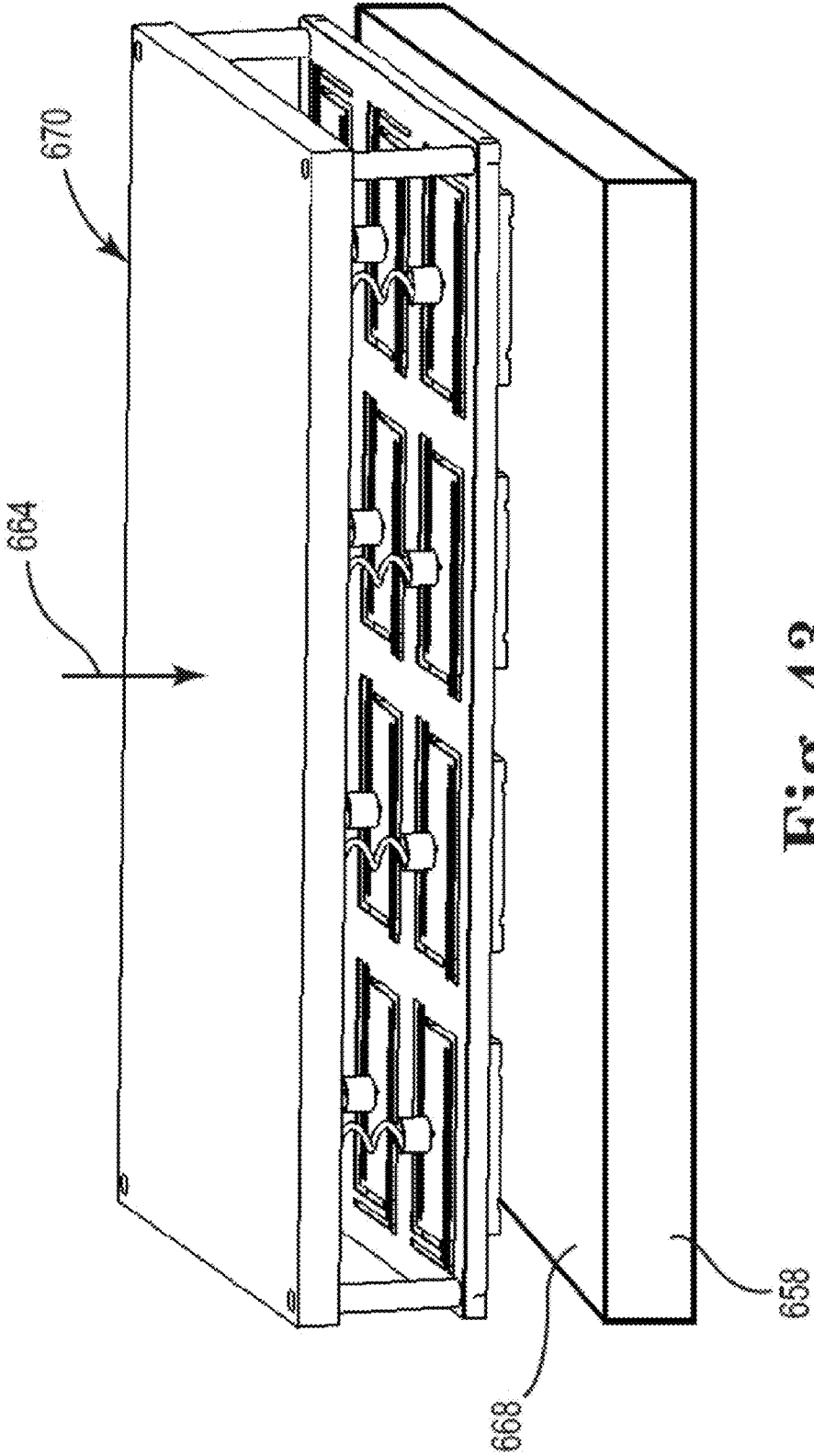


Fig. 43

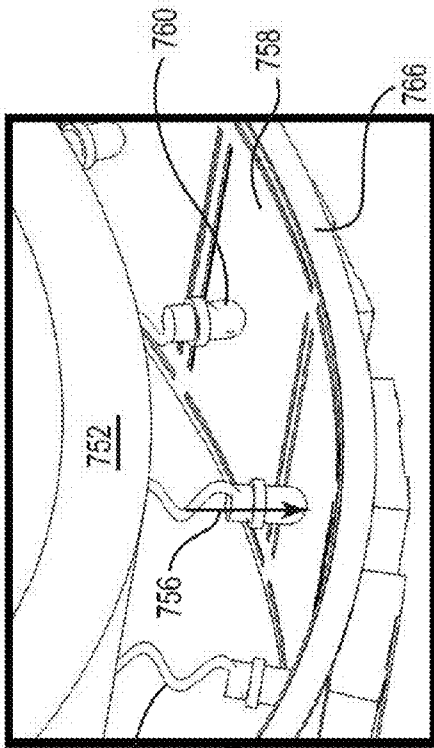


Fig. 44B

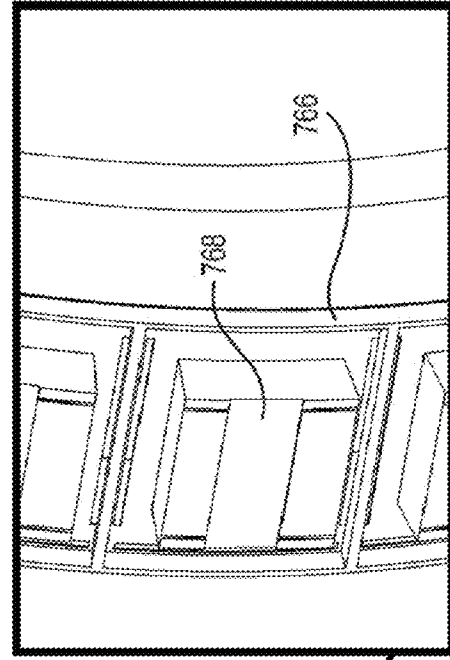


Fig. 44C

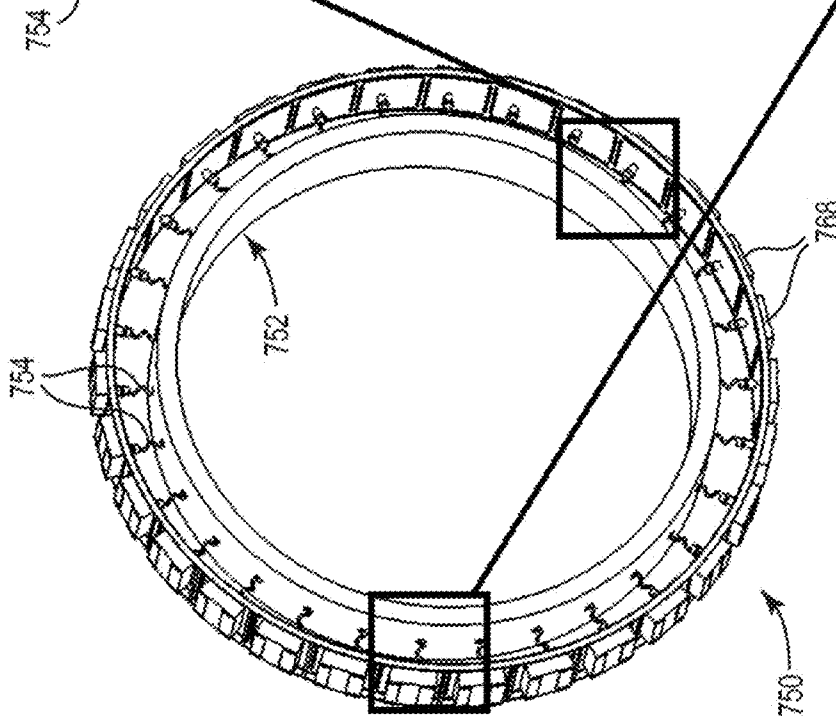


Fig. 44A

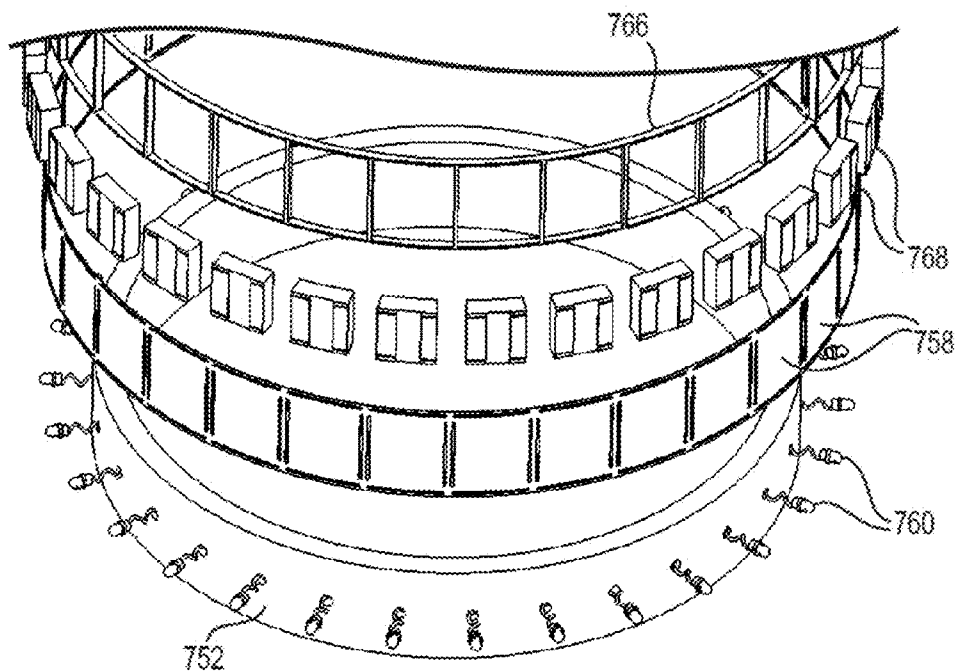


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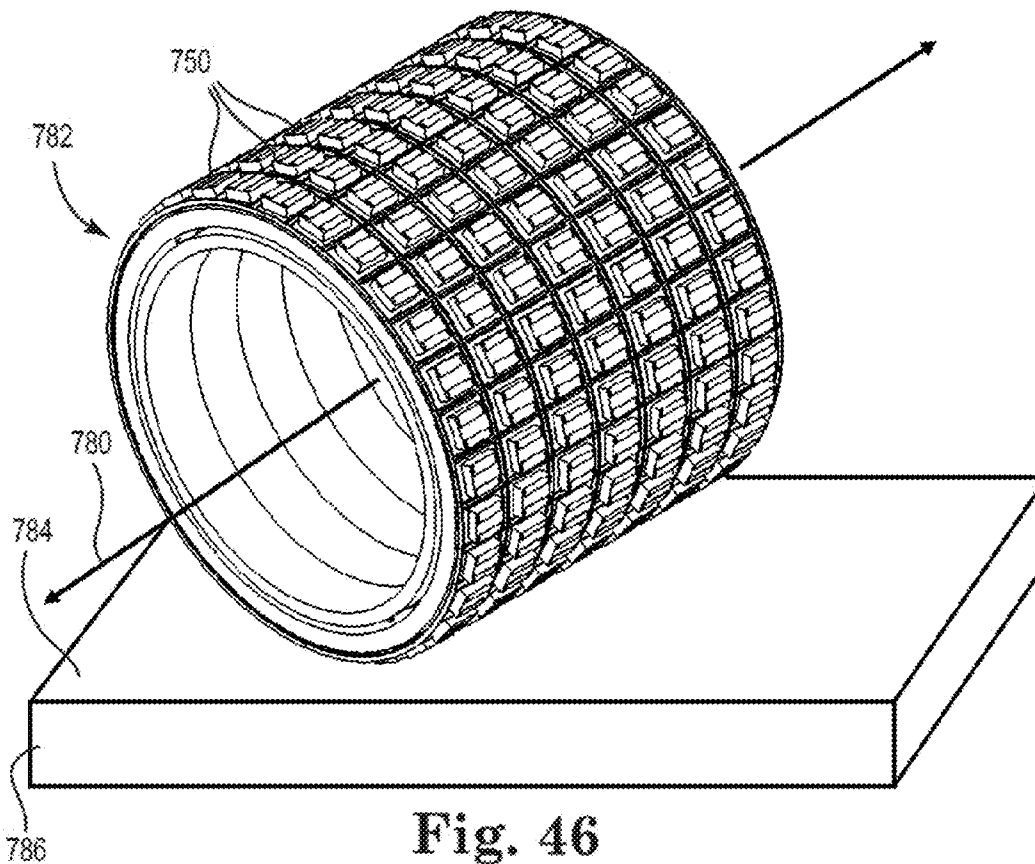


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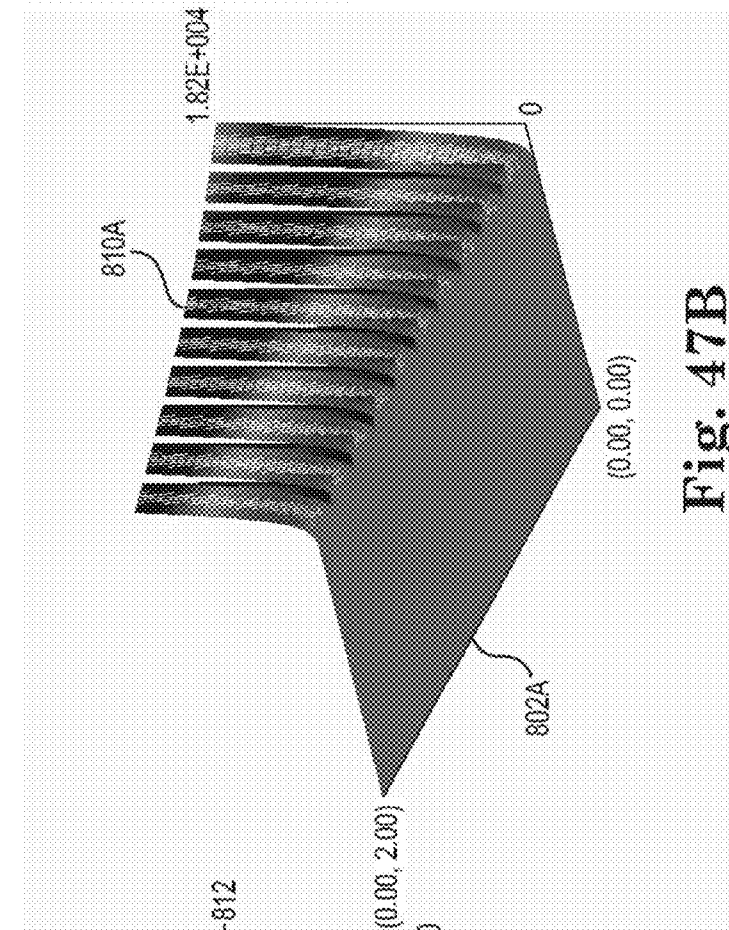


