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(54) **Title:** ELECTROMAGNETICALLY BONDED PUMPS AND PUMP SUBASSEMBLIES AND METHODS OF FABRICATION

(57) **Abstract:** Example embodiments of piezoelectric pumps and subassemblies for pumps (including diaphragm pumps, both piezoelectric and non-piezoelectric) are formed with structure and/or materials suitable for electromagnetic bonding, and are formed by electromagnetic bonding processes, such as laser welding, for example. In a first example embodiment of electromagnetic bonding pump fabrication technology, a pump (20) is comprised of a base member (22) and a diaphragm layer (24). The diaphragm layer (24) covers at least a portion of the base member and defines a pumping chamber (26) between the base member (22) and the diaphragm layer (24). The diaphragm layer (24) comprises a piezoelectric central region (30) selectively deformable upon application of an electrical signal for pumping fluid into and out of the pumping chamber (26). An electromagnetically transmissive region (32) essentially surrounds the central piezoelectric region (30). An electromagnetic weld (34) bonds the electromagnetically transmissive region (30) of the diaphragm layer to the base member (22). In a second example embodiment, a pump (20') comprises a pump base member (22) having a pump chamber surface (44) and a valve interface surface (46). An inlet port (36) and an outlet port (38) are provided in the pump base member. A piezoelectric diaphragm layer (24) is electromagnetically welded to the pump chamber surface (44) for defining a pumping chamber (26) between the pump base member and the diaphragm layer. A valve subassembly (50) is electromagnetically welded to the valve interface surface (46) for providing an inlet valve (52) which selectively opens and closes the inlet port (36) and an outlet valve (54) which selectively opens and closes the outlet port (38).

WO 2006/113343 A2

ELECTROMAGNETICALLY BONDED PUMPS AND PUMP SUBASSEMBLIES AND METHODS OF FABRICATION

BACKGROUND

[0001] This application is related to United States Patent Application Serial Number 11/104,661, filed April 13, 2005, entitled MULTILAYER VALVE STRUCTURES AND METHODS OF MAKING SAME, which is incorporated by reference herein in its entirety.

[0002] FIELD OF THE INVENTION

[0003] The present invention pertains to pumps and subassemblies for pumps, and methods of making pumps and pump subassemblies.

[0004] RELATED ART AND OTHER CONSIDERATIONS

[0005] Many types of pumps have been devised for pumping fluid, such as (for example) piston pumps, diaphragm pumps, peristaltic pumps, just to name a few. These pumps have different types of actuators and moving parts which act upon fluid in a pumping chamber. Typically the pumping chamber is defined by a pump body which has an inlet port and an outlet port. Communication of fluid through the inlet port and into the chamber, and out of the output port, is usually gated by one or more valves.

[0006] Diaphragm-type pumps typically comprise a pumping chamber defined by a diaphragm and a relatively rigid or stationary housing or enclosure in which the diaphragm is mounted. Fluid acted upon by the diaphragm is admitted into the pumping chamber through an inlet valve and exits the pumping chamber via an outlet valve. Although a central portion of the diaphragm moves in the pumping chamber, an edge of the diaphragm is clasped by the housing and usually retained in the stationary housing by some sort of flexible yet fluid-tight seal. Various means for clasping the diaphragm in the housing have been used, such as (for example) gaskets, O-rings, and adhesives.

[0007]Examples of pumps with piezoelectric diaphragms are shown in PCT Patent Application PCT/US01/28947, filed 14 September 2001; United States Patent Application Serial Number 10/380,547, filed March 17, 2003, entitled "Piezoelectric Actuator and Pump Using Same"; United States Patent Application Serial Number 10/380,589, filed March 17, 2003, entitled "Piezoelectric Actuator and Pump Using Same", and United States Provisional Patent Application 60/670,692, filed April 13, 2005, entitled "PIEZOELECTRIC DIAPHRAGM ASSEMBLY WITH CONDUCTORS ON FLEXIBLE FILM", all of which are incorporated herein by reference.

[0008]Precision fabrication and alignment of components for pumps can be difficult and expensive. Therefore, what is needed, and an object of the present invention, are techniques and structures to permit pumps and pump components to be constructed in simple and relatively accurate processes.

BRIEF SUMMARY

[0009]Example embodiments of piezoelectric pumps and subassemblies for pumps are formed with structure and/or materials suitable for electromagnetic bonding, and are formed by electromagnetic bonding processes, such as laser welding, infrared welding, or ultrasonic welding, for example. Example modes of methods of fabricating such pumps and pump assemblies are disclosed.

[00010] In a first example embodiment of electromagnetic bonding pump fabrication technology, a pump is comprised of a base member and a diaphragm layer. The diaphragm layer covers at least a portion of the base member and defines a pumping chamber between the base member and the diaphragm layer. The diaphragm layer comprises a piezoelectric central region selectively deformable upon application of an electrical signal for pumping fluid into and out of the pumping chamber. An electromagnetically transmissive region essentially surrounds the central piezoelectric

region. An electromagnetic weld bonds the electromagnetically transmissive region of the diaphragm layer to the base member.

[00011] In a second example embodiment, a pump comprises a pump base member having a pump chamber surface and a valve interface surface. An inlet port and an outlet port are provided in the pump base member. A piezoelectric diaphragm layer is electromagnetically bonded to the pump chamber surface for defining a pumping chamber between the pump base member and the diaphragm layer. A valve subassembly is electromagnetically bonded to the valve interface surface of the pump base member for providing an inlet valve which selectively opens and closes the inlet port and an outlet valve which selectively opens and closes the outlet port. The piezoelectric diaphragm layer can be comprised as in the first embodiment.

[00012] In the first embodiment and the second embodiment, the electromagnetically transmissive region is preferably comprised of a thermal polymer, a thermo-plastic elastomer, or a thermoplast (or a combination thereof), suitable for electromagnetic bonding. In accordance with an overlap bonding or welding technique, the electromagnetically transmissive region (being transmissive to the electromagnetic radiation involved in the bonding) forms an upper layer and the pump base member serves as a lower layer which absorbs the radiation of the bonding, whereby a bond (e.g., in the form of a weld or seam) is formed for bounding the pumping chamber.

[00013] For the second embodiment, the valve subassembly comprises a pump interface layer having an interface layer inlet flap and an interface layer outlet flap; a subassembly cover layer having a cover layer inlet flap and a cover layer outlet flap; and, an intermediate layer positioned between the interface layer and the cover layer, the intermediate layer having an intermediate layer inlet flap and an intermediate layer outlet flap. At least one of the interface layer and the cover layer (preferably the interface layer) is formed from an electromagnetically transmissive material. An electromagnetic inlet valve bond (e.g., in the form of a weld or a seam) bonds the inlet flap of the interface layer to the inlet flap of the cover layer for forming the inlet valve, so that the inlet valve comprises the inlet flap of the intermediate layer sandwiched between the inlet flap of the interface layer and the inlet flap of the cover layer. Similarly, an electromagnetic outlet valve weld or seam bonds the outlet flap of the interface layer to the outlet flap of the cover layer for forming the outlet valve, so that

the outlet valve comprises the outlet flap of the intermediate layer sandwiched between the outlet flap of the interface layer and the outlet flap of the cover layer.

[00014] Example embodiments of valve subassemblies for pumps (diaphragm and non-diaphragm; piezoelectric and non-piezoelectric) are also provided. A first valve subassembly embodiment comprises a pump interface layer having an interface layer flap; a subassembly cover layer having at least one cover layer flap; and, an intermediate layer positioned between the interface layer and the cover layer, the intermediate layer having at least one intermediate layer flap. At least one of the interface layer and the cover layer (preferably the interface layer) is formed from an electromagnetically transmissive material. An electromagnetic bond (e.g., in the form of a weld or seam) adheres the flap of the interface layer to the flap of the cover layer to form a valve flap, the valve flap comprising the flap of the intermediate layer sandwiched between the flap of the interface layer and the flap of the cover layer. The subassembly cover layer is bonded (e.g., by an electromagnetic weld or seam) to the pump interface layer.

[00015] A second valve subassembly embodiment resembles the first valve subassembly embodiment, but further has a pump base member. The pump base member has a port formed therein. In the second valve subassembly embodiment, an electromagnetic subassembly attachment weld or seam bonds the interface layer to the base member.

[00016] In the valve subassembly embodiments, preferably the electromagnetically transmissive material is a thermal polymer, a thermo-plastic elastomer, or a thermoplast, or a combination thereof. The intermediate layer may serve as a stabilizing or stiffener layer, and can comprise an electroconductive metal. The cover layer can comprise an elastomer.

[00017] The valve flap comprised of the interface layer flap, the intermediate layer flap, and the cover layer flap can have any convenient shape, and in an illustrated example has an essentially U shape.

[00018] In the valve subassembly embodiments, two or more valve flaps can be provided, with one valve flap serving, e.g., as an inlet valve and another valve flap

serving as an outlet valve. In such two-flap implementations, if the valves are actively driven (e.g., by an electrical signal) the intermediate layer first flap and the intermediate layer second flap are electrically isolated and connected to separate drive signals. In other variations, more than two valve flaps can be formed, e.g., four valve flaps.

[00019] Methods are provided for fabricating the various pump embodiments and valve subassembly embodiments. In some methods, plural electromagnetic bonds can be formed essentially simultaneously by using, e.g., electromagnetically transmissive materials and providing electromagnetic absorptive zones therein for the electromagnetic bonding.

BRIEF DESCRIPTION OF THE DRAWINGS

[00020] The foregoing and other objects, features, and advantages of the invention will be apparent from the following more particular description of preferred embodiments as illustrated in the accompanying drawings in which reference characters refer to the same parts throughout the various views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

[00021] Fig. 1 is an exploded view showing structure of and steps for fabricating a first example embodiment of a pump according to electromagnetic bonding technology.

[00022] Fig. 2 is an exploded view showing structure of and steps for fabricating a second example embodiment of a pump according to electromagnetic bonding technology.

[00023] Fig. 3 is a top isometric view of the pump fabricated by the steps of Fig. 2.

[00024] Fig. 4 is a bottom isometric view of the pump fabricated by the steps of Fig. 2.

[00025] Fig. 5 is an exploded view showing structure of and steps for fabricating a valve subassembly for a pump according to electromagnetic bonding technology.

[00026] Fig. 6A and Fig. 6B are top and bottom views showing structure of and steps for fabricating a third example embodiment of a pump according to electromagnetic bonding technology.

[00027] Fig. 7 is a diagrammatic view depicting an essentially simultaneous electromagnetic bonding operation performed for the embodiment of Fig. 6A and Fig. 6B.

[00028] Fig. 8 is an exploded, sectioned view showing structure of and steps for fabricating a fourth example embodiment of a pump according to electromagnetic bonding technology.

[00029] Fig. 9 is an exploded, sectioned view showing structure of and steps for fabricating a fifth example embodiment of a pump according to electromagnetic bonding technology.

DETAILED DESCRIPTION OF THE DRAWINGS

[00030] In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular architectures, interfaces, techniques, etc. in order to provide a thorough understanding of the present invention. However, it will be apparent to those skilled in the art that the present invention may be practiced in other embodiments that depart from these specific details. In other instances, detailed descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the present invention with unnecessary detail.

