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(54) **DYNAMIC TACTILE INTERFACE AND METHODS**

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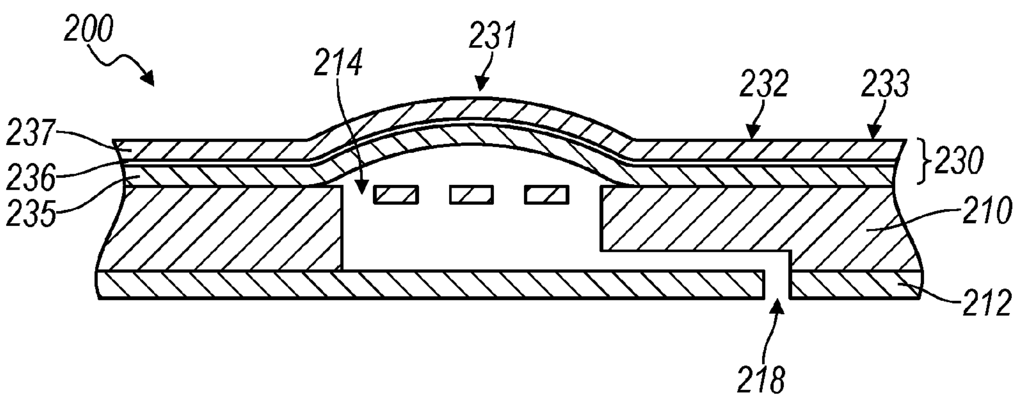
(57) **ABSTRACT**

A dynamic tactile interface includes: a substrate including a first transparent material and defining an attachment surface, an open channel opposite the attachment surface, and a fluid conduit intersecting the open channel and passing through the attachment surface; a tactile layer including a second transparent material and defining a tactile surface, a peripheral region bonded to the attachment surface opposite the tactile surface, and a deformable region adjacent the fluid conduit and disconnected from the attachment surface; a closing panel bonded to the substrate opposite the attachment surface and enclosing the open channel to define a fluid channel; a working fluid; and a displacement device configured to displace the working fluid into the fluid channel and through the fluid conduit to transition the deformable region from a retracted setting to an expanded setting.