Fig. 47B

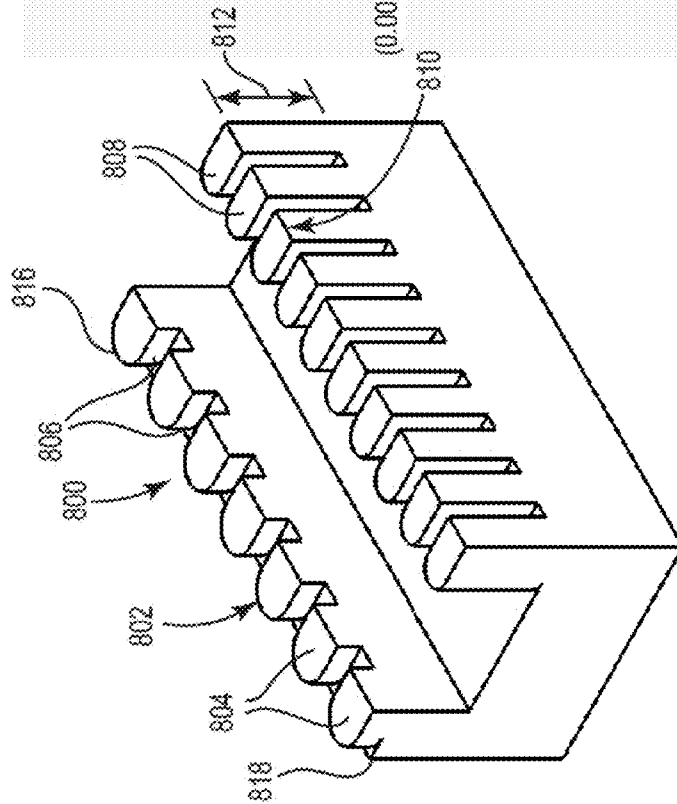


Fig. 47A

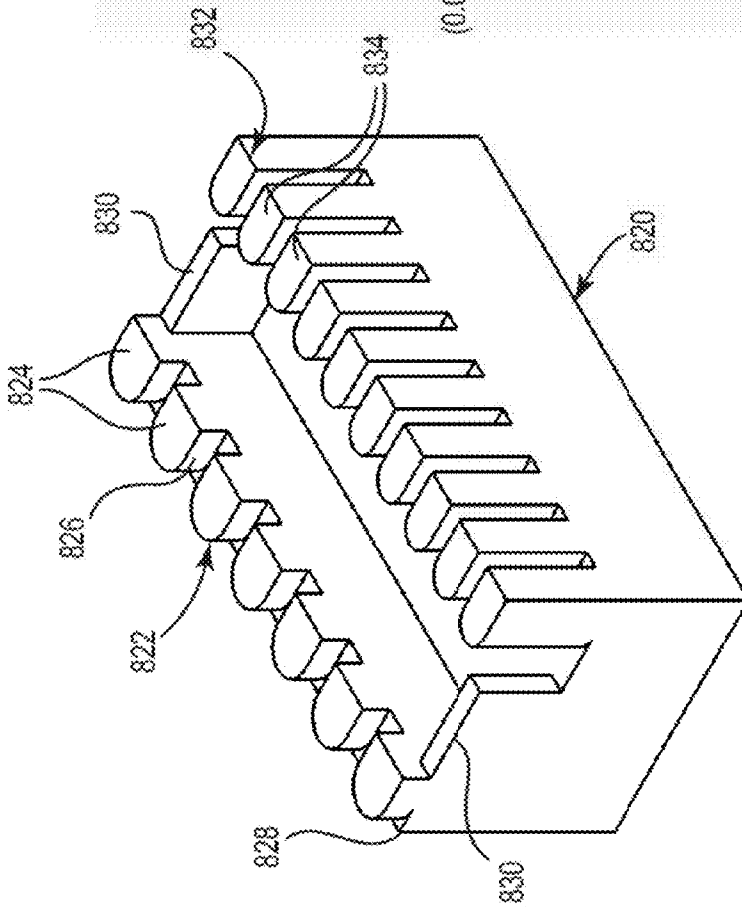


Fig. 48A

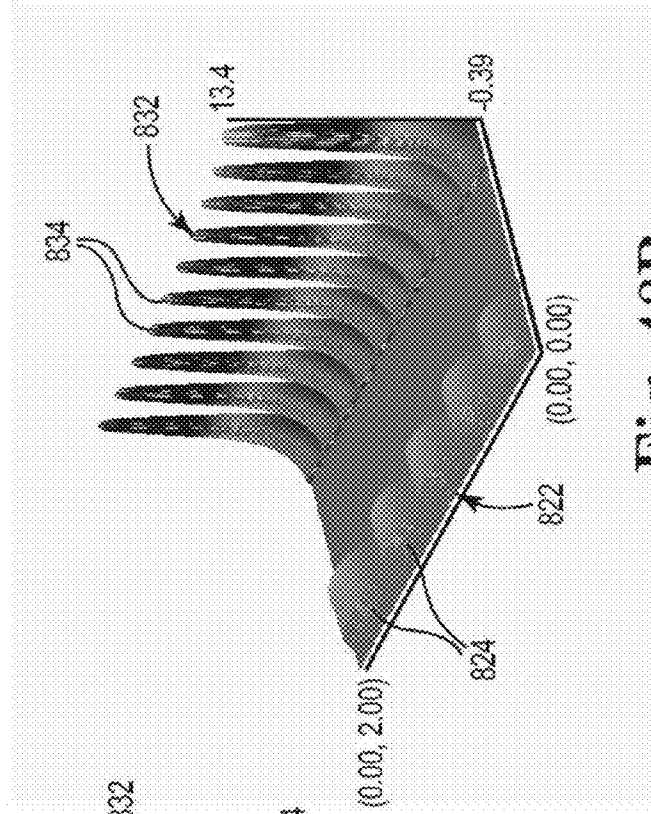


Fig. 48B

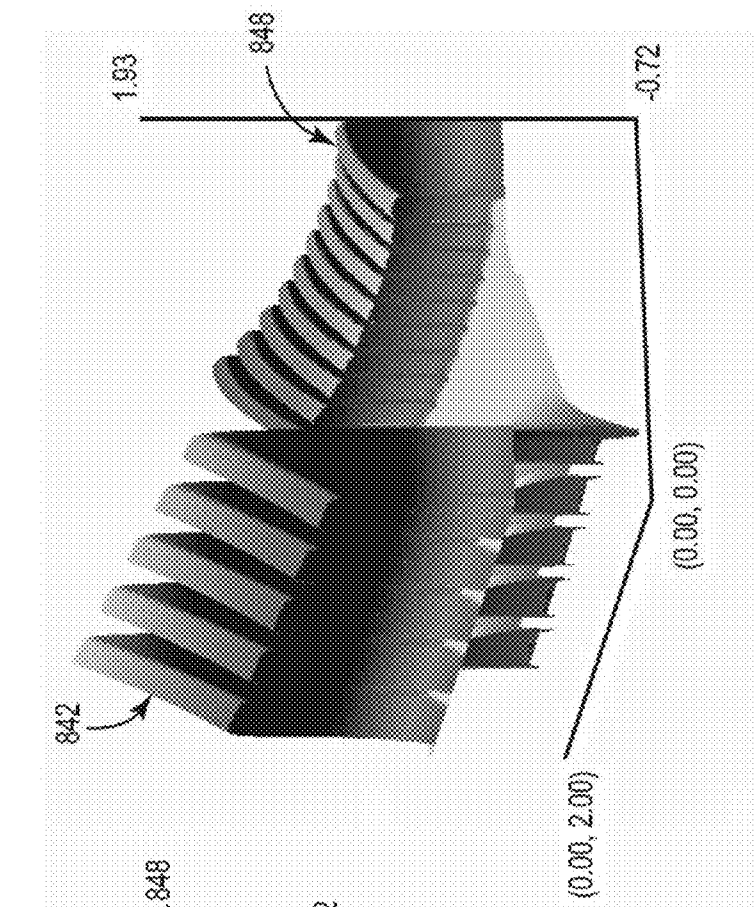


Fig. 49A

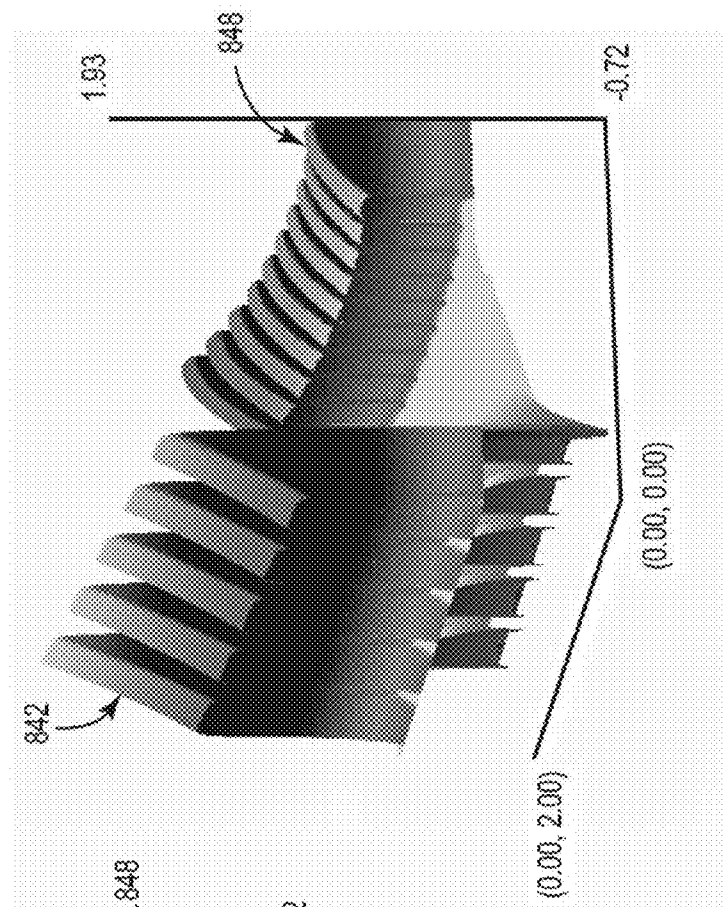


Fig. 49B

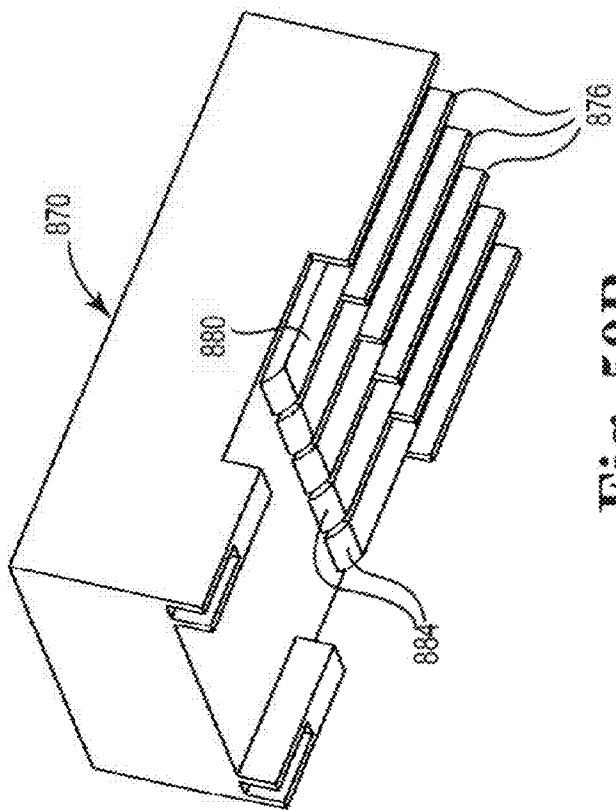


Fig. 50B

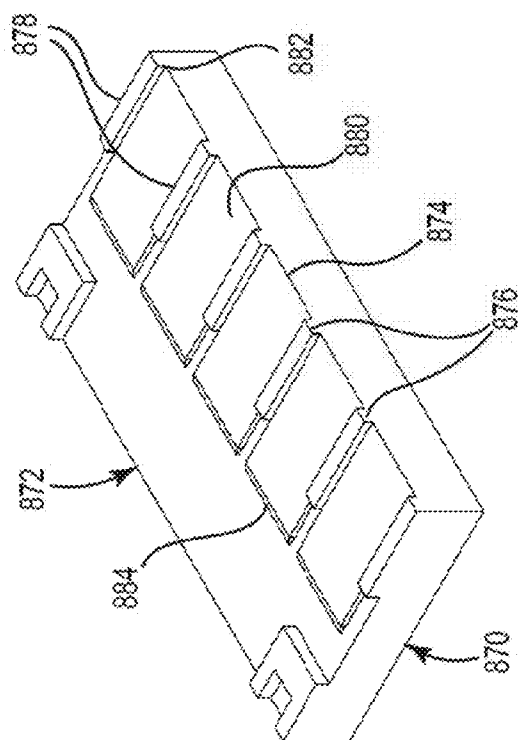


Fig. 50A

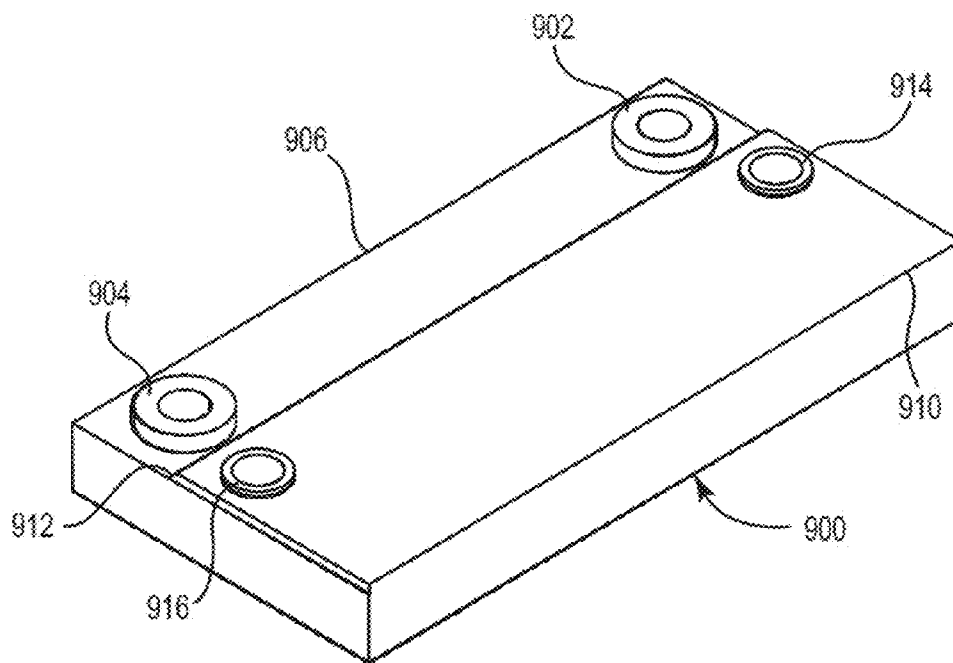


Fig. 51

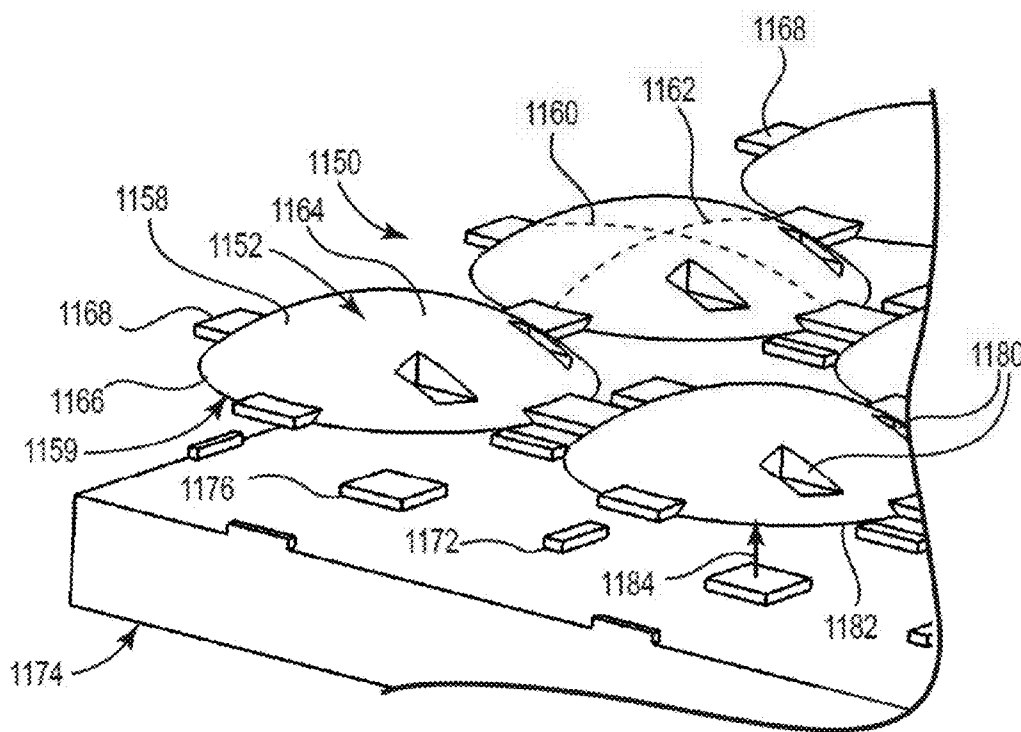


Fig. 52A

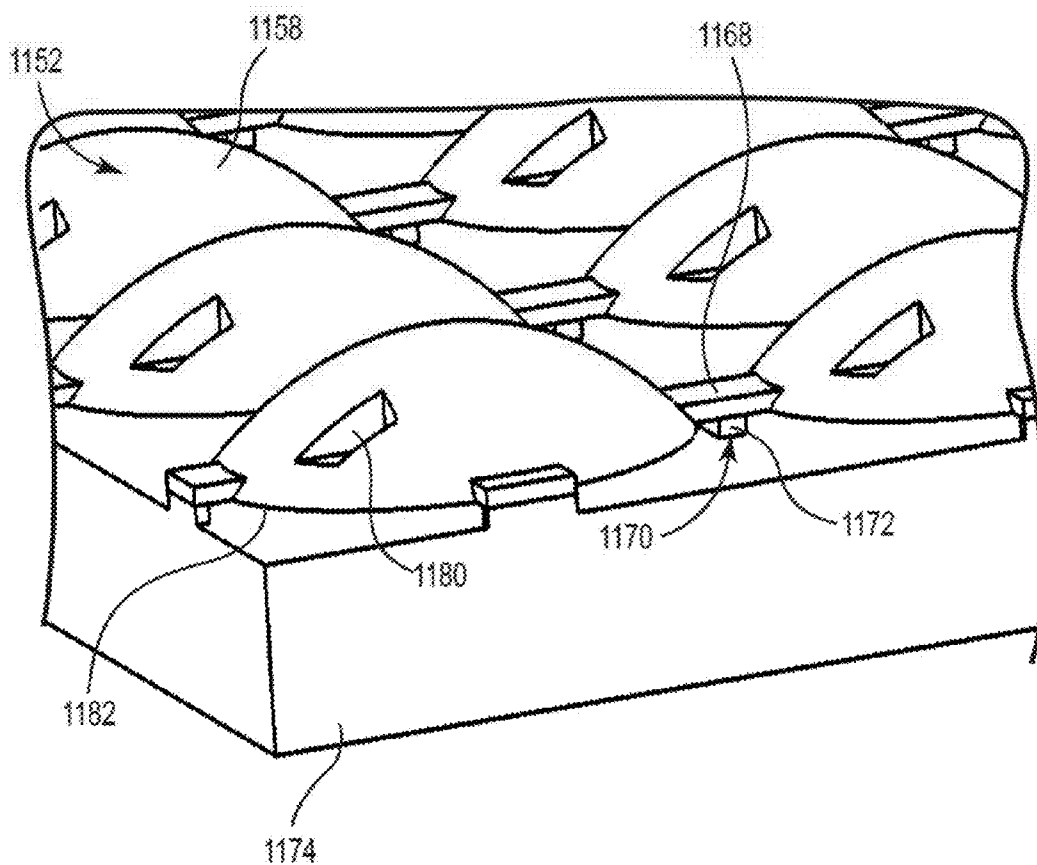


Fig. 52B

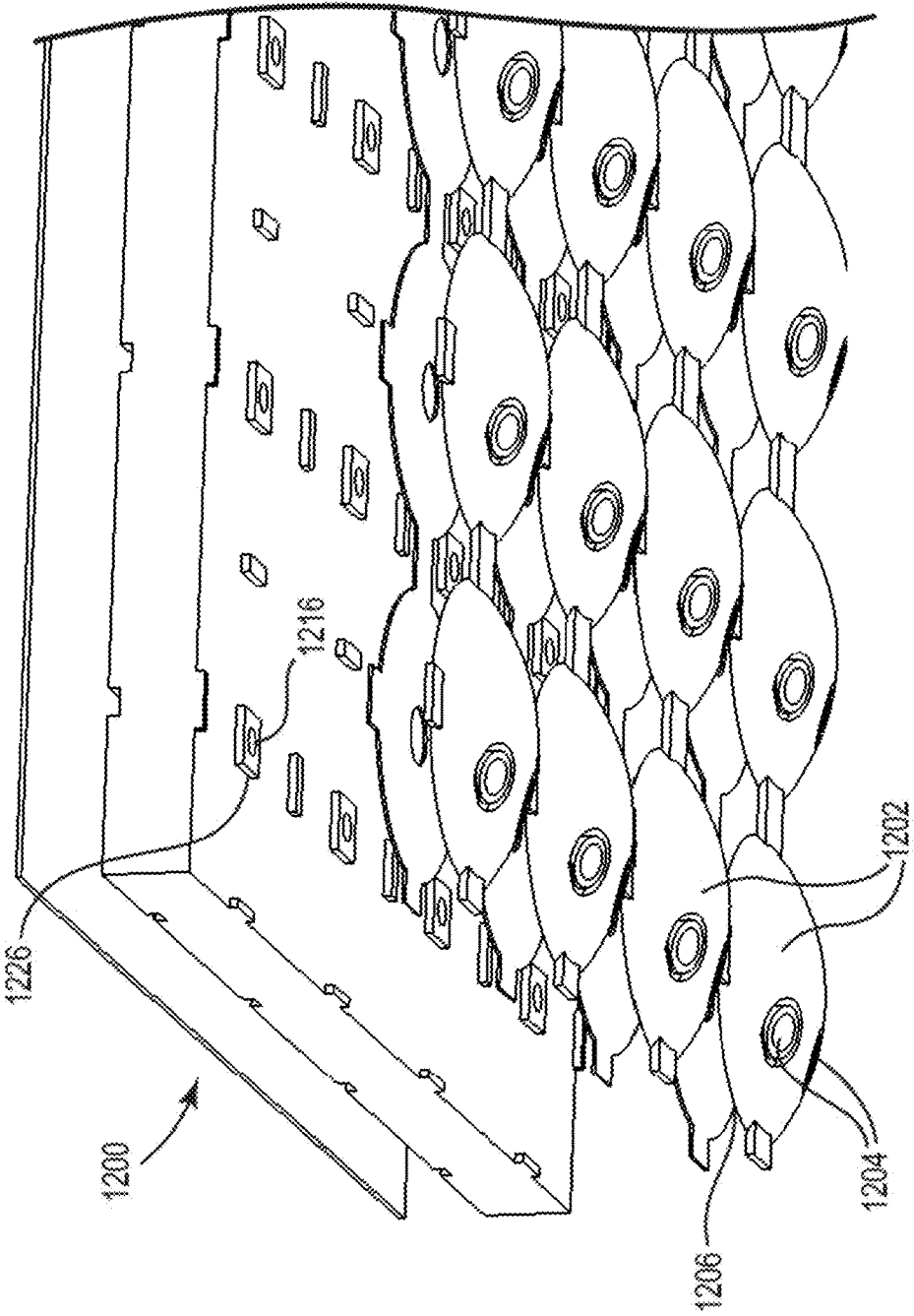


Fig. 53A

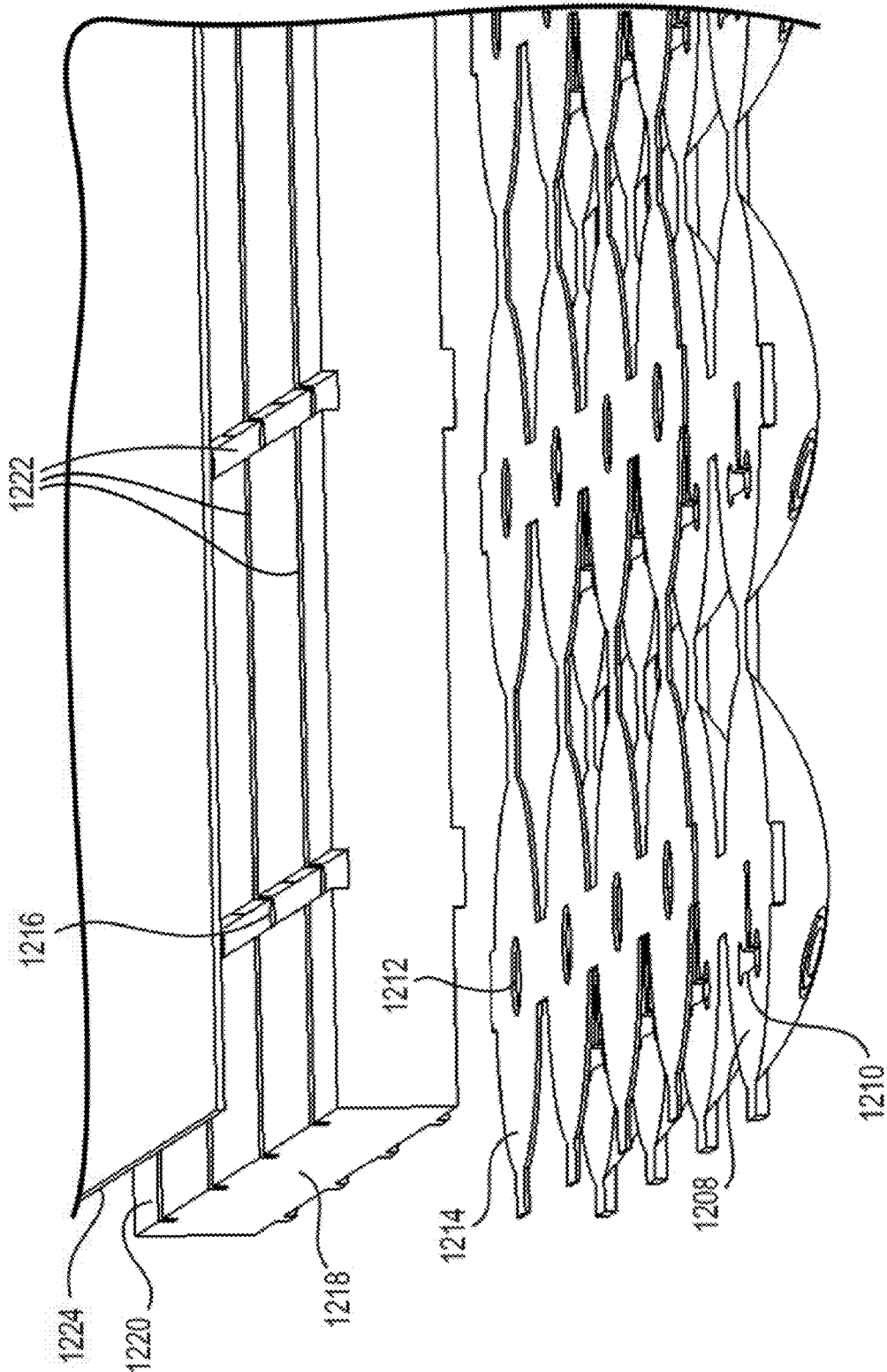


Fig. 53B

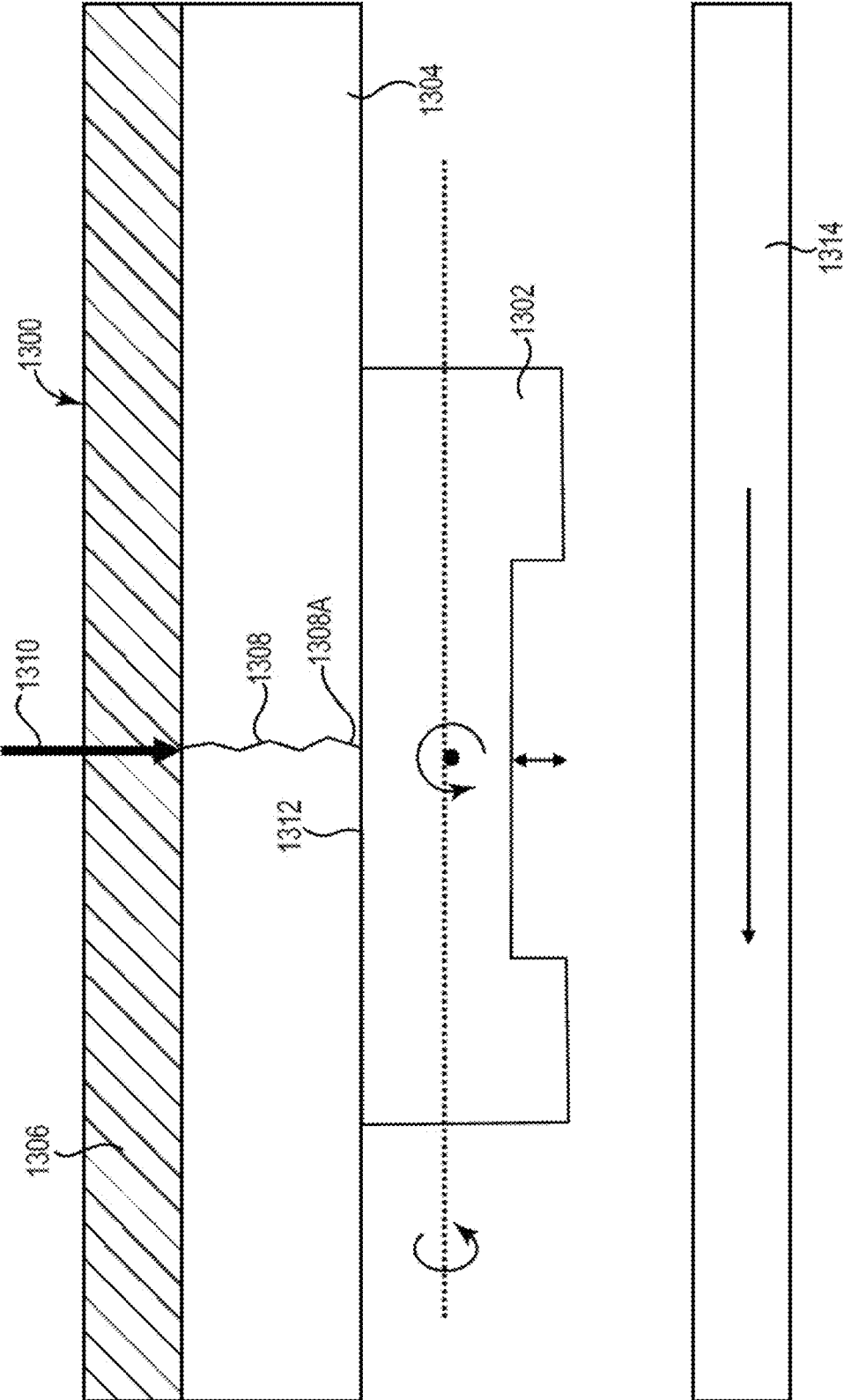


Fig. 54

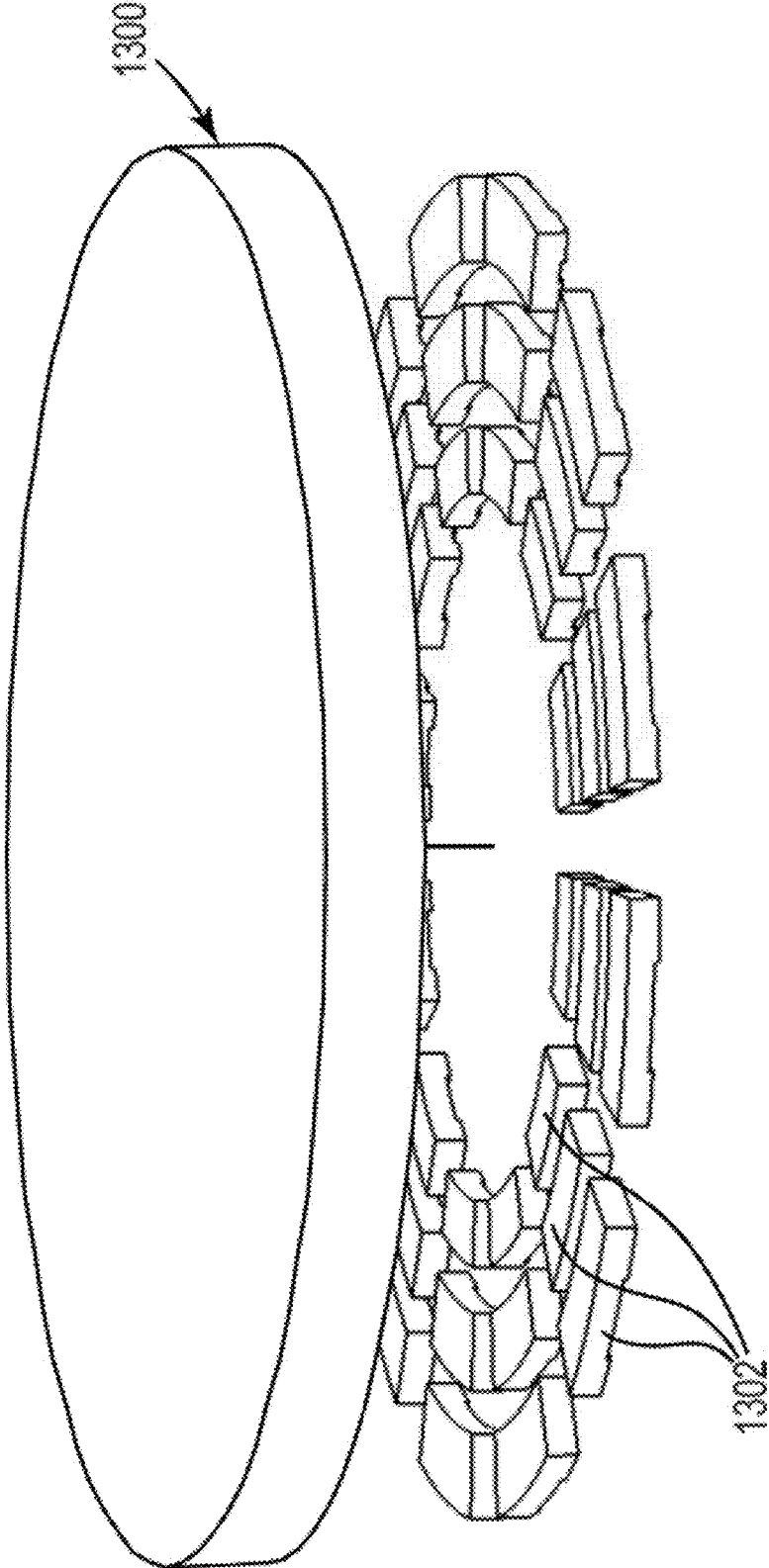


Fig. 55

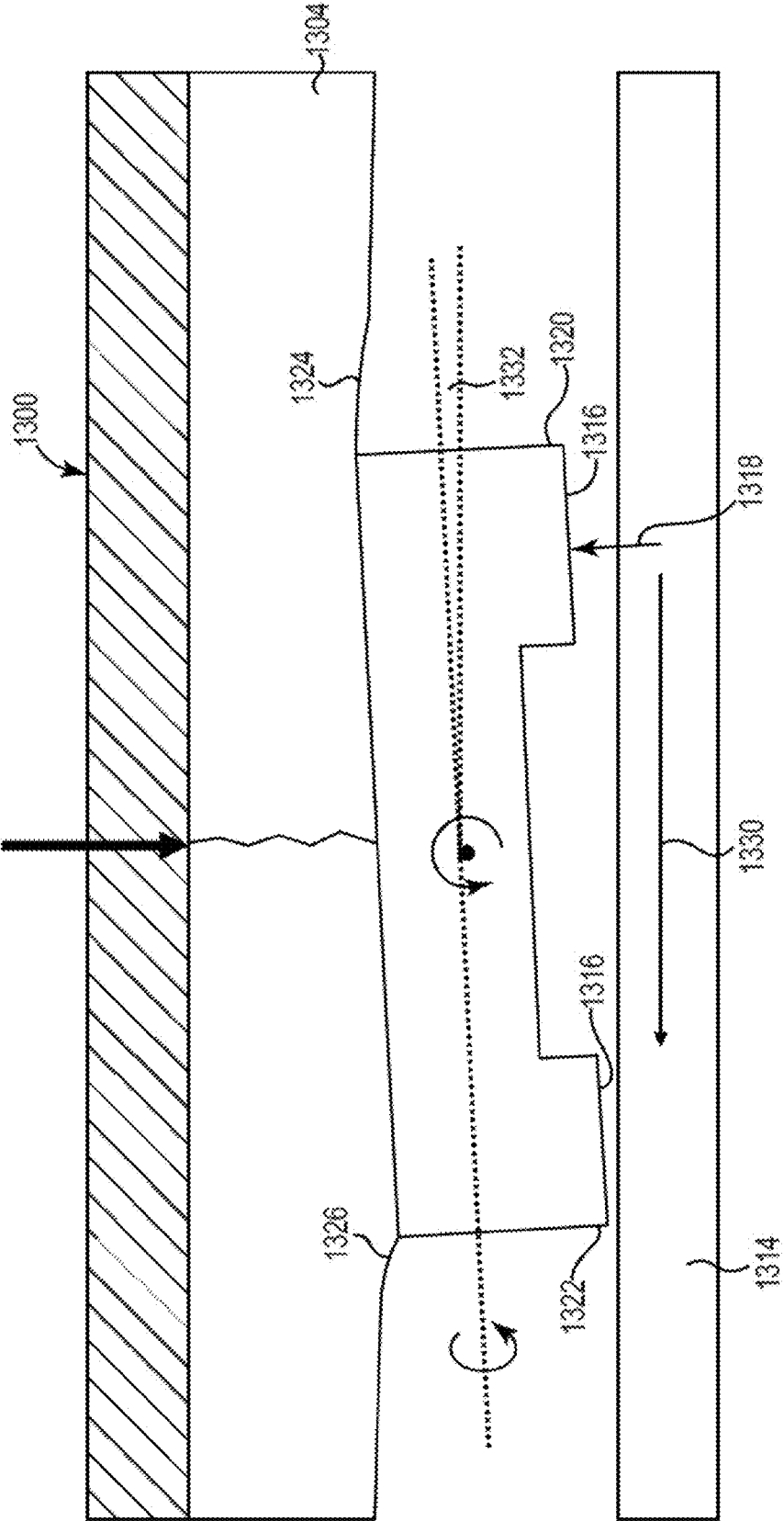


Fig. 56

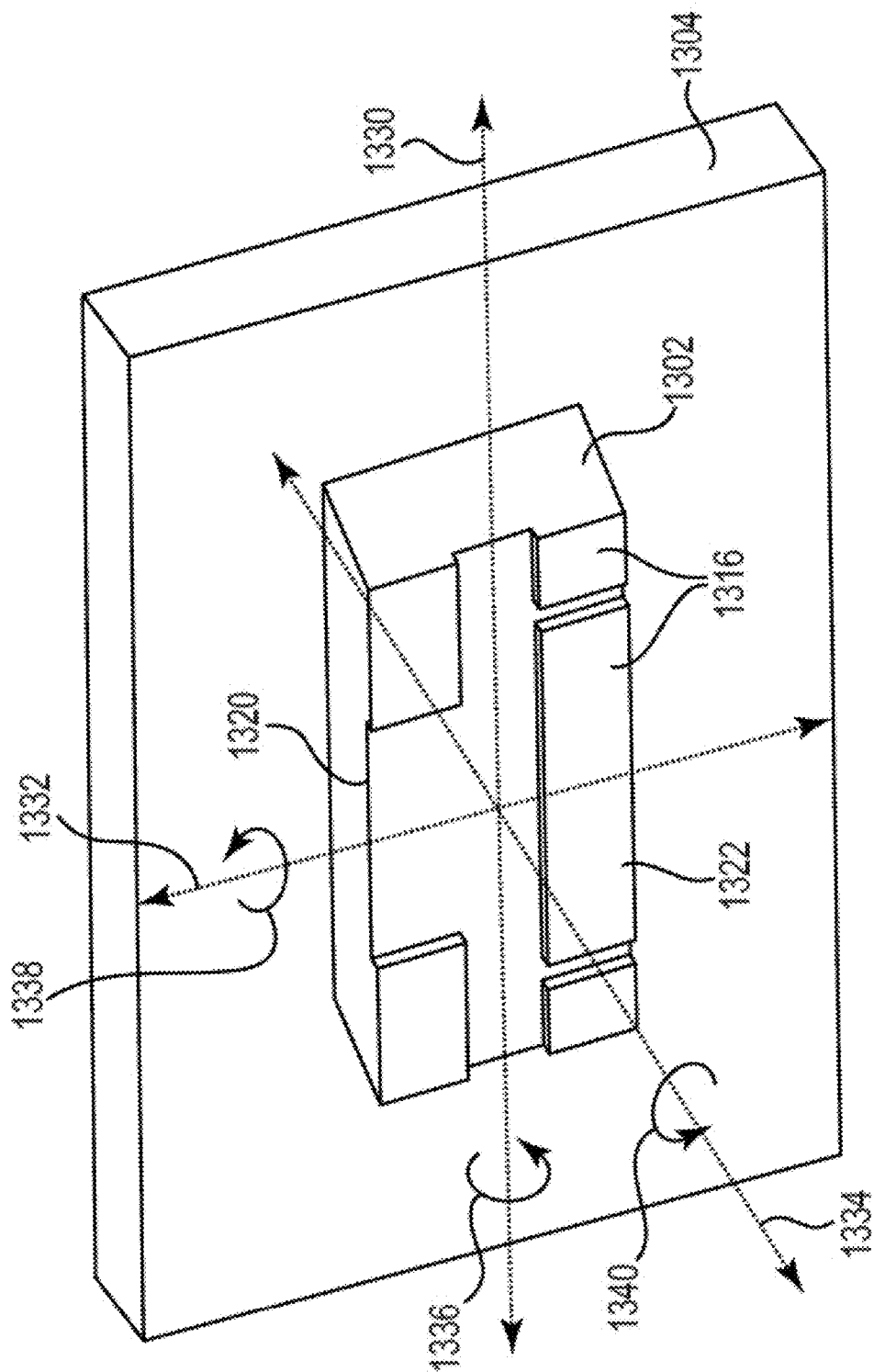


Fig. 57

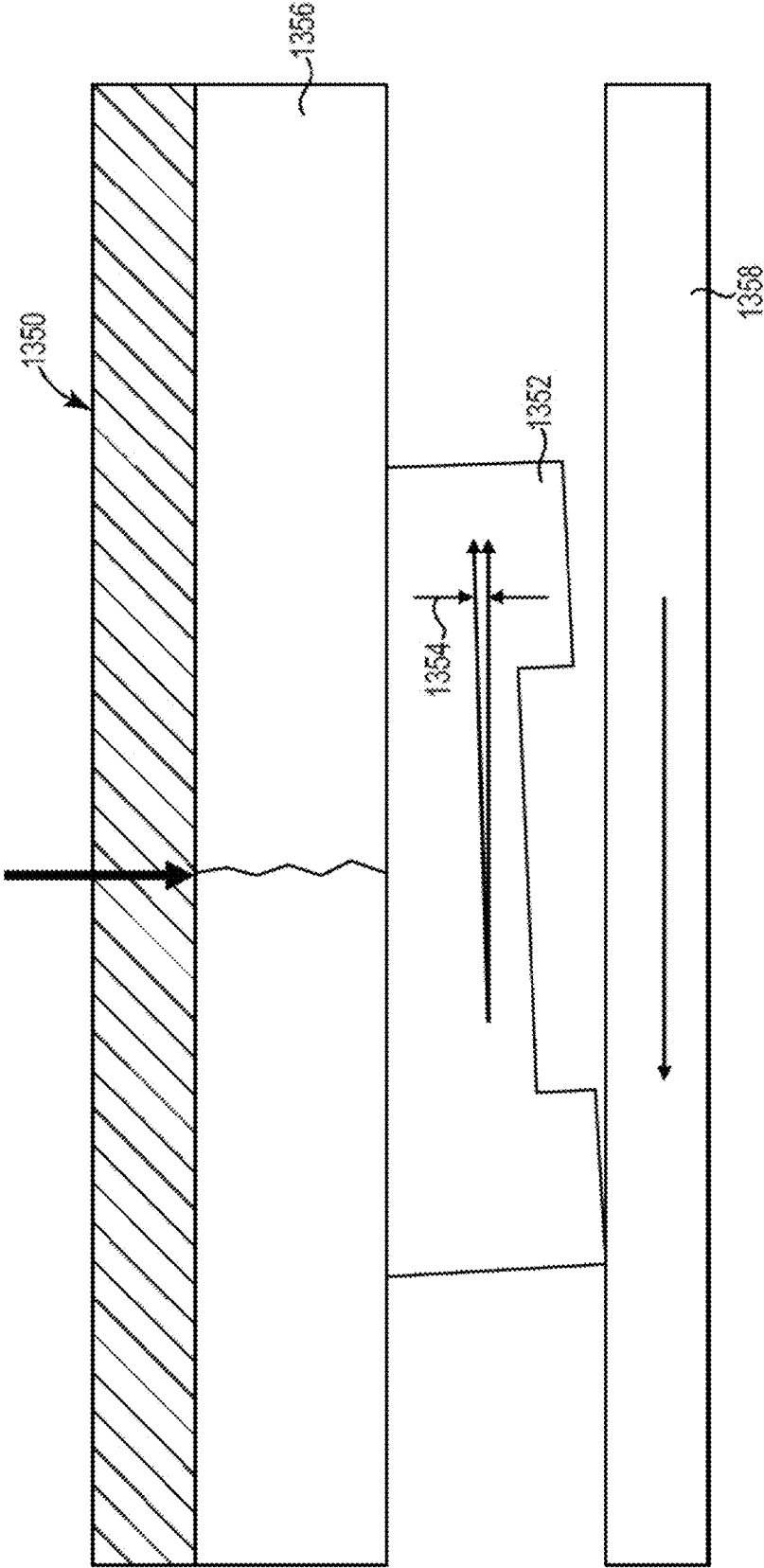


Fig. 58

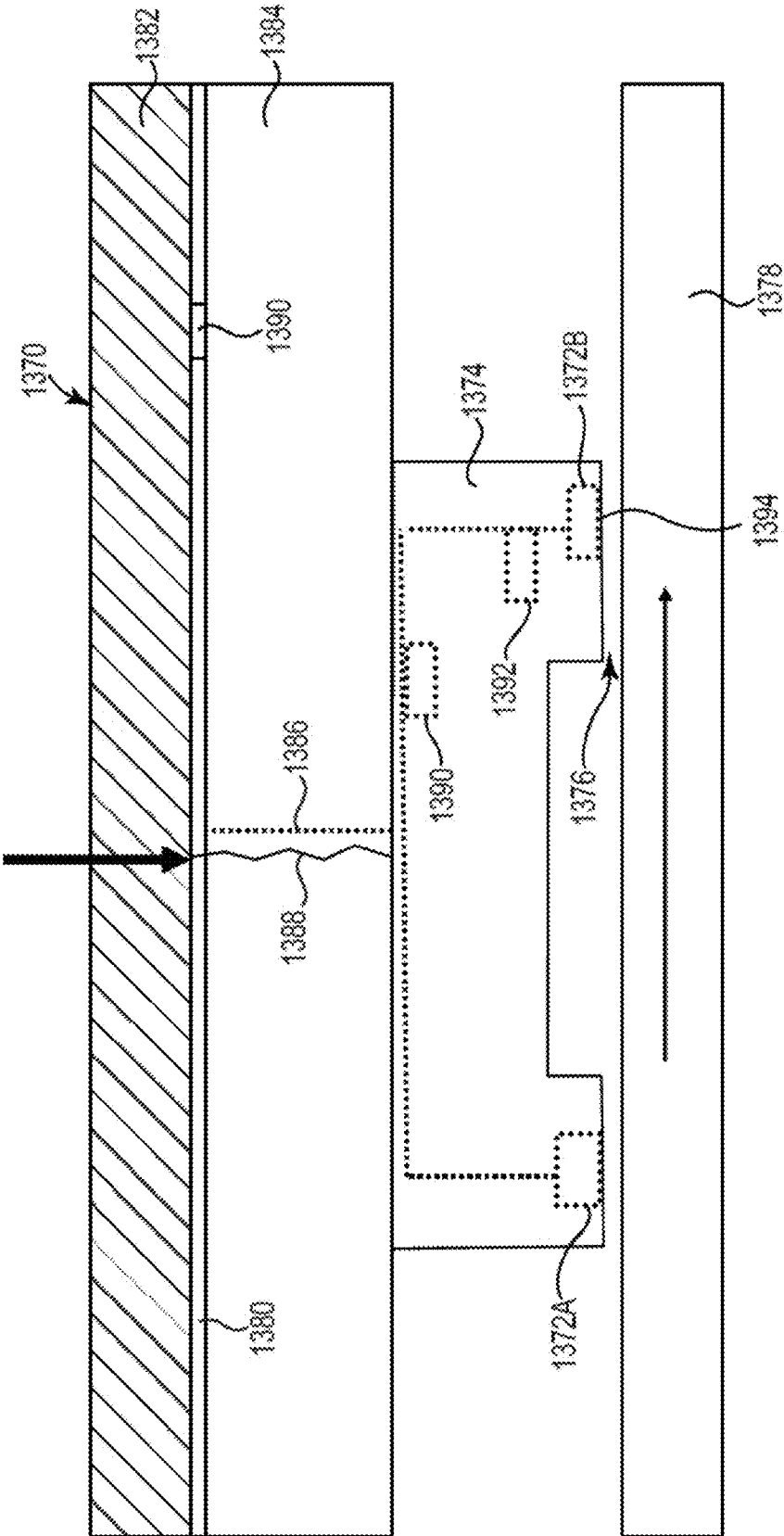


Fig. 59

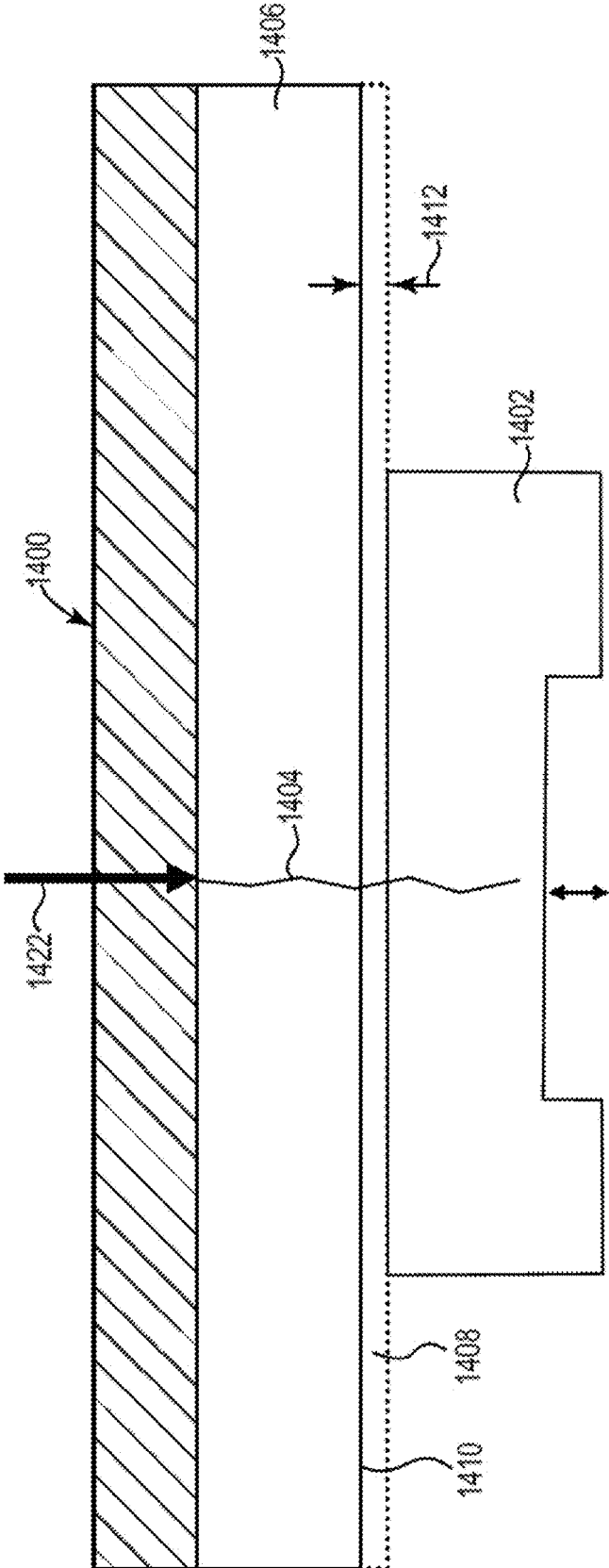


Fig. 60

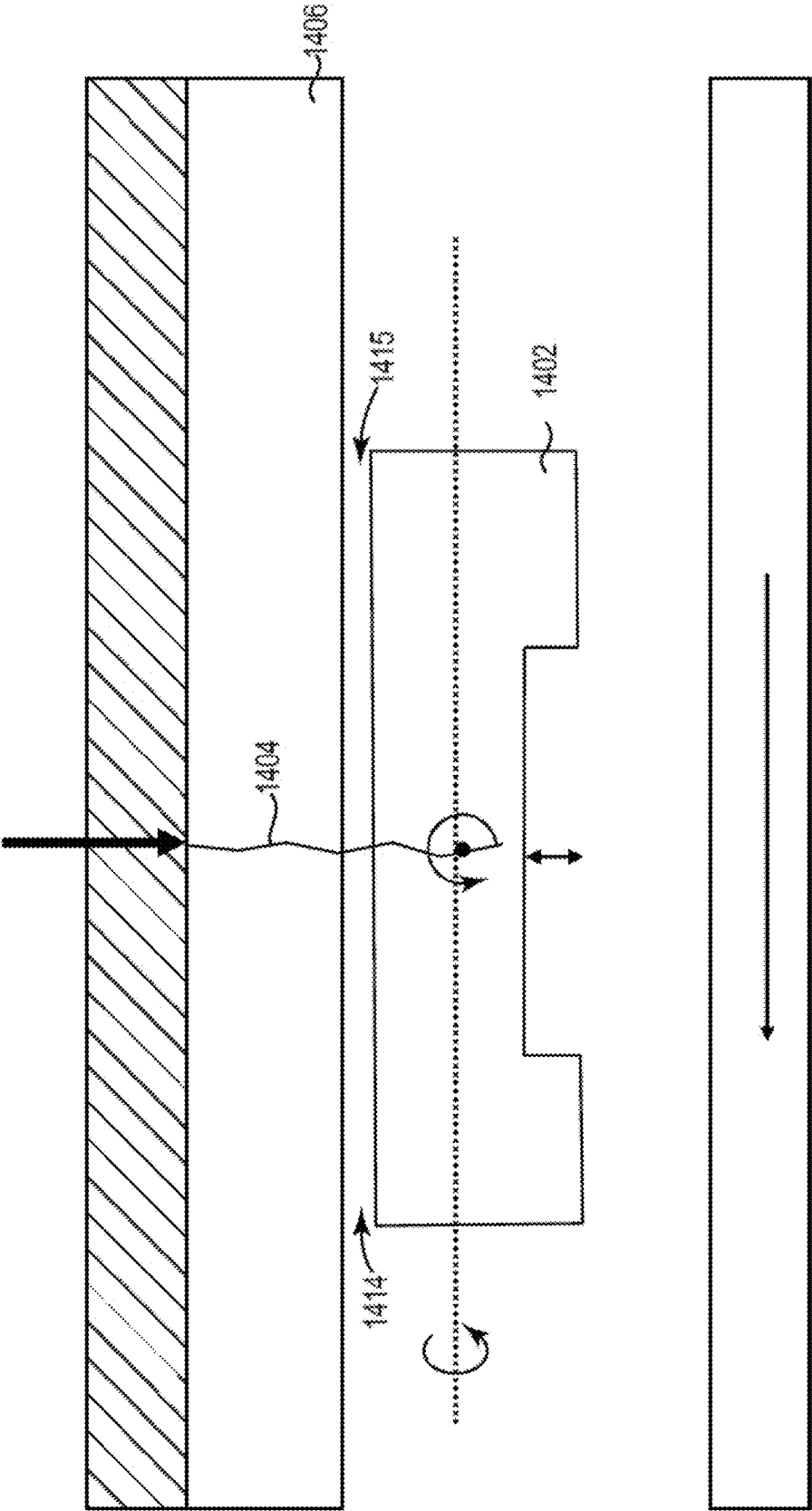


Fig. 61A

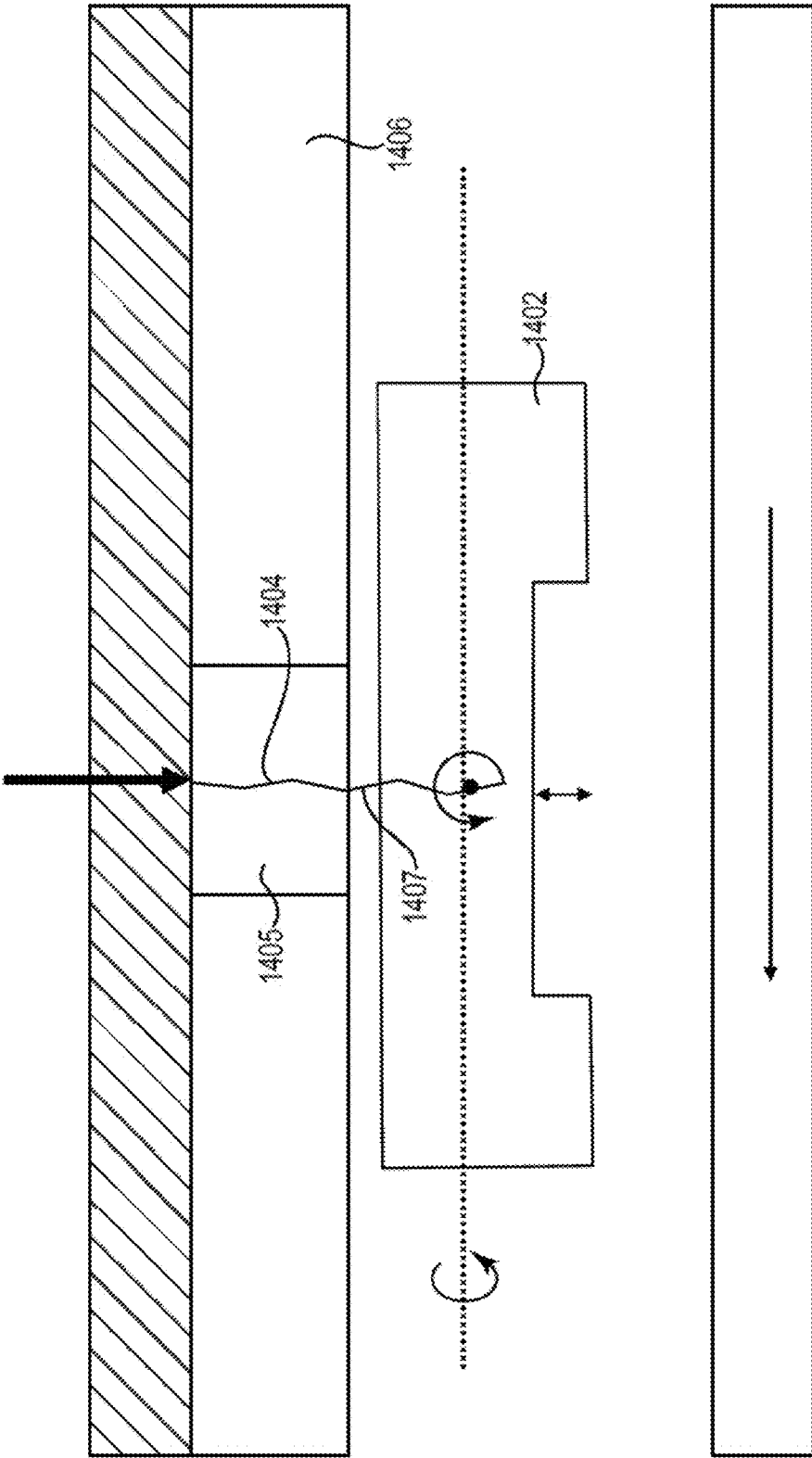


Fig. 61B

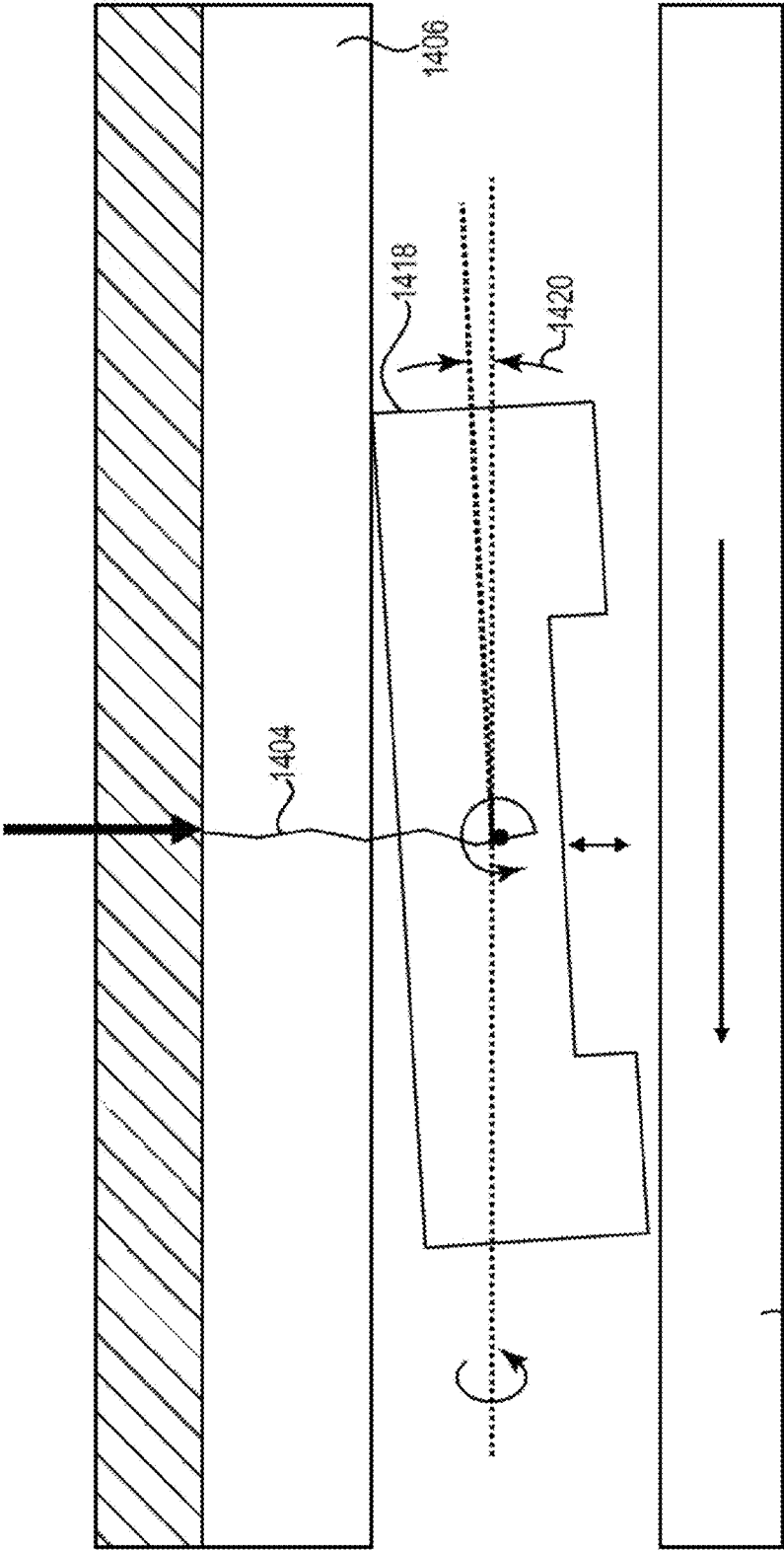


Fig. 62

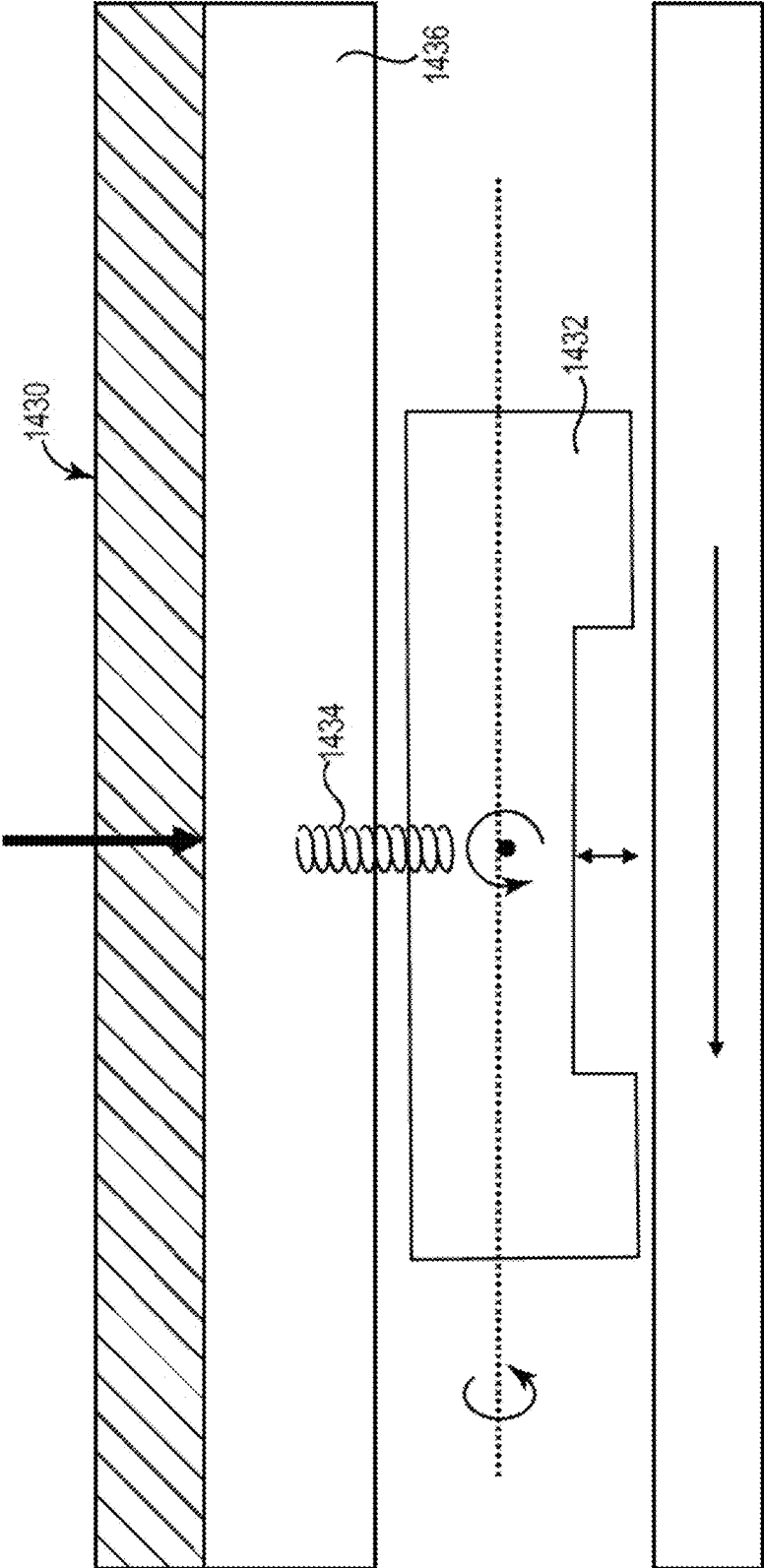


Fig. 63

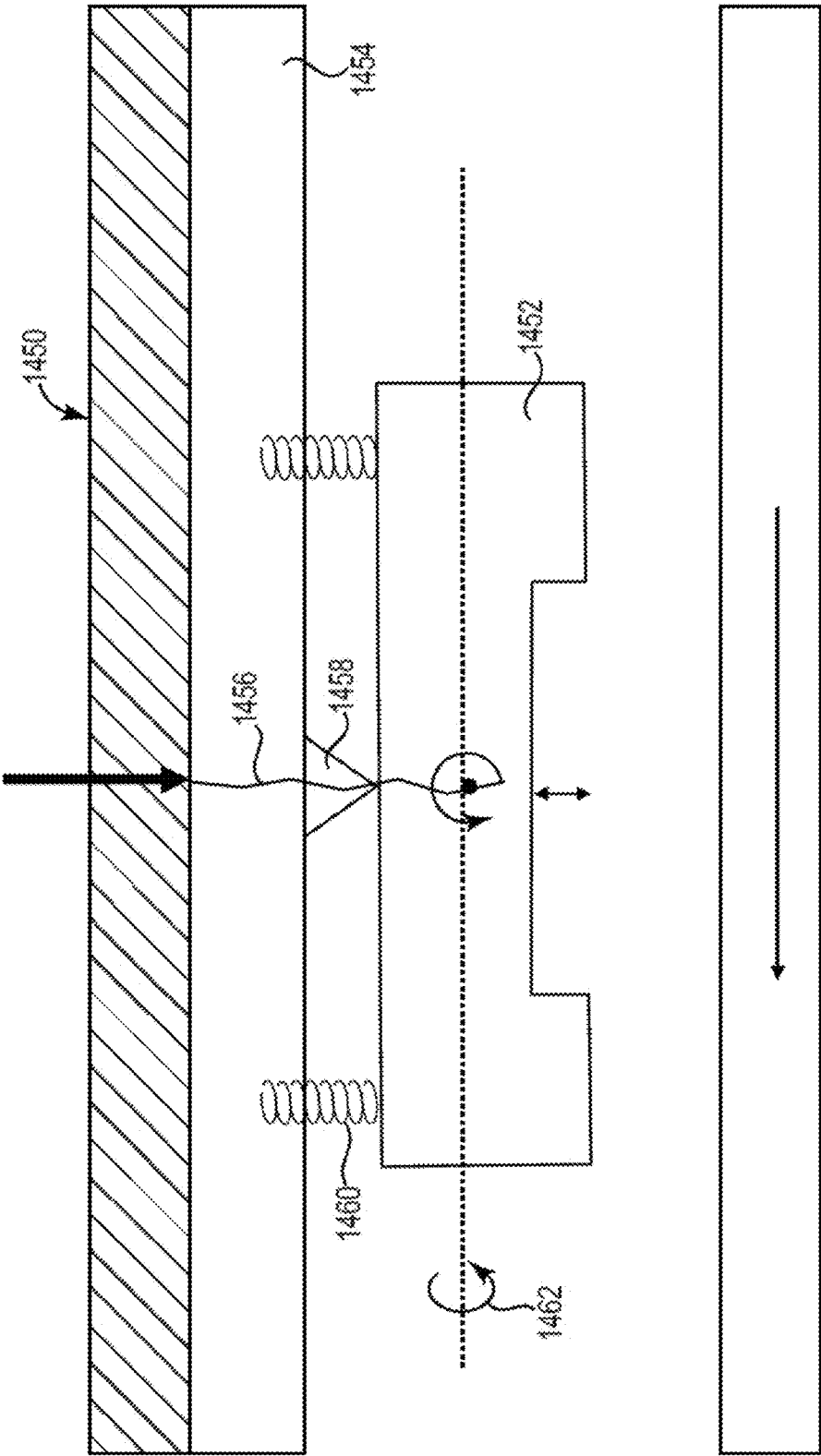


Fig. 64

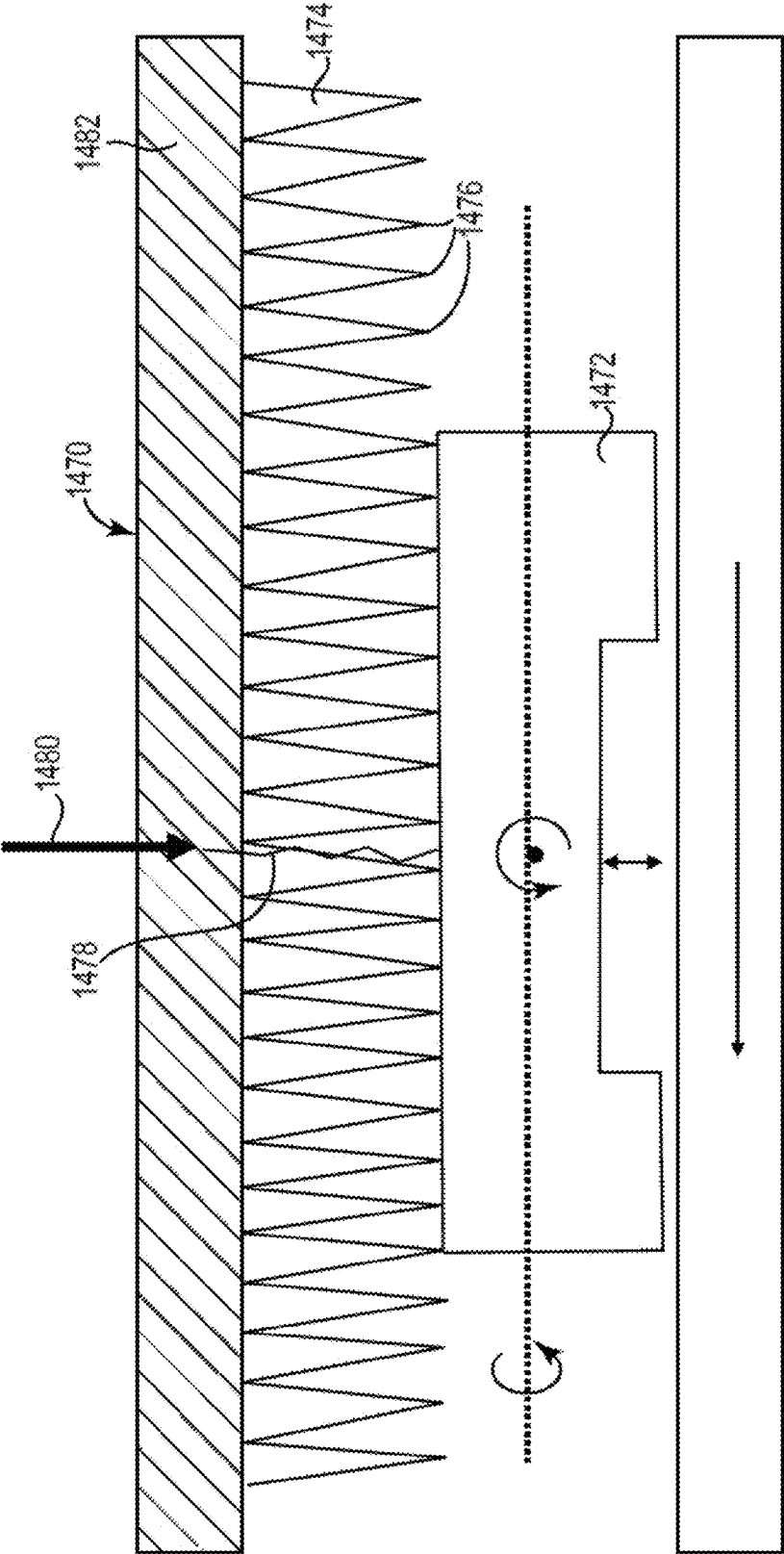


Fig. 65

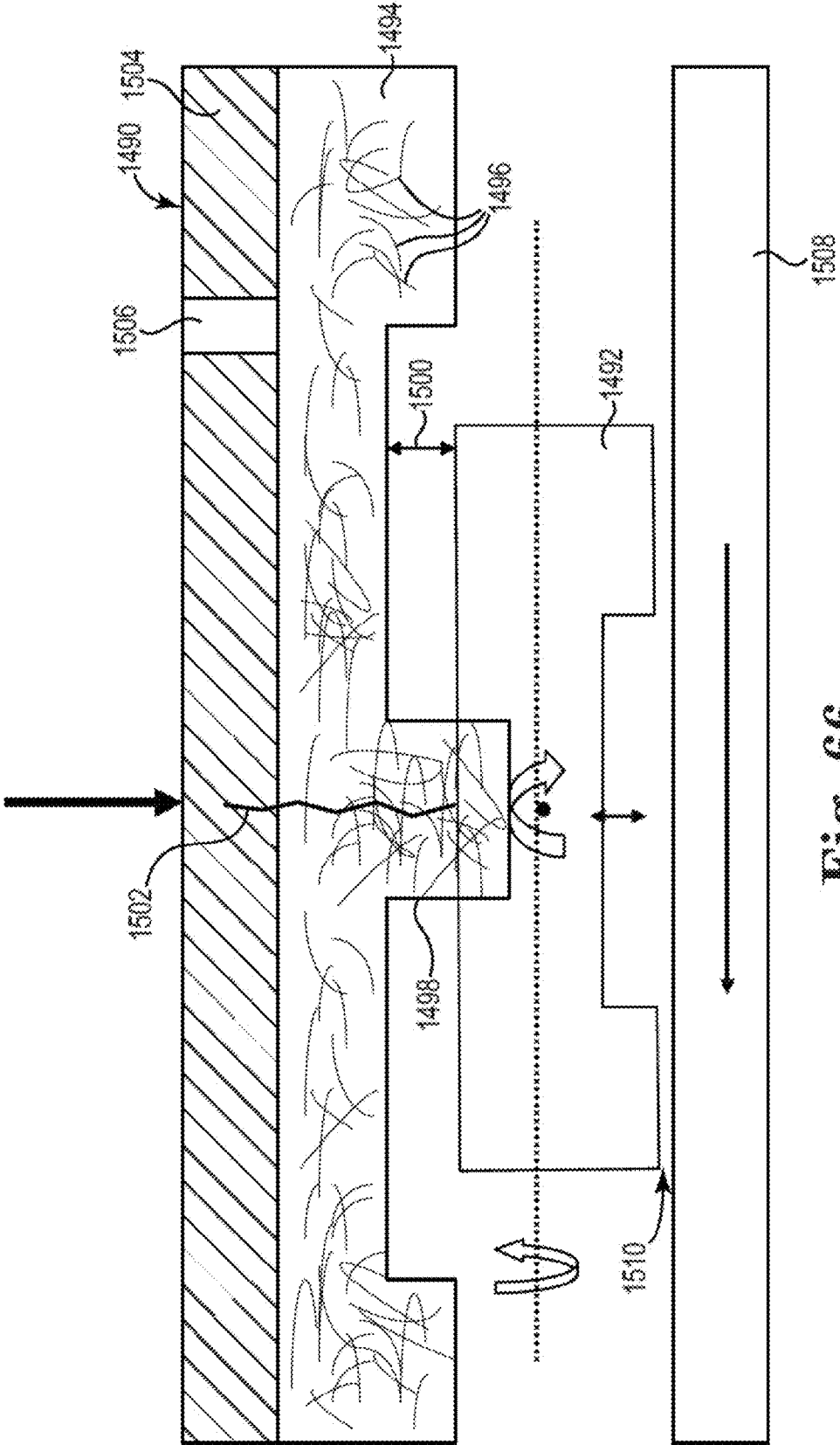


Fig. 66

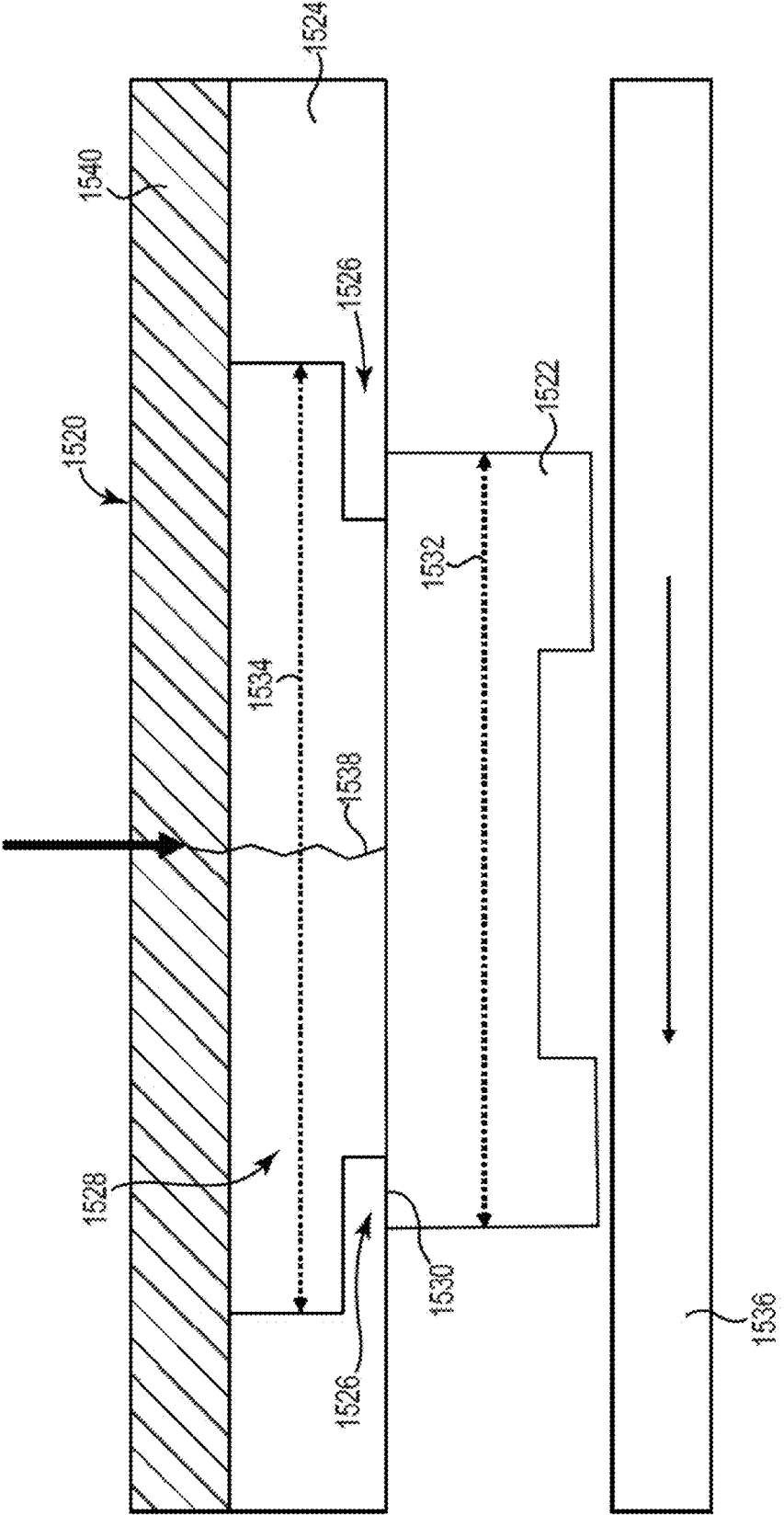


Fig. 67

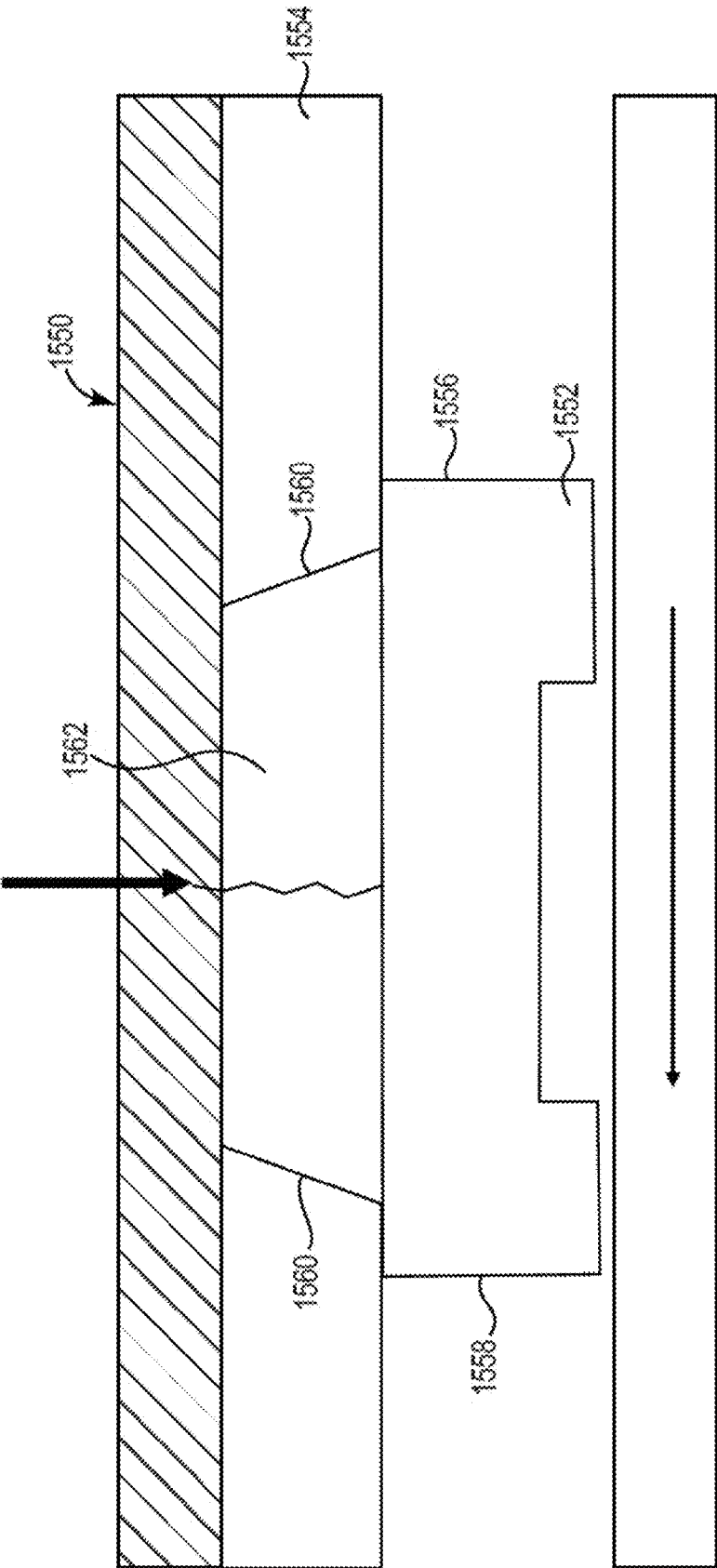


Fig. 68

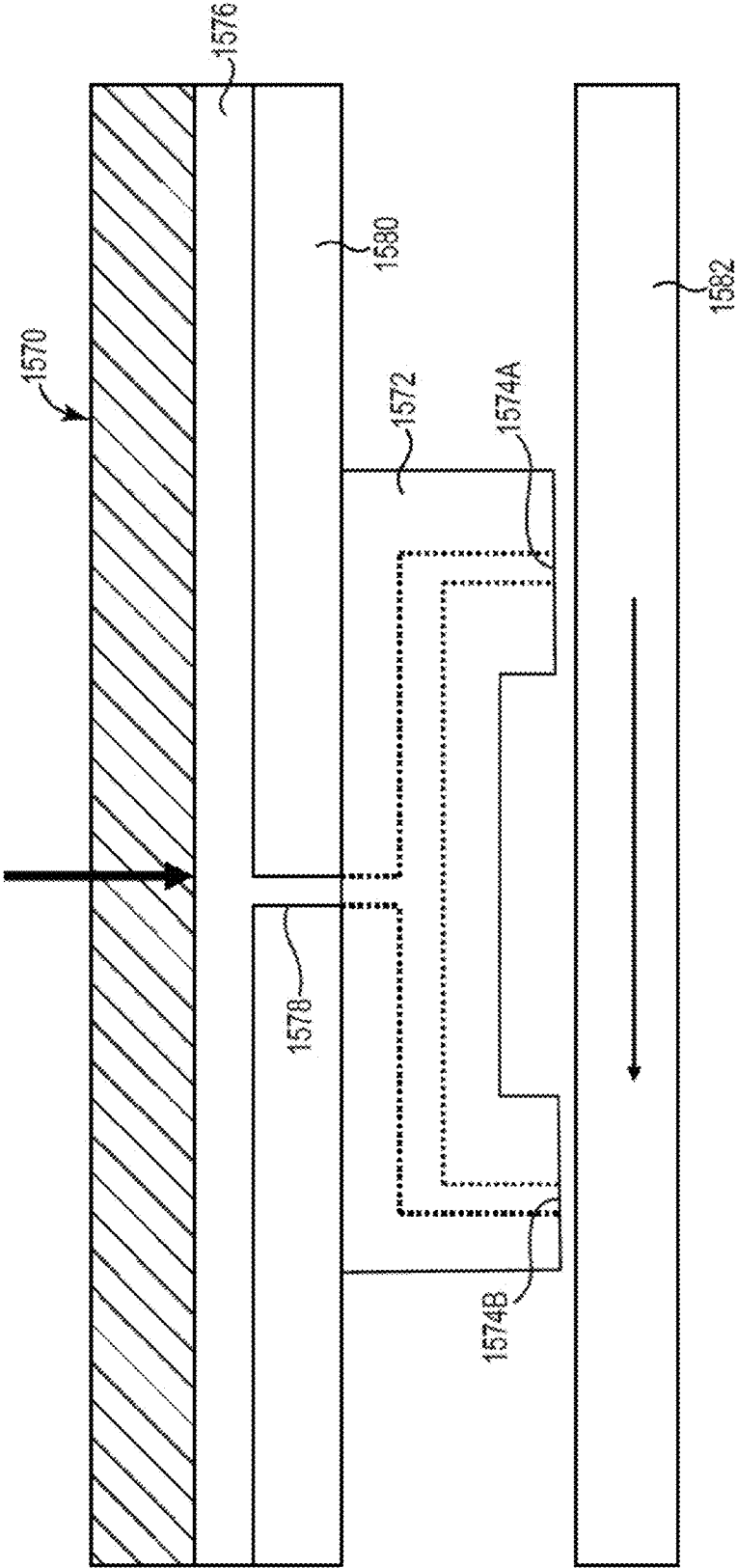


Fig. 69

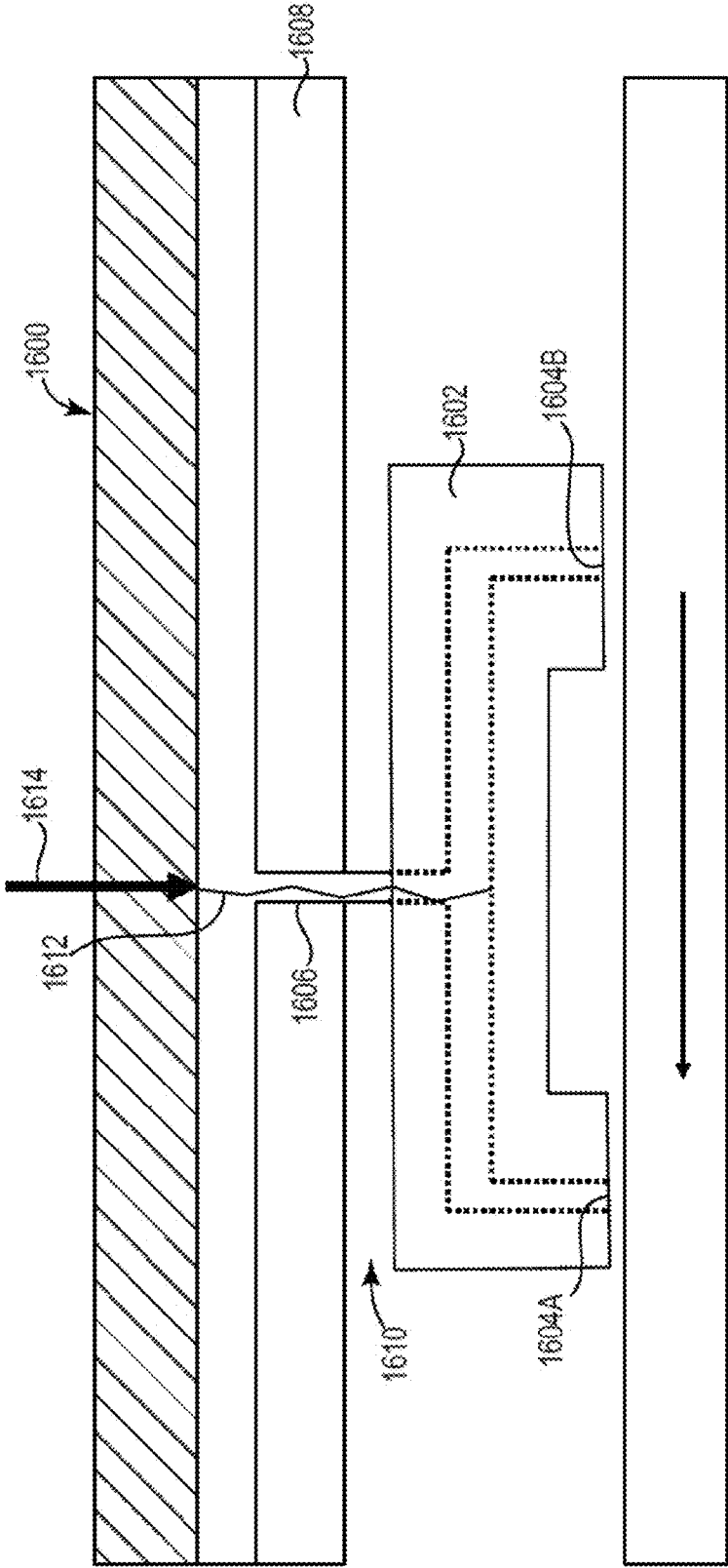


Fig. 70

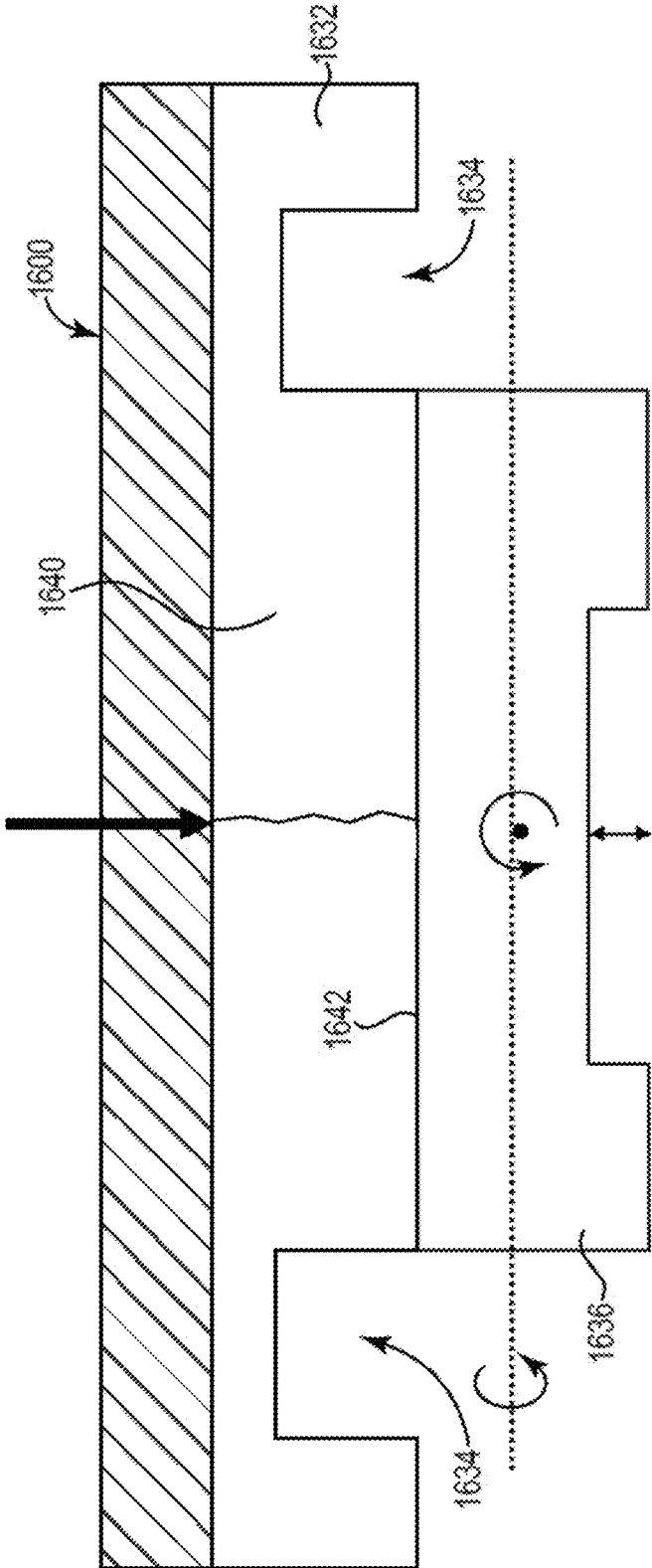


Fig. 71

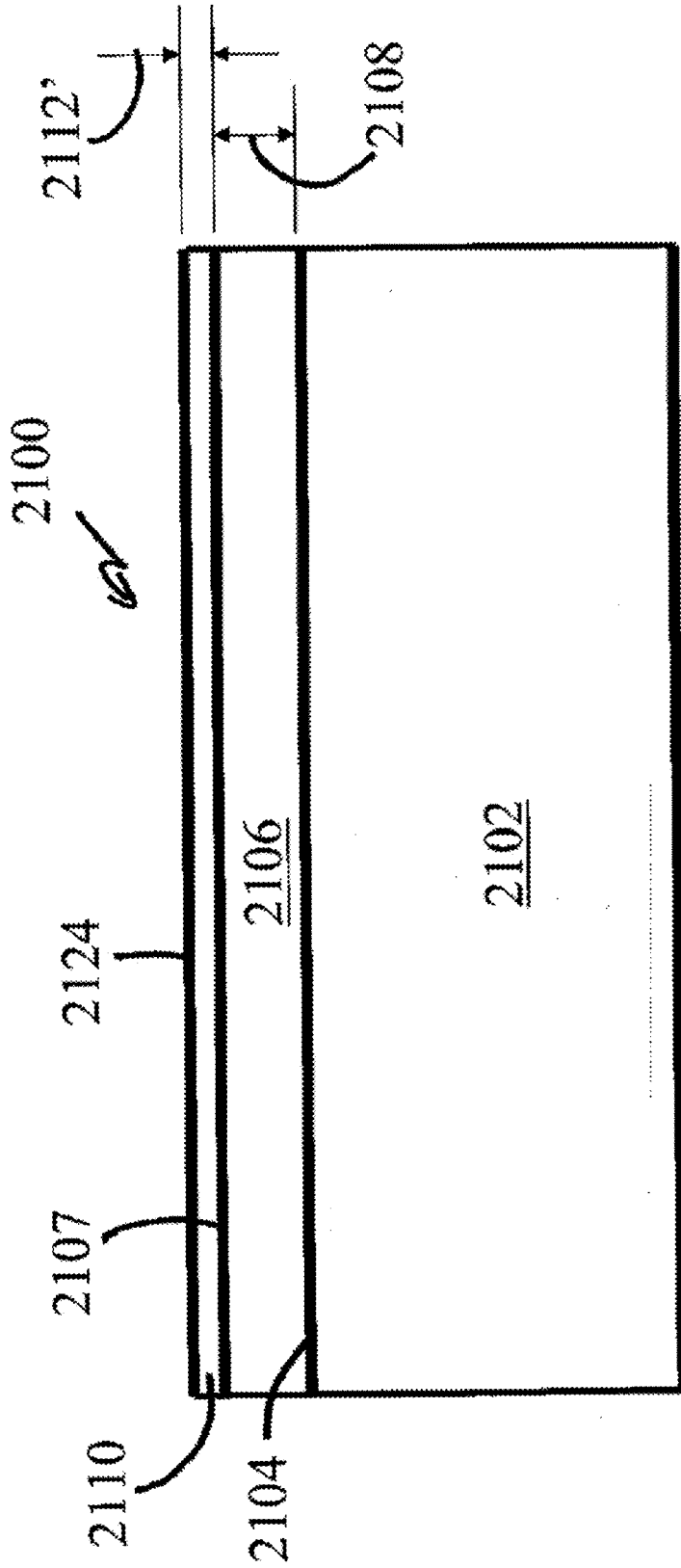


Figure 72

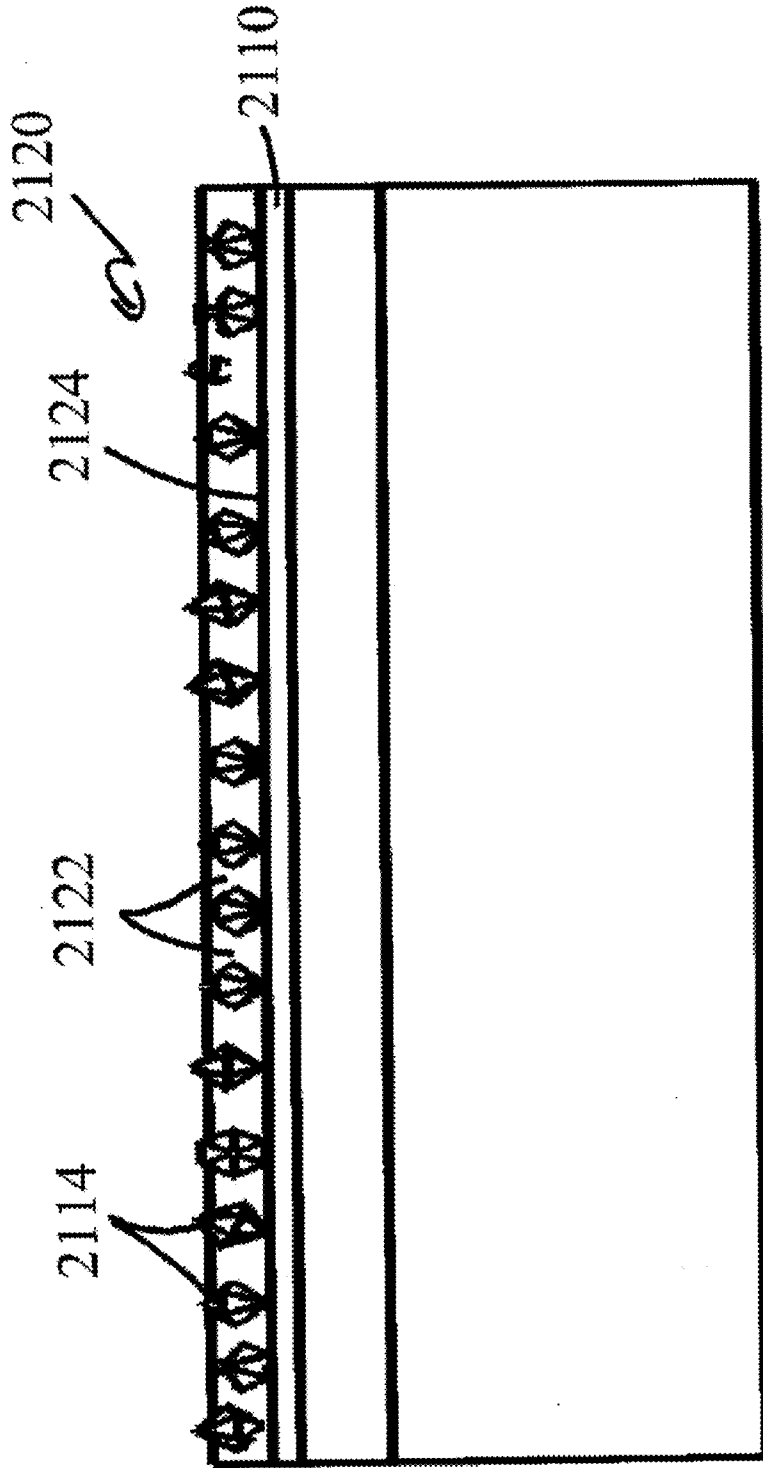


Figure 73

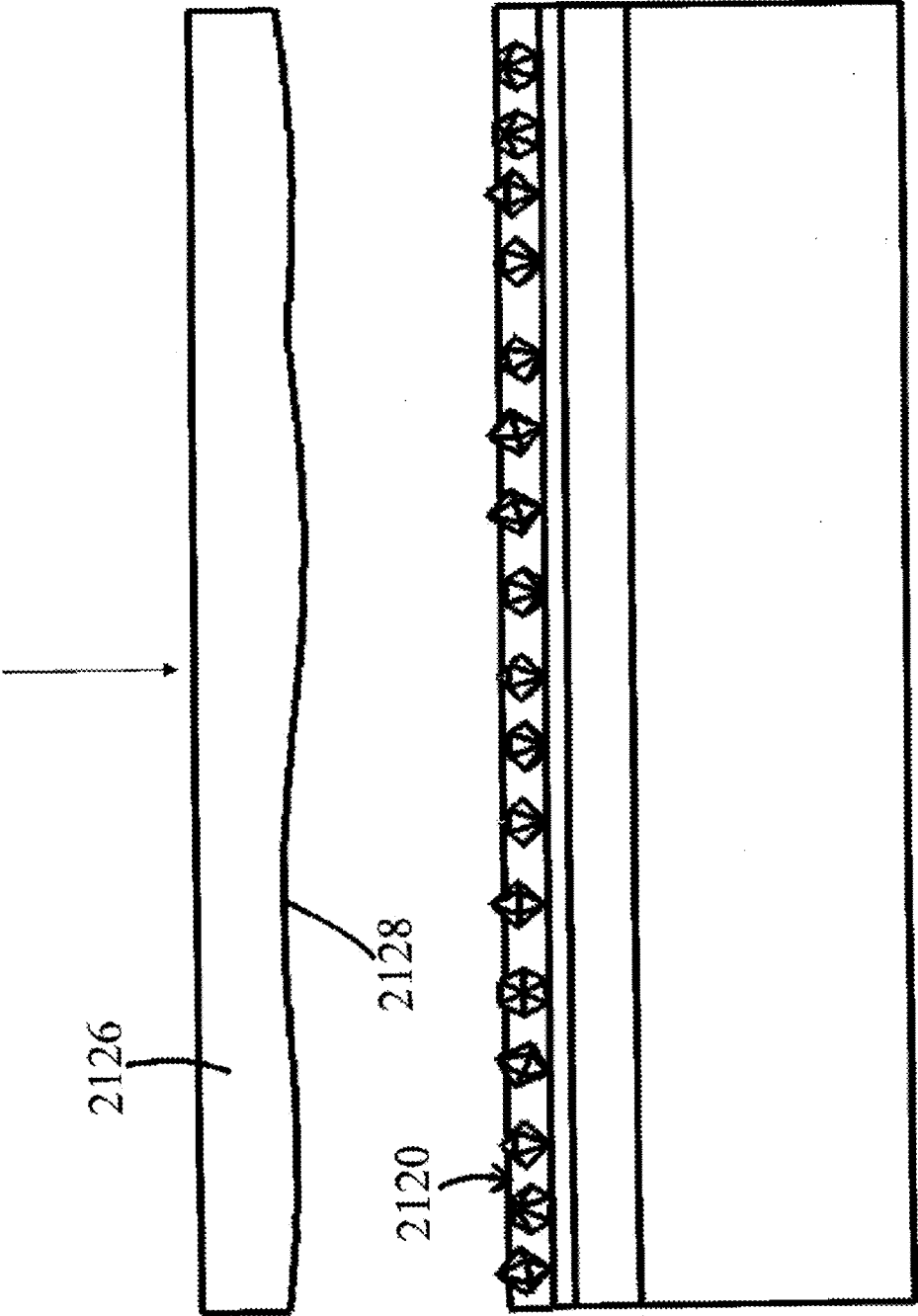


Figure 74

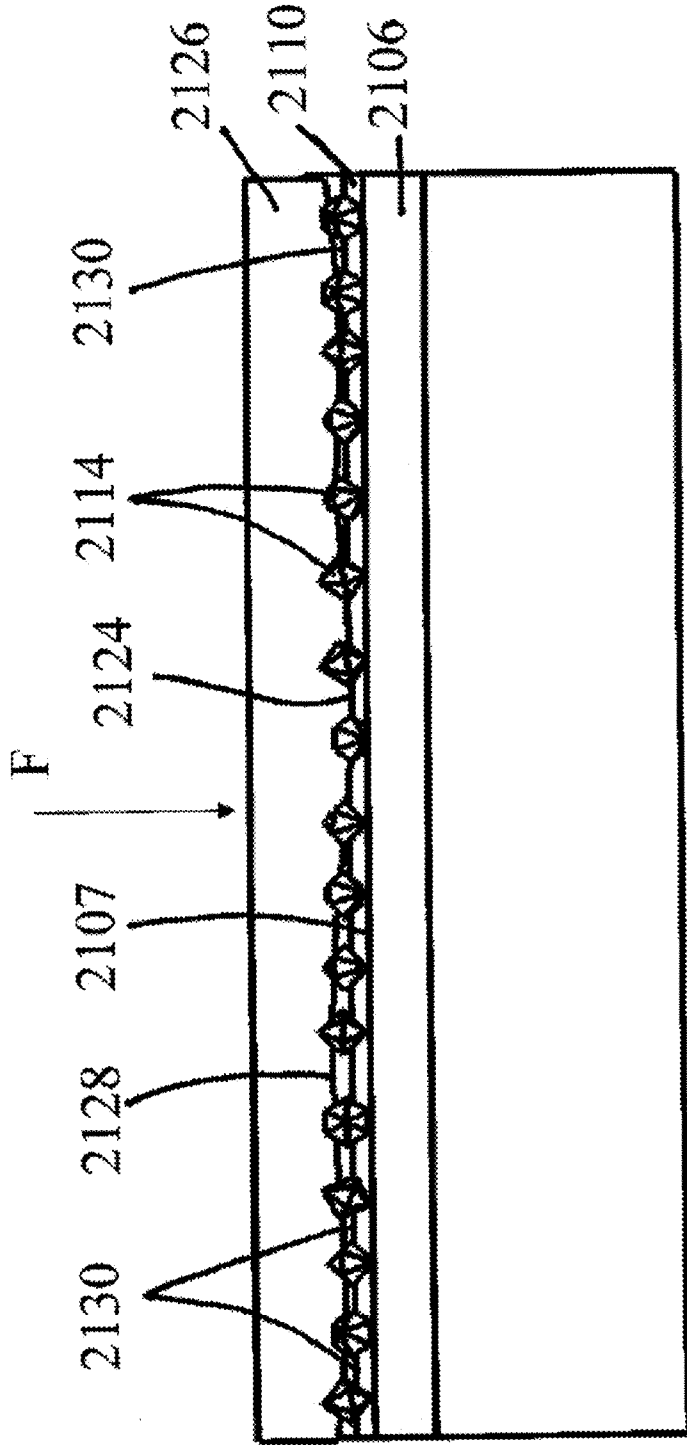


Figure 75

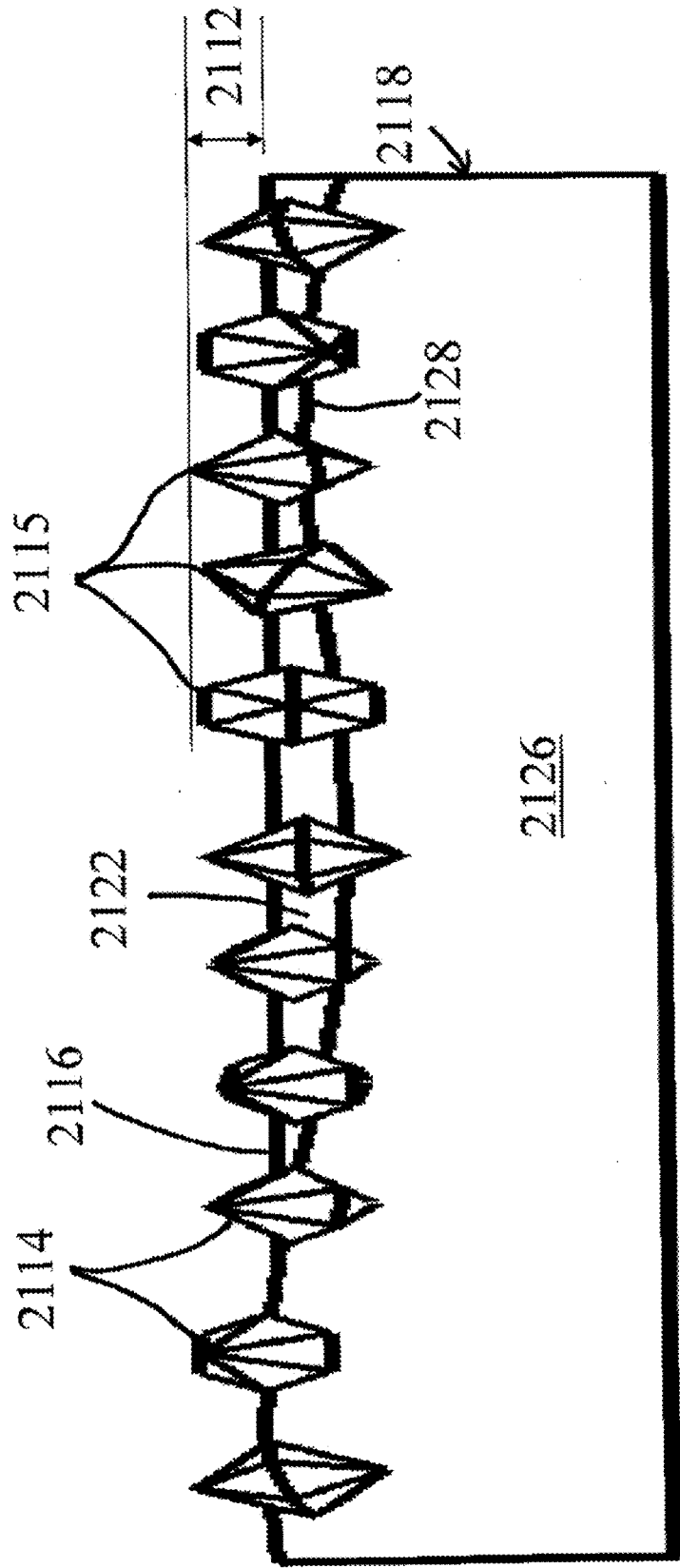


Figure 76A

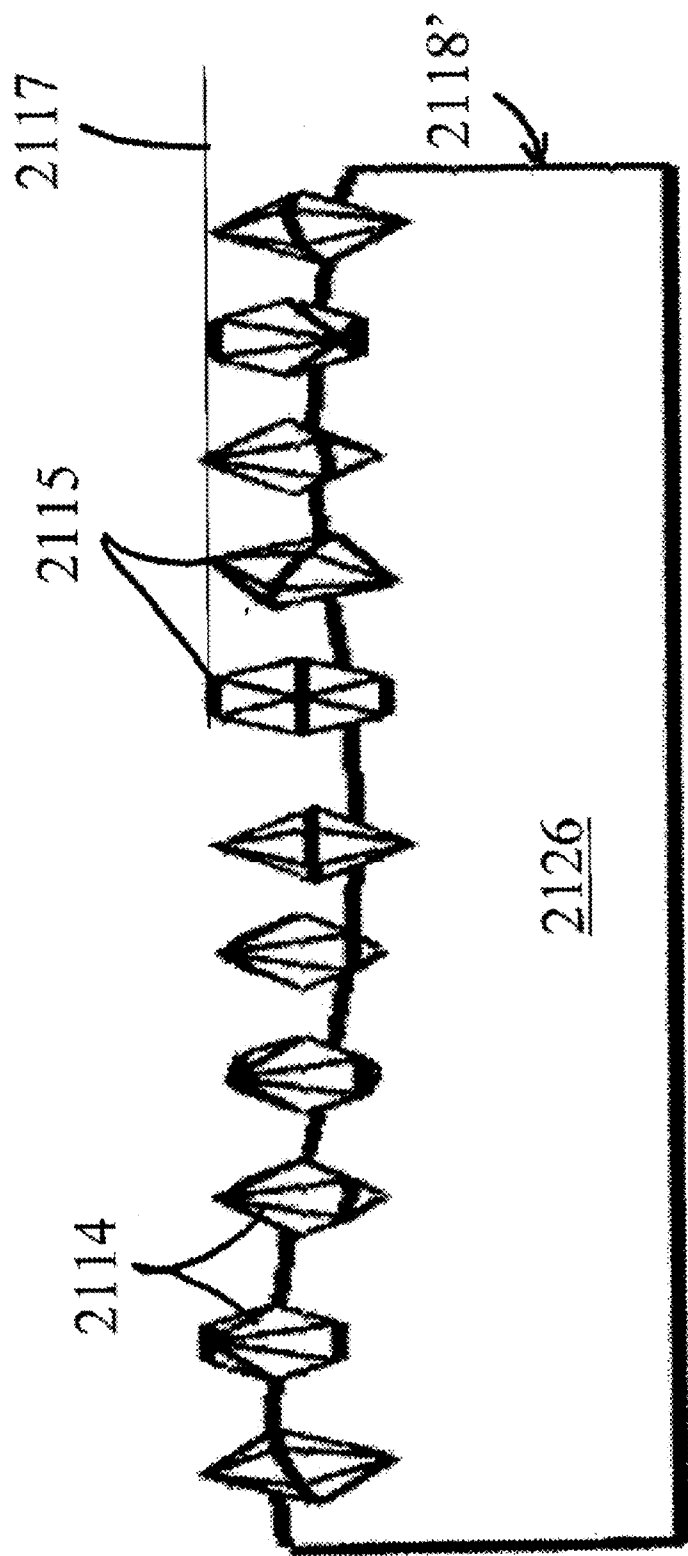


Figure 76B

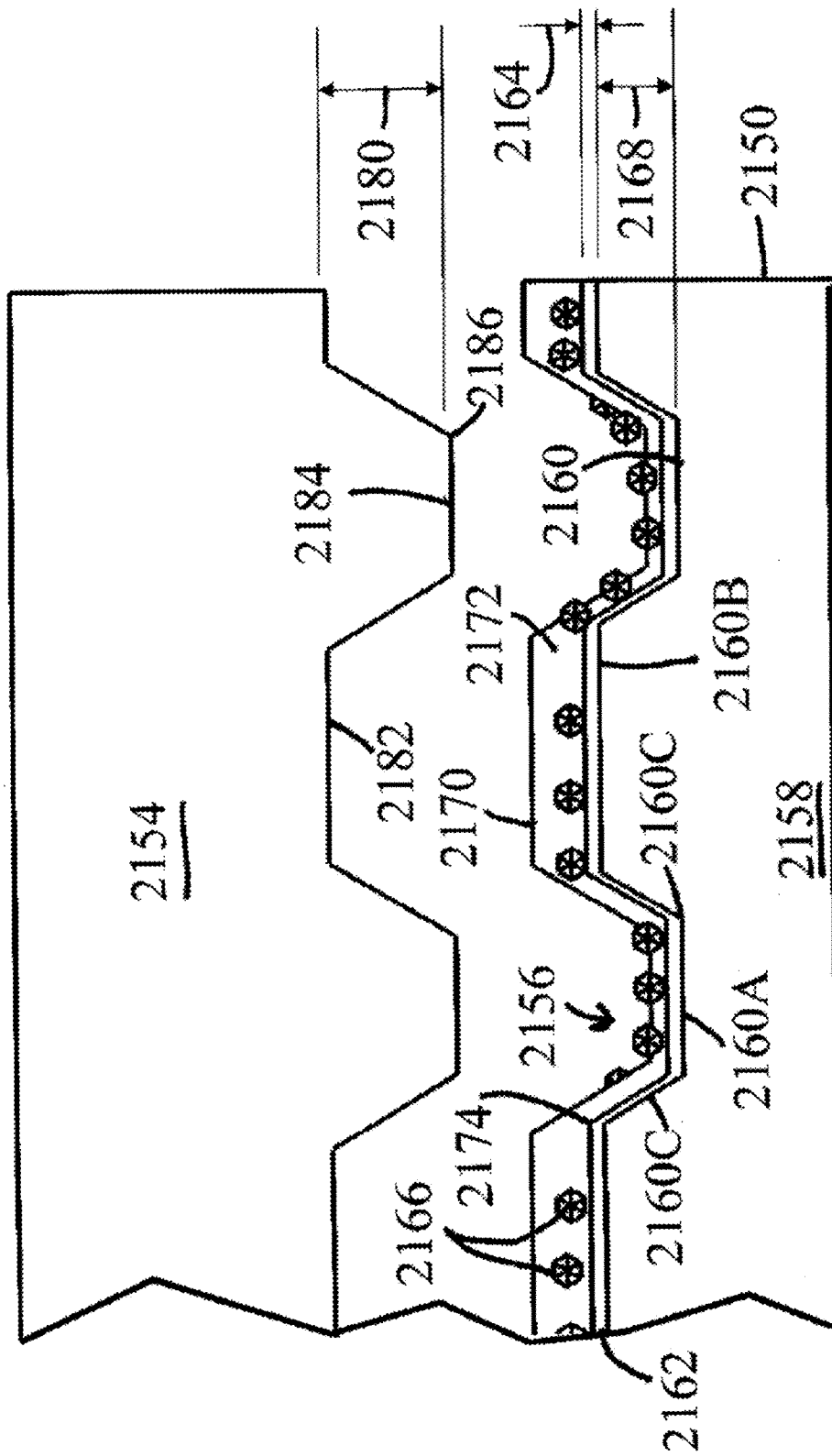


Figure 77

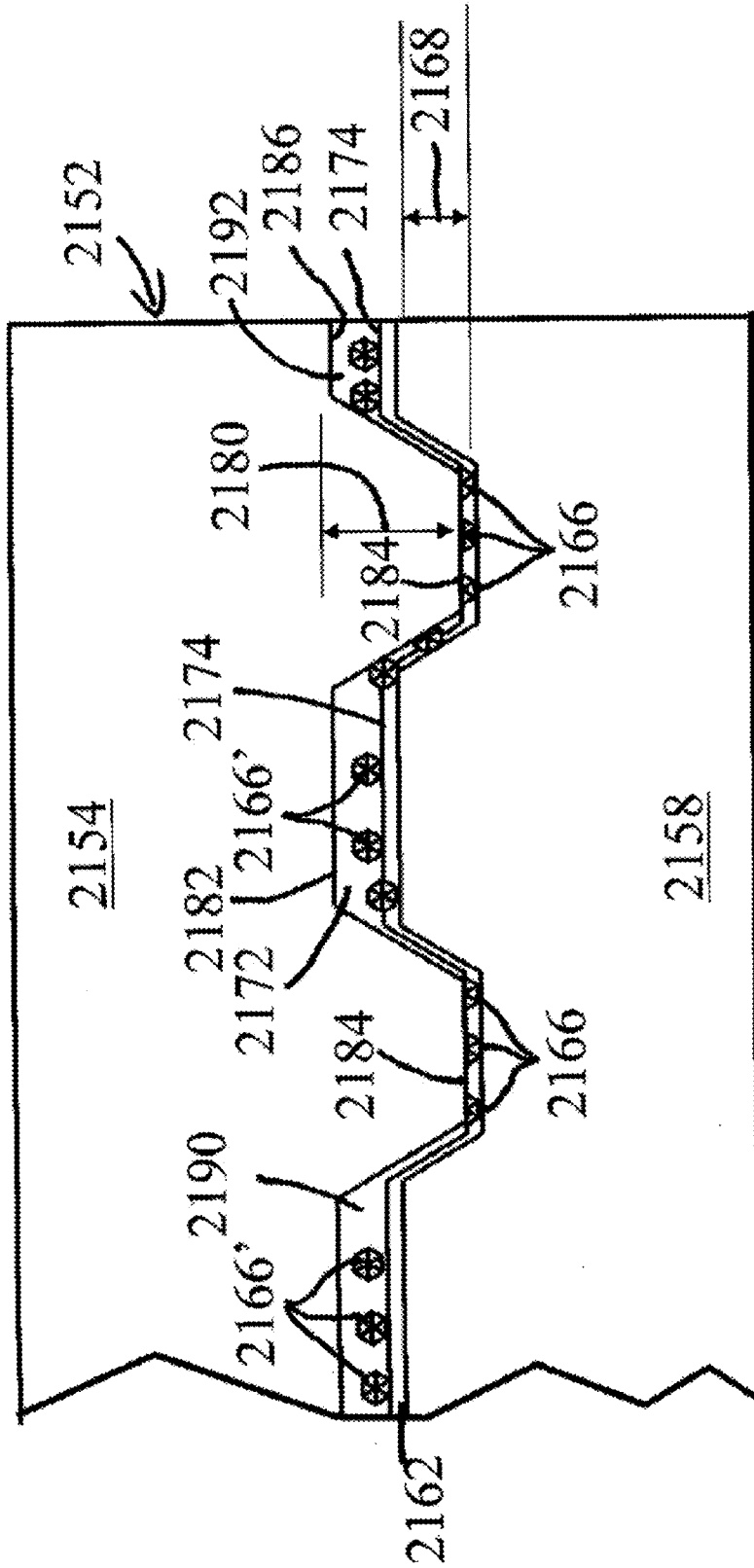


Figure 78

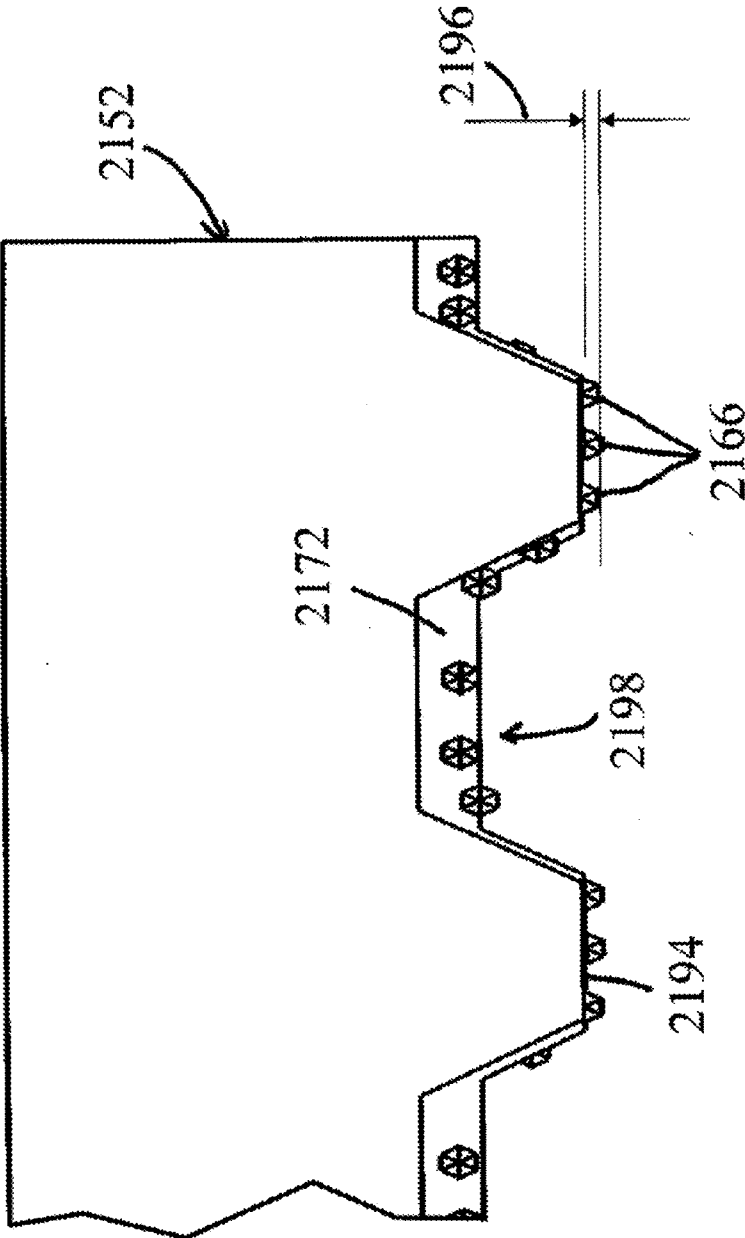


Figure 79

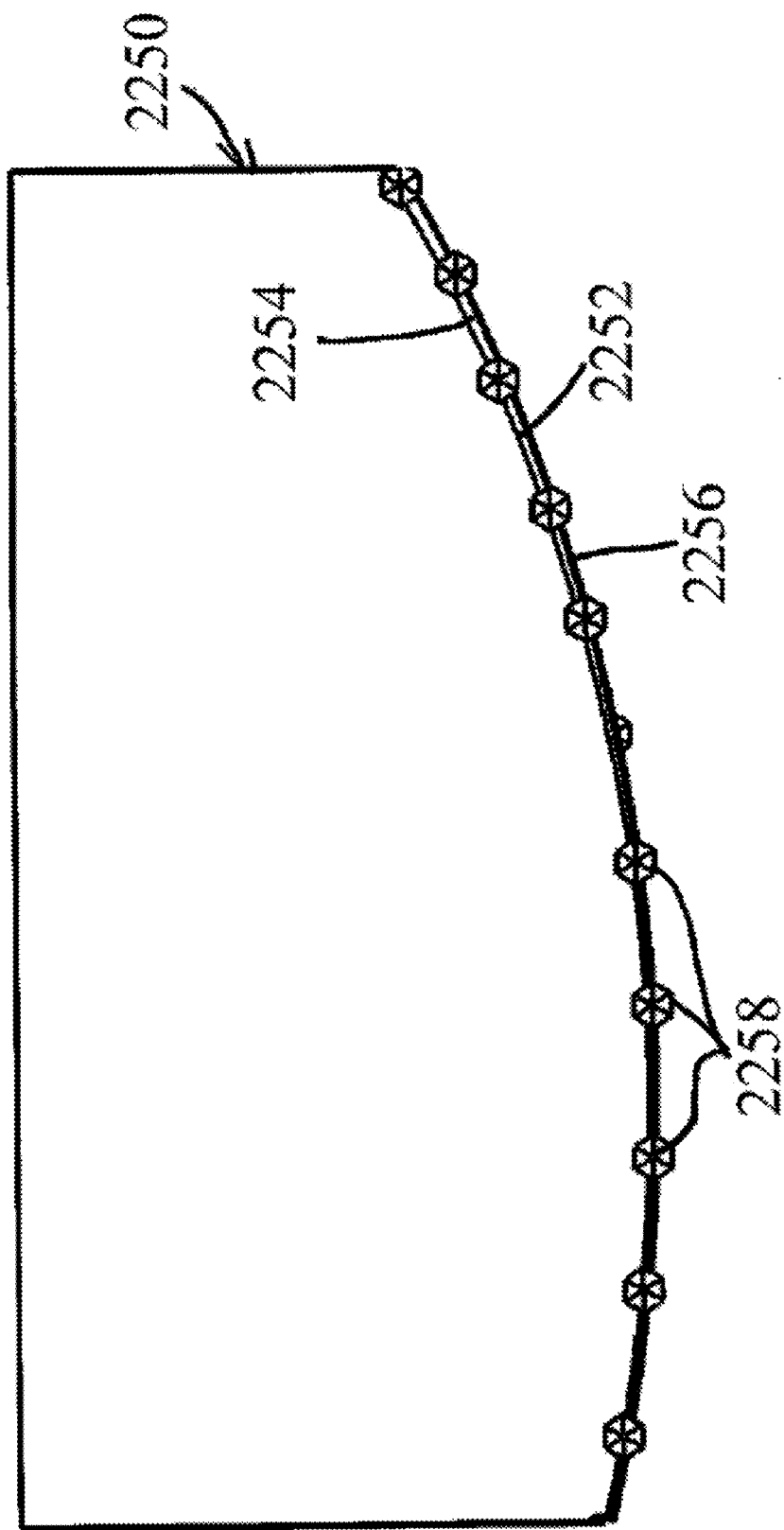


Figure 80

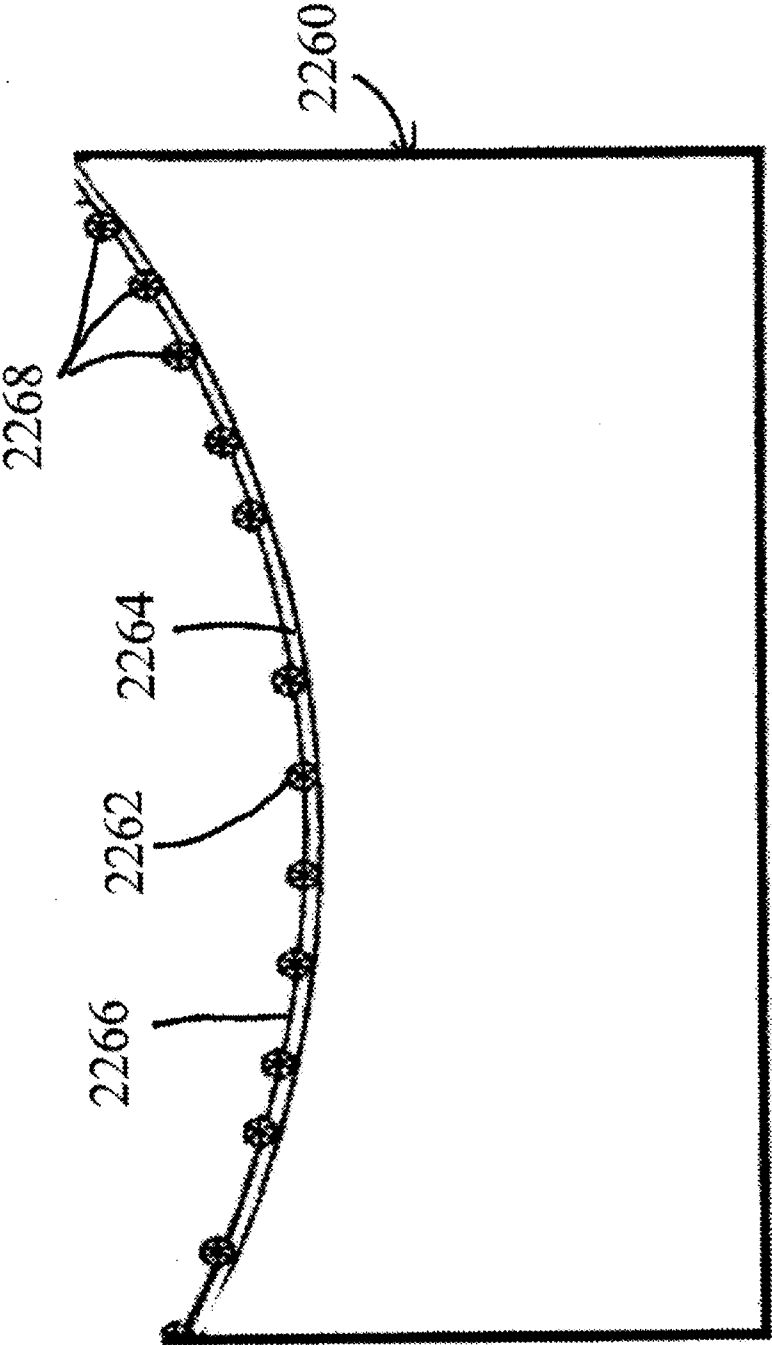


Figure 81

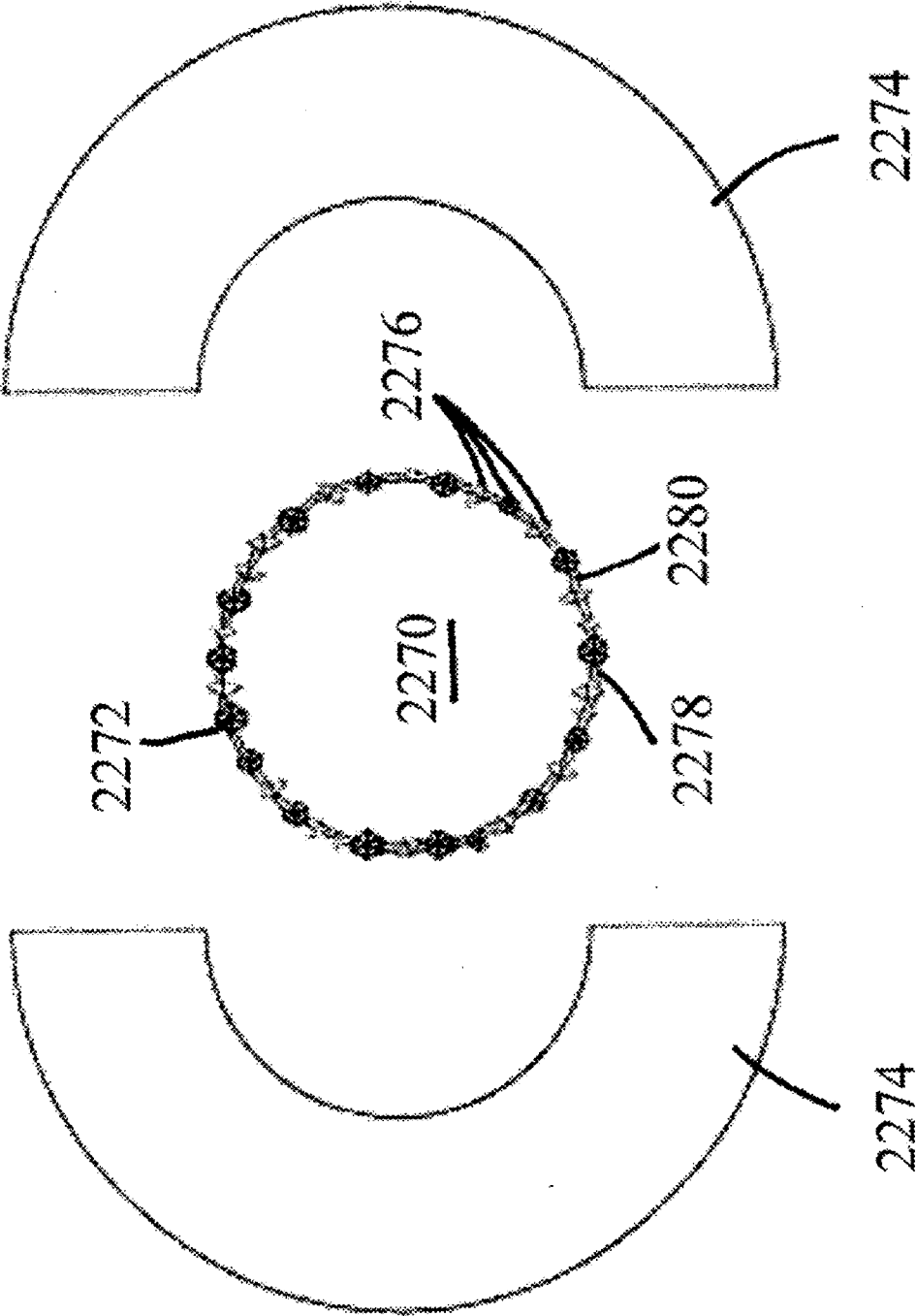


Figure 82

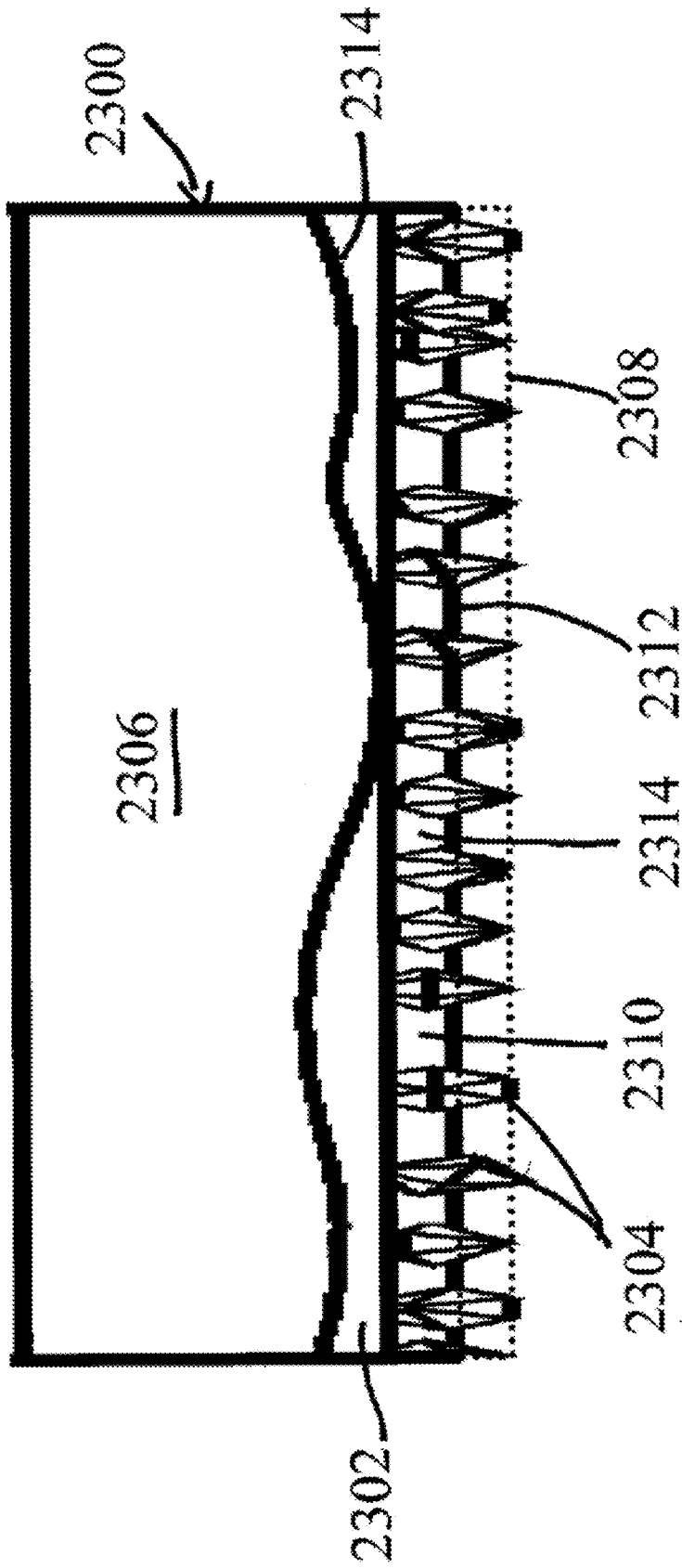


Figure 83

ABRASIVE ARTICLE

RELATED APPLICATIONS

[0001] The present application is a continuation of U.S. application Ser. No. 12/784,908, entitled Array of Abrasive Members with Resilient Support, filed May 21, 2010, which is a continuation-in-part of U.S. application Ser. No. 12/766,473, entitled Abrasive Article with Array of Gimbalbed Abrasive Members and Method of Use, filed Apr. 23, 2010, which claims the benefit of U.S. Provisional Patent Application Nos. 61/174,472 entitled Method and Apparatus for Atomic Level Lapping, filed Apr. 30, 2009; 61/187,658 entitled Abrasive Member with Uniform Height Abrasive Particles, filed Jun. 16, 2009; 61/220,149 entitled Constant Clearance Plate for Embedding Diamonds into Lapping Plates, filed Jun. 24, 2009; 61/221,554 entitled Abrasive Article with Array of Gimbalbed Abrasive Members and Method of Use, filed Jun. 30, 2009; 61/232,425 entitled Constant Clearance Plate for Embedding Abrasive Particles into Substrates, filed Aug. 8, 2009; 61/232,525 entitled Method and Apparatus for Ultrasonic Polishing, filed Aug. 10, 2009; 61/248,194 entitled Method and Apparatus for Nano-Scale Cleaning, filed Oct. 2, 2009; 61/267,031 entitled Abrasive Article with Array of Gimbalbed Abrasive Members and Method of Use, entitled Dec. 5, 2009; and 61/267,030 entitled Dressing Bar for Embedding Abrasive Particles into Substrates, filed Dec. 5, 2009, all of which are hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] The present disclosure is directed to an abrasive article including a flexible backing supported by an adhesive layer including load bearing particles and an adhesive matrix. At least a portion of the load bearing particles is substantially enveloped in the adhesive matrix and is in contact with the flexible backing.

BACKGROUND OF THE INVENTION

[0003] Semiconductor wafers are typically fabricated using photolithography, which is adversely affected by inconsistencies or unevenness in the wafer surface. This sensitivity is accentuated with the current drive toward smaller, more highly integrated circuit designs. After each layer of the circuit is etched on the wafer, an oxide layer is put down as the base for the next layer. Each layer of the circuit can create roughness and waviness to the wafer that is preferably removed before depositing the next circuit layer. For many semiconductor applications the chemical mechanical processing (“CMP”) is customized for each layer. A change in a single processing parameter, such as for example, pad design, slurry formulation, or pressure applied by the pad, can require the entire CMP process to be redesigned and recertified.

[0004] Magnetic media have similarly stringent planarization requirements as data densities approach 1 Terabyte/inch² (1 Tbit/in²) and beyond, especially on bit patterned media and discrete track media, such as illustrated in U.S. Pat. Publication 2009/0067082. FIGS. 1 and 2 illustrate the shape of bits formed by etching, such as ion milling or reactive etching. Note that the tops of the bits are rounded, leading to head media spacing loss, roughness at the rounded areas, and magnetic damage due to etching of magnetic materials. Such bits are not viable for magnetic recording. The uneven material increases head media spacing and potential damage to the diamond-like-carbon overcoats. CMP processes have proven

inadequate to achieving smooth and flat tops both before and after magnetic material deposition.