[00031] As hereinafter explained and illustrated by way of example, non-limiting embodiments, piezoelectric pumps and subassemblies for pumps are formed with structure and/or materials suitable for electromagnetic bonding, and are formed by electromagnetic bonding processes, such as but not limited to laser welding, infrared welding, or ultrasonic welding, for example. The pumps have piezoelectric diaphragms which serve as actuators. The subassemblies include valve subassemblies for pumps. The pumps with which the valve subassemblies are used need not be piezoelectric, nor even diaphragm-type pumps. Example modes of methods of fabricating such pumps and pump assemblies are disclosed.

[00032] Fig. 1 illustrates both structure of and steps for fabricating a first example embodiment of a pump. As with other pump embodiments and other subassembly embodiments described herein, fabrication occurs using electromagnetic bonding

technology. Fig. 1 particularly shows a pump 20 which is comprised of a base plate or pump base member 22 and a diaphragm layer 24. The diaphragm layer 24 covers at least a portion of the base member and defines a pumping chamber 26 between the pump base member 22 and the diaphragm layer 24.

[00033] The diaphragm layer 24 comprises a piezoelectric central region 30 selectively deformable upon application of an electrical signal for pumping fluid into and out of the pumping chamber. An electromagnetically transmissive region 32 essentially surrounds the central piezoelectric region 30. An electromagnetic bond, illustrated by electromagnetic weld seam 34, secures the electromagnetically transmissive region 32 of the diaphragm layer 24 to the base member 22. Although not a separate component per se, the electromagnetic weld seam 34 is separately illustrated in exploded fashion in Fig. 1 to illustrate its approximate shape and location.

[00034] As shown in Fig. 1, the piezoelectric central region 30 is preferably circular, although other shapes are also possible. The electromagnetically transmissive region 32, which preferably has an annular shape, is secured by overmolding or other suitable technique to the periphery or outer perimeter of piezoelectric central region 30.

[00035] The electromagnetically transmissive region 32 can be comprised of a thermal polymer, a thermo-plastic elastomer, a thermoplast, or a combination thereof, so long as suitable for electromagnetic bonding. As used herein, “electromagnetic energy”, "electromagnetic bonding", and “electromagnetic welding” encompass any bonding process using any portion of the electromagnetic spectrum, including but not limited to laser welding, infrared welding, and ultrasonic welding.

[00036] Laser welding is a non-contact process for welding parts that overlap one another. The laser beam penetrates an upper part and is absorbed in the lower part by melting the interface and creating a weld between the two parts. The absorption and transmission of the laser beam in the parts is controlled by pigmentation and choice of laser wavelength. Examples of a thermoplastics or thermoplastic elastomers which are suitable for laser welding include ABS (acrylonitrile butadiene styrene), PA (polyamide), PC (polycarbonate), PS (polystyrene), SAN (styrene acrylonitrile), PE (polyethylene copolymer), and PMMA (polymethylmethacrylate (acrylic)).

[00037] Infrared welding is also a non-contact process and includes through-transmission infrared welding (TTIR) in which radiation is passed through a transparent polymer to an absorbing interface that is in contact with the transparent polymer. Heat generation at the interface melts the transparent polymer. Example materials that can be used as the electromagnetic transmissive material for infrared welding include PTFE (polytetrafluoroethylene ("TEFLON")), UHMW (ultra-high molecular weight polyethylene), and polyimides.

[00038] In contrast to laser welding and infrared welding, ultrasonic welding is a contact process which requires some manipulation or vibration of the welded parts.

[00039] As further illustrated in Fig. 1, pump base member 22 has an inlet port 36 and an outlet port 38 formed therein. The inlet port 36 and outlet port 38 are formed entirely through the thickness of pump base member 22, so that fluid can enter through inlet port 36 into pumping chamber 26 and so that fluid can exit pumping chamber 26 through outlet port 38. In the particular example illustrated in Fig. 1, inlet port 36 has an essentially U shape, while outlet port 38 has a circular or slightly elliptical shape. Differing shapes for inlet port 36 and outlet port 38 are certainly possible in other implementations. The number of ports provided in pump base member 22 is not confined to two, since a greater of ports may instead be provided such as, for example, two or more inlet ports and/or two or more outlet ports.

[00040] By way of non-limiting example, the pump base member 22 of the embodiment of Fig. 1 takes the form of an essentially flat (planar) plate having a substantially square shape. Proximate each of its four corners, pump base member 22 has through holes or fastening apertures 40. The fastening apertures 40 may be used to secure an unillustrated pump cover or housing to pump base member 22 for protecting and encasing diaphragm layer 24. Other ways for connecting a pump cover or housing are also possible. Either internal or external to the pump cover, a suitable drive circuit or other drive electronics may be mounted for applying a drive signal to the piezoelectric central region 30, thereby causing the piezoelectric central region 30 to deform and serve as a piezoelectric actuator for pumping fluid through pumping chamber 26. Examples of such drive electronics are included among those described in United States Patent Application Serial Number 10/816,000 (attorney docket 4209-26), filed April 2, 2004 by Vogeley et al., entitled "Piezoelectric Devices and Methods and

Circuits for Driving Same", which is incorporated herein by reference in its entirety, or by documents referenced and/or incorporated by reference therein.

[00041] The pump 20 of the first example embodiment can be separately fabricated and sold or delivered to a pump integrator who may interconnect the pump with a fluid source and fluid utilization device via, e.g., appropriate valves or the like. The size or relative positioning of the pump components and their quantities may vary depending on application or environment of use of the pump.

[00042] In addition to illustrating the example structure of pump 20, Fig.1 also depicts basic, example steps for fabricating the first example pump embodiment. Included in the fabrication technique is a step of positioning diaphragm layer 24 upon pump base member 22. As understood from the foregoing description, the diaphragm layer 24 comprises piezoelectric central region 30 and electromagnetically transmissive region 32 which essentially surrounds the diaphragm region. The pump base member 22 may be marked (or even recessed) as indicated by alignment circle 42 to serve as a guide for placement of diaphragm layer 24 thereof, and for alignment of electromagnetically transmissive region 32 with alignment circle 42. When pumping chamber 26 and piezoelectric central region 30 are essentially circular, the electromagnetically transmissive region 32 has a substantially annular shape, but may extend with other shaped perimeter and (if desired) may extend substantially beyond alignment circle 42 to assure sufficient bonding area.

[00043] The fabrication method of Fig. 1 further includes a step of applying electromagnetic energy to the electromagnetically transmissive region 32 to bond the diaphragm layer 24 to the pump base plate 22, thereby defining pump chamber 26 between the diaphragm layer 24 and the pump base plate 22. Preferably the electromagnetic energy which is applied for the bonding has a wavelength suitable for polymer joining, e.g., polymer laser welding or infrared welding. The bonding can be accomplished using an overlap technique wherein the electromagnetically transmissive region 32, upon which the beam is first incident, permits transmission of the beam. After passing through the electromagnetically transmissive region 32, the beam is incident upon the pump base member 22. Relevant portions or even all of the pump base member 22 are/is comprised of an energy absorptive material which is close to and/or thereby absorptive of the wavelength of the electromagnetic energy used for the

bonding. In fact, as used herein phrases such as "energy absorptive material", "energy absorbing material", "optically dark" and the like refer to materials which have wavelengths which are close to and/or thereby absorptive of the wavelength of the electromagnetic energy used for the bonding, and which thereby facilitate formation of a bond (e.g., in the form of a seam or weld). For example, in some embodiments (e.g., for some modes of laser welding), the pump base member 22 can be comprised of an optically dark material, with "optically dark" being an example of energy absorptive and not necessarily being with reference to the human eye but rather to a specified wavelength of electromagnetic energy (whether visible light, infrared, or whatever part of the spectrum) used for the bonding. A bond or weld seam occurs where the electromagnetic is absorbed. The alignment circle 42 depicts the position where the electromagnetic bond (e.g., weld or seam) 34 is formed for securing the diaphragm layer 24 to the pump base member 22.

[00044] The step of applying the electromagnetic energy can thus comprise directing an electromagnetic beam (such as a laser beam or infrared beam) on an essentially closed path through the electromagnetically transmissive region 32 and around the central piezoelectric region 30. Directing the electromagnetic beam in this manner results in formation of the electromagnetic bond 34 in the position depicted by alignment circle 42. Thus, in the particular illustration of Fig. 1, the path of direction of the electromagnetic beam is an essentially circular path. Other path configurations are possible in other embodiments.

[00045] Fig. 2 illustrates, in exploded format, both structure of and steps for fabricating a second example embodiment of a pump. As assembled, the pump 20' of Fig. 2 is also seen from the top in Fig. 3 and from the bottom in Fig. 4. The pump 20' of the second example embodiment resembles pump 20 of the first example embodiment of Fig. 1 in having, e.g., a base plate or pump base member 22 and a diaphragm layer 24. The pump base member 22 has a pump chamber surface 44 (see Fig. 3) and a valve interface surface 46 (see Fig. 2 and Fig. 4). An inlet port 36 and an outlet port 38 are provided in the pump base member. Piezoelectric diaphragm layer 24 is electromagnetically welded to the pump chamber surface 44 for defining pumping chamber 26 between the pump base member 22 and diaphragm layer 24. As with the first embodiment, diaphragm layer 24 of pump 20' comprises a piezoelectric central region 30 selectively deformable upon application of an electrical signal for pumping

fluid into and out of the pumping chamber. An electromagnetically transmissive region 32 essentially surrounds the central piezoelectric region 30. An electromagnetic bond, illustrated by electromagnetic weld seam 34, bonds the electromagnetically transmissive region 32 of the diaphragm layer 24 to the base member 22.

[00046] In addition, pump 20' comprises a valve subassembly 50 which is also shown in exploded fashion in Fig. 2. Valve subassembly 50 is electromagnetically welded to valve interface surface 46 of the pump base member 22 for providing (as shown in Fig. 4) an inlet valve 52 which selectively opens and closes the inlet port 36 and an outlet valve 54 which selectively opens and closes the outlet port 38.

[00047] For pump 20' of the second example embodiment, valve subassembly 50 comprises a pump interface layer 60 having an interface layer inlet flap 62 and an interface layer outlet flap 64; a subassembly cover layer 70 having a cover layer inlet flap 72 and a cover layer outlet flap 74; and, an intermediate layer 80 positioned between interface layer 60 and cover layer 70, intermediate layer 80 having an intermediate layer inlet flap 82 and an intermediate layer outlet flap 84. At least one of the interface layer 60 and the cover layer 80 (preferably the interface layer 60) is formed from an electromagnetically transmissive material.

[00048] For the valve subassembly embodiments described herein, preferably the electromagnetically transmissive material is a thermal polymer, a thermo-plastic elastomer, a thermoplast, or a combination thereof. The intermediate layer 80 may serve as a stabilizing or stiffener layer, and can comprise an electroconductive metal. The cover layer is preferably either entirely or partially dark to absorb the electromagnetic energy of the weld process, and may be an elastomer, for example.