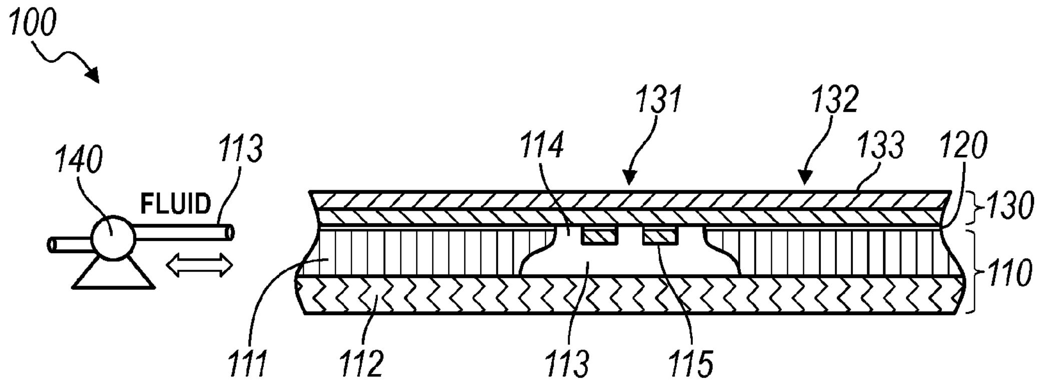


FIG. 1A

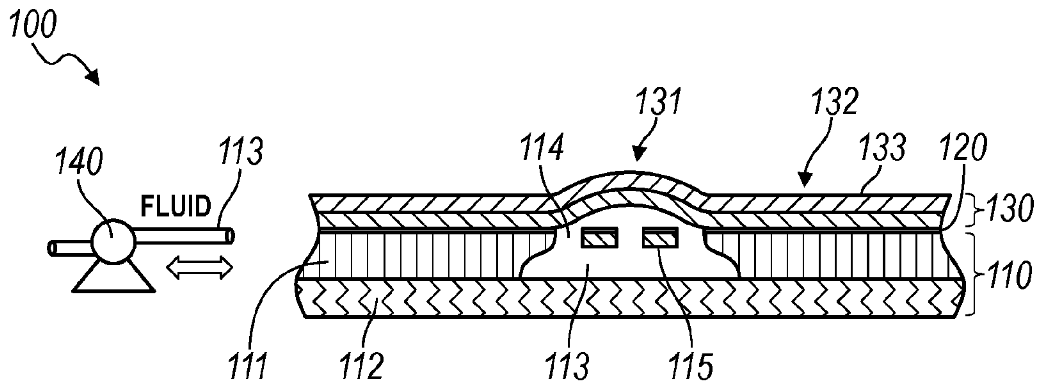


FIG. 1B

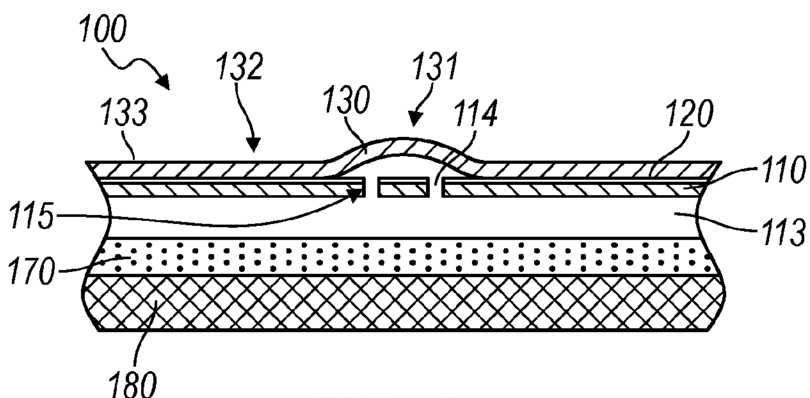


FIG. 2

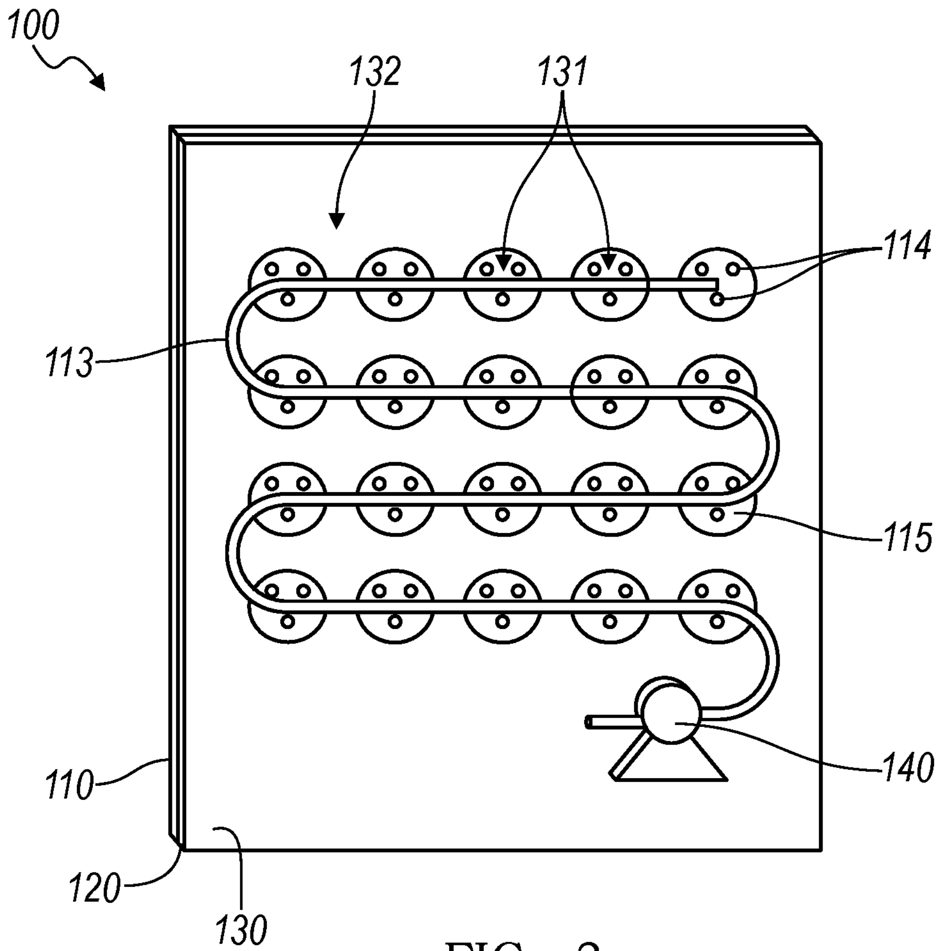


FIG. 3

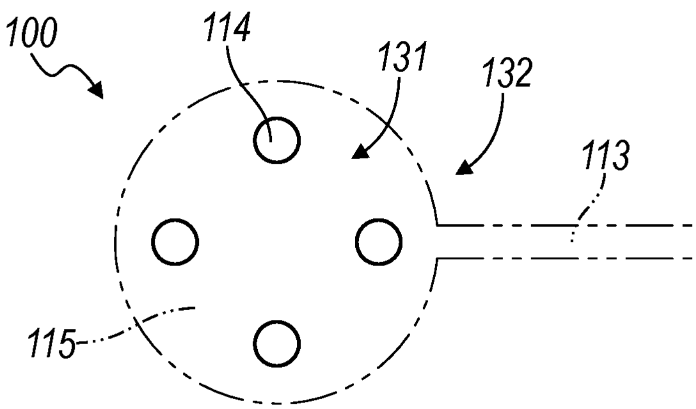


FIG. 4

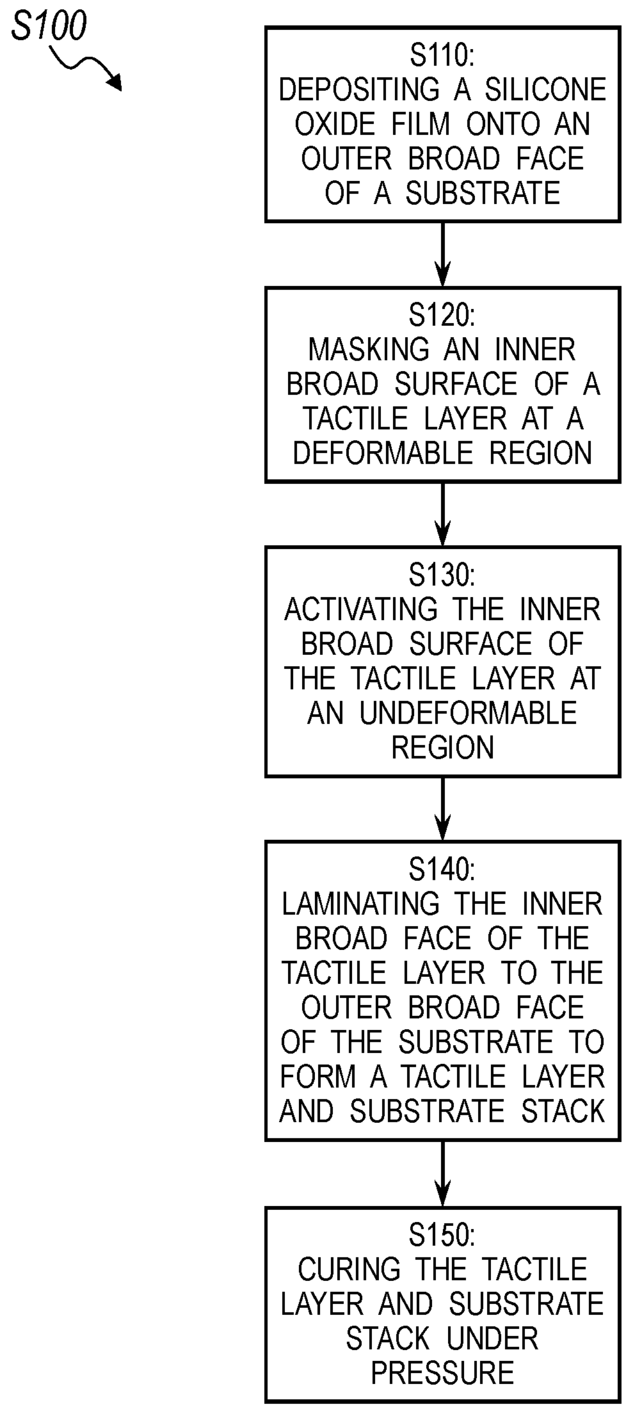