[0005] CMP is currently the primary approach to planarizing wafers, semiconductors, optical components, magnetic media for hard disk drives, and bit patterned or discrete track media (collectively “substrates”). CMP uses pads to press sub-micron sized particles suspended in the slurry against the surface of the substrate. The nature of the material removal varies with the hardness of the CMP pad. Soft CMP pads conform to the nanotopography and tend to remove material generally uniformly from the entire surface. Hard CMP pads conform less to the nanotopography and therefore remove more material from the peaks or high spots on the surface and less material from low spots.

[0006] Traditionally, soft CMP pads have been used to remove a uniform surface layer, such as removing a uniform oxide layer on a semiconductor device. Polishing a substrate with a soft pad also transfers various features from the polishing pad to the substrate. Roughness and waviness is typically caused by uneven pressure applied by the pad during the polishing process. The uneven pressure can be caused by the soft pad topography, the run out of the moving components, or the machined imperfections transferred to the pads. Run-out is the result of larger pressures at the edges of the substrate due to deformation of the soft pad. Soft pad polishing of heterogeneous layered materials, such as semiconductor devices, causes differential removal and damage to the electrical devices.

[0007] A CMP pad is generally of a polyurethane or other flexible organic polymer. The particular characteristics of the CMP pad such as hardness, porosity, and rigidity, must be taken into account when developing a particular CMP process for processing of a particular substrate. Unfortunately, wear, hardness, uneven distribution of abrasive particles, and other characteristics of the CMP pad may change over the course of a given CMP process. This is due in part to water absorption as the CMP pad takes up some of the aqueous slurry when encountered at the wafer surface during CMP. This sponge-like behavior of the CMP pad leads to alteration of CMP pad characteristics, notably at the surface of the CMP pad. Debris coming from the substrate and abrasive particles can also accumulate in the pad surface. This accumulation causes a “glazing” or hardening of the top of the pad, thus making the pad less able to hold the abrasive particles of the slurry and decreasing the pad’s overall polishing performance. Further, with many pads the pores used to hold the slurry become clogged, and the overall asperity of the pad’s polishing surface becomes depressed and matted.

[0008] Shortcomings of current CMP processes affect other aspects of substrate processing as well. The sub-micron particles used in CMP tend to agglomerate and strongly adhere to each other and to the substrate, resulting in nanoscale surface defects. Van der Waals forces create a very strong bond between these surface debris and the substrate. Once surface debris form on a substrate it is very difficult to effectively remove them using conventional cleaning methods. Various methods are known in the art for removing surface debris from substrates after CMP, such as disclosed in U.S. Pat. Nos. 4,980,536; 5,099,557; 5,024,968; 6,805,137 (Bailey); 5,849,135 (Selwyn); 7,469,443 (Liou); 6,092,253 (Moinpour et al.); 6,334,229 (Moinpour et al.); 6,875,086 (Golzarian et al.); 7,185,384 (Sun et al.); and U.S. Patent Publication Nos. 2004/0040575 (Tregub et al.); and **2005/0287032** (Tregub et al.), all of which are incorporated by

reference, but have proven inadequate for the next generation semiconductors and magnetic media.

[0009] Current processing of substrates for semiconductor devices and magnetic media treats uniform surface layer reduction, planarization to remove waviness, and cleaning as three separate disciplines. The incremental improvements in each of these disciplines have not kept pace with the shrinking feature size of features demanded by the electronics industry.

BRIEF SUMMARY OF THE INVENTION

[0010] The present disclosure is directed to an abrasive article including a flexible backing having opposing first and second surfaces. The first surface of the flexible backing includes abrasive features. An adhesive layer including load bearing particles and an adhesive matrix is disposed on the second surface of the flexible backing. At least a portion of the load bearing particles is substantially enveloped in the adhesive matrix and is in contact with the second surface of the polymer substrate.

[0011] The flexible backing is selected from the group consisting of metal foil, cloth, paper, vulcanized fiber, non-woven materials, polymeric materials, ceramics, or composites thereof. The polymeric substrate is selected from the group consisting of polyester, polypropylene, polyethylene, polyamide, polyimide. The load bearing particles have an average diameter that is substantially equal to the thickness of the adhesive layer. Examples of suitable particles include fused aluminum oxide, heat treated aluminum oxide, white fused aluminum oxide, porous aluminas, transition aluminas, zirconia, tin oxide, ceria, fused alumina zirconia, or alumina-based sol gel derived abrasive particles.

[0012] The present disclosure is directed to an abrasive article including a rigid backing having opposing first and second surfaces. The first surface of the rigid backing includes abrasive features. An adhesive layer including load bearing particles and an adhesive matrix is disposed on the second surface of the rigid backing. At least a portion of the load bearing particles is substantially enveloped in the adhesive matrix and is in contact with the second surface of the polymer substrate.