[00049] Should the cover layer 70 be electromagnetically transmissive, a portion(s) or zone(s) of the cover layer at which the electromagnetic bond is to occur is made, formed, or treated to be energy absorptive (e.g., optically dark) for the purpose of absorbing the electromagnetic energy of the bonding process. For example, a dark pigment may be introduced or applied to the cover layer 70 in the bonding zone(s). The bonding zone(s) may be a perimeter of the cover layer 70 or an area near the perimeter, and an area around the cover layer inlet flap 72 and cover layer outlet flap 74.

[00050] An electromagnetic inlet valve bond 92 bonds inlet flap 62 of interface layer 60 to inlet flap 72 of cover layer 70 for forming inlet valve 52 (see Fig. 4). Thus, inlet valve 52 comprises inlet flap 82 of intermediate layer 80 sandwiched between inlet flap 62 of interface layer 60 and inlet flap 72 of cover layer 70. Similarly, an electromagnetic outlet valve bond 94 bonds outlet flap 64 of interface layer 60 to outlet flap 74 of cover layer 70 for forming outlet valve 54 (see Fig. 4). Accordingly, outlet valve 54 comprises outlet flap 84 of intermediate layer 80 sandwiched between outlet flap 64 of interface layer 60 and outlet flap 74 of cover layer 70. The inlet valve bond 92 and electromagnetic outlet valve bond 94 are illustrated in exploded fashion in Fig. 2 for providing an understanding of the position and shape of the respective seams.

[00051] As shown in Fig. 2, in some example implementations intermediate layer 80 may comprise two discrete and separated segments, e.g., intermediate layer segment 80I and intermediate layer segment 80O. The intermediate layer segment 80I bears intermediate layer inlet flap 82, the intermediate layer segment 80O bears intermediate layer outlet flap 84. A tab 80IT is provided at a circumference portion of intermediate layer segment 80I, and similarly a tab 80OT is provided at a circumference portion of intermediate layer segment 80O. The tabs 80IT and 80OT may be used as electrical leads in an implementation in which the segments of the intermediate layer 80 are metallic and are connected to receive an electrical signal.

[00052] In a variation of the illustrated embodiment, one or both of intermediate layer inlet flap 82 and intermediate layer outlet flap 84 can each have mounted or overlaid thereon a piezoelectric material so that one or both of inlet valve 52 and outlet valve 54 can function as active valves. The structure and operation of such an active valve arrangement is understood from U.S. Patent Application SN 11/024,937, filed December 30, 2004, which is incorporated by reference herein in its entirety.

[00053] Intermediate layer 80, or the segments comprising intermediate layer 80, is/are thus embedded between two other layers, which preferably are elastomer layers, so that intermediate layer 80 (or the segments thereof) is/are sealed between pump interface layer 60 and subassembly cover layer 70. This may be particularly beneficial in an implementation in which, for example, the interface layer is a metallic layer. Moreover, depending on tolerances, the intermediate layer 80 may even have the

capability of slightly floating within a pocket formed by the welding of pump interface layer 60 and subassembly cover layer 70.

[00054] The valves 52, 54 (which are comprised of the respective interface layer flaps 62, 64; the respective intermediate layer flaps 82, 84; and the respective cover layer flaps 72, 74) can have any convenient shape. In the illustrated example, each flap and thus the valves 52, 54 have an essentially U shape. Thus, the respective flaps may be formed by a U-shaped cut out in the respective layer. Preferably, in order to provide floating positioning of intermediate layer 80 between pump interface layer 60 and subassembly cover layer 70, intermediate layer inlet flap 82 and intermediate layer outlet flap 84 are slightly smaller than the respective flaps 62, 72 and 64, 74, with which they are aligned. The flaps of the different layers are aligned with respect to a width direction of the layers.

[00055] The pump interface layer 60 is preferably formed from a material which is electromagnetic transmissive to the electromagnetic energy utilized for the welding. Preferably but not necessarily, pump interface layer 60 is planar and coextensive in size with pump base member 22, and has fastening apertures 96 which are aligned with fastening apertures 40 of pump base member 22.

[00056] The shapes of the layers comprising valve subassembly 50, e.g., pump interface layer 60, subassembly cover layer 70, and intermediate layer 80 are illustrated as being essentially circular. However, in other embodiments layers of differing shapes can be utilized.

[00057] The subassembly cover layer 70 may have alignment marks or indentations 98 thereon to serve as a template or guide for placement of intermediate layer 80. Such alignment marks or indentations 98 essentially are an image of intermediate layer 80, or segments comprising intermediate layer 80.

[00058] As shown in Fig. 4, inlet valve 52 has a dimple 99 formed on a underside surface thereof in alignment with inlet port 36. In similar fashion, outlet valve 54 has a dimple formed on an upper surface thereof in alignment with outlet port 38 (see Fig. 2). In other embodiments, inlet valve 52 and outlet valve 54 can be formed without dimples.

[00059] In addition to illustrating the example structure of pump 20', Fig. 2 also depicts basic, example steps for fabricating the second example pump embodiment. Included in the fabrication technique are the two basic steps of the first embodiment of Fig. 1, e.g., positioning diaphragm layer 24 upon pump base member 22 and applying electromagnetic energy to the electromagnetically transmissive region 32 to weld the diaphragm layer 24 to the pump base plate 22. Further steps are also included for forming the valve subassembly 50 and mounting valve subassembly 50 to valve interface surface 46 of pump base member 22.

[00060] The step of forming valve subassembly 50 comprises three basic substeps. A first such substep comprises forming at least one (and preferably two) flaps in each of the interface layer 60 (e.g., interface layer inlet flap 62 and interface layer outlet flap 64), the intermediate layer 80 (e.g., intermediate layer inlet flap 82 and intermediate layer outlet flap 84), and cover layer 70 (e.g., cover layer inlet flap 72 and cover layer outlet flap 74). As such, interface layer 60 has an interface layer first flap 62 and an interface layer second flap 64; intermediate layer 80 has an intermediate layer first flap 82 and an intermediate layer second flap 84; and, cover layer 70 has a cover layer first flap 72 and a cover layer second flap 74.

[00061] A second substep involves bonding the first flap 62 of the interface layer 60 to the first flap 72 of the cover layer 70 for forming a first valve flap or inlet valve 52, the first valve flap or inlet valve 52 comprising the first flap 82 of the intermediate layer 80 sandwiched between first flap 62 of interface layer 60 and first flap 72 of cover layer 70. Such bonding for forming inlet valve 52 is represented by inlet valve bond 92 shown in Fig. 2. As mentioned above, the intermediate layer inlet flap 82 is preferably sized to be narrower than interface layer inlet flap 62 and cover layer inlet flap 72, with the result that inlet valve bond 92 does not contact intermediate layer inlet flap 82.

[00062] For two valve embodiments, the second substep also includes bonding second flap 64 of interface layer 60 to second flap 74 of cover layer 70 for forming a second valve flap or outlet valve 54, the second valve flap or outlet valve 54 comprising second flap 84 of intermediate layer 80 sandwiched between second flap 64 of interface layer 60 and second flap 74 of cover layer 70. Such bonding for forming outlet valve 54 is represented by electromagnetic outlet valve bond 94 shown in Fig. 2. In like manner as described above, the intermediate layer outlet flap 84 is preferably sized to be narrower

than interface layer outlet flap 64 and cover layer outlet flap 74, with the result that outlet valve bond 94 does not contact intermediate layer outlet flap 84.

[00063] The bonding included in the second substep can be performed by directing a beam of electromagnetic energy in the pattern depicted by inlet valve bond 92 (e.g., in the form of a weld or seam) and electromagnetic outlet valve bond 94 (e.g., in the form of a weld or seam) as shown in Fig. 2. Preferably the electromagnetic energy which is applied for the bonding comprises a laser beam, an infrared beam, or an ultrasonic beam having a wavelength suitable for polymer joining, e.g., polymer laser welding, infrared welding, or ultrasonic welding. The welding can be accomplished using an overlap technique wherein the pump interface layer 60 upon which the electromagnetic beam is first incident, permits transmission of the electromagnetic beam. After passing through pump interface layer 60, the electromagnetic beam is incident upon subassembly cover layer 70. The subassembly cover layer 70 is comprised of an energy absorptive material which is close to the wavelength of the electromagnetic energy used for the bonding. A bond (e.g., in the form of a weld or seam) occurs where the electromagnetic energy is absorbed. Thus, inlet valve bond 92 and electromagnetic outlet valve bond 94 depict the positions where the electromagnetic weld is formed for securing subassembly cover layer 70 to pump interface layer 60, with intermediate layer 80 being embedded therebetween.

[00064] The third substep of forming valve subassembly 50 comprises sealing the periphery of subassembly cover layer 70 to pump interface layer 60, thereby encasing intermediate layer 80 between subassembly cover layer 70 and pump interface layer 60 so that fluid will not intrude to reach intermediate layer 80. This third substep can be accomplished by electromagnetic bonding in similar manner as the second substep, but with the electromagnetic beam positioned and directed to travel proximate but just inside the periphery of subassembly cover layer 70, and thereby trace the cover bond (in the form of weld or seam) 102 shown in Fig. 2. In fact, the substep of bonding periphery of subassembly cover layer 70 to pump interface layer 60 can occur simultaneously with the preceding substep of bonding the flaps. At this point, the valve subassembly 50 is now substantially complete as a stand alone part or subassembly.

[00065] To realize the pump 20' of Fig. 2, valve subassembly 50 must next be mounted to valve interface surface 46 of pump base member 22. This mounting can be

accomplished by an electromagnetic bonding operation. As in the other electromagnetic bonding operations described in the fabrication of pump 20', preferably the electromagnetic energy which is applied for the bonding comprises an electromagnetic beam having a wavelength suitable for polymer joining, e.g., polymer laser welding, infrared welding, or ultrasonic welding. The electromagnetic beam is first incident on the underside of pump interface layer 60 and is further incident on valve interface surface 46 of pump base member 22. The electromagnetic beam traces a path depicted by subassembly electromagnetic bond (e.g., weld or seam) 104, which in Fig. 2 is illustrated as a dashed, double-dotted line superimposed on pump interface layer 60. The electromagnetic beam passes through pump interface layer 60, and is incident on valve interface surface 46 of pump base member 22. Since pump base member 22 is comprised of energy absorptive materials which are optically close to the wavelength of the electromagnetic energy used for the bonding, the bond 104 occurs where the electromagnetic is absorbed. The electromagnetic subassembly attachment bond 104 serves to bond the entire valve subassembly 50 to valve interface surface 46 of pump base member 22. Other profiles for bond 104 are also possible.

[00066] Example embodiments of valve subassemblies for pumps (diaphragm and non-diaphragm; piezoelectric and non-piezoelectric) are also provided. A first valve subassembly embodiment comprises the components above described in conjunction with valve subassembly 50 of Fig. 2, which are separately shown (in exploded form) as a separate unit in Fig. 5. Units such as valve subassembly 50 may be made and sold separately for combination by others (e.g., pump integrators) with differing types of pumps (not limited to piezoelectric pumps or even to diaphragm pumps). The positioning of inlet valve 52 and outlet valve 54 (see Fig. 4) may be suitably arranged according to specification or design requirements of the pump to which valve subassembly 50 will be mounted. A method of making the first valve subassembly embodiment is understood from the preceding discussion of fabrication of valve subassembly 50 as described with reference to Fig. 2. However, in the first valve subassembly embodiment, the valve subassembly is delivered as a stand-alone unit, so that the mounting of the valve subassembly into a pump or other device is left to another (e.g., pump integrator) and thus can either be by the electromagnetic bonding technique herein described, or by other techniques.

[00067] Thus, a first valve subassembly embodiment comprises a pump interface layer having an interface layer flap; a subassembly cover layer having a cover layer flap; and, an intermediate layer positioned between the interface layer and the cover layer, the intermediate layer having an intermediate layer flap. At least one of the interface layer and the cover layer (preferably the interface layer) is formed from an electromagnetically transmissive material. An electromagnetic weld or seam bonds the flap of the interface layer to the flap of the cover layer to form a valve flap, the valve flap comprising the flap of the intermediate layer sandwiched between the flap of the interface layer and the flap of the cover layer.

[00068] A second valve subassembly embodiment resembles the first valve subassembly embodiment, but further includes a pump base member such as pump base member 22 shown in Fig. 2. A method of making the second valve subassembly embodiment is understood from the preceding discussion of fabrication of valve subassembly 50 as described with reference to Fig. 2 and (unlike the first valve subassembly embodiment) includes the electromagnetic bonding of seam 104 for bonding valve subassembly 50 to valve interface surface 46 of pump base member 22. The pump base member has one or more ports formed therein. Units of the second valve subassembly embodiment, which include both valve subassembly 50 and a pump base member, may be made and sold separately for combination by others who may build the rest of a pump on the pump base member.

[00069] Fig. 6A and Fig. 6B illustrate a further embodiment of a pump wherein all electromagnetic bonding operations can be performed essentially simultaneously, if so desired. In the embodiment of Fig. 6A and Fig. 6B, the base member 22(6) is formed from an electromagnetically transmissive material, but has certain electromagnetically absorptive zones embedded or formed therein or thereon (e.g., by pigmentation, for example). In Fig. 6A the vantage point of base member 22(6) is through the transparent pump interface layer 60. Moreover, base member 22(6) and pump interface layer 60 are coextensive and pump interface layer 60 is transparent, for which reason base member 22(6) and pump interface layer 60 are essentially indistinguishable in Fig. 6A.

[00070] Yet the absorptive zones embedded or formed in/on base member 22(6) are discernible since they are shown as shaded in Fig. 6A and Fig. 6B. Among the absorptive zones embedded or formed in base member 22(6) are two valve bonding

zones 112 and 114 (for the electromagnetic bonding of inlet valve 52 and outlet valve 54, respectively); cover bonding zone 116 (for electromagnetic bonding of subassembly cover layer 70 to pump interface layer 60); and valve subassembly bonding zone 118 (for electromagnetic bonding of the entire valve subassembly 50 to valve interface surface 46 of base member 22(6)). In an essentially simultaneous operation, one or more (preferably four) electromagnetic beams are incident on the plane of Fig. 6A from the perspective of the viewer, with the beams tracing the paths shown by the electromagnetic bonds (e.g., weld or seams) 92, 94, 102, and 104. The inlet valve bond 92 is formed over valve welding absorptive zone 112; the outlet valve bond 94 is formed over valve welding absorptive zone 114; the electromagnetic cover bond 102 is formed over the cover bonding zone 116; and, the subassembly attachment bond 104 is formed over valve subassembly bonding zone 118. Suitably, cover bonding zone 116 has an essentially circular shape, and valve subassembly bonding zone 118 has more of a rectangular or picture frame shape.

[00071] The vantage point in Fig. 6B is toward the pump chamber surface 44 of base member 22(6), e.g., the surface opposite the valve interface surface 46 to which pump interface layer 60 is attached. Fig. 6B shows only features of interest to formation of the diaphragm portions of the pump. While the electromagnetically transmissive nature of base member 22(6) might also permit visibility of features of valve subassembly 50, for most part such features of valve subassembly 50 are not shown in Fig. 6B for sake of clarity. Fig. 6B particularly shows how diaphragm layer 24 is electromagnetic welded along weld or seam 34 to diaphragm layer absorption bonding zone 120. Depending on configuration, the actuator element 120 may be coextensive with and common to cover bonding zone 116.

[00072] The embodiment of Fig. 6A and Fig. 6B facilitates a fabrication process in which essentially all the components of the pump can be fitted together and then electromagnetically welded in an essentially simultaneous electromagnetic bonding operation. In this regard, Fig. 7 shows how electromagnetic beams can be directed from opposite sides of the pump for the essentially simultaneous electromagnetic bonding operation, the beams being referenced by reference numerals corresponding to the seams they make but suffixed with the letter “B”. Fig. 7 thus shows how beams 92B and 94B form the inlet valve weld 92 and the outlet valve weld 94 in respective absorptive zones 112 and 114; how beam 102B forms the electromagnetic cover bond

102 in cover bonding zone 116; and, how beam 104 forms the subassembly attachment bond 104 in valve subassembly bonding zone 118. Although two depictions of some beams are shown, it will be understood that in practice the two depictions represent a single beam which traverses a path or circuit defined by the respective absorption zone. The Fig. 6A and Fig. 6B embodiment thus facilitates the essentially simultaneous electromagnetic bonding operation, while also alternatively permitting the welding operations to be performed seriatim or in non-simultaneous fashion should such be desired.

[00073] Fig. 8 illustrates another example embodiment susceptible to essentially simultaneous electromagnetic bonding, in similar manner to Fig. 7. The elements of Fig. 8 are illustrated in cut-away form, only half of each element being shown. In the example embodiment of Fig. 8, the base member 22(8) is essentially optically clear (e.g., transmissive of the electromagnetic energy used for the bonding), except that the pump chamber area 26 is coated with an electromagnetic absorptive dye or similar substance. Pump interface layer 60(8) has both its top and bottom surfaces entirely coated with an electromagnetic absorptive dye or similar substance. Subassembly cover layer 70(8) is optically clear to the electromagnetic beam.

[00074] In a method of fabrication for the embodiment of Fig. 8, the entire assembly is placed into a suitable holder or fixture, with the underside of base member 22(8), i.e., valve interface surface 46, has having placed thereon the pump interface layer 60(8), the intermediate layer 80, and the subassembly cover layer 70(8), in this order and aligned as previously discussed for formation of inlet valve 52 and outlet valve 54. The pump chamber surface 44 of base member 22(8) has the diaphragm layer 24 positioned thereof in same manner as the previously described embodiments.

[00075] An electromagnetic beam from the top side traces a path (laser path #1) illustrated as bond 104. The beam for path #1 passes through the optically clear portion of base plate 22(8) (beyond the periphery of diaphragm layer 24 and is absorbed on the top side of pump interface layer 60(8). This forms bond 104 between base plate 22 and pump interface layer 60(8).

[00076] The same electromagnetic beam from the top side then traces path #2, which is reflected by bond 34. The beam for path #2 passes through diaphragm layer 24 and is

absorbed on the dye layer of base plate 22(8) which covers the pump chamber portion 26 of base plate 22 (8). This absorption forms bond 34 between diaphragm layer 24 and base plate 22(8).

[00077] A second laser from the bottom side, traces path #3 (102, 94, 92). The beam in tracing path #3 passes through subassembly cover layer 70(8) and is absorbed on the bottom side of pump interface layer 60(8). This forms bonds 102, 94 and 92.

[00078] In the embodiment of Fig. 8, with both sides of pump interface layer 60(8) coated with dye, the layer is effectively a "black body" and thus absorptive of the electromagnetic beam.

[00079] Fig. 9 illustrates another example embodiment susceptible to essentially simultaneous electromagnetic bonding, also similar to Fig. 7 and similar to Fig. 8 by being depicted in cutaway fashion. In Fig. 9, both diaphragm layer 24(9) and subassembly cover layer 70(9) are electromagnetically transparent (e.g., optically clear) to the electromagnetic beam. Pump base plate/member 22(9) has two dye paths printed on it for creating bonds 34 and 104. The first dye path is on the top side (e.g., pump chamber surface 44) of pump base plate 22(9), in the pump chamber area 26 and corresponds to the diameter of bond 34. The second dye path is on the bottom side of pump base plate 22(9) (i.e., on valve interface surface 46) and corresponds to the diameter of bond 104. The pump interface layer 60(9) has three dye paths on the bottom side, the three dye paths basically corresponding in shape and position to bonds 102, 94 and 92.

[00080] In a method of fabrication for the embodiment of Fig. 9, the entire assembly is placed into a suitable holder or fixture, with the underside of base member 22(9), i.e., valve interface surface 46, has having placed thereon the pump interface layer 60(9), the intermediate layer 80, and the subassembly cover layer 70(9), in this order and aligned as previously discussed for formation of inlet valve 52 and outlet valve 54. The pump chamber surface 44 of base member 22(9) has the diaphragm layer 24 positioned thereof in same manner as the previously described embodiments.

[00081] An electromagnetic beam from the top side traces path #1. The electromagnetic beam passes through layer diaphragm layer 24(9) and is absorbed on the top side of pump base plate 22(9), thereby forming bond 34.

[00082] A second electromagnetic, from the bottom side (e.g., from valve interface surface 46), traces path #2. The beam in tracing path #2 bypasses subassembly cover layer 70(9) (because the beam is beyond the boundary of layer subassembly cover layer 70(9)) and passes through layer pump interface layer 60(9). The beam is absorbed on the bottom side of layer pump base plate 22(9), on the dye path that corresponds to seam 104, forming bond 104 between layer pump interface layer 60(9) and layer pump base plate 22(9).

[00083] The same electromagnetic beam from the bottom side then traces path #3. In so doing, the beam passes through layer subassembly cover layer 70(9) and is absorbed on the dye paths on the bottom side of layer pump interface layer 60(9) that correspond to bonds 102, 94 and 92, thereby forming bonds 102, 94 and 92.

[00084] The dye path approach of Fig. 9 is a more complex solution than the dye layer approach of Fig. 8, but allows for more layers to exist in a given assembly.

[00085] Laser welding and/or bonding technology using dyes for through-transmission laser welding are generally taught in one or more of the following (all of which are incorporated herein by reference for showing, e.g., materials and dyes which serve as examples of use for the technology described herein): US Patent Publication US 2005/0000641; US Patent Publication US 2004/0234752; US Patent Publication US 2004/0244905; and, US Patent Publication US 2005/0000618.

[00086] The technology described herein further compasses a pump comprising a pump base member having a pump chamber surface and a valve interface surface, an inlet port and an outlet port provided in the pump base member; a piezoelectric diaphragm layer which is electromagnetically bonded to the pump chamber surface for defining a pumping chamber between the pump base member and the diaphragm layer; and, a valve subassembly. The valve subassembly is electromagnetically bonded to the valve interface surface of the pump base member for providing an inlet valve which selectively opens and closes the inlet port and an outlet valve which selectively opens

and closes the outlet port. One or more of the piezoelectric diaphragm layer and the valve subassembly can be formed in various ways, and thus are not confined to the exemplary fabrication techniques or structures mentioned above with respect to other example, non-limiting embodiments.