[0013] The present disclosure is also directed to a polishing pad including a flexible backing having opposing first and second surfaces. An adhesive layer including load bearing particles and an adhesive matrix is disposed on the second surface of the flexible backing. At least a portion of the load bearing particles is substantially enveloped in the adhesive matrix and is in contact with the second surface of the polymer substrate. Abrasive features are located at an interface of the first surface of the flexible backing with a substrate. The abrasive features polish the substrate during motion of the polishing pad relative to the substrate.

[0014] The abrasive features can be one or more of an abrasive material attached to the first surface, a slurry of free abrasive particles located at the interface with the substrate, or a combination thereof. One or more fluid bearing features is optionally on the first surface configured to generate lift forces during motion of the polishing pad relative to the substrate. The first surface of the flexible backing can include at least one of topography following or topography removing feature. At least a portion of the load bearing particles is preferably in contact with a rigid support.

[0015] The present disclosure is also directed to a method of making an abrasive article including the step of locating an adhesive layer including load bearing particles and an adhe-

sive matrix between a surface of the flexible backing and rigid support. At least a portion of the load bearing particles is substantially enveloped in the adhesive matrix and is in contact with the second surface of the polymer substrate. At least a portion of the load bearing particles is preferably in contact with the rigid support.

[0016] While the abrasive features generally have a hardness greater than the substrate, this property is not required for every embodiment since any two solid materials that repeatedly rub against each other will tend to wear each other away. For example, relatively soft polymeric abrasive features molded on the abrasive members can be used to remove surface contaminants or can interact with free abrasive particles to remove material from the surface of a harder substrate. As used herein, "abrasive feature" refers to a portion of an abrasive member that comes in physical contact with a substrate or a contaminant on a substrate, independent of the relative hardness of the respective materials and the resulting cut rate.

[0017] FIG. 3A is a schematic illustration of a topography following abrasive member **1000** in accordance with an embodiment of the present invention. The abrasive member **1000** is typically designed to follow the topography by assuring that the trailing edge area has the largest pressure peak. For example, the fluid bearing can be pitched to ensure that the leading edge is spaced substantially higher above the substrate than the trailing edge. The trailing edge **1006** of the abrasive member **1000** applies a cutting force to nanometer-scale and/or micron-scale height variations **1008** on the surface **1004**, while following the millimeter-scale and/or micrometer-scale wavelengths in the waviness **1010** on the substrate. Consequently, the abrasive member **1000** removes a generally uniform layer of material **1012** from peaks **1014** as well as valleys **1016** on the surface **1004**, such as for example, removing or controlling the thickness of an oxide layer. As used herein, "topography following" refers to an individually gimbaled abrasive member that generally follows millimeter-scale and/or micrometer-scale wavelengths of waviness on a substrate, while engaging with nanometer-scale height variations to primarily remove a generally uniform amount of material from the surface.

[0018] FIG. 3B is a schematic illustration of a topography removing abrasive member **1050** in accordance with an embodiment of the present invention. The leading edge **1056** and/or trailing edge **1058** of the abrasive member **1050** applies a cutting force to peaks **1060** of millimeter-scale and/or micrometer-scale wavelengths of the waviness **1062** on the surface **1054** of the substrate, with minimal engagement with the valleys **1064**. Consequently, the abrasive member **1050** removes more material from the peaks **1060** than the valleys **1064**. As used herein, "topography removing" refers to an individually gimbaled abrasive member that primarily removes nanometer-scale and/or micrometer-scale height variations from peaks of millimeter-scale and/or micrometer-scale wavelengths in the waviness on a substrate.

[0019] FIG. 3C is a schematic illustration of a cleaning abrasive member **1100** in accordance with an embodiment of the present invention. The leading edge **1114** and/or the trailing edge **1106** of the abrasive member **1100** follows the millimeter-scale and/or micrometer-scale wavelengths in the waviness **1108** on the substrate, while applying a cutting force to nanometer-scale and/or micron-scale contaminants **1110**. The abrasive member **1100** preferably has a spacing **1112** such that little or no material is removed from the

surface **1104** of the substrate other than the contaminants **1110**. As used herein, “cleaning” refers to an individually gimbaled abrasive member that generally follows millimeter-scale and/or micrometer-scale wavelengths in the waviness of a substrate, while primarily engaging with nanometer-scale and/or micrometer-scale height contaminant on the surface, with little or no material removal from the surface.

[0020] Since the abrasive members engage with nanometer-scale and micrometer-scale structures, it is unlikely that any particular embodiment will perform one of the topography following, topography removing, or cleaning functions to the exclusion of the other two. Rather, the present application adopts a probabilistic approach that a particular embodiment is more likely to perform one function, recognizing that the other two functions are also likely being performed in varying degrees.

[0021] For example, the topography following abrasive member **1000** of FIG. 3A can also remove some or all of the surface contaminants **1110** of FIG. 3C. In another example, the pressure applied to peaks **1014** in FIG. 3A may be greater than in the valleys **1016**, resulting in more material removal from the peaks **1014**, such as illustrated in FIG. 3B. The topography removing abrasive member **1050** may engage sidewalls **1066** of the peaks **1060** or the valley **1064**, such as illustrated in FIG. 3A. The cleaning abrasive member **1100** may contact the surface **1104** and remove a generally uniform layer of material from the substrate, along with the contaminants **1110**. Therefore, the definitions of “topography following”, “topography removing”, and “cleaning” should not be read as mutually exclusive. It should be assumed that the design parameters of the abrasive members can be modified to emphasize more of one function than the others.

[0022] Various abrasive features are available for the present abrasive members, such as for example, a surface roughness formed on the leading and/or trailing edges of the abrasive members. That surface roughness may include a hard coat, such as for example, diamond-like-carbon. In another embodiment, the abrasive features may be discrete abrasive particles, such as for example, fixed diamonds. In yet another embodiment, the abrasive features may be structured abrasives, discussed further below.

[0023] For example, to remove all the wavelengths smaller than a desired value, the dimensions of the abrasive members can be greater than the target wavelengths. The wavelengths are determined by the gas pressure profile generated by the abrasive member and the size of the abrasive member. As a rule of thumb, the smallest circumferential wavelength is about one-fourth the length of the abrasive members.

[0024] The dimensions of the abrasive members and the pressure profile due to the hydrostatic and/or hydrodynamic lift (gas and/or liquid) determine the ability of the abrasive member to follow the waviness of the substrate. Assuming that the abrasive members can follow $\frac{1}{4}$ of its size, then all wavelengths smaller than the $\frac{1}{4}$ will cause interference with the abrasive members and material removal will ensue due to the interactions. Portions of the abrasive members generate a hydrodynamic lift causing predictable waviness following capability and stabilizing force countering the cutting forces.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

[0025] FIG. 1 is the configuration of a single bit on a bit patterned media for a hard disk drive.

[0026] FIG. 2 is a perspective view of an array of bits on a bit patterned media.

[0027] FIG. 3A is a schematic illustration of a topography following abrasive member in accordance with an embodiment of the present disclosure.

[0028] FIG. 3B is a schematic illustration of a topography removing abrasive member in accordance with an embodiment of the present disclosure.

[0029] FIG. 3C is a schematic illustration of a cleaning abrasive member in accordance with an embodiment of the present disclosure.

[0030] FIG. 4 is a schematic illustration of an idealized bit for bit patterned media in accordance with an embodiment of the present disclosure.

[0031] FIG. 5 is an exploded view of an abrasive article with gimbaled abrasive members in accordance with an embodiment of the present disclosure.

[0032] FIG. 6 is a perspective view of a preload mechanism for the abrasive article of FIG. 5.

[0033] FIG. 7 is a perspective view of a gimbal structure for the abrasive article of FIG. 5.

[0034] FIG. 8 is a detailed perspective view of a gimbal structure for the abrasive article of FIG. 5.

[0035] FIG. 9 is a perspective view of the abrasive members for the abrasive article of FIG. 5.

[0036] FIG. 10 is another perspective view of the abrasive members for the abrasive article of FIG. 5.

[0037] FIG. 11 is a perspective view of the abrasive article of FIG. 5 polishing a substrate in accordance with an embodiment of the present disclosure.

[0038] FIG. 12 is a perspective view of the fluid bearing surface on the abrasive members of FIG. 5.

[0039] FIG. 13 is a detailed perspective view of the fluid bearing surface on the abrasive members of FIG. 5.

[0040] FIG. 14 is a conceptual view of an abrasive member interacting with a substrate in a topography following mode in accordance with an embodiment of the present disclosure.

[0041] FIG. 15 is a conceptual view of an abrasive member interacting with a substrate in a topography removing mode in accordance with an embodiment of the present disclosure.

[0042] FIG. 16 is a conceptual drawing of a roughened abrasive surface in accordance with an embodiment of the present disclosure.

[0043] FIG. 17 is a side sectional view of an abrasive surface with nano-scale diamonds attached to a polymeric backing in accordance with an embodiment of the present disclosure.

[0044] FIGS. 18A and 18B are conceptual illustrations of a structured abrasive surface in accordance with an embodiment of the present disclosure.

[0045] FIG. 19 is a perspective view of a unitary abrasive article in accordance with an embodiment of the present disclosure.

[0046] FIG. 20 is a perspective view of the gimbal assemblies of the abrasive article of FIG. 19.

[0047] FIG. 21 is a perspective view of the fluid bearing surfaces of the abrasive article of FIG. 19.

[0048] FIG. 22 is an exploded view of an abrasive article with an integral hydrostatic bearing structure in accordance with an embodiment of the present disclosure.

[0049] FIG. 23 is a top view of the abrasive article of FIG. 22 with the membrane removed.

[0050] FIG. 24 is a detailed top view of the abrasive article of FIG. 22 with the membrane removed.