[00087] In the illustrated embodiments of the valve subassemblies, provision is made for two valves, e.g., for forming inlet valve 52 and outlet valve 54. It should be understood that for some types of pumps the pump base member to which the particular valve subassembly is bonded may have only one port (in which case a second port may be elsewhere provided in a pump body). Accordingly, in accordance with the present technology it is also contemplated that a valve subassembly is fabricated for such one-port pump base member with only one flap for each of the pump layers corresponding to pump interface layer 60, subassembly cover layer 70, and intermediate layer 80. The resulting single valve may either be an inlet valve or an outlet valve, as required by the configuration of the pump with which the valve subassembly is to be employed.

[00088] It has been mentioned herein that at least one of the interface layer and the cover layer, and preferably the interface layer, is formed from an electromagnetically transmissive material. It is also possible to form the cover layer with an electromagnetically transmissive material, particularly if a perimeter or bonding zone of the cover layer has embedded pigmentation or other properties that render the bonding zone susceptible to electromagnetic bonding at the wavelength of the electromagnetic beam.

[00089] Although various embodiments have been shown and described in detail, the claims are not limited to any particular embodiment or example. None of the above description should be read as implying that any particular element, step, range, or function is essential such that it must be included in the claims scope. The scope of patented subject matter is defined only by the claims. The extent of legal protection is defined by the words recited in the allowed claims and their equivalents. It is to be understood that the invention is not to be limited to the disclosed embodiment, but on the contrary, is intended to cover various modifications and equivalent arrangements.

WHAT IS CLAIMED IS:

1. A pump comprising:

a base member (22) having at least one port;

a diaphragm layer (24) covering at least a portion of a surface of the base member (22) and defining a pumping chamber (26) between the base member (22) and the diaphragm layer (24), the diaphragm layer (24) being bonded by a first bond to the base member (22);

a valve subassembly (50) positioned on the base member (22) for selectively communicating fluid through the port, the valve subassembly (50) being bonded by a second bond to the base member (22);

wherein at least one of the first bond and the second bond is an electromagnetic weld.

2. The apparatus of claim 1, wherein the diaphragm layer (24) covers at least a portion of a first surface of the base member (22) and the valve subassembly (50) is positioned on a second surface of the base member (22), the second surface being opposite the first surface.

3. The apparatus of claim 1, wherein both the first bond and the second bond are electromagnetic welds.

4. The apparatus of claim 1, wherein the bond is one of a laser bond, an infrared bond, and an ultrasonic bond.

5. The apparatus of claim 1, wherein the base member (22) has a region which is transmissive of electromagnetic energy of the electromagnetic weld and an electromagnetic absorptive zone in which at least one of the first bond and the second bond is formed.

6. A method of making a pump comprising:

forming a first bond to mount a diaphragm layer (24) to a base member (22) whereby the diaphragm layer (24) covers at least a portion of a surface of the base member (22) and defines a pumping chamber (26) between the base member (22) and the diaphragm layer (24);

forming a second bond to mount a valve subassembly (50) to the base member (22), the valve subassembly (50) being situated for selectively communicating fluid through a port formed in the base member (22);

using electromagnetic bonding to form one of the first bond and the second bond.

7. The method of claim 6, further comprising:

forming the first bond to mount the diaphragm layer (24) to the base member (22) whereby the diaphragm layer (24) covers at least a portion of a first surface of the base member (22); and

forming the second bond to mount a valve subassembly (50) to a second surface of the base member (22), the second surface being opposite to the first surface.

8. The method of claim 6, further comprising using electromagnetic bonding to form both the first bond and the second bond.

9. The method of claim 8, further comprising essentially simultaneously forming the first bond and the second bond.

10. The method of claim 6, wherein the electromagnetic bonding is one of laser welding, infrared welding, and ultrasonic welding.

11. The method of claim 6, wherein the base member (22) has a region which is transmissive of electromagnetic energy of the electromagnetic weld and an electromagnetic absorptive zone, and further comprising:

directing an electromagnetic beam in a path in the electromagnetic absorptive zone to form one of the first bond and the second bond.

12. A pump comprising:

a base member (22);

a diaphragm layer (24) covering at least a portion of the base member (22) and defining a pumping chamber (26) between the base member (22) and the diaphragm layer (24), the diaphragm layer (24) comprising:

a piezoelectric central region (30) selectively deformable upon application of an electrical signal for pumping fluid into and out of the pumping chamber (26);

an electromagnetically transmissive region (32) essentially surrounding the central piezoelectric region;

an electromagnetic weld for bonding the electromagnetically transmissive region (32) of the diaphragm layer (24) to the base member (22).

13. The apparatus of claim 12, wherein the base member (22) is an essentially planar plate having an inlet port (36) and an outlet port (38).

14. The apparatus of claim 12, wherein the electromagnetically transmissive region (32) is comprised of a thermal polymer, a thermo-plastic elastomer, a thermoplast, or a combination thereof.

15. The apparatus of claim 12, wherein the base member (22) has a region which is transmissive of electromagnetic energy of the electromagnetic weld and an electromagnetic absorptive zone in which the electromagnetic weld is formed.

16. A method of fabricating a pump comprising:

positioning a diaphragm layer (24) upon a pump base member (22), the diaphragm layer (24) comprising a central piezoelectric region and an electromagnetically transmissive region (32) which essentially surrounds the diaphragm region; and

applying electromagnetic energy to the electromagnetically transmissive region (32) to weld the diaphragm layer (24) to the pump base plate, thereby defining a pump chamber between the diaphragm layer (24) and the pump base plate.

17. The method of claim 16, wherein the step of applying the electromagnetic energy comprises directing an electromagnetic beam on an essentially closed path through the electromagnetically transmissive region (32) of the diaphragm layer (24) and around the central piezoelectric region of the diaphragm layer (24) to form the pump chamber.

18. The method of claim 16, wherein the electromagnetic beam is one of a laser beam, an infrared beam, and an ultrasonic beam.

19. The method of claim 16, wherein the base member (22) has a region which is transmissive of electromagnetic energy of the electromagnetic weld and an electromagnetic absorptive zone, and further comprising:

directing an electromagnetic beam in a path in the electromagnetic absorptive zone to form a bond.

20. A valve subassembly (50) for a pump comprising:

a pump interface layer (60) having an interface layer flap;

a subassembly cover layer (70) having a cover layer flap;

an intermediate layer (80) positioned between the interface layer and the cover layer, the intermediate layer (80) having an intermediate layer flap;

at least one of the interface layer and the cover layer being formed from a electromagnetically transmissive material;

an electromagnetic weld for bonding the flap of the interface layer to the flap of the cover layer to form a valve flap, the valve flap comprising the flap of the intermediate layer sandwiched between the flap of the interface layer and the flap of the cover layer.

21. The apparatus of claim 20, wherein the interface layer is the electromagnetically transmissive.

22. The apparatus of claim 20, wherein the electromagnetically transmissive material is a thermal polymer, a thermo-plastic elastomer, a thermoplast, or a combination thereof.

23. A method of fabricating a valve subassembly (50) for a pump comprising:

forming flaps in each of an interface layer, an intermediate layer, and a cover layer;

positioning the intermediate layer between the interface layer and the cover layer;

electromagnetically bonding the flap of the interface layer to the flap of the cover layer whereby a valve flap is formed, the valve flap being comprised of the flap of the intermediate layer sandwiched between the flap of the interface layer and the flap of the cover layer.

24. The method of claim 23, further comprising:

forming at least one of the interface layer and the cover layer from an electromagnetically transmissive material;

electromagnetically welding the flap of the interface layer to the flap of the cover layer.

25. The method of claim 24, further comprising forming the interface layer from the electromagnetically transmissive material.

26. The method of claim 24, wherein the electromagnetically transmissive material is a thermal polymer, a thermo-plastic elastomer, a thermoplast, or a combination thereof.

27. The method of claim 23, further comprising welding the flap of the interface layer to the flap of the cover layer by traversing an electromagnetic beam around a pattern which outlines a shape of the valve flap.

28. The method of claim 27, wherein the electromagnetic beam is one of a laser beam, an infrared beam, and an ultrasonic beam.

29. The method of claim 27, wherein the pattern is formed in the interface layer.

30. A pump subassembly comprising:

a pump base member (22), the pump base member (22) having a port formed therein;

a valve for selectively opening and closing the port, the valve comprising:

a pump interface layer (60) having an interface layer flap;

a subassembly cover layer (70) having a cover layer flap;

an intermediate layer positioned between the interface layer and the cover layer, the intermediate layer having an intermediate layer flap;

at least one of the interface layer and the cover layer being formed of an electromagnetically transmissive material;

an electromagnetic flap weld for bonding the flap of the interface layer to the flap of the cover layer whereby the flap of the intermediate layer sandwiched between the flap of the interface layer and the flap of the cover layer forms a valve flap aligned with the port, the valve flap being deflectable for selectively opening and closing the port;

an electromagnetic cover weld for welding the cover layer to the interface layer; and

a valve subassembly (50) weld for welding the interface layer to the base member (22).

31. The apparatus of claim 30, wherein the interface layer is electromagnetically transmissive.

32. The apparatus of claim 30, wherein the electromagnetically transmissive material is a thermal polymer, a thermo-plastic elastomer, a thermoplast, or a combination thereof.

33. The apparatus of claim 30, wherein the electromagnetic cover weld extends substantially around a periphery of the cover layer.

34. A method of fabricating a valve subassembly (50) for a pump comprising:

(1) forming flaps in each of an interface layer, an intermediate layer, and a cover layer;

(2) positioning the intermediate layer between the interface layer and the cover layer thereby forming a multilayer sandwich;

(3) positioning the multilayer sandwich on a pump base member (22);

(4) bonding the flap of the interface layer to the flap of the cover layer whereby a valve flap is formed, the valve flap being comprised of the flap of the intermediate layer sandwiched between the flap of the interface layer and the flap of the cover layer;

(5) bonding the cover layer to the interface layer; and

(6) bonding the interface layer to the pump base member (22).

35. The method of claim 34, further comprising performing steps (4) – (6) after both step (2) and step (3) have been performed.

36. The method of claim 34, further comprising performing steps (4) – (6) essentially simultaneously.

37. The method of claim 34, further comprising performing steps (4) before step (3).

38. The method of claim 34, further comprising:

forming at least one of the interface layer and the cover layer from an electromagnetically transmissive material;

electromagnetically welding the flap of the interface layer to the flap of the cover layer.

39. The method of claim 38, further comprising forming the interface layer from the electromagnetically transmissive material.

40. The method of claim 38, wherein the electromagnetically transmissive material is a thermal polymer, a thermo-plastic elastomer, a thermoplast, or a combination thereof.

41. The method of claim 34, further comprising welding the flap of the interface layer to the flap of the cover layer by traversing an electromagnetic beam around a pattern which outlines a shape of the valve flap.

42. The method of claim 41, wherein the electromagnetic beam is one of a laser beam, an infrared beam, and an ultrasonic beam.

43. The method of claim 41, wherein the pattern is formed in the interface layer.

44. A pump comprising:

a pump base member (22) having a pump chamber surface (44) and a valve interface surface (46);

an inlet port (36) and an outlet port (38) provided in the pump base member (22);

a piezoelectric diaphragm layer (24) which is electromagnetically welded to the pump chamber surface (44) for defining a pumping chamber (26) between the pump base member (22) and the diaphragm layer (24);

a valve subassembly (50) which is electromagnetically welded to the valve interface surface (46) of the pump base member (22) for providing an inlet valve (52) which selectively opens and closes the inlet port (36) and an outlet valve (54) which selectively opens and closes the outlet port (38).

45. The pump of claim 44, wherein the piezoelectric diaphragm layer (24) comprises:

a piezoelectric central region (30) selectively deformable upon application of an electrical signal for pumping fluid into and out of the pumping chamber (26);

an electromagnetically transmissive region (32) essentially surrounding the central piezoelectric region;

an electromagnetic weld for bonding the electromagnetically transmissive region (32) of the diaphragm layer (24) to the pump chamber surface (44) of the pump base member (22).

46. The apparatus of claim 45, wherein the electromagnetically transmissive region (32) is comprised of a thermal polymer, a thermo-plastic elastomer, a thermoplast, or a combination thereof.

47. The pump of claim 44, wherein the valve subassembly (50) comprises:

a pump interface layer (60) having an interface layer inlet flap and an interface layer outlet flap;

a subassembly cover layer (70) having a cover layer inlet flap and a cover layer outlet flap;

an intermediate layer positioned between the interface layer and the cover layer, the intermediate layer having an intermediate layer inlet flap and an intermediate layer outlet flap;

at least one of the interface layer and the cover layer being formed from a electromagnetically transmissive material;

an electromagnetic inlet valve (52) weld for bonding the inlet flap of the interface layer to the inlet flap of the cover layer for forming the inlet valve (52), the inlet valve (52) comprising the inlet flap of the intermediate layer sandwiched between the inlet flap of the interface layer and the inlet flap of the cover layer;

an electromagnetic outlet valve (54) weld for bonding the outlet flap of the interface layer to the outlet flap of the cover layer for forming the outlet valve (54), the outlet valve (54) comprising the outlet flap of the intermediate layer sandwiched between the outlet flap of the interface layer and the outlet flap of the cover layer.

48. The apparatus of claim 47, wherein the interface layer is the electromagnetically transmissive.

49. The apparatus of claim 47, wherein the electromagnetically transmissive material is a thermal polymer, a thermo-plastic elastomer, a thermoplast, or a combination thereof.

50. The apparatus of claim 47, wherein the inlet valve (52) is centrally formed with respect to the interface layer, the intermediate layer, and the cover layer.

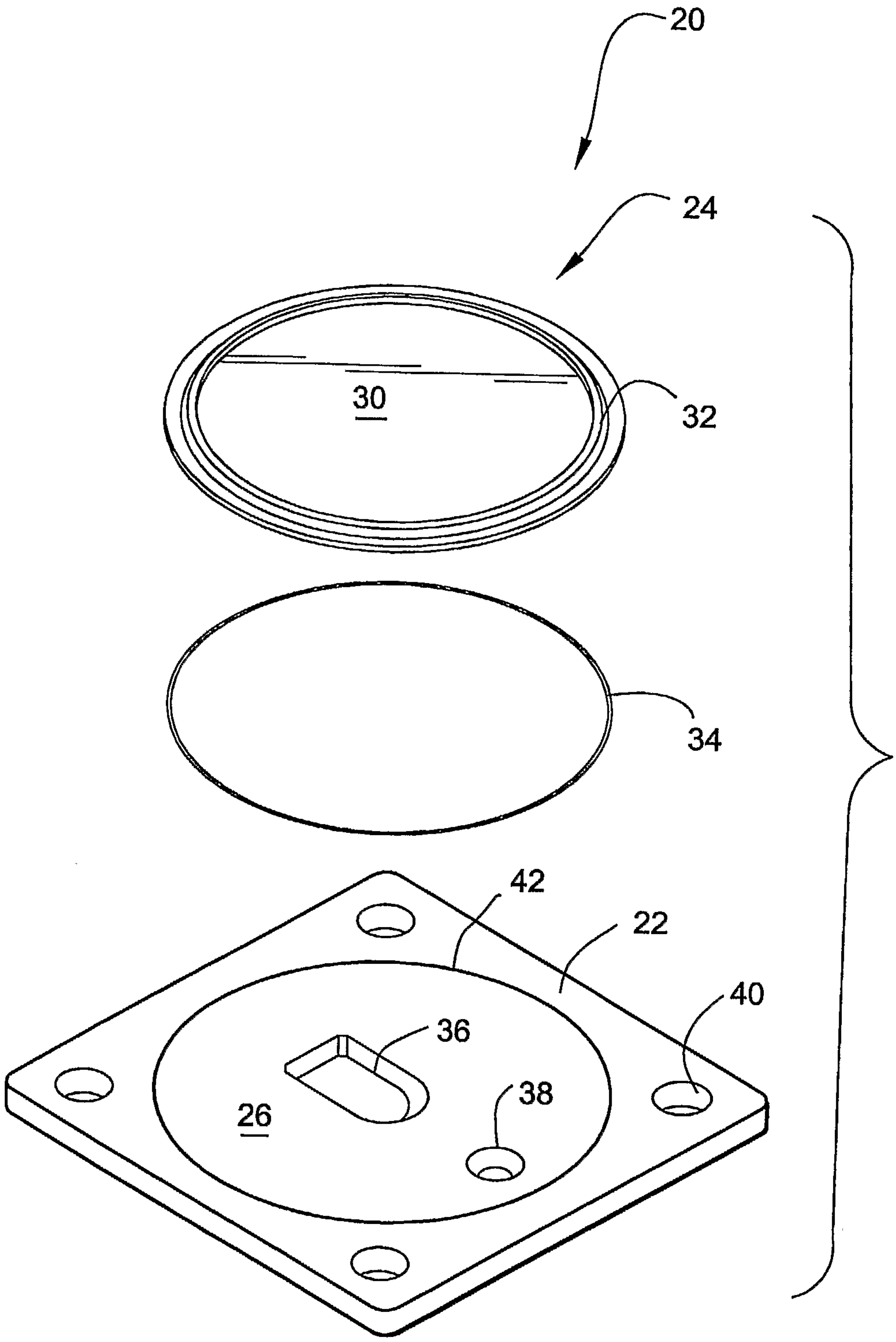

Fig. 1

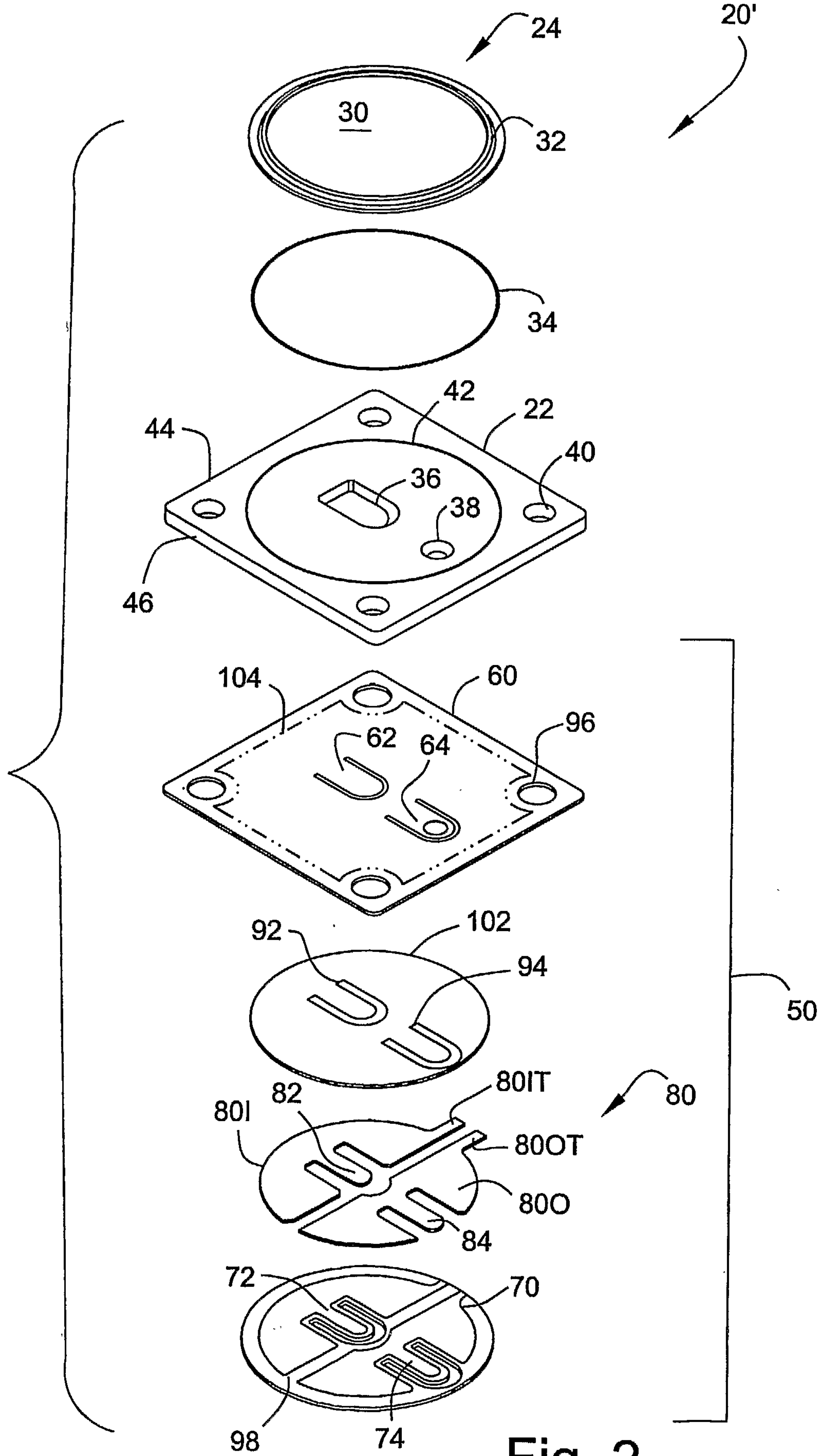
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Fig. 2