[0051] FIG. 25 illustrates the fluid bearing surfaces of the abrasive article of FIG. 22.

[0052] FIG. 26 is a perspective view of an alternate abrasive article with fluid bearing surfaces that comprise abrasive composites in accordance with an embodiment of the present disclosure.

[0053] FIGS. 27A and 27B are side schematic illustrations of abrasive members with various abrasive composite structures at the fluid bearing surfaces in accordance with an embodiment of the present disclosure.

[0054] FIGS. 28 and 29 illustrate an alternate abrasive article with grooved fluid bearing surface in accordance with an embodiment of the present disclosure.

[0055] FIGS. 30A and 30B are schematic illustrations of double sided substrate processing using an abrasive article in accordance with an embodiment of the present disclosure.

[0056] FIG. 31 is a perspective view of a hydrostatic abrasive member assembly in accordance with an embodiment of the present disclosure.

[0057] FIG. 32 is a bottom perspective view of an abrasive member in accordance with an embodiment of the present disclosure.

[0058] FIG. 33 is a bottom perspective view of the abrasive member of FIG. 32.

[0059] FIG. 34 is a bottom perspective view of a gimbal mechanism in accordance with an embodiment of the present disclosure.

[0060] FIG. 35 is an exploded view of the hydrostatic abrasive member assembly of FIG. 31.

[0061] FIGS. 36 and 37 are perspective views of the hydrostatic abrasive member assembly of FIG. 31.

[0062] FIG. 38 is a bottom perspective view of the hydrostatic abrasive member assembly of FIG. 31.

[0063] FIG. 39A is a perspective view of an annular fluid bearing surface in accordance with an embodiment of the present disclosure.

[0064] FIG. 39B is a pressure profile graph of the fluid bearing of FIG. 39A.

[0065] FIG. 40 is a perspective view of a hydrodynamic abrasive member in accordance with an embodiment of the present disclosure.

[0066] FIG. 41 is a pressure profile graph for the abrasive member of FIG. 40.

[0067] FIG. 42 is an exploded view of a hydrodynamic abrasive member assembly in accordance with an embodiment of the present disclosure.

[0068] FIG. 43 is a perspective view of the hydrodynamic abrasive member assembly of FIG. 42.

[0069] FIGS. 44A-44C are various views of a cylindrical array of abrasive members in accordance with an embodiment of the present disclosure.

[0070] FIG. 45 is an exploded view of the cylindrical array of abrasive members of FIGS. 44A-44C.

[0071] FIG. 46 is a plurality of the cylindrical array abrasive member assemblies of FIGS. 44A-44C in accordance with an embodiment of the present disclosure.

[0072] FIG. 47A is a schematic illustration of an abrasive member for topography following applications in accordance with an embodiment of the present disclosure.

[0073] FIG. 47B is a pressure profile for the abrasive member of FIG. 47A.

[0074] FIG. 48A is a schematic illustration of an abrasive member for topography following applications in accordance with an embodiment of the present disclosure.

[0075] FIG. 48B is a pressure profile for the abrasive member of FIG. 48A.

[0076] FIG. 49A is a schematic illustration of an abrasive member for topography removing applications in accordance with an embodiment of the present disclosure.

[0077] FIG. 49B is a pressure profile for the abrasive member of FIG. 49A.

[0078] FIGS. 50A and 50B illustrate a hydrodynamic abrasive member for use in CMP in accordance with an embodiment of the present disclosure.

[0079] FIG. 51 illustrates a hydrostatic abrasive member for use in CMP in accordance with an embodiment of the present disclosure.

[0080] FIGS. 52A and 52B illustrate an alternate abrasive article with curve fluid bearing surfaces in accordance with an embodiment of the present disclosure.

[0081] FIGS. 53A and 53B illustrate a hydrostatic version of the abrasive article of FIGS. 52A and 52B in accordance with an embodiment of the present disclosure.

[0082] FIG. 54 is a schematic illustration an abrasive article with a resilient polymeric support in accordance with an embodiment of the present disclosure.

[0083] FIG. 55 is an exploded view of the abrasive article of FIG. 54.

[0084] FIG. 56 is a schematic illustration of the abrasive article of FIG. 54 subject to hydrodynamic forces in accordance with an embodiment of the present disclosure.

[0085] FIG. 57 is a perspective view of the abrasive member of FIG. 54.

[0086] FIG. 58 is a schematic illustration of an array of abrasive members preconfigured with a pitch angle in accordance with an embodiment of the present disclosure.

[0087] FIG. 59 is a schematic illustration of an array of abrasive members with embedded sensors in accordance with an embodiment of the present disclosure.

[0088] FIG. 60 is a schematic illustration of a method of making an array of cantilevered abrasive members in accordance with an embodiment of the present disclosure.

[0089] FIG. 61A is the array of cantilevered abrasive members of FIG. 60 with the sacrificial layer removed in accordance with an embodiment of the present disclosure.

[0090] FIG. 61B is the array of alternate cantilevered abrasive members with the sacrificial layer removed in accordance with an embodiment of the present disclosure.

[0091] FIG. 62 is a schematic illustration of the array of cantilevered abrasive members of FIG. 60 subject to hydrodynamic forces in accordance with an embodiment of the present disclosure.

[0092] FIG. 63 is the array of alternate cantilevered abrasive members in accordance with an embodiment of the present disclosure.

[0093] FIG. 64 is an alternate abrasive article in accordance with an embodiment of the present disclosure.

[0094] FIG. 65 is an abrasive article with a discontinuous resilient polymeric support in accordance with an embodiment of the present disclosure.

[0095] FIG. 66 is an abrasive article with a non-woven resilient polymeric support in accordance with an embodiment of the present disclosure.

[0096] FIG. 67 is an alternate abrasive article with a discontinuous resilient polymeric support in accordance with an embodiment of the present disclosure.

[0097] FIG. 68 is another alternate abrasive article with a discontinuous resilient polymeric support in accordance with an embodiment of the present disclosure.

[0098] FIG. 69 is an abrasive article with pressure ports in accordance with an embodiment of the present disclosure.

[0099] FIG. 70 is an alternate abrasive article with pressure ports in accordance with an embodiment of the present disclosure.

[0100] FIG. 71 is an alternate abrasive article with a structured elastomeric support in accordance with an embodiment of the present disclosure.

[0101] FIG. 72 is a schematic side sectional view of a fixture for making an abrasive article in accordance with an embodiment of the present invention.

[0102] FIG. 73 illustrates an abrasive slurry deposited on the fixture of FIG. 72 in accordance with an embodiment of the present invention.

[0103] FIG. 74 illustrates a substrate engaged with the abrasive slurry FIG. 73 in accordance with an embodiment of the present invention.

[0104] FIG. 75 illustrates the abrasive particles embedded in the substrate and the spacer layer of FIG. 74 in accordance with an embodiment of the present invention.

[0105] FIG. 76A is a schematic sectional view of an abrasive article in accordance with an embodiment of the present invention.

[0106] FIG. 76B is a schematic sectional view of an alternate abrasive article without the adhesive layer in accordance with an embodiment of the present invention.

[0107] FIG. 77 is a schematic side sectional view of an alternate fixture with a structured surface for making an abrasive article in accordance with an embodiment of the present invention.

[0108] FIG. 78 illustrates a substrate engaged with the abrasive slurry of FIG. 77 in accordance with an embodiment of the present invention.

[0109] FIG. 79 is a schematic sectional view of an abrasive article with a structure surface in accordance with an embodiment of the present invention.

[0110] FIG. 80 is a schematic sectional view of an abrasive article with a convex surface in accordance with an embodiment of the present invention.

[0111] FIG. 81 is a schematic sectional view of an abrasive article with a concave surface in accordance with an embodiment of the present invention.

[0112] FIG. 82 is a schematic sectional view of an abrasive article with a cylindrical or spherical surface in accordance with an embodiment of the present invention.

[0113] FIG. 83 is a schematic sectional view of an abrasive article with abrasive particles sintered to a substrate in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0114] FIG. 4 is a conceptual illustration of bit 20 showing an ideal form for bit pattern bit. Top 22 of the bit 20 is flat promoting constant head media spacing during read and write operations. An abrasive article with an array of gimballed abrasive members in accordance with an embodiment of the present disclosure will permit the bit 20 of FIG. 4 to be manufactured in a production setting.

[0115] FIG. 5 is an exploded view of an abrasive article 50 with an array of gimballed abrasive members 52 in accordance with an embodiment of the present disclosure. The abrasive article 50 includes gimbal structure 54, preload

mechanism 56, and the abrasive members 52. The abrasive article 50 can be manufactured in circular and non-circular shapes. The abrasive members 52 can be arranged in a regular pattern a random configuration, an off-set pattern or a variety of other configurations.

[0116] FIG. 6 provides a detailed view of the preload mechanism 56 of FIG. 5. The preload mechanism 56 includes a series of outer rings 58 each with a plurality of preload beams 60 configured to apply a preload on each of the abrasive members 52 (see e.g., FIG. 11). The preload applied by the beams 60 is preferably concentrated toward the center of the abrasive members 52 so as to not interfere with pitch and roll motions during polishing. Alternatively, the preload beams 60 are positioned to promote topography following or topography removing behavior in the abrasive members 52.

[0117] FIGS. 7 and 8 illustrate the gimbal structure 54 of FIG. 5. Framework 62 supports an array of gimbal assemblies 64. In the illustrated embodiment, each gimbal assembly 64 includes one or more arms 66, a cross member 68 and spring members 70 with attachment features 72. The gimbal assemblies 64 allow each of the abrasive members 52 to independently follow millimeter-scale and micrometer-scale waviness of the substrate during polishing.

[0118] The gimbal assemblies 64 control the static attitude or pitch of each abrasive member 52. The arms 66, cross members 68, and spring member 70 permit the abrasive members 52 to move through at least pitch and roll, while assuring adequate torque is applied to the abrasive members 52. The members 66, 68, and 70 can be configured to promote topography following or topography removing behavior in the abrasive members 52. Various alternate gimbal assemblies are disclosed in U.S. Pat. Nos. 5,774,305; 5,856,896; 6,069,771; 6,459,260; 6,493,192; 6,714,386; 6,744,602; 6,952,330; 7,057,856; and 7,203,033, which are hereby incorporated by reference.

[0119] FIG. 9 illustrates the array of abrasive members 52 prior to assembly onto the gimbal assemblies 64. The abrasive members 52 can be made from a variety of materials, such as for example, metal, ceramic, polymers, or composites thereof. The abrasive members 52 are preferably arranged in a random or off-set pattern to impart a uniform polishing pattern onto the substrate.

[0120] The abrasive members 52 can be fabricated individually as discrete structures or ganged together such as illustrated in FIG. 10. For example, the abrasive members 52 can be fabricated using a mold injection process. In the embodiment of FIG. 10, spacing structures 80 are molded between the abrasive members 52. The spacing structures 80 position the abrasive members 52 during assembly with the gimbal structure 54. The spacing structures 80 can be maintained or removed after assembly is completed.

[0121] FIG. 11 illustrates the assembled abrasive article 50 positioned to lap substrate 106. The substrate 106 can be a wafer, a wafer-scale semiconductor, magnetic media for hard disk drives, bit patterned or discrete track media, a convention disk for a hard disk drive, or any other substrate. The preload beams 60 on the preload mechanism 56 apply preload 82 to the abrasive members 52. In the illustrated embodiment, the preload beams 60 apply the preload 82 directly to the respective attachment features 72 on the gimbal assemblies 64.

[0122] As illustrated in FIG. 11, air shearing forces between the rotating substrate 106 and the abrasive article 50 entrain an air cushion that applies fluid dynamic lift 108 (referred to hereinafter as “lift” or “dynamic lift”) on fluid

bearing surfaces **90** on the abrasive member **52**. The lift **108** can be located at the leading edge **94** and/or the trailing edge **98**, although in the illustrated embodiment the lift **108** is concentrated at the leading edge **94** to each abrasive member **52**. In an alternate embodiment, the substrate **106** is stationary and the abrasive article **50** rotates. Although the most common fluid used to generate the fluid dynamic lift **108** is air, it is also possible that the lift **108** is generated by a liquid, such as a lubricant. As used herein, the phrase “fluid bearing” refers generically to a fluid (i.e., liquid or gas) present at an interface between an abrasive member and a substrate that applies a lift force on the abrasive member. Fluid bearings can be generated hydrostatically, hydrodynamically, or a combination thereof.

[0123] The dynamic lift **108** causes the abrasive members **52** to assume an attitude or pitch during the relative rotation of a substrate **106**. The gimbal assemblies **64** allow the abrasive members **52** to follow the micrometer-scale and/or millimeter-scale wavelengths of waviness (“waviness”) on the substrate **106**, while removing nanometer-scale and/or micrometer-scale height variations. Typically, the leading edges **94** of the abrasive members **52** generate a hydrostatic lift countering the forces generated at the interference **104** between the trailing edge **98** and the substrate **106**.

[0124] Since each of the abrasive members **52** can independently adjust to the waviness of the substrate **106** and maintain a constant cutting force/pressure, the amount of material removed across the substrate **106** is substantially uniform. The present embodiment is particularly well suited to remove a uniform amount of an oxide layer on a semiconductor. The ability of the abrasive members **52** to follow the waviness enables uniform material removal at a level not attainable by conventional CMP processes. In the case of an air bearing, it is desirable to have a boundary layer of lubricant between the abrasive members **52** and the substrate **106**.

[0125] The preload force **82** is preferably a fraction of the amount used during conventional lapping. The present system and method typically reduces the preload force **82** by an order of magnitude or more. In one embodiment, the preload **82** is in the range of about 0.1 grams/millimeter² to about 10 grams/millimeter² of surface being lapped, compared to about 1 kg/millimeter² for conventional lapping using an oil flooded lapping media.

[0126] FIGS. **12** and **13** illustrate one possible geometry of the fluid bearing surface **90** of the abrasive members **52**. The fluid bearing surfaces **90** include various fluid bearing features **92** that promote the creation of a fluid bearing with the substrate **106**. In the illustrated embodiment, leading edge **94** of the fluid bearing surface **90** includes a pair of pressure pads **96A**, **96B** (collectively “**96**”) separated by gap **97**. The trailing edge **98** includes pressure pad **100**. A discussion of the lift created by rotating rigid disks is provided in U.S. Pat. No. 7,218,478, which is hereby incorporated by reference.

[0127] In one embodiment, the pads **96**, **100** can be formed with a crown and cross-curve. The leading edges **94** of the pressure pads **96A**, **96B** are optionally tapered or stepped to help initiate aerodynamic lift (see, e.g., FIG. **47A**). Negative suction force areas can be fabricated in the fluid bearing surface **90** to stabilize the abrasive members **52** during the flying. The fluid bearing surface **90** can also include trenches to enable higher pressurization during the flying.

[0128] FIG. **14** is a schematic illustration of the engagement between the abrasive members **52** with the substrate **106** in the topography following mode in accordance with an

embodiment of the present disclosure. The peaks **83** and valleys **81** are intended to illustrate nanometer-scale and/or micrometer-scale height variations, although their size relative to the abrasive member **52** is greatly exaggerated. The micrometer-scale and/or millimeter-scale waviness is not illustrated for the sake of simplicity.

[0129] The valleys **81** between the peaks **83** entrain sufficient air to permit the abrasive members **52** to “fly” over the substrate **106**, even while the trailing edge **98** is in contact with general texture level **105** of the substrate **106**.

[0130] The leading edges **94** of the abrasive members **52** are raised above the substrate **106** due to lift **108** acting on fluid bearing surface **86**. Engagement of the abrasive members **52** with the substrate **106** is defined by pitch angle **79A** and roll angle **79B** of the abrasive members **52**, and clearance **101** with the substrate **106**.

[0131] The gimbal assembly **56** (see FIG. **11**) provides the abrasive members **52** with roll and pitch stiffness that balance by the roll and pitch moments **74** generated by the lift force **108**. The frictional forces **76** generated during lapping cause a tipping moment **78** opposite to the moment **74**, causing the leading edges **94** of the abrasive members **52** to move toward the substrate **106**.

[0132] In some embodiments, the lift **108** may be purely aerodynamic, creating a stable, uniform fluid bearing. In some embodiments, the lift **108** may be caused, in part, by lubricant **84** on the substrate **106**. Abrasive members **52** in full contact with the substrate **106** experience a large amount of forces and vibrations during the polishing process. The cutting forces and moments tend to cause vibrations and bouncing. The preload and gimbal stiffness need to balance the cutting forces. A lubricant **84** is desirable to keep the frictional forces and cutting forces low enough to prevent chattering and the like.

[0133] A boundary layer lubrication regime of a thin film a few atoms thick adhered to the surface of the substrate **106** can be used. Alternatively, the lapping can occur in a fully flood environment. Consequently, the fluid dynamic lift **108** according to the present disclosure may be aerodynamic and/or hydrodynamic in nature. Discussion of the lift created by rotating rigid disks is provided in U.S. Pat. Nos. 7,193,805 and 7,218,478, which are hereby incorporated by reference.

[0134] The moment **74** generated by the lift **108** is preferably greater than the moment **78** generated by frictional forces **76** at the interface of the pad **100** with the surface of the substrate **106**. The trailing edge **98** is located below the general texture level **105** of the substrate **106** during interference lapping. In operation, the interference between the abrasive members **52** and the substrate **106** is essentially continuous. As used herein, “interference lapping” refers to a clearance with an abrasive member that is less than about half a peak-to-valley roughness of a substrate.

[0135] In one embodiment, trailing edge **98** is located at about mid-plane **103** of the peak-to-valley roughness **109**. Clearance **101** between the mid-plane **103** and the trailing edge **98** is preferably less than half the peak-to-valley roughness **109** of the substrate **106**. For example, if the peak-to-valley roughness **109** is about 50 nanometers, the clearance **101** of the abrasive members **52** is less than about 25 nanometers. As used herein, “clearance” refers to a distance between an abrasive member and a mid-plane of a peak-to-valley roughness of a substrate.

[0136] In one embodiment, actuators **120** are provided to thermally expand portions of the abrasive member **52** to per-

form contact detection with the substrate **106**. Contact detection refers to bringing an actuated portion of a fluid bearing surface into contact with a substrate, and then decreasing the actuation to establish a desired level of interference with nanometer-scale and/or micrometer-scale height variations on a surface of a substrate. Contact detection between the abrasive member and the substrate can be performed with a variety of methods including, position signal disturbance stemming from fluid bearing modulation, amplitude ratio and harmonic ratio calculations based on Wallace equations, and piezoelectric based acoustic emission sensors. Various actuators and contact detection systems are disclosed in commonly assigned U.S. patent application Ser. No. 12/424,441 (Boutaghou, et al.), filed Apr. 15, 2009, which is hereby incorporated by reference.

[0137] FIG. 15 is a schematic illustration of the engagement between the abrasive members **52** with the substrate **106** in the topography removing mode in accordance with an embodiment of the present disclosure. The nanometer-scale and/or micrometer-scale height variations is not illustrated for the sake of simplicity.

[0138] The abrasive members **52** have a length **52A** measured relative to the motion **107** with substrate **106** that is greater than an approximate wavelength **85** of the peaks **83**. The spaces **81** between the peaks **83** entrain sufficient air to permit the abrasive members **52** to “fly” over the substrate **106** at fly height **89** so the trailing edge **98**, and in some embodiments the leading edge **94**, impacts the peaks **83** or debris **87** located above the fly height **89**. The lubricant **84** can be a mono-layer or a flooded environment.

[0139] As with the topography following embodiment, the gimbal assembly **56** (see FIG. 11) and the lift force **108** provide the abrasive members **52** with sufficient pitch and roll stiffness to counteract the tipping moment **78** caused by collisions with the peaks **83** or surface debris **87**. The interference between the abrasive members **52** and the substrate **106** may be continuous or intermittent. In the illustrated embodiment, the peaks **83A** have been removed by the abrasive member **52**.

[0140] The abrasive members **52** may include abrasive features at the leading edges **94** and/or trailing edges **98**, abrasive particles are interposed between the abrasive members **52** and the substrate **106**, or a combination thereof.

[0141] As illustrated in FIG. 13, the pads **96**, **100** may include abrasive features **110** that cause interference with the substrate **106** in order to remove material at the desired rate. In one embodiment, the abrasive features **110** are texture or patterns on the pads **96**, **100**, such as illustrated in FIG. 16. The abrasive features **110** are preferably in the nanometer range to allow for fluid bearings to be formed. In one embodiment, the abrasive features **110** have a peak-to-peak roughness of about 20 nanometers to about 100 nanometers. The texture **110** can be formed on the pads **96**, **100** or transferred from the mold used to manufacture the abrasive members **52**.

[0142] The abrasive features **110** are preferably covered with a hard coat, such as for example, diamond-like-carbon or other hard overcoats depending on the application. The desired peak-to-peak roughness after application of the hard coat varies from about 10 nanometers to about 30 nanometers to provide effective cutting. The peak-to-valley roughness is preferably about 25 nanometers to about 50 nanometers.

[0143] Abrasive members **52** constructed from polymers are compatible with diamond-like-carbons. Diamond-like-carbon (“DLC”) thickness varies from about 50 nanometers

to about 200 nanometers to provide a hard surface capable of burnishing the substrate. It is highly desirable to generate DLC hardness in the range of 70-90 GPa (Giga-Pascals) to further improve the burnishing process.

[0144] In one embodiment the DLC is applied by chemical vapor deposition. As used herein, the term “chemically vapor deposited” and “CVD” refer to materials deposited by vacuum deposition processes, including, but not limited to, thermally activated deposition from reactive gaseous precursor materials, as well as plasma, microwave, DC, or RF plasma arc-jet deposition from gaseous precursor materials. Various methods of applying a hard coat to a substrate are disclosed in U.S. Pat. Nos. 6,821,189 (Coad et al.); 6,872,127 (Lin et al.); 7,367,875 (Slutz et al.); and 7,189,333 (Henderson), which are hereby incorporated by reference.

[0145] In another embodiment, nano-diamonds (i.e., with a major diameter less than 1 micrometer) are attached to the pads **96**, **100** via existing processes (CVD encapsulation, brazing, adhesives, embedding, etc.). Methods of uniformly dispersing nanometer size abrasive grains are disclosed in U.S. Pat. Pub. No. 2007/0107317 (Takahagi et al.), which is hereby incorporated by reference. Various geometrical features and arrangement of abrasive particles on abrasive articles are disclosed in U.S. Pat. Nos. 4,821,461 (Holmstrand), 3,921,342 (Day), and 3,683,562 (Day), and U.S. Pat. Pub. No. 2004/0072510 (Kinoshita et al), which are hereby incorporated by reference. A two-step adhesion process for attaching diamonds to the pads **96**, **100** is disclosed in U.S. Pat. Nos. 7,198,553 and 6,123,612, which are hereby incorporated by reference.

[0146] FIG. 17 illustrates abrasive particles **340**, such as nano-scale diamonds, attached to a polyamide backing layer **342** located on the pads **96**, **100** that act as the abrasive features **110** in accordance with an embodiment of the present disclosure. In another embodiment, a slurry of nano-scale diamonds and adhesive are spin coated, sprayed coated, or otherwise deposited directly onto the pads **96**, **100**. A method and system for fabricating the nano-scale diamond abrasive is disclosed in U.S. Provisional Patent Application No. 61/187,658 entitled Abrasive Member with Uniform Height Abrasive Particles, filed on Jun. 16, 2009, which is hereby incorporated by reference.

[0147] FIGS. 18A and 18B illustrate perspective and side views of an engineered surface **130** imparted to the pads **96**, **100** that act as abrasive features **110** in accordance with an embodiment of the present disclosure. The engineered surface **130** is preferably nanometer-scale or micrometer-scale. The depth of the grooves **132** with respect to the peaks **134** must be controlled to within less than about 100 nanometers to promote the formation of a fluid bearing with the substrate **106**. The peaks **134** can be textured to promote interference and polishing while the grooves **132** contribute to the fluid bearing lift. If the grooves **132** are too deep (microns), the fluid bearing generation will not be possible and the entire system will be in contact with uncontrolled gas film thickness. A hard coat, such as DLC, is preferably applied to the engineered surface **130**.

[0148] The engineered surface **130** allows for precise stress management between the polished substrate and the nano-features. Such precise stress management yields a predictable surface finish and the gap allows for residual material to be removed. Various engineered surfaces **130** are disclosed in U.S. Pat. Nos. 6,194,317 (Kaisaki et al); 6,612,917 (Bruxvoort); 7,160,178 (Gagliardi et al.); 7,404,756 (Ouderkirk et

al.); and U.S. Publication No. 2008/0053000 (Palmgren et al.), which are hereby incorporated by reference.

[0149] In another embodiment, a slurry of abrasive particles is located at the interface **104** (see, e.g., FIGS. **11**, **50A**, **50B**, and **51**), such as for example, in a standard chemical-mechanical polishing process. The abrasive members **52** with or without abrasive features can be used with the abrasive slurry. Various methods of chemical-mechanical processing are disclosed in U.S. Pat. No. 6,811,467 (Beresford et al.) and U.S. Pat. Publication Nos. 2004/0072510 (Kinoshita et al.) and **2008/0004743** (Goers et al.), which are hereby incorporated by reference.

[0150] As noted above, the abrasive features **110** generally have a hardness greater than the substrate **106**, but this property is not required since any two solid materials that repeatedly rub against each other will tend to wear each other away. The abrasive features can be any portion of an abrasive member **52** that forms an interface with a substrate **106** or a contaminant **87** on a substrate **106**, independent of the relative hardness of the respective materials and the resulting cut rate.

[0151] In some embodiments, the abrasive members **52** are manufactured with one or more sensors to monitor the polishing process, such as for example, acoustic emission or friction sensor. The present interference lapping preferably results in a surface finish or roughness (Ra) of less than about 20 Angstrom, and more preferably less than about 0.2 Angstrom.

[0152] In applications using full oil lubrication an interface can be designed to form an oil hydrodynamic film. Typically, the oil film thickness is substantially thicker than an air film thickness due to the viscosity of the lubricant. The height or roughness of the abrasive features on the pads **96**, **100** need to be higher than the film thickness to guarantee interference with the substrate **106**. Various hydrodynamic features are disclosed in U.S. Pat. No. 6,157,515 (Boutaghou), which is hereby incorporated by reference. Oil hydrodynamic formation requires larger pressures and preloads **82** to be applied to overcome the lift **108** generated by the oil viscosity. Pressure relief features are preferably formed in the pads **96**, **100**.

[0153] In yet another embodiment, a hydrodynamic bearing is not (fully) formed between the abrasive members **52** and the substrate **106**. The abrasive members **52** are in full contact with the substrate **106**. The gimballing structure **54** allows the abrasive members **52** to follow the waviness of the substrate **106** during polishing, but not the nanometer-scale or micrometer-scale height variations. In the case of a full contacting abrasive members **52**, nanometer-scale or micrometer-scale height variations is defined with respect to the length **52A** of the abrasive members **52** (see FIG. **11**). Since no gas bearing features are fabricated on this embodiment, no hydrostatic bearing is formed and the abrasive members **52** will not be able to follow the nanometer-scale or micrometer-scale height variations, and these features are removed. The following characteristic of this structure is controlled by the friction forces and the cutting forces emanating from the interface. The friction forces can be minimized by fabricating contacting pads (not shown) to lower the contact area while providing a low friction interface especially in the presence of a lubricant.

[0154] FIGS. **19-21** illustrate a fully integrated gimbaled abrasive article **150** in accordance with an embodiment of the present disclosure. Preload structure **152** includes circumferential ribs **154** and radial ribs **156** to impart a desired preload onto abrasive members **158**. Gimbal assemblies **160** include

a collection of flexible ribs **162**, **164** connecting the preload structure **152** to the abrasive members **158**. The abrasive article **150** is preferably fabricated as a single unit, such as by injection molding. The fabrication process can include multiple mold injection steps to meet the system requirements.

[0155] Instead of applying the preload directly to the abrasive members **158**, the preload is applied by the preload structure **152** through the gimbal assemblies **160**. This configuration is ideal for low preload applications. Care must be taken not to cause excessive deformation of the gimbal assemblies **160** during preload applications. FIG. **21** illustrates fluid bearing features **164** fabricated on the abrasive members **158**, such as discussed above. The fluid bearing surfaces **164** can include any of the abrasive features discussed herein.

[0156] FIGS. **22-25** illustrate an alternate abrasive article **200** with an array of abrasive members **212** having an integrated hydrostatic bearing structure **202** in accordance with an embodiment of the present disclosure. Membrane **216** seals gas conduits **204** in the bearing structure **202**.

[0157] FIGS. **23** and **24** illustrate the integrated hydrostatic bearing structure **202** without sealing membrane **216** shown. Gas conduits **204** are fabricated in gimbal assembly **206** and along preload ribs **208**. Holes **210** extending through the abrasive members **212** to fluid bearing surfaces **214** (see FIG. **25**). The gas conduits **204** are externally pressurized to provide a hydrostatic bearing on each abrasive member **212**. The fluid bearing surfaces **214** can include any of the abrasive features discussed herein.

[0158] As best illustrated in FIG. **25**, fluid bearing surfaces **214** of the abrasive members **212** are fabricated with button pressure ports **218** to form a hydrostatic bearing on each abrasive member **212**. The hydrostatic bearing generated at each fluid bearing surface **214** is designed to counter the cutting forces during the polishing process. For illustrative purposes, a button bearing design is shown. See also, FIG. **39A**. Additional configurations can easily be adapted such as multiple ports onto each abrasive member **212** to enable the abrasive member to form a pitch and roll moment.

[0159] In one preferred embodiment, a pressure port **218** is located near the leading edges **220** to increase the pitch of the abrasive members **212** for topography following applications. In another embodiment, pressure ports **218** are located at both the leading edges **220** and trailing edges **222** of the abrasive members **212** to configure the pitch for topography removing applications.

[0160] The abrasive article **200** is particularly useful when the relative speed between the substrate and the abrasive members **212** is not high enough to form a fluid bearing or hydrodynamic film. The external pressure applied to the abrasive members **212** forms a hydrostatic film capable of following the substrate waviness and countering the cutting forces emanating from the interference between the peaks of the abrasive member **200** and the substrate.

[0161] The hydrostatic fluid bearing may be used in combination with a hydrodynamic fluid bearing. In one embodiment, the hydrostatic fluid bearing is used during start-up rotation and/or ramp-down of the abrasive article **200** relative to a substrate.

[0162] In another embodiment, the hydrostatic fluid bearing is used simultaneously with a hydrodynamic fluid bearing. The pressure ports **218** located near the inner edge **224** and outer edge **226** of the abrasive article **200** can be pressurized to offset loss of pressure at the fluid bearing in those

locations. Consequently, the pressure of the fluid bearing surfaces **214** across width **228** of the abrasive article **200** can be precisely controlled to reduce run out.

[0163] FIG. 26 illustrates an alternate abrasive article **300** in which the fluid bearing features **302A**, **302B**, **302C** (“**302**”) comprise abrasive particles **304** dispersed within a binder **306** in accordance with an embodiment of the present disclosure. The abrasive composites **312** act as the abrasive features in the illustrated embodiment.

[0164] In the illustrated embodiment, the fluid bearing features **302** are coextensive with abrasive members **308**. The abrasive members **308** are also preferably coextensive with the backing layer **310**. The term “coextensive” refers to attachment, bonding, or permeation of the materials comprising the various components **302**, **308**, and **310**. Additional details concerning the general characteristics of the abrasive composites and methods of manufacture can be found in U.S. Pat. Nos. 5,152,917 (Pieper et al.); 5,958,794 (Bruxvoort), 6,121,143 (Messner et al.) and U.S. Patent Publication Nos. 2005/0032462 (Gagliardi et al.) and 2007/0093181 (Lugg et al.), all of which are hereby incorporated by reference.

[0165] The abrasive particles **304** are optionally located only at the fluid bearing feature **302A** at the trailing edge **316**, but can optionally be provided at the fluid bearing features **302B**, **302C** at the leading edge **318** of the abrasive members **308**. The abrasive particles **304** may be non-homogeneously dispersed in a binder **306**, but it is generally preferred that the abrasive particles **304** are homogeneously dispersed in the binder.

[0166] The abrasive particles **304** may be associated with at least one fluorochemical agent. The fluorochemical agent may be applied to the surface of the abrasive particles **304** by mixing the particles in a fluid containing one or more fluorochemical agents, or by spraying the one or more fluorochemical agents onto the particles. The fluorochemical agents associated with abrasive particles may be reactive or unreactive.

[0167] Fine abrasive particles **304** are preferred for the construction of the fluid bearing features **302**. The size of the abrasive particles are preferably less than about 1 micrometer and typically between about 10 nanometers to about 200 nanometers. The size of the abrasive particle **304** is typically specified to be the longest dimension. In almost all cases there will be a range or distribution of particle sizes. In some instances, it is preferred that the particle size distribution be tightly controlled such that the resulting fixed abrasive article provides a consistent surface finish on the wafer. The abrasive particles may also be present in the form of an abrasive agglomerate. The abrasive particles in each agglomeration may be held together by an agglomerate binder. Alternatively, the abrasive particles may bond together by inter-particle attraction forces. Examples of suitable abrasive particles **304** include fused aluminum oxide, heat treated aluminum oxide, white fused aluminum oxide, porous aluminas, transition aluminas, zirconia, tin oxide, ceria, fused alumina zirconia, or alumina-based sol gel derived abrasive particles.

[0168] The backing layer **310** preferably includes a plurality of areas of weakness **314** that permit the abrasive members **308** to gimbal (i.e., pitch, roll, and yaw) with respect to the backing layer **310**. The areas of weakness **314** can be perforations, slits, grooves, and/or slots formed in the backing layer **310**. The areas of weakness **314** also permit the passage of the liquid medium before, during, or after use.

[0169] The backing layer **310** is preferably uniform in thickness. A variety of backing materials are suitable for this

purpose, including both flexible backings and backings that are more rigid. Examples of typical flexible abrasive backings include polymeric film, primed polymeric film, metal foil, cloth, paper, vulcanized fiber, nonwovens and treated versions thereof and combinations thereof. One preferred type of backing is a polymeric film. Examples of such films include polyester films, polyester and co-polyester films, microvoided polyester films, polyimide films, polyamide films, polyvinyl alcohol films, polypropylene film, polyethylene film, and the like. The thickness of the polymeric film backing generally ranges between about 20 to about 1000 micrometers, preferably between about 50 to about 500 micrometers.

[0170] A preferred method for making the abrasive composites **312** having precisely shaped abrasive composites **312** is described in U.S. Pat. No. 5,152,917 (Pieper et al) and U.S. Pat. No. 5,435,816 (Spurgeon et al.), both incorporated herein by reference. Other descriptions of suitable methods are reported in U.S. Pat. Nos. 5,437,754; 5,454,844 (Hibbard et al.); U.S. Pat. No. 5,437,754 (Calhoun); and U.S. Pat. No. 5,304,223 (Pieper et al.), all incorporated herein by reference.