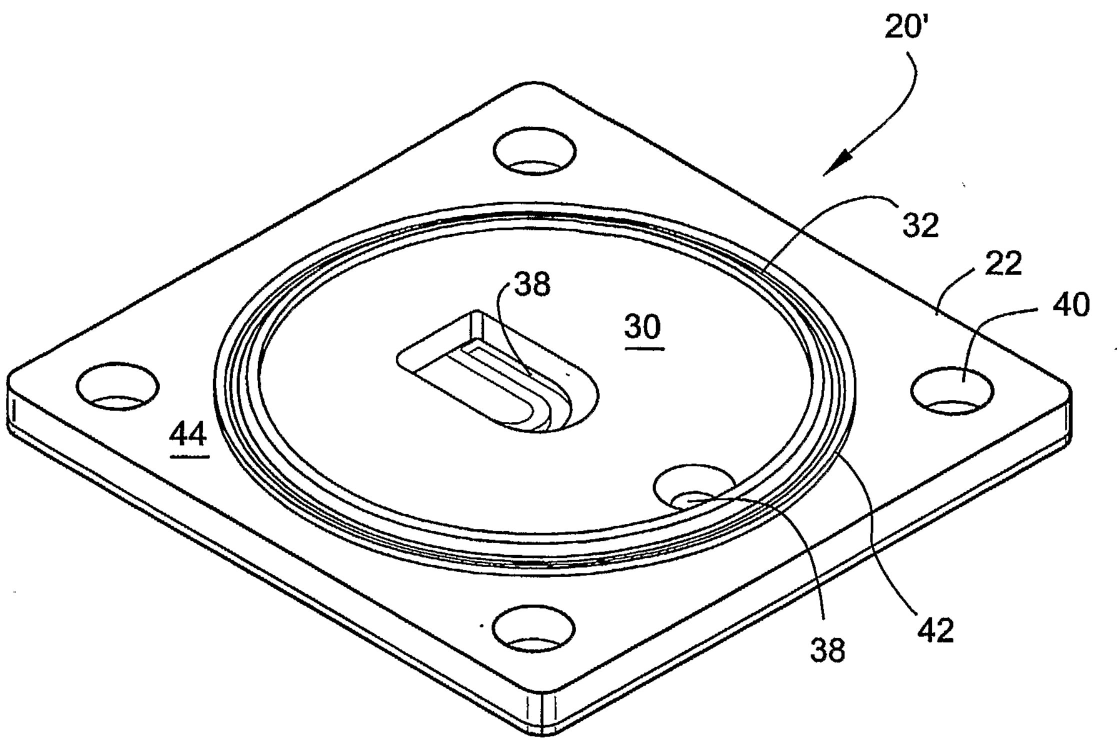

Fig. 3

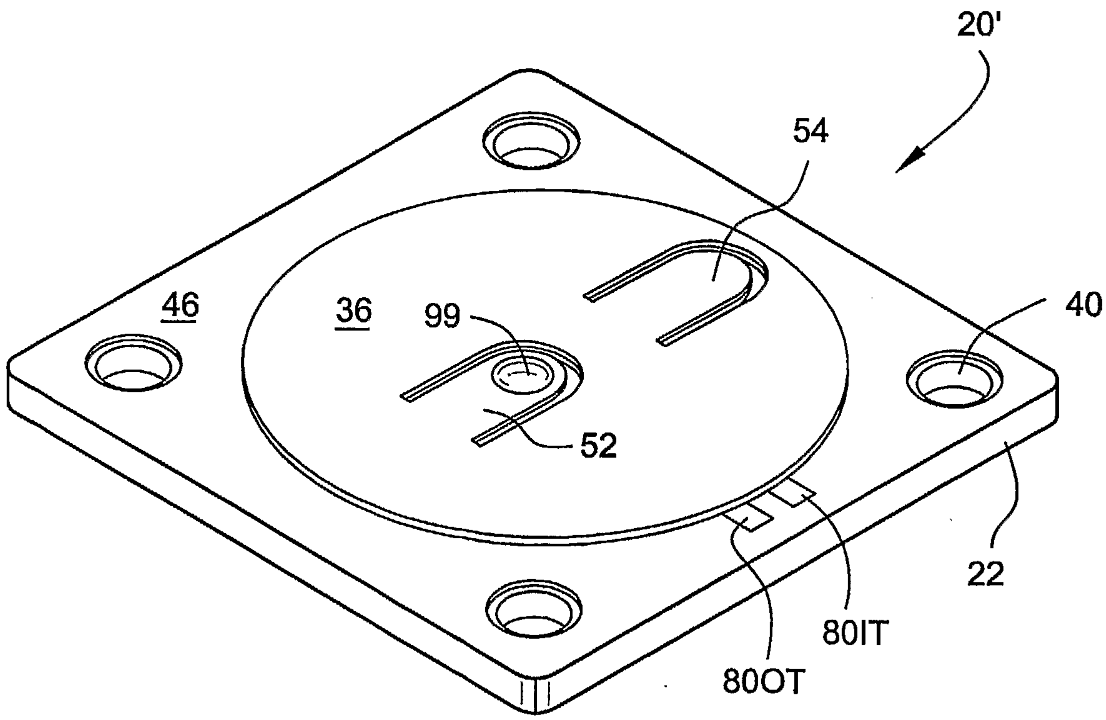

Fig. 4

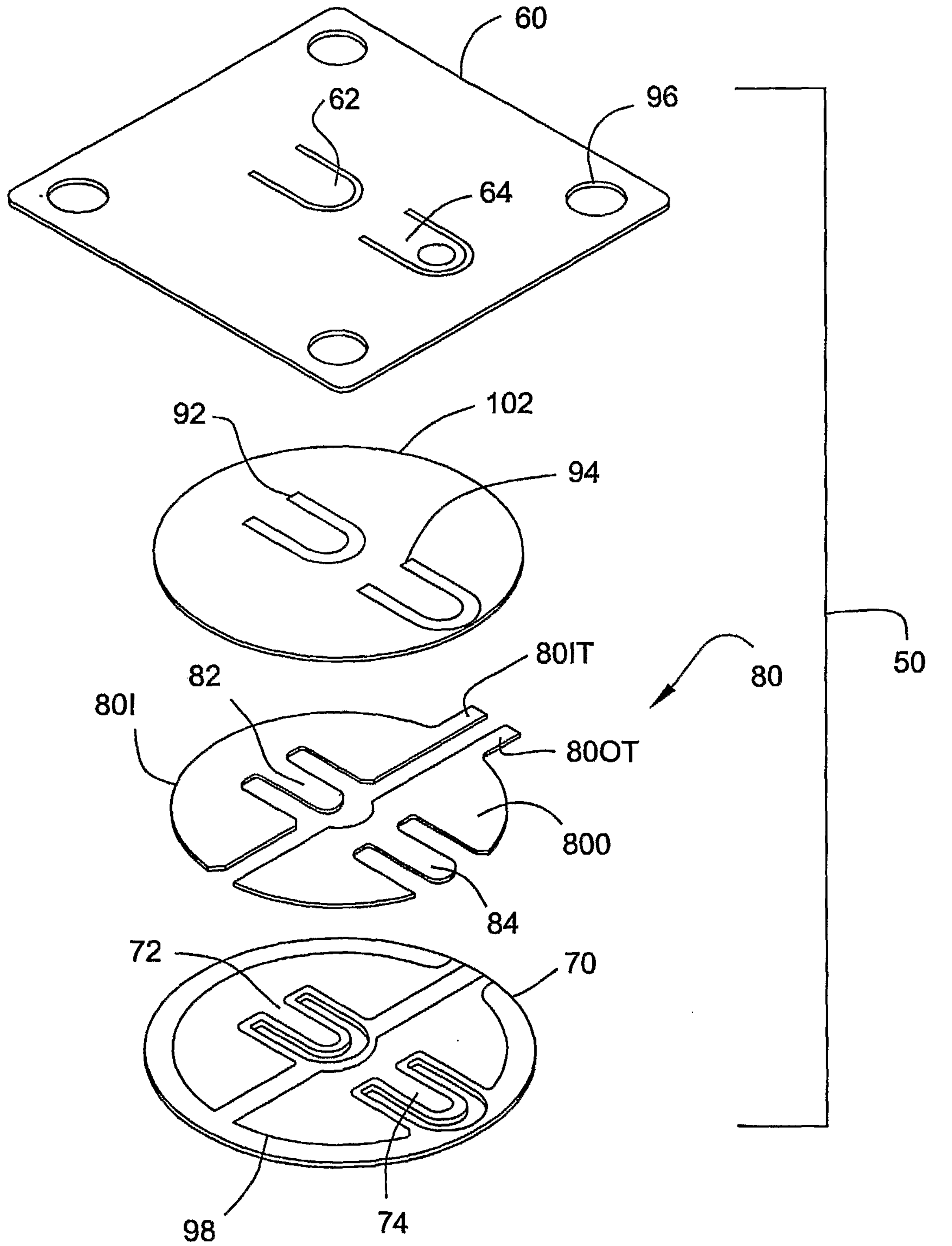

Fig. 5

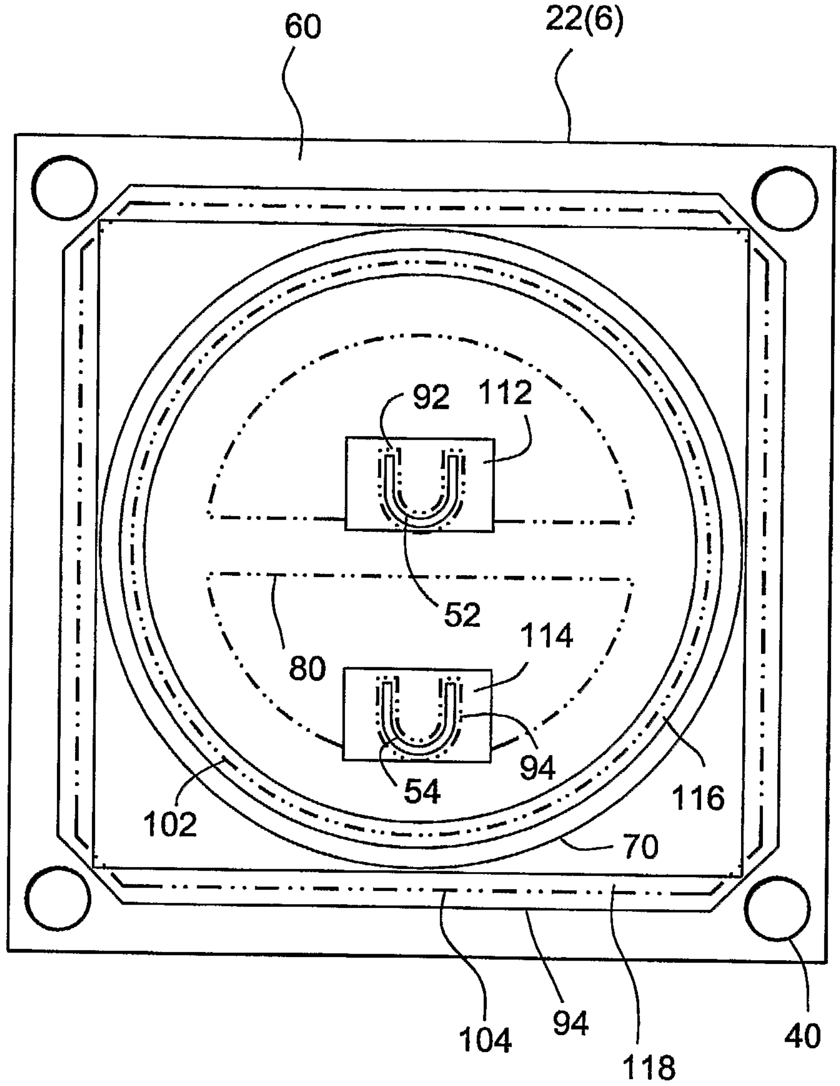

Fig. 6A

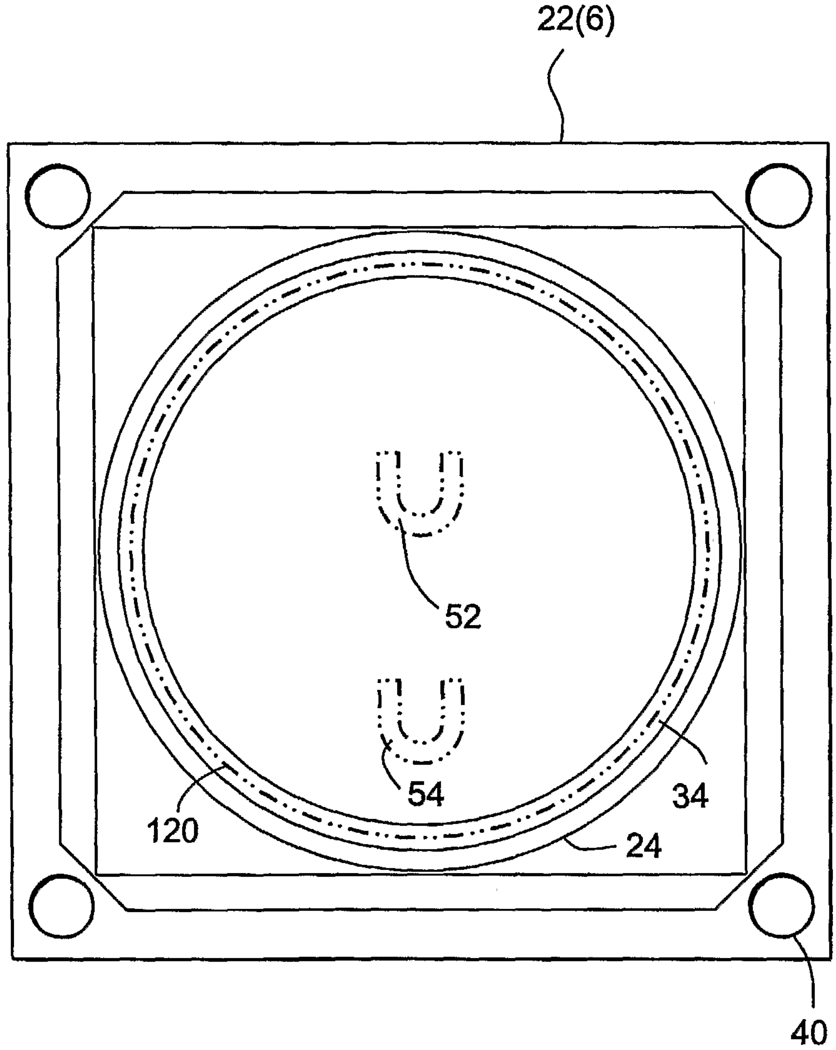

Fig. 6B

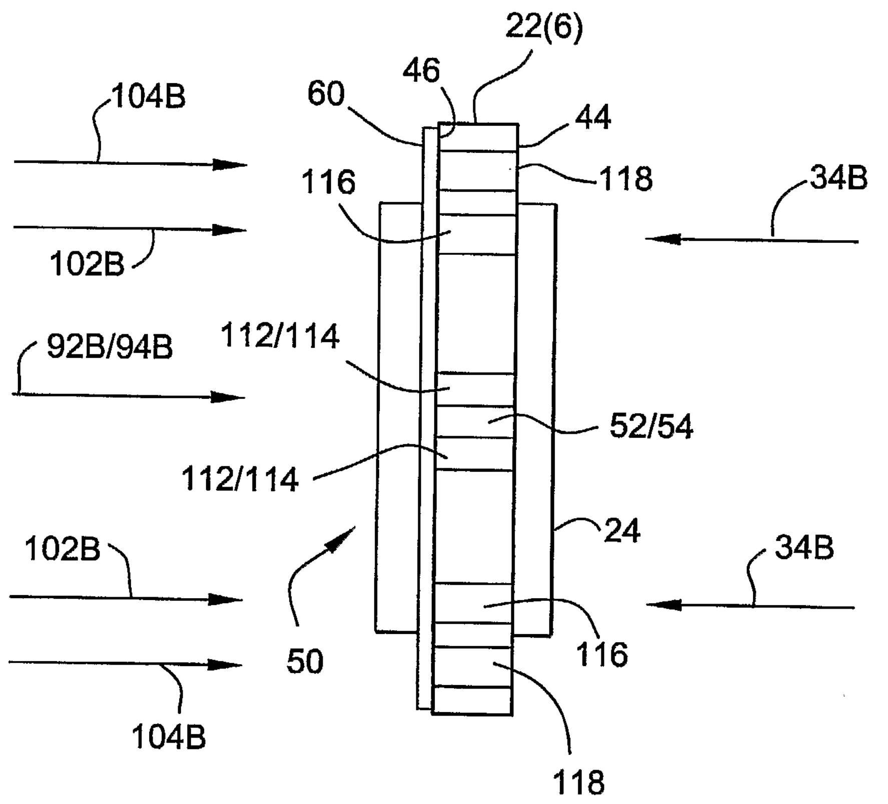
22(6)
46
60
44
104B
116
118
34B
102B