[0171] Production tools for making the abrasive members **308** may be in the form of a belt, a sheet, a continuous sheet or web, a coating roll such as a rotogravure roll, a sleeve mounted on a coating roll, or die. The production tool may be made of metal, (e.g., nickel), metal alloys, or plastic. The production tool is fabricated by conventional techniques, including photolithography, knurling, engraving, hobbing, electroforming, or diamond turning. For example, a copper tool may be diamond turned and then a nickel metal tool may be electroplated off of the copper tool. Preparations of production tools are reported in U.S. Pat. No. 5,152,917 (Pieper et al.); U.S. Pat. No. 5,489,235 (Gagliardi et al.); U.S. Pat. No. 5,454,844 (Hibbard et al.); U.S. Pat. No. 5,435,816 (Spurgeon et al.); PCT WO 95/07797 (Hoopman et al.); and PCT WO 95/22436 (Hoopman et al.), all incorporated herein by reference. In an alternate embodiment, the abrasive members **308** are used in combination with the gimbal mechanism such as disclosed in FIG. 5.

[0172] FIG. 27A is a side view of the abrasive members **308** of FIG. 26 in which the abrasive particles **304** do not extend above surface **320** of the fluid bearing features **302**. FIG. 27B illustrates an alternate embodiment in which some of the abrasive particles **304** extend above the surface **320** of the fluid bearing features **302**. A hard coat, such as diamond-like-carbon is optionally applied to the protruding abrasive particles **304** of FIG. 27B. In both embodiments, the backing layer **310** includes a plurality of areas of weakness **314**.

[0173] Due to the rigidity of the abrasive members **308**, a preload **322** can be applied directly to rear surfaces **324** of the backing layer **310** opposite the abrasive members **308**, such as for example, the preload mechanism **56** illustrated in FIG. 5. The areas of weakness **314** permit the abrasive members **308** to gimbal relative to the backing layer **310**. In another embodiment, the abrasive members **308** are combined with the gimbal structure **54** and the preload mechanism **56** of FIG. 5 so that the backing layer **310** does not provide the gimbal function.

[0174] In one embodiment, one or more protrusions **326** are optionally located near leading edge **318** to prevent the fluid bearing surfaces **302B**, **302C** from impacting the substrate. The protrusions **326** can be created from a variety of materials, such as for example, diamond-like-carbon.

[0175] FIGS. 28 and 29 are perspective views of an alternate abrasive article **350** in which the fluid bearing features

352A, 352B, 352C (“**352**”) include a plurality of grooves **354** oriented generally parallel to the direction of travel **356** of the abrasive members **358** relative to the substrate. The grooves **354** release fluid located at the interface between the fluid bearing features **352**, reducing the lift on the abrasive members **358**.

[0176] The grooves **354** reduce the fly height of the abrasive members **358**. In applications where the fluid is a liquid, the grooves **354** permit a low fly height and/or a low preload. The grooved abrasive members **358** are particularly well suited to fully flooded applications.

[0177] The depth of the grooves **354** must be sufficient to reduce hydrodynamic pressure between the abrasive members **358** and the substrate. In most cases, the grooves **354** have a depth of greater than about 20 micrometers.

[0178] By reducing the hydrodynamic film, it is possible to use lubricants with a higher viscosity and/or maintain a low preload on each abrasive member **358**, while still achieving interference with the substrate. In some applications, the grooves **354** allow a reduction in the hydrodynamic film while allowing the use of nano-scale diamonds attached to the fluid bearing features **352**.

[0179] In one embodiment, nano-scale diamonds attached to a polymeric film, such as illustrated in FIG. 14B, are attached to the fluid bearing features **352**. The grooves **354** permit the load on the abrasive members **358** to be sufficiently low so as to not substantially deform the polymeric film **342**. In another embodiment, the fluid bearing features **352** are grooved abrasive composites.

[0180] Designing length **360** of the abrasive members **358** to be greater than the target wavelength permits the abrasive members **358** to interact with the peaks of the waviness for topography removing applications. Alternatively, reducing the length **360** will cause the abrasive members **358** to follow the contour of the waviness and provide more uniform material removal for topography following applications.

[0181] The grooves **354** also permit the fly height to be engineered for particular applications. Assuming all other processing variables are held constant, increasing the size or number of grooves **354** reduces fly height, and hence, increases interference between the substrate.

[0182] The fly height of the abrasive members **358** above the substrate can also be engineered, such as by changing the size and shape of the fluid bearing features **352**. Some variables critical to fly height include the size and shape of gap **362** between the fluid bearing features **352A, 352B**, the length **364** and width **366** of the fluid bearing features **352A, 352B**, and the length **368** and width **370** of the fluid bearing features **352C**.

[0183] In one embodiment, a series of different abrasive articles **350** are designed with different sized abrasive members **358** and/or fluid bearing features **352** used to polish a substrate. For example, the abrasive article **350** may initially target peaks only, followed by an abrasive article **350** designed to follow the contour.

[0184] FIGS. 30A and 30B are schematic illustrations of a pair of abrasive articles **400, 402** simultaneously lapping opposite surfaces **404, 406** of substrate **408** in accordance with an embodiment of the present disclosure. The fixing process used to mount substrates (e.g., wax mounting, vacuum chucking, etc.) causes topography from the backside of the substrate to be transmitted to the front side and causes nanotopography. While free mounting of substrates does not transmit nanotopography, substrate flatness is not guaranteed.

The best flatness and nanotopography is obtained using double-sided polishing. Since the substrate is polished in a free state, nanotopography is minimized and good flatness is achieved. The substrate **408** is preferably gripped by its edges **410** by mechanism **411** and rotated about axis **412**, such as disclosed in U.S. Pat. Nos. 7,185,384 (Sun et al.); 6,334,229 (Moinpour et al.); and 6,092,253 (Moinpour et al.), all of which are incorporated by reference.

[0185] In the embodiment of FIG. 30A, leading edges **414** of the individual abrasive members **416** are illustrated below the axis **412**, and trailing edges **418** above the axis **412**. The fluid bearings generated by the opposing abrasive articles **400, 402** generate opposing forces **420, 422** that permit simultaneous lapping of both surfaces **404, 406** with minimum deformation of the substrate **408**. Simultaneously lapping both surfaces **404, 406** of a substrate **406** held between opposing fluid bearings provides superior results over current lapping techniques. In another embodiment, the abrasive articles **400, 402** are rotated relative to the substrate **408**.

[0186] In the embodiment of FIG. 30B, leading edges **414** of the abrasive articles **402** are illustrated above the axis **412** permitting the abrasive articles to be counter rotated. Counter rotating the abrasive articles **400, 402** may permit the substrate **408** to be free floating. In this embodiment, the mechanism **411** acts as a barrier to the edges **410** to maintain the substrate **408** generally concentric with the abrasive articles **400, 402**, but does not otherwise restrain the substrate **408**.

[0187] FIG. 31 is a bottom perspective view of hydrostatic abrasive article **550** with an array of hydrostatic abrasive members **552** in accordance with an embodiment of the present disclosure. External pressure source **554** is applied to each of the abrasive members **552** to control clearance **556** with the substrate **558**. Preload **612** biases the abrasive members **552** toward the substrate **558**. Polishing is accomplished by relative motion between the hydrostatic abrasive article **550** and the substrate **558**, such as linear, rotational, orbital, ultrasonic, and the like. In one embodiment, that relative motion is accomplished with an ultrasonic actuator such as disclosed in commonly assigned U.S. Provisional Patent Application Ser. No. 61/232,525, entitled Method and Apparatus for Ultrasonic Polishing, filed Aug. 10, 2009, which is hereby incorporated by reference.

[0188] FIG. 32 illustrates an embodiment of an individual abrasive member **552** with both hydrostatic and hydrodynamic fluid bearing capabilities designed into bottom surface **560** in accordance with an embodiment of the present disclosure. The bottom surface **560** of the abrasive member **552** includes both air bearing features **564** and pressure ports **566**.

[0189] Leading edge **562** of the abrasive member **552** includes a pair of fluid bearing pads **564A, 564B** (collectively “**564**”) each with at least one associated pressure port **566A, 566B**. Trailing edge **570** also includes a pair of fluid bearing pads **572A, 572B** (collectively “**572**”) and associated pressure ports **566C, 566D**. The fluid bearing surfaces **574** on the trailing edge **570** enhance the stability of the abrasive member **552** at the interface with a surface defect.

[0190] The fluid bearing pads **572** on the trailing edge **570** have less surface area than the fluid bearing pads **564** at the leading edge **562**. Consequently, the leading edge **562** typically flies higher than the trailing edge **570**, which sets the pitch of the abrasive member **552** relative to the substrate **558** (see, e.g., FIG. 14). The trailing edge **570** is typically designed to be in interference with the surface defects on the substrate **558**. Both leading edge and trailing edge structures

564, 572 contribute to holding the abrasive member 552 at a desired clearance 556 from the substrate 558 and controlling the amount of interference with surface defects. It is also possible to control the pressure applied to the pressure ports 566A, 566B at the leading edge 562 to increase or decrease the pitch of the abrasive member 552.

[0191] The hybrid abrasive member 552 can operate with a hydrostatic fluid bearing and/or a hydrodynamic fluid bearing. The hydrostatic pressure ports 566 apply lift to the abrasive member 552 prior to movement of the substrate 558. The lift permits clearance 556 to be set before the substrate 558 starts to move. Consequently, preload 612 does not damage the substrate 558 during start-up. Once the substrate 558 reaches its safe speed and the hydrodynamic fluid bearing is fully formed, the hydrostatic fluid bearing can be reduced or terminated. The procedure can also be reversed at the end of the polishing process.

[0192] In another embodiment, both the hydrostatic and hydrodynamic fluid bearings are maintained during at least a portion of the polishing process. The pressure ports 566 can be used to supplement the hydrodynamic bearing during the polishing process. For example, the pressure ports 566 may be activated to add stiffness to the fluid bearing during initial passes over the substrate 558. The hydrostatic portion of the fluid bearing is then reduced or terminated part way through the polishing process. The pressure ports 566 can also be used to adjust or fine tune the attitude and/or clearance of the abrasive members 552 relative to the substrate 558.

[0193] As best illustrated in FIG. 35, the abrasive members 552 are preferably formed in an array with a spacing structure 576. In one embodiment, the abrasive members 552 and spacing structure 576 are injection molded from a polymeric material to form an integral structure. Alternatively, discrete abrasive members 552 can be bonded or attached to the gimbal mechanisms 590. The bottom surface 560 optionally includes intermediate pad 574 to increase the cutting surfaces to remove surface defects. To enhance the cutting action abrasive features are optionally fabricated onto the pads 564, 572, 574, as discussed above.

[0194] FIG. 33 illustrates a top view of the abrasive member 552 of FIG. 32. Pressure cavity 580 is fabricated on the back surface 582 of the abrasive member 552 that acts as a plenum for the delivery of pressurized gas out through the pressure ports 566.

[0195] FIG. 34 illustrates a gimbal assembly 588 that contains an array of gimbal mechanisms 590 of FIG. 31. Each gimbal mechanism 590 includes four L-shaped springs 592A, 592B, 592C, 592D (collectively "592") that suspend the abrasive members 552 above the substrate 558 in accordance with an embodiment of the present disclosure. Box-like structure 594 is optionally fabricated on each gimbal structure 590 to help align the abrasive members 552. The box-like structure 594 also includes a port 596 that delivers the pressurized gas to the backs of the abrasive members 552 and out the pressure ports 566.

[0196] FIG. 35 is an exploded view of the hydrostatic abrasive article 550 of FIG. 31. External pressure source 554 delivers pressurized gas (e.g., air) to plenum 600 in preload structure 602. Cover 604 is provided to enclose the plenum 600. A plurality of pressure ports 606 in the plenum 600 are fluidly coupled to the pressure ports on the gimbal mechanism 590 by bellows couplings 608.

[0197] Springs 610 transfer the preload 612 from the preload structure 602 to each of the gimbal mechanisms 590. The

externally applied load 612, the geometry of the hydrostatic bearing 564, 572, and the external pressure control the desired spacing 556 between the abrasive members 552 and the substrate 558.

[0198] Holder structure 620 is attached to the preload structure 602 by stand-offs 622. The holder structure 620 sets the preload 624 applied on each abrasive member 552 and limits the deformation of the gimbal mechanisms 590 in order to avoid damage while the individual preload 624 is applied. An adhesive layer (not shown) attaches the abrasive members 552 to the gimbal box-like structure 594. The external preload 612 applied to the array of abrasive members 552 is greater than or equal to the preloads 624 generated by the independently suspended abrasive members 552 in order to allow the gimbal mechanisms 590 to comply with the substrate 558 and not interfere with the holder structure 620.

[0199] FIGS. 36 and 37 illustrates dimple structure 630 interposed between the springs 610 and the gimbal mechanism 590. The dimple structure 630 delivers the preload as a point source. Offset from the springs 610 and the dimple 630 is a flexible bellow 608 that delivers the external pressure to each individual abrasive member 552 via the gimbal mechanisms 590. The gimbal mechanisms 590, preload structure 602, and holder structure 620 can also be used in a hydrodynamic application without the pressure ports 566 and bellows couplings 608.

[0200] FIG. 38 is a bottom view of the hydrostatic abrasive article 550 with the individual abrasive members 552 organized in a serial fashion. Note that other configurations can easily be accommodated, such as for example an off-set or random pattern.

[0201] Alternate hydrostatic slider height control devices are disclosed in commonly assigned U.S. Provisional Patent Application Ser. No. 61/220,149 entitled Constant Clearance Plate for Embedding Diamonds into Lapping Plates, filed Jun. 24, 2009 and Ser. No. 61/232,425 entitled Dressing Bar for Embedding Abrasive Particles into Substrates, which are hereby incorporated by reference. A mechanism for creating a hydrostatic fluid bearing for a single abrasive member attached to a head gimbal assembly is disclosed in commonly assigned U.S. Provisional Patent Application Ser. No. 61/172,685 entitled Plasmon Head with Hydrostatic Gas Bearing for Near Field Photolithography, filed Apr. 24, 2009, which is hereby incorporated by reference.

[0202] Controlling the magnitude of the pressure applied to the abrasive members changes the clearance between the substrate and the abrasive members. The frequency response of the system is independent of the compliance of the material selected for the abrasive member but can be engineered by the selection of the gimballing mechanism, including the hydrostatic bearing design. The pressure generated by the hydrostatic bearing contributes to forming pitch, z-height, and roll forces that counter the cutting forces emanating from surface defects interaction and potential contact with the substrate.

[0203] FIG. 39A illustrates a circular hydrostatic abrasive member 640 in accordance with an embodiment of the present disclosure. The cylindrical shaped recess 642 and pressure port 644 create a generally constant pressure at center, with a logarithmical decaying pressure radially outward.

[0204] FIG. 39B is a graphical illustration of the pressure profile for the circular abrasive member of FIG. 39A. The circular abrasive member has a generally constant pressure profile 646 in center region 642 adjacent to the pressure port 644. The pressure at the outer edges 648 of the abrasive

member matches ambient pressure. This pressure profile operates similar to a spring. One embodiment envisions a cylindrical shaped recess, such as **642**, at each corner of the abrasive member of FIG. **31**.

[0205] FIG. **40** illustrates a hydrodynamic abrasive member **650** in accordance with an embodiment of the present disclosure. The abrasive member **650** is generally the same as discussed above, except that no pressure ports are required. Fluid bearing surfaces **652A**, **652B**, **652C**, **652D**, **652E** (collectively “**652**”) located along the leading edge **654** and trailing edge **656** create hydrodynamic lift between the abrasive member **650** and the substrate **658** (see FIG. **43**). The air for the fluid bearing enters along the leading edge **654** and exits along the trailing edge **656**. The fluid bearing surfaces **652** also enhance the stability at the interface and a cutting surface to remove surface defects from the substrate **658**.

[0206] The conditions promoting hydrodynamic lift are bearing design, gas/liquid shearing, and linear velocity of the abrasive member **650** relative to the substrate **658**. Such conditions can promote the formation of a fluid film (oil, water, gas) between the abrasive member and the substrate. The relative velocity is obtained by rotating the substrate **658** and/or the abrasive members **650**.

[0207] Hydrodynamic abrasive article **670** of the present embodiment is best illustrated in FIGS. **42** and **43**. An array of abrasive members **650** is attached to preload structure **660** by an array of gimbal mechanisms **662**. Preload **664** is transmitted to the gimbal mechanisms **662** by dimpled springs **666**, generally as discussed above. The suspended abrasive members **650** have a static pitch and roll stiffness through the hydrodynamic fluid bearing and a z-stiffness through the gimbal mechanisms **662**. The fluid bearing surfaces **652** can include any of the abrasive features discussed herein.

[0208] The hydrodynamic fluid film formed at each abrasive member **650** controls the dynamic response of the structure. The frequency response of such system can be designed to be in the 10-100 kHz range, which is sufficient to comply with the substrate surface **668** and to interact with surface debris. The spacing between the polishing surfaces **652C**, **652D**, **652E** can be controlled to cause interaction with surface defects with little to no material removal from the substrate **658**. In order for the fluid bearing surfaces **652** to develop a stable interface, the hydrodynamic forces must be greater than external disturbances caused by the interference or contact between the polishing surfaces **652C**, **652D**, **652E** and the surface defects.

[0209] FIG. **41** illustrates a pressure curve generate by the abrasive member **650** of FIG. **40**. Note that the pressure vanishes to atmospheric pressure at the edges of the fluid bearing surfaces and builds-up to a maximum **672** at the trailing edge fluid bearing surfaces **652C**, **652D**, **652E**. Each of the fluid bearing surfaces pressurizes under the shear force of the lubricating fluid (air or liquid) to generate a force contributing to counter the preload **664** and the cutting forces emanating from the polishing or polishing operation. The pressure formed under the fluid bearing surfaces maintains a certain clearance between the substrate **658** and the abrasive members **650**.

[0210] FIGS. **44A-44C** illustrate an abrasive member assembly **750** with an array of abrasive members **768** arranged in a cylindrical array in accordance with an embodiment of the present disclosure. FIG. **45** is an exploded view of the abrasive member assembly **750** of FIG. **44A-44C**.

[0211] The abrasive member **750** preferably forms a contact interface with the substrate, although this embodiment may be used with a hydrodynamic or hydrostatic bearing. Cylinder preload fixture **752** includes a plurality of dimpled spring members **754** that apply an outward radial preload **756** on each gimbal mechanism **758**. The preload **756** is transferred by dimple member **760** acting on rear surface **762** of the gimbal mechanisms **758**. The gimbal mechanisms **758** are interconnected into a gimbal assembly **764** by support structure **766**. The individual abrasive members **768** are attached to the gimbal mechanisms **758**.

[0212] FIG. **46** illustrates a plurality of the abrasive member assemblies **750** of FIG. **45** arranged in a stack configuration **782**. The cylindrical structure can be used to clean planar or non-planar substrates. In one embodiment, axis of rotation **780** is oriented parallel to the surface **784** of the substrate **786**. The stacked configuration **782** is optionally rotated while engaged with the substrate **786**. The substrate **786** can be stationary or moving.

[0213] A hydrostatic bearing can optionally be generated at the interface of the abrasive members **768** and the substrate via external pressurization means, as discussed above. The hydrostatic approach permits the abrasive members **768** to hover over the substrate surface at any desired clearance while still being able to interact and remove surface defects. A stable contacting interface can also be used with the abrasive members **768**. The abrasive members **768** can either be a porous sponge-like material or a hard coated slider. The gimbal mechanisms **758** and preload mechanisms **754** permit the abrasive members **768** to follow the run-out and waviness of the substrate while the abrasive members **768** intimately contact and clean the substrate.

[0214] Alternate methods of controlling the height of the abrasive members above the substrate are disclosed in commonly assigned U.S. Provisional Patent Application Ser. No. 61/220,149 entitled Constant Clearance Plate for Embedding Diamonds into Lapping Plates, filed Jun. 24, 2009 and Ser. No. 61/232,425 entitled Dressing Bar for Embedding Abrasive Particles into Substrates, which are hereby incorporated by reference. A mechanism for creating a hydrostatic fluid bearing for a single abrasive member attached to a head gimbal assembly is disclosed in commonly assigned U.S. Provisional Patent Application Ser. No. 61/172,685 entitled Plasmon Head with Hydrostatic Gas Bearing for Near Field Photolithography, filed Apr. 24, 2009, which is hereby incorporated by reference.

[0215] Controlling the magnitude of the pressure applied to the abrasive members changes the clearance between the substrate and the abrasive members. The frequency response of the system is independent of the compliance of the material selected for the abrasive members but can be engineered by the selection of the gimbaling mechanism, including the hydrostatic bearing design. The pressure generated by the hydrostatic bearing contributes to forming pitch, z-height and roll forces that counter the cutting forces emanating from surface defects interaction and potential contact with the substrate.

Example 1

[0216] FIG. **47A** illustrates an abrasive member **800** modeled for topography following applications. The leading edge **802** includes a plurality of discrete features **804** separated by cavities **806** that permit air flow and particles to enter. The

cavity depth **812** is about 2 micrometers to about 3 micrometers to promote a negative suction force.

[0217] The leading edge pads **804** are formed with rounded surfaces **816** to promote the redistribution of debris and lubricant. This example of a low contact force abrasive member **800** includes leading edge step **818** that increases lift at the leading edge **802**.

[0218] FIG. 47B is a graphical illustration of the contact pressure of the abrasive member **800** with the substrate. The leading edge pressure **802A** is preferably zero. Trailing edge pressure **810A** shows a minor negative suction force. Upon application of large loads (e.g., up to 12 grams) the leading edge **802** does not contact the substrate, while the trailing edge **810** follows the topography of the substrate.

[0219] Table 1 shows that the leading edge **802** clears the substrate, while the trailing edge **810** is in contact. This approach permits the trailing edge **810** to follow the substrate waviness. The leading and trailing edge pressurization contribute to the stability of the design during asperity interactions and debris removal. This design is ideal for cleaning debris and removing nano level amounts of material in the presence of a thin film lubricant.

TABLE 1

Preload (grams)	Negative pressure (grams)	Positive pressure (grams)	Contact force (grams)	Pitch (micr [Ⓣ] radians)/Fly height (nm)
3	-0.89	3.88	0	318/24
5	-1.03	6.02	0.01	233/10
8	-1.18	8.93	0.24	163/4.2
10	-1.27	10.72	0.54	130/2.5
12	-1.31	12.47	0.83	113/1.7

Ⓣ indicates text missing or illegible when filed

Example 2

[0220] FIG. 48A illustrates an abrasive member **820** modeled for topography following applications. The leading edge **822** includes a plurality of discrete features **824** separated by slots **826** that permit air flow and particles to enter. This example of a low contact force abrasive member **820** includes leading edge step **828** and extended sides **830** to increase the negative pressure force (suction force). The leading edge step **828** has a depth of about 0.1 micrometers to about 0.5 micrometers to promote the formation of higher pressure at the leading edge **822**. Note that the trailing edge **832** is formed of discrete pads **834** to reduce the spacing between the substrate and the abrasive member, and to allow for circulation of lubricant and debris.

[0221] FIG. 48B is a graphical illustration of the contact pressure for the abrasive member **820** against the substrate. The contact forces are concentrated at the pads **834** located at trailing edge **832**. The negative pressure saturates around 3.5 grams while the positive pressure increases to balance the applied load while keeping a pitch angle causing the spacing between the leading edge **822** and the substrate. The design provides very good contact stiffness contributing to the stability of the abrasive member. The abrasive member **820** has a pitch that permits the leading edge **822** to remain above the substrate. This design transmits about 15 percent of the applied load to the substrate, which is greater than the force in Example 1. This design is ideal for cleaning and removing

debris from wafers in the presence of a thin film lubricant. Nanometer-level removal from this design is expected.

[0222] Table 2 provides a summary of various performance parameters for the abrasive member as a function of preload.

TABLE 2

Preload (grams)	Negative pressure (grams)	Positive pressure (grams)	Contact force (grams)	Pitch (micr [Ⓣ] radians)/Fly height (nm)
3	-2.9	5.7	0.26	200/3.3
5	-3.18	7.5	0.6314	159/1.4
8	-3.4	10.2	1.14	118/0.5
11	-3.5	13.0	1.6	91/0.18
12	CRASH			

Ⓣ indicates text missing or illegible when filed

Example 3

[0223] FIG. 49A illustrates an abrasive member **840** modeled for topography removing applications. The leading edge **842** includes a plurality of discrete features **844** separated by slots **846** that permit air flow and particles to enter. The trailing edge **848** similarly includes a plurality of discrete features **850** separated by slots **852**. The features **844**, **850** have a height **854** of about 2 micrometers and are formed with rounded leading edge surfaces to distribute both lubricant and wear debris.

[0224] The height **854** is sufficient to create a positive pressure profile at the top of the pads **844**, **850** and a negative suction force at the trailing side **845** of the features **844** in cases of air as a lubricant. The proper selection of the pressure distributions controls the pitch angle of the abrasive member **840** and the minimum spacing above the substrate.

[0225] In the case of topography removing, the abrasive member **840** does not follow certain target wavelengths of waviness. The pitch angle of the abrasive member **840** is therefore substantially reduced to cause both the leading edges **842** and the trailing edges **848** to not follow the target wavelengths of waviness and to cause wear of the interacting surfaces.

[0226] A simple exercise demonstrates the capability of this design given in Table 3. By varying the externally applied preloads from about 0.1 grams to about 10 grams, a reduction in the pitch angle and spacing is attained, causing a higher level of wear and interactions between both the leading and trailing edges **842**, **848** and the substrate. The low pitch angle also inhibits follow of the target wavelengths.

[0227] Note that at 5 grams of preload a negative suction force and a total positive pressure is generated to counter the contact force of 2.56 grams and the 5 grams of preload. An increase in preload as shown causes a substantially linear increase in contact force responsible for the removal of material at the substrate. FIG. 49B is a graphical illustration of the contact pressure of the abrasive member **840** with the substrate. Note the negative pressure at the leading edge **842**.

[0228] Table 3 provides a summary of various performance parameters for the abrasive member as a function of preload.

TABLE 3

Preload (grams)	Negative Pressure (grams)	Positive Pressure (grams)	Contact force (grams)	Pitch (micro-radians)/fly height (nm)
Ⓢ.1	-2.33	2.43	0	31/21
1	-2.39	3.31	0.075	12/14
5	-2.4	4.91	2.56	4/4.8
7	-2.48	5.35	4.13	2.6/3.2
10	-2.50	5.97	6.53	8/1.5

Ⓢ indicates text missing or illegible when filed

Example 4

[0229] FIGS. 50A and 50B illustrate an abrasive member 870 for use with free abrasive particles, such as in CMP. Leading edge pressurization causes the abrasive member 870 to pitch upward so leading edge 872 does not contact the substrate. The pitch also contributes to the ability of the abrasive member 870 to follow the topography of the substrate.

[0230] Rails 876 at trailing edge 874 help pressurize the bearing and cause the trailing edge 874 to contact the substrate. Top surfaces 878 of the rails 876 are in direct contact with the substrate if desired. These surfaces 878 can be textured and coated with hard coatings to cause defect removal and burnishing. The rails 876 control the spacing between the abrasive member 870 and the substrate and provide a predictable interference between the trapped free abrasive particles and the substrate.

[0231] A series of shaped recessed pads 880 are fabricated at the trailing edge 874 between the rails 876 to interact with the free abrasive particles present in the chemical mechanical polishing slurry. The recesses have a depth 882 of about 10 nanometers to about 50 nanometers relative to rails 876, which is smaller than the diameter of the free abrasive particles. The leading edges 884 of the recessed pads 880 are shaped to allow progressive entrance of the free abrasive particles to the interface of the abrasive member 870 with the substrate.

[0232] The design presents a leading edge 884 pressurized zone and a trailing edge 874 pressurized zone. The trailing edge 874 is able to both follow the topography while the recessed pads 880 cause the free abrasive particles to be in intimate contact with the substrate. The resulting contact pressure is substantially uniform and independent of the substrate topography.

Example 5

[0233] FIG. 51 illustrates abrasive member 900 for use with free abrasive particles, similar to CMP. In the case of conditions where a hydrodynamic film is difficult to establish, such as for example in the case of slow spinning plates and the presence of large amount of debris interfering with the formation of a hydrodynamic film, it is desirable to switch to a hydrostatic bearing concept.

[0234] One or more button bearings 902, 904 are fabricated at the leading edge 906, such as illustrated in FIGS. 39A and 39B. Pad 908 is formed at the trailing edge 910. The pad 908 includes ramp 912 that promotes movement of the free abrasive particles into the interface with the substrate. The trailing

edge 910 is in contact with the slurry, causing the free abrasive particles to contact the surface and remove material. The hydrostatic bearing establishes a stable bearing and assures topography following. The hydrostatic bearing provides a substantially constant polishing pressure across the substrate.

[0235] Additional button bearings 914, 916 are optionally located on the pad 908 to establish a desired spacing profile with the substrate, including pitch, nominal spacing (minimum), and a roll attitude of the abrasive member 900.

Example 6

[0236] FIGS. 52A and 52B illustrates an abrasive article 1150 with an array of abrasive member 1152 with integrated preload 1154 and gimbal structure 1156 in accordance with an embodiment of the present disclosure. The illustrated abrasive members 1152 includes spherical fluid bearing structures 1158 each with crown 1160 (curvature in the direction of travel) and camber 1162 (curvature perpendicular to the crown) 1160. The illustrated curvature is substantially exaggerated to illustrate the concept. The abrasive members 1152 can be cylindrical or spherical in form.

[0237] The height differential from center 1164 of the fluid bearing structure 1158 to the edge 1166 is preferably about 10 nanometers to about 100 nanometers to permit the fluid bearing to form. The spherical nature of the fluid bearing surface 1158 is desirable for interacting with free abrasive particles contained in slurry for chemical mechanical polishing.

[0238] Each abrasive member 1152 includes a plurality of extensions 1168 that form the individual gimbal assemblies 1170. As best illustrated in FIG. 52B, the extensions 1168 are mounted to tabs 1172 on preload pad 1174, such as for example, by an adhesive, solvent bonding, ultrasonic welding, and the like. The extensions 1168 can flex and twist on either side of the tabs 1172 so the abrasive members 1152 can be independently displace vertically, and in pitch and roll. For ease of manufacturing the abrasive members 1152 and extension 1168 are molded as a unitary structure.

[0239] Preload members 1176 are positioned between the preload pad 1174 and rear surfaces 1159 of the abrasive members 1152. The preload members 1176 are preferably resilient to permit deflection of the abrasive members 1152 in the vertical direction. The preload members 1176 are preferably attached to either the preload pad 1174 or the abrasive members 1152. In an alternate embodiment, the preload pad 1174 is made of a resilient material. The preload 1184 is applied simply by pushing the entire assembly 1150 against the substrate.

[0240] The abrasive members 1152 optionally include one or more cavities or steps 1180 near leading edge 1182 to promote formation of a fluid bearing. By changing the curvature of the fluid bearing surface 1158, the shape or location of the cavities 1180, or a variety of other variables, the abrasive members can be either topography following or topography removing. If the curvature of the fluid bearing surface 1158 is increased above about 100 nanometers, the maximum pressure tends to form at the center 1164. The spherical configuration permits a progressive interactions with free abrasives. The spherical shape also allows for a point like contact with desirable topography following properties.

Example 7

[0241] FIGS. 53A and 53B illustrates an abrasive article 1200 with an array of abrasive member 1202 substantially as

shown in FIGS. 52A and 52B with hydrostatic ports 1204 in accordance with an embodiment of the present disclosure. The hydrostatic ports 1204 are preferably button bearings, such as disclosed in FIG. 39A, located at leading edges 1206 of the abrasive members 1202.

[0242] Rear surfaces 1208 of each abrasive member 1202 includes channels 1210 that fluidly communicate with opening 1212 in sealing layer 1214. As best illustrated in FIG. 53A, the openings 1212 fluidly communicate with holes 1216 in preload members 1226. Rear surface 1220 of preload pad 1218 includes a series of channels 1222 and backing layer 1224. As a result, a pressurized gas delivered to the channels 1222 flows through the backing layer, to the channels 1210 in the abrasive members 1202 and out the pressure ports 1204.

Resilient Support

[0243] FIGS. 54 and 55 illustrate abrasive article 1300 with an array of abrasive members 1302 coupled to resilient support 1304 in accordance with an embodiment of the present disclosure. Resilience refers to a property of a material to absorb energy when it is deformed elastically and then, upon unloading, to have this energy recovered. The resilient support is preferably an elastomer (e.g., a polymer with viscoelastic properties).

[0244] In the illustrated embodiment, resilient support 1304 is a layer of resilient material and the abrasive members 1302 are discrete structures arranged in a circular array. Each abrasive member 1302 can articulate independently in at least pitch 1336 and roll 1338 (see FIG. 57).

[0245] The resilient supports of the embodiments discussed herein are a lower cost alternative to mechanical gimbal mechanisms. While some embodiments the resilient supports may lack the frequency response of a mechanical gimbal, the resilient supports are more resistant to vibration or chatter. By modifying the resilient support, pitch and roll stiffness can be engineered for the particular application. The resilient supports can be made using a wide variety of techniques, such as for example, molding, stamping, laser cutting, and can be constructed from one or more layers.

[0246] The stiffness of the air bearing is preferably greater than the stiffness of the resilient support 1304, so the dominant factor effecting the engagement of the abrasive members 1302 with substrate 1314 is the air bearing. Once the air bearing is formed the frequency response is typically comparable to that of mechanical gimbals, with greater resistance to harmonic vibration and chatter. Additionally, frequency response is typically less important for some topography removing applications.

[0247] In the illustrate embodiment, resilient layer 1304 does not completely decouple pitch and roll displacement of a single abrasive member 1302, as can be done with a mechanical gimbal. The ability to use low-cost molding techniques to make the abrasive article 1300, however, outweighs this limitation for some embodiments.

[0248] In one embodiment, the resilient support 1304 is bonded to the abrasive member 1302. As used herein, “bond” or “bonding” refers to, for example, adhesive bonding, solvent bonding, ultrasonic welding, thermal bonding, and the like. In another embodiment, the resilient support 1304 and the abrasive members 1302 are fused together during the molding process.

[0249] Preload structures 1306 biases preload member 1308 to transmit preload 1310 to rear surface 1312 of the abrasive members 1302. In the preferred embodiment, each

abrasive member 1302 has one or more discrete preload members. The preload members 1308 are preferably embedded or molded in the resilient layer 1304. The stiffness of the air bearing is preferably balanced with the stiffness of preload structure 1306.

[0250] The abrasive members 1302 are preferably rigid so that they pivot around distal end 1308A of the preload member 1308. In the illustrated embodiment, the preload member 1308 is a metallic spring member that permits Z-axis 1334 displacement of the abrasive members 1302, although a rigid preload member can also be used (see FIG. 57). As used herein, “spring members” refers to a wide variety of spring structures, such as for example, coil springs, leaf springs, flat springs, cantilever springs, and the like.

[0251] As illustrated in FIG. 56, air shearing forces generated by relative motion 1330 of the abrasive article 1300 relative to substrate 1314 to entrain an air cushion that interacts with air bearing features 1316 to create hydrodynamic forces 1318. The air bearing features 1316 are preferably configured so generate greater lift 1318 at leading edge 1320 then at trailing edge 1322. As a result, the abrasive members 1302 assume an attitude or pitch angle 1332. Resilient layer 1304 compresses at location 1324 and stretches at location 1326 to accommodate the pitch angle 1332.

[0252] The hydrodynamic forces 1318 are preferably substantially greater than the stiffness of the resilient layer 1304. The pitch angle 1332 is preferably controlled by other factors, such as for example, the configuration of the air bearing features 1316, the speed of the abrasive article 1300 relative to the substrate 1314, and the like. FIG. 57 illustrates one possible embodiment of the air bearing features 1316. The resilient layer 1304 allows the abrasive member 1302 to articulate in all six degrees of freedom X-axis 1330, Y-axis 1332, Z-axis 1334, pitch 1336, roll 1338, and yaw 1340.

[0253] As discussed herein, the trailing edge 1322 preferably includes abrasive features. The abrasive features can be one or more of an abrasive material attached to the air bearing features 1316, a slurry of free abrasive particles located at the interface of the air bearing features 1316 and the substrate 1314, air bearing features 1316 made from abrasive particles disbursed in a binder, nano-scale roughened surface of the air bearing features 1316 coated with a hard coat, or nano-scale diamonds attached to the air bearing features 1316 at trailing edges 1322 of the abrasive members 1302, or a combination thereof. The substrate 1314 can be a wafer, a wafer-scale semiconductor, magnetic media for hard disk drives, bit patterned or discrete track media, a convention disk for a hard disk drive, or any other substrate.

[0254] FIG. 58 illustrates an alternate abrasive article 1350 with abrasive members 1352 pre-configured with pitch angle 1354 in accordance with an embodiment of the present disclosure. The pre-configured pitch attitude 1354 reduces the amount of deformation of the resilient backing 1356 required to establish the desired flying attitude of the abrasive members 1352 relative to substrate 1358. The pre-configured pitch angle 1354 is preferably established during the molding process.

[0255] FIG. 59 illustrates an alternate abrasive article 1370 with one or more sensors 1372A, 1372B (collectively “1372”) located in abrasive members 1374 in accordance with an embodiment of the present disclosure. Sensor 1372 can be used to perform contact detection in order to establish gap 1376 between the abrasive member 1374 and substrate 1378, to monitor material removal from the substrate 1378,

and/or to monitor surface roughness of the substrate **1378**. The sensors **1372** can be a shear based transducer such as disclosed in U.S. Pat. No. 6,568,992 (Angelo et al.); a lapping sensor such as disclosed in U.S. Pat. No. 5,494,473 (Dupuis et al.) and U.S. Publication No. 2005/0071986 (Lackey et al.); a piezoelectric sensors disclosed in U.S. Pat. No. 6,543,299 (Taylor); and the like, all of which are hereby incorporated by reference.

[0256] In another embodiment, one or more heaters **1392** can be included to thermally expand the abrasive members **1374** as a mechanism of controlling the gap **1376** and/or to shape the contact surface **1394**. Various arrangements of heaters are disclosed in U.S. Pat. Nos. 7,428,124 and 7,430,098 (Song, et al.); 7,388,726 (McKenzie et al.); and U.S. Pat. Publication No. 2007/0035881 (Burbank et al.), which are hereby incorporated by reference.

[0257] In the illustrated embodiment, circuit layer **1380** is located between the preload structure **1382** and the resilient layer **1384**. The electrical connection between the circuit layer **1380** and the sensors **1372** can be made using a separate electrical conductor **1386** embedded in the resilient layer **1384**. In another embodiment, preload member **1388** acts as the electrical conductor **1386**.

[0258] Additional circuitry or electrical devices **1390** can be located in the circuit layer **1380** or in the abrasive members **1374**, such as for example, ground planes, power planes, transistors, capacitors, resistors, RF antennae, shielding, filters, memory devices, embedded IC, and the like. In one embodiment, the electrical devices **1390** can be formed using printing technology, adding intelligence to the abrasive members **1374**. The availability of printable silicon inks provides the ability to print electrical devices **1390**, such as disclosed in U.S. Pat. No. 7,485,345 (Renn et al.); 7,382,363 (Albert et al.); 7,148,128 (Jacobson); 6,967,640 (Albert et al.); 6,825,829 (Albert et al.); 6,750,473 (Amundson et al.); 6,652,075 (Jacobson); 6,639,578 (Comiskey et al.); 6,545,291 (Amundson et al.); 6,521,489 (Duthaler et al.); 6,459,418 (Comiskey et al.); 6,422,687 (Jacobson); 6,413,790 (Duthaler et al.); 6,312,971 (Amundson et al.); 6,252,564 (Albert et al.); 6,177,921 (Comiskey et al.); 6,120,588 (Jacobson); 6,118,426 (Albert et al.); and U.S. Pat. Publication No. 2008/0008822 (Kowalski et al.), which are hereby incorporated by reference.

[0259] FIGS. **60** and **61** illustrate an alternate abrasive article **1400** with an array of cantilevered abrasive members **1402** in which preload member **1404** combines the preload function with the articulation function in accordance with an embodiment of the present disclosure. The embodiment of FIG. **61** substantially decouples pitch and roll displacement of the abrasive members **1402**. The preload member **1404** is preferably embedded in abrasive members **1402**, such as during the molding process. In one embodiment, preload member **1404** is molded into resilient support **1406**.

[0260] In one embodiment, sacrificial layer **1408**, such as for example a photo mask, is then applied to surface **1410** of the resilient support **1406**. The abrasive members **1402** are then molded over the preload member **1404** protruding from the sacrificial layer **1408**. Thickness **1412** of the sacrificial layer **1408** determines gap **1414** (see FIG. **61**) between the abrasive members **1402** and the resilient support **1406**.

[0261] As illustrated in FIG. **61A**, once the sacrificial layer **1408** is removed, the abrasive member **1402** is retained in cantilevered configuration **1415** relative to the resilient support **1406** by preload member **1404**. The preload member **1404** also applies preload **1422** to the abrasive members **1402**,

as discussed above. The preload member **1404** retains the abrasive members **1402** in a cantilevered relationship with resilient support **1406**, and determines pitch and roll stiffness. The stiffness of the resilient support **1406** is optionally increased to create a stop on deflection of the abrasive member **1402**.

[0262] In an alternate embodiment illustrated in FIG. **61B**, preload member **1404** is retained in a less resilient or rigid material **1405** surrounded by resilient support **1406**. Consequently, resistance to displacement of the abrasive members **1402** is concentrated in distal portion **1407** of the preload member **1404**.

[0263] In one embodiment, the thickness **1412** is selected to permit the abrasive members **1402** to assume a desired pitch angle **1420** relative to substrate **1416**. As illustrated in FIG. **62**, leading edge **1418** contacts, or is adjacent to, the layer **1406** after formation of an air bearing. The layer **1406** acts to limit or resist further increases in the pitch angle **1420**. The interaction of the leading edge **1418** with the layer **1406** attenuates vibration of the abrasive member **1402**.

[0264] As illustrated in FIG. **62**, the preload member **1404** flexes to permit the abrasive member **1402** to move in all six degrees of freedom. In the preferred embodiment, the preload member **1404** is constructed from metal to provide high frequency response during interaction with substrate **1416**. The preload member **1404** can be supplemented with any of the resilient or spring structures disclosed herein.

[0265] FIG. **63** illustrates an alternate abrasive article **1430** with an array of cantilevered abrasive members **1432** in accordance with an embodiment of the present disclosure. In the illustrated embodiment, resilient support **1434** is a coiled spring structure embedded in the abrasive members **1432** and the resilient support **1436**. Resilient support **1436** optionally has greater stiffness to limit articulation of the abrasive members **1432**.

[0266] FIG. **64** illustrates an alternate abrasive article **1450** with an array of abrasive members **1452** in accordance with an embodiment of the present disclosure. Abrasive members **1452** are retained to resilient support **1454** by tension member **1456** that extends through pivot structure **1458**. The pivot structure **1458** is preferably constructed from a resilient material that permits some Z-axis displacement.

[0267] In the illustrated embodiment, the tension member **1456** is highly flexible and provide minimal resistance to the abrasive members **1452** pivoting on pivot structure **1458**. In one embodiment, the tension member **1456** is an extension of pivot structure **1458**, instead of a separate structure. In another embodiment, tension member **1456** is a polymeric structure, such as a monofilament.

[0268] In the preferred embodiment, a plurality of spring structures **1460** are embedded in resilient support layer **1454**. The spring structures **1460** are preferably located along centerline of the abrasive members **1452** (x-axis) so as to reduce resistance to roll **1462**. Although the spring structures **1460** are illustrated as coil springs, a variety of other spring structures may be used, such as for example, leaf springs, flat springs, cantilever springs, and the like.

[0269] Alternatively, the resilient supports **1460** can be embedded in the abrasive members **1452** and/or the resilient support layer **1454**. In yet another embodiment, the spring structures **1460** are elastomeric members.

[0270] FIG. **65** illustrates an alternate abrasive article **1470** with an array of abrasive members **1472** with textured resilient support **1474** in accordance with an embodiment of the

present disclosure. Altering the texture permits the pitch and roll stiffness to be adjusted. The abrasive members **1472** are preferably bonded to peaks **1476** of the textured support structure **1474**. The textured resilient support **1474** has reduced stiffness relative to a continuous layer. Preload member **1478** applies preload **1480** to the abrasive members **1472**. Preload member **1478** can be embedded in the textured resilient support **1474** and/or layer **1482**.

[0271] FIG. 66 illustrates an alternate abrasive article **1490** with an array of abrasive members **1492** with non-woven resilient support **1494** in accordance with an embodiment of the present disclosure. The non-woven resilient support **1494** preferably includes spring metal and polymeric fibers **1496** in a non-woven configuration to increase frequency response.

[0272] In the illustrate embodiment, the non-woven resilient support **1494** is non-planar. Resilient protrusion **1498** is preferably embedded in the abrasive members **1492**, such as by overmolding, to create gap **1500** to facilitate pivoting. Preload member **1502** is optionally embedded in layer **1504** for greater stability. In one embodiment, layer **1504** includes a plurality of openings **1506** through which debris abraded from substrate **1508** is removed from interface **1510** by force of vacuum.

[0273] FIG. 67 illustrates an alternate abrasive article **1520** with an array of abrasive members **1522** on discontinuous resilient support **1524** in accordance with an embodiment of the present disclosure. Resilient support **1524** is molded with a plurality of cantilevered projections **1526** extending into openings or recesses **1528**. The abrasive members **1522** are bonded to the cantilevered projections **1526** at interfaces **1530**.

[0274] Changing the geometry of the projections **1526** permits the pitch and roll stiffness to be modified for the particular application. In particular, increase the width of the projections **1526** increases roll stiffness. In one embodiment, additional projections **1526** are formed in the resilient support **1524** that engage with side edges of the abrasive members **1522** to enhance roll stiffness.

[0275] The abrasive members **1522** preferably have dimension **1532** in at least one direction that is less than corresponding dimension **1534** of the recess **1528**. Consequently, during engagement with substrate **1536**, only the resilience of the cantilevered projections **1526** resist displacement of the abrasive members **1522**. Preload member **1538** is preferably embedded in layer **1540**.

[0276] FIG. 68 illustrates an abrasive article **1550** with an array of abrasive members **1552** on an alternate discontinuous resilient support **1554** in accordance with an embodiment of the present disclosure. In the illustrated embodiment, only leading and trailing edges **1556**, **1558** of the abrasive members **1552** are bonded to the resilient support **1554**. Side edges of the abrasive members **1552** are preferably free floating over recess **1562**. Tapers **1560** formed in openings **1556** result in a steep increase in stiffness of the resilient support **1554** as a function of displacement of the abrasive members **1552**.

[0277] FIG. 69 illustrates abrasive article **1570** having an array of abrasive members **1572** with hydrostatic pressure ports **1574A**, **1574B** (collectively “**1574**”) in accordance with an embodiment of the present disclosure. Plenum **1576** is fluidly coupled by conduit **1578** that extends through resilient support **1580**. The pressure generated by the hydrostatic pressure port **1574** contributes to forming pitch angle, z-height,

and roll forces that counter the cutting forces emanating from surface defects interaction and potential contact with the substrate **1582**.

[0278] A hydrostatic bearing may be used in combination with a hydrodynamic fluid bearing, such as during start-up rotation and/or ramp-down of the abrasive article **1570** relative to a substrate. The hydrostatic bearing controls the interface with the substrate **1582** until hydrodynamic air bearing is at least partially formed, as discussed above. Thereafter, the hydrostatic bearing is preferably reduced or terminated.

[0279] FIG. 70 illustrates abrasive article **1600** having an array of cantilevered abrasive members **1602** with hydrostatic pressure ports **1604A**, **1604B** (collectively “**1604**”) in accordance with an embodiment of the present disclosure. Conduit **1606** extends above resilient support **1608** and into the abrasive members **1602**, creating gap **1610**. The conduit **1606** is preferably sufficiently resilient to permit the abrasive member **1602** to move through at least pitch and roll, but also acts as the preload member. In an alternate embodiment, separate preload member **1612** extends through conduit **1606** to provide the preload **1614**, without interfering with the flow of pressurized air to the pressure ports **1604**. In one embodiment, resilient support **1608** has increased stiffness to limit displacement of the abrasive members **1602**. In alternate embodiment, layer **1608** is made from a resilient material to supplement the resilient of the conduit **1606**.

[0280] FIG. 71 illustrates an alternate abrasive article **1630** with structured elastomeric support **1632** in accordance with an embodiment of the present disclosure. Recesses **1634** surround and mechanically isolate abrasive members **1636** to facilitate articulation when subject to hydrodynamic forces and/or engagement with substrate **1638**. In the illustrated embodiment, protrusions **1640** have generally the same dimensions as the second surface **1642** of the abrasive members **1636**. In alternate embodiments, the protrusions **1640** can have cross sectional dimensions greater than or less than the second surface **1642** of the abrasive members **1636**.

[0281] FIG. 72 illustrates fixture **2100** for making an abrasive article in accordance with a method of the present invention. Master plate **2102** is machined and polished to a substantially flat surface **2104**.

[0282] Roughness of a surface can be measured in a number of different ways, including peak-to-valley roughness, average roughness, and RMS roughness. Peak-to-valley roughness (Rt) is a measure of the difference in height between the highest point and lowest point of a surface. Average roughness (Ra) is a measure of the relative degree of coarse, ragged, pointed, or bristle-like projections on a surface, and is defined as the average of the absolute values of the differences between the peaks and their mean line.

[0283] The master plate **2102** is preferably silicon, silicon carbide, or silicon nitride, since wafer planarization infrastructure is capable of achieving a roughness (Ra) of about 0.5 Angstroms. The fine finish requirements for the surface **2104** includes peak-to-peak short length waviness of about 10 nanometers to about 40 nanometers, peak-to-peak long waviness of less than about 5 microns, and surface finish quality with an Ra of 0.5 Angstroms. Planarization of silicon is disclosed in U.S. Pat. Nos. 6,135,856 (Tjaden et al.) and 6,194,317 (Kaisaki et al.) are hereby incorporated by reference.

[0284] Once the master plate **2102** is machined, a hard coat **2106** is preferably applied to protect the surface **2104**. Surface **2107** of the hard coat **2106** generally tracks the surface **2104** of the master plate **2102**. The desired thickness **2108** of

the hard coat **2106** can be in the range of about 100 nanometers or greater. In one embodiment, the hard coat **2106** is diamond-like carbon (“DLC”) with a thickness **2108** of about 100 nanometers to about 200 nanometers. DLC hardness is preferably more than about 5 GPa to adequately protect the surface **2104**. It is highly desirable to generate DLC hardness in the range of 70-90 GPa.

[0285] In one embodiment the DLC is applied by chemical vapor deposition. As used herein, the term “chemically vapor deposited” or “CVD” refers to materials deposited by vacuum deposition processes, including, but not limited to, thermally activated deposition from reactive gaseous precursor materials, as well as plasma, microwave, DC, or RF plasma arc-jet deposition from gaseous precursor materials. Various methods of applying a hard coat to a substrate are disclosed in U.S. Pat. Nos. 6,821,189 (Coad et al.); 6,872,127 (Lin et al.); 7,367,875 (Slutz et al.); and 7,189,333 (Henderson), which are hereby incorporated by reference.

[0286] The next step is to apply a spacer layer **2110**. The spacer layer **2110** is preferably a low surface energy coating, such as for example Teflon. The spacer layer **2110** acts as a spacer to set height **2112** of particles **2114** protrude above reference surface **2116** on the abrasive article **2118** (see FIG. 76A). Consequently, by varying the thickness **2112'** of the spacer layer **2110**, the height **2112** of the particles **2114** can be controlled.

[0287] In some embodiments, the thickness **2112'** may be different than the height **2112** of the particles **2114** to compensate for deformation of the spacer layer **2110** during impregnation of the substrate (see FIG. 75) and other manufacturing variability. As a result, the thickness **2112'** of the spacer layer **2110** corresponds to the desired height the particles **2114** protrude above the reference surface **2116**, but there is not necessarily a one-to-one correlation.

[0288] In one embodiment the spacer layer **2110** is a preformed sheet bonded or adhered to the surface **2107** of the hard coat **2106**. In another embodiment, the spacer layer **2110** is sprayed or printed onto the surface **2107**, such as disclosed in U.S. Pat. No. 7,485,345 (Renn et al.) and U.S. Pat. Publication No. 2008/0008822 (Kowalski et al.), which are hereby incorporated by reference.

[0289] As illustrated in FIG. 73 adhesive slurry **2120** of adhesive **2122** containing particles **2114** is distributed evenly over surface **2124** of the spacer layer **2110**. Using a spacer layer **2110** made from a low surface tension material aids in wetting the adhesive **2122**. Methods of uniformly dispersing nanometer size abrasive grains are disclosed in U.S. Pat. Pub. No. 2007/0107317 (Takahagi et al.), which is hereby incorporated by reference.

[0290] Particle of any composition and size can be used with the method and apparatus of the present invention. The preferred particles **2114** are diamonds with primary diameters less than about 1 micrometer, also referred to as nanoscale. For some applications, however, the diamonds can have a primary diameter of about 100 nanometers to about 20 micrometers.

[0291] Substrate **2126** illustrated in FIG. 74 is then pressed against the adhesive slurry **2120**. In the illustrated embodiment, the substrate **2126** is a tin plate. Note that surface **2128** of the substrate **2126** has some waviness, which will be covered by adhesive **2122** in the abrasive article **2118** according to the present invention. The substrate **2126** can be manufac-

ured from a variety of metals, polymeric materials, ceramics, or composites thereof. The substrate **2126** can also be flexible, rigid, or semi-rigid.

[0292] As illustrated in FIG. 75, the substrate **2126** is applied with a sufficient force *F* to cause the particles **2114** to substantially penetrate the spacer layer **2110**, without substantial penetration or indentations in the hard coat **2106**. The particles **2114** are also embedded in surface **2128** of the substrate **2126**. The particles **2114** typically penetrate the relatively softer spacer layer **2110** until they contact the hard coat **2106** before penetrating the substrate **2126**. The adhesive **2122** preferably fills gaps **2130** between the surface **2128** of the substrate **2126** and the surface **2124** of the spacer layer **2110**. The adhesive **2122** also follows the contour of the surface **2124** of the spacer layer **2110**, as will be discussed below.

[0293] The spacer layer **2110** permits the particles **2114** to contact the surface **2107** of the hard coat **2106** and limits the amount of penetration into the substrate **2126**. Depending on the material selected, the thickness of the spacer layer **2110** may be increased to compensate for deformation during the impregnating step of FIG. 75.

[0294] The surface **2128** of the substrate **2126** preferably has a flatness that is less than about the height of the particles **2114**, so the particles **2114** are sufficiently embedded in the surface **2128**. If the particles **2114** are not sufficiently embedded into the substrate **2126**, the adhesive **2122** may be the primary mode of attachment, leading to release during lapping.

[0295] FIG. 76A illustrates the abrasive article **2118**, with the sacrificial spacer layer **2110** removed in accordance with an embodiment of the present invention. Using a spacer layer **2110** made from a low surface tension material facilitates removal of the master plate **2102**. The at least partially cured adhesive **2122** forms a reference surface **2116** from which height **2112** of the particles **2114** can be measured. The reference surface **2116** corresponds to the shape of the surface **2124** of the spacer layer **2110**.

[0296] The waviness of the surface **2128** on the substrate is not reflected in the uniform height **2112** of the particles **2114** or the reference surface **2116**. The uniform distance **2112** between the peaks **2115** of the particles **2114** and the reference surface **2116** permits formation of a substantially uniform hydrodynamic film relative to the height **2112** of the particles **2114**. As used herein, “substantially uniformly” and “substantially flat” refers to both an entire surface of a substrate or an abrasive article and to selected portions of the substrate or abrasive article. For example, localized uniformity or flatness may be sufficient for some applications.

[0297] Various processes can be used to activate and/or cure the adhesive **2122** to bond the diamonds **2114** to the substrate **2126** and create the reference surface **2116**, such as for example ultraviolet or infrared RF energy, chemical reactions, heat, and the like. As used herein, “cure” or “activate” refers to any chemical transformation (e.g., reacting or cross-linking), physical transformation (e.g., hardening or setting), and/or mechanical transformation (e.g., drying or evaporating) that allows an adhesive to change or progress from a first physical state (generally liquid or flowable) into a more permanent second physical state or form (generally solid).

[0298] FIG. 76B illustrates an alternate abrasive article **2118'** without an adhesive in accordance with an embodiment of the present invention. The particles **2114** are embedded in the substrate **2126**, so an adhesive is not required. The peaks

2115 of the particles **2114** are substantially coplanar **2117**. In embodiments where the abrasive article is not planar, the peaks of the particles correspond to the contour of the surface of the master plate. Any of the embodiments disclosed herein can be created without the adhesive in the slurry of particles.

[0299] The present methods provide a number of benefits over prior art diamond charged lapping plates. The present abrasive article **2118** provides a uniform height **2112** of the diamonds **2114** (“dh”) with respect to a substantially flat reference surface **2116**. There is no need to condition the present abrasive article **2118**. Knowledge of the lapping conditions, lubricant type, and the lapped bar can be used to calculate the hydrodynamic film thickness (“hf”) relative to the reference surface **2116** formed by the cured adhesive **2122**. Once the hydrodynamic film thickness is known, the interference (“I”) can be calculated from the uniform height **2112** of the diamonds **2114** from the hydrodynamic film ($I=dh-hf$). The substantially flat reference surface **2116** provides a generally uniform hydrodynamic film, which translates into uniform forces at the slider bar/abrasive article interface. Constant interference (I) of the abrasive diamonds **2114** during the lapping process leads to a notable reduction in occurring of scratches, a substantial improvement in pole tip recession critical to the performance of magnetic recording heads, and a substantial improvement in surface roughness.

[0300] Note that the substrate **2126** has historically been a tin plate because of ease of charging the diamonds **2114** and dressing the plate. Since the height **2112** of the protruding diamonds **2114** is controlled by the thickness of the spacer layer **2110**, however, other relatively harder materials are also good candidates for this application, such as for example soft steels, copper, aluminum, and the like.

[0301] While the application discussed above is lapping slider bars for disk drives, for the present abrasive article **2118** has a wide range of other industrial applications, such as for example lapping semiconductor wafers and polishing metals.

[0302] FIG. 77 illustrates a fixture **2150** for manufacturing an abrasive article **2152** with a structured substrate **2154** (see FIG. 79) in accordance with an embodiment of the present invention. The desired structures **2156** are machined in the master plate **2158**. The structures **2156** can be linear, curvilinear, regular, irregular, continuous, discontinuous, or a variety of other configurations. Various structured substrates and adhesives suitable for use in the present invention are disclosed in U.S. Pat. Nos. 6,194,317 (Kaisaki et al.); 6,612,917 (Bruxvoort); 7,160,178 (Gagliardi et al.); 7,404,756 (Ouderkerk et al.); and U.S. Publication No. 2008/0053000 (Palmgren et al.), which are hereby incorporated by reference.

[0303] In the illustrated embodiment, the structures **2156** are a series of grooves. The surfaces **2160** of the grooves **2156** can be machined with a continuous curvilinear shape, a series of discrete curvilinear or flat shapes with transition locations, or a combination thereof. In the illustrated embodiment, the grooves **2156** include valleys **2160A**, peaks **2160B**, and side surfaces **2160C** (collectively “**2160**”). The peaks **2160B** have substantially uniform peak height **2168**.

[0304] In the illustrated embodiment, the master plate **2158** is machined with a hard ceramic material such as TiC or TiN. The hard coat is optional and is not shown in the embodiment of FIG. 77. Spacer layer **2162** is then deposited on the surface **2160** of the grooved master plate **2158** with a thickness **2164** corresponding the desired protruding height of particles

2166. An adhesive slurry **2170** including adhesive **2172** and particles **2166** is distributed evenly over the grooved surface **2174** of the spacer layer **2162**.

[0305] As illustrated in FIG. 78, the substrate **2154** with features **2182** generally corresponding to grooves **2156** is then pressed against the adhesive slurry **2170** with a sufficient force to cause the particles **2166** to substantially penetrate the spacer layer **2162**, without substantial penetration into the master plate **2158**. The particles **2166** also penetrate into the substrate **2154**, primarily at peaks **2184**.

[0306] The grooves **2182** in the substrate **2154** are preferably fabricated with a peak height **2180** greater than peak height **2168** of the grooves **2156** machined in the grooved master plate **2158**. The greater peak height **2180** on the substrate **2154** permits the particles **2166** located along critical peaks **2184** to be firmly embedded in the substrate **2154**. Any inaccuracy in the machining of the heights **2168**, **2180** of the grooves **2156**, **2182** is preferably located in the non-critical valleys **2190** on the abrasive article **2152**. Note that portion of the particles **2166'** located in the valleys **2190** are not embedded in the substrate **2154**, but are secured to the substrate **2154** by the adhesive **2172**.

[0307] The spacer layer **2162** controls the depth of penetration of the particles **2166** into the substrate **2154**. The adhesive **2172** fills any gaps **2192** between the surface **2186** of the substrate **2154** and the surface **2174** of the spacer layer **2162**. The flatness requirement of the substrate **2154** is less than about the height of the abrasives particles **2166** so as to be embedded a sufficient amount in the surface **2186** of the substrate **2154**.

[0308] FIG. 79 illustrates the abrasive article **2152**, with the sacrificial spacer layer **2162** removed. The at least partially cured adhesive **2172** forms a substantially flat reference surface **2194** from which height **2196** of the particles **2166** can be measured. The reference surface **2194** also provides a substantially uniform hydrodynamic film relative to the height **2196** of the particles **2166**.

[0309] The grooves **2198** in the abrasive article **2152** are designed to promote lubricant transfer from inner diameter to outer diameter under centrifugal forces to carry the wear by-products and reduce the height of the hydrodynamic film to promote aggressive material removal. Various geometrical features and arrangement of particles on abrasive articles are disclosed in U.S. Pat. Nos. 4,821,461 (Holmstrand), 3,921,342 (Day), and 3,683,562 (Day), and U.S. Pat. Pub. No. 2004/0072510 (Kinoshita et al), which are hereby incorporated by reference.

[0310] The present method of manufacturing abrasive articles includes preparing a master plate with a shape that is generally a mirror image of the desired uniform height fixed abrasive article. A hard coat is optionally applied protect the surface of the master plate. A spacer layer is deposited on the master plate or hard coat. Adhesive slurry containing adhesive and particles is distributed evenly over surface of the spacer layer. A substrate with a surface that is generally a mirror image of the master plate is then pressed against the adhesive slurry to embed the particles into the substrate. The spacer layer controls the penetration of the particles into the substrate. The adhesive fills gaps between the surface of the substrate and the surface of the spacer layer. The substrate containing the embedded particles is separated from the master plate and the sacrificial spacer layer is removed. The at least partially cured adhesive forms a substantially flat reference surface between the protruding particles.

[0311] It will be appreciated that the present method of manufacturing abrasive articles can be used with a variety of shaped substrates, such as for example concave surfaces, convex surfaces, cylindrical surfaces, spherical surfaces, and the like. The present method is not dependent on the size or composition of the particles.

[0312] FIG. 80 is a side sectional view of a uniform height fixed abrasive article 2250 with a convex surface 2252 in accordance with an embodiment of the present invention. The convex surface 2252 can be circular, curvilinear, and a variety of other regular and irregular curved shapes. As with the embodiments discussed above, adhesive 2254 provides a uniform reference surface 2256. The particles 2258 extend a substantially uniform amount above the reference surface 2256. The reference surface 2256 is also smooth so as to promote a substantially uniform hydrodynamic film.

[0313] FIG. 81 is a side sectional view of a fixed abrasive article 2260 with a concave surface 2262 in accordance with an embodiment of the present invention. The concave surface 2262 can be circular, curvilinear, and a variety of other regular and irregular curved shapes. As with the embodiments discussed above, adhesive 2264 provides a uniform reference surface 2266. The particles 2268 extend a substantially uniform amount above the reference surface 2266.

[0314] FIG. 82 is a top view of a fixed abrasive article 2270 with a cylindrical surface 2272 and the associated master plates 2274 in accordance with an embodiment of the present invention. The particles 2276 extend a substantially uniform amount above the reference surface 2278 created by the cured adhesive 2280.

[0315] The curved abrasive articles of FIGS. 80-82 are particularly suited for polishing machined metal parts, such as for example components for engines and transmissions, where a significant reduction in friction will translate into greater fuel efficiency.

[0316] FIG. 83 illustrates a fixed abrasive article 2300 in accordance with any of the embodiments disclosed above, that uses the two step adhesion process disclosed in U.S. Pat. Nos. 7,198,553 and 6,123,612, which are hereby incorporated by reference. The particles 2304 are embedded in the substrate 2306 using sacrificial layer 2308 as discussed herein. Elevated heat and pressure are applied to a sintered powder matrix material and a brazing alloy 2302 to create a chemical bond between the particles 2304 and surface 2314 of the substrate 2306. The sacrificial spacer 2308 (shown in phantom) is preferably a soft metal to avoid excessive deformation during heating of the matrix 2302.

[0317] The matrix 2302 lacks the ability to fill the spaces 2310 between the sintered material 2302 and the spacer 2308. A low viscosity curable material 2314, such as for example a thermo-set adhesive, is optionally provided to fill the spaces 2310 and to provide the reference surface 2312 between the particles 2304. The curable material 2314 also acts as a corrosion barrier to protect the sintered material 2302 from corrosion and other interaction in chemical mechanical polishing applications. In an alternate embodiment, the curable material 2314 is omitted.

[0318] Where a range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range is encompassed within the present embodiments. The upper and lower limits of these smaller ranges which may independently be included in the

smaller ranges is also encompassed within the disclosure, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either both of those included limits are also included in this disclosure.

[0319] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which these inventions belong. Although any methods and materials similar or equivalent to those described herein can also be used in the practice or testing of the present inventions, the preferred methods and materials are now described. All patents and publications mentioned herein, including those cited in the Background of the application, are hereby incorporated by reference to disclose and describe the methods and/or materials in connection with which the publications are cited.

[0320] The publications discussed herein are provided solely for their disclosure prior to the filing date of the present application. Nothing herein is to be construed as an admission that the present inventions are not entitled to antedate such publication by virtue of prior invention. Further, the dates of publication provided may be different from the actual publication dates which may need to be independently confirmed.

[0321] Other embodiments of the invention are possible. Although the description above contains much specificity, these should not be construed as limiting the scope of the invention, but as merely providing illustrations of some of the presently preferred embodiments of this invention. It is also contemplated that various combinations or sub-combinations of the specific features and aspects of the embodiments may be made and still fall within the scope of the inventions. It should be understood that various features and aspects of the disclosed embodiments can be combined with or substituted for one another in order to form varying modes of the disclosed inventions. Thus, it is intended that the scope of at least some of the present inventions herein disclosed should not be limited by the particular disclosed embodiments described above.

[0322] Thus the scope of this invention should be determined by the appended claims and their legal equivalents. Therefore, it will be appreciated that the scope of the present invention fully encompasses other embodiments which may become obvious to those skilled in the art, and that the scope of the present invention is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean "one and only one" unless explicitly so stated, but rather "one or more." All structural, chemical, and functional equivalents to the elements of the above-described preferred embodiment that are known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the present claims. Moreover, it is not necessary for a device or method to address each and every problem sought to be solved by the present invention, for it to be encompassed by the present claims. Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims.

What is claimed is:

1. An abrasive article comprising:
a flexible backing having opposing first and second surfaces;

abrasive features on the first surface of the flexible backing; and
 an adhesive layer comprising load bearing particles and an adhesive matrix, the adhesive layer disposed on the second surface of the flexible backing,
 wherein at least a portion of the load bearing particles is substantially enveloped in the adhesive matrix and is in contact with the second surface of the polymer substrate.

2. The abrasive article of claim 1 further comprising a rigid support attached to the adhesive layer comprising the load bearing particles.

3. The abrasive article of claim 2, wherein at least a portion of the load bearing particles is in contact with the rigid support.

4. The abrasive article of claim 1, wherein the flexible backing is selected from the group consisting of metal foil, cloth, paper, vulcanized fiber, non-woven materials, polymeric materials, ceramics, or composites thereof.

5. The abrasive article of claim 4, wherein the polymeric substrate is selected from the group consisting of polyester, polypropylene, polyethylene, polyamide, polyimide.

6. The abrasive article of claim 1, wherein the load bearing particle has an average diameter that is substantially equal to the thickness of the adhesive layer.

7. An abrasive article comprising:
 a backing having opposing first and second surfaces;
 abrasive features on the first surface of the backing; and
 an adhesive layer comprising load bearing particles and an adhesive matrix, the adhesive layer disposed on the second surface of the backing,
 wherein at least a portion of the load bearing particles is substantially enveloped in the adhesive matrix and is in contact with the second surface of the polymer substrate.

8. The abrasive article of claim 1 wherein the backing is one of rigid or flexible.

9. A polishing pad comprising:
 a flexible backing having opposing first and second surfaces;
 an adhesive layer comprising load bearing particles and an adhesive matrix, the adhesive layer disposed on the second surface of the flexible backing, wherein at least a portion of the load bearing particles is substantially enveloped in the adhesive matrix and is in contact with the second surface of the polymer substrate; and
 abrasive features located at an interface of the first surface of the flexible backing with a substrate, the abrasive features polishing the substrate during motion of the polishing pad relative to the substrate.

10. The polishing pad of claim 9 wherein the abrasive features comprise one or more of an abrasive material attached to the first surface, a slurry of free abrasive particles located at the interface with the substrate, or a combination thereof.

11. The polishing pad of claim 9 comprising one or more fluid bearing features on the first surface configured to generate lift forces during motion of the polishing pad relative to the substrate.

12. The polishing pad of claim 9 wherein the first surface comprise at least one of topography following or topography removing feature.

13. The polishing pad of claim 9 wherein at least a portion of the load bearing particles is in contact with a rigid support.

14. A method of making an abrasive article comprising the steps of locating an adhesive layer comprising load bearing particles and an adhesive matrix between a second surface of the flexible backing and rigid support, wherein at least a portion of the load bearing particles is substantially enveloped in the adhesive matrix and is in contact with the second surface of the polymer substrate.

15. The method of claim 14 wherein a least a portion of the load bearing particles is in contact with the rigid support.

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