92B/94B
112/114
52/54
112/114
24
102B
34B
50
116
104B
118

Fig. 7

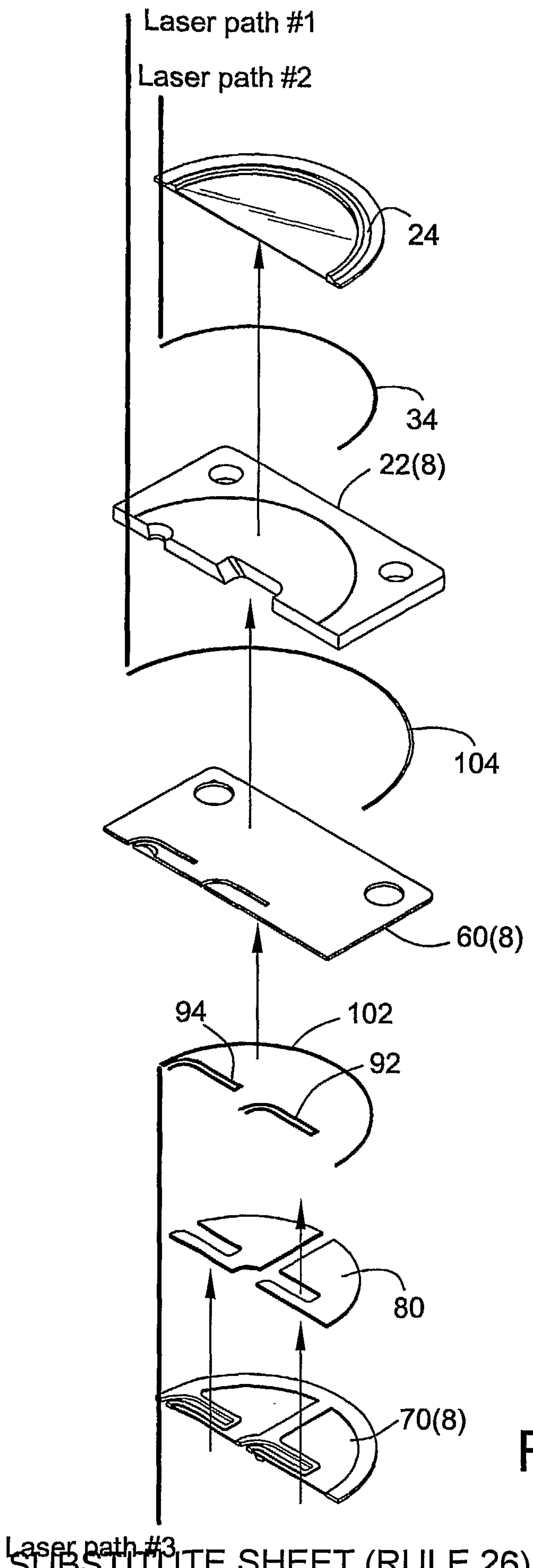
Laser path #1
Laser path #2
24
34
22(8)
104
60(8)
94
102
92
80
70(8)
Laser path #3

Fig. 8

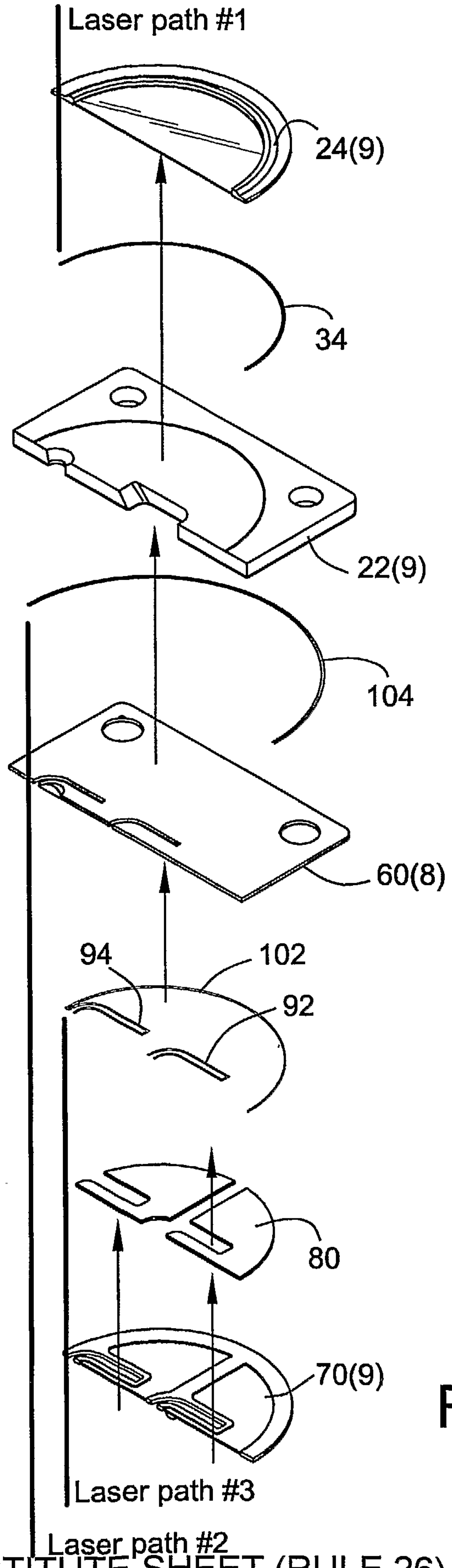
Laser path #1
24(9)
34
22(9)
104
60(8)
94
102
92
80
70(9)
Laser path #3
Laser path #2

Fig. 9