S100
S110:
DEPOSITING A SILICONE OXIDE FILM ONTO AN OUTER BROAD FACE OF A SUBSTRATE
S120:
MASKING AN INNER BROAD SURFACE OF A TACTILE LAYER AT A DEFORMABLE REGION
S130:
ACTIVATING THE INNER BROAD SURFACE OF THE TACTILE LAYER AT AN UNDEFORMABLE REGION
S140:
LAMINATING THE INNER BROAD FACE OF THE TACTILE LAYER TO THE OUTER BROAD FACE OF THE SUBSTRATE TO FORM A TACTILE LAYER AND SUBSTRATE STACK
S150:
CURING THE TACTILE LAYER AND SUBSTRATE STACK UNDER PRESSURE

FIG. 5

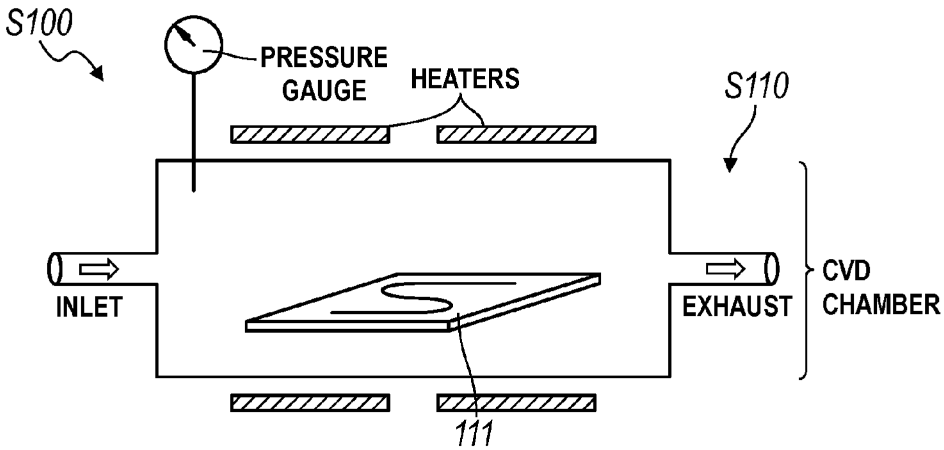


FIG. 6A

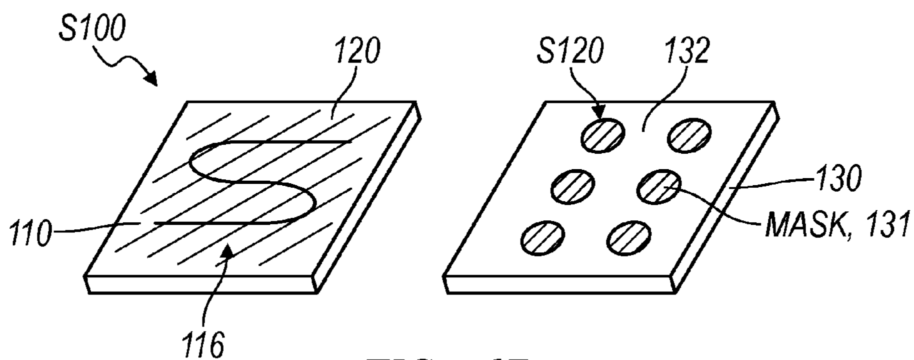


FIG. 6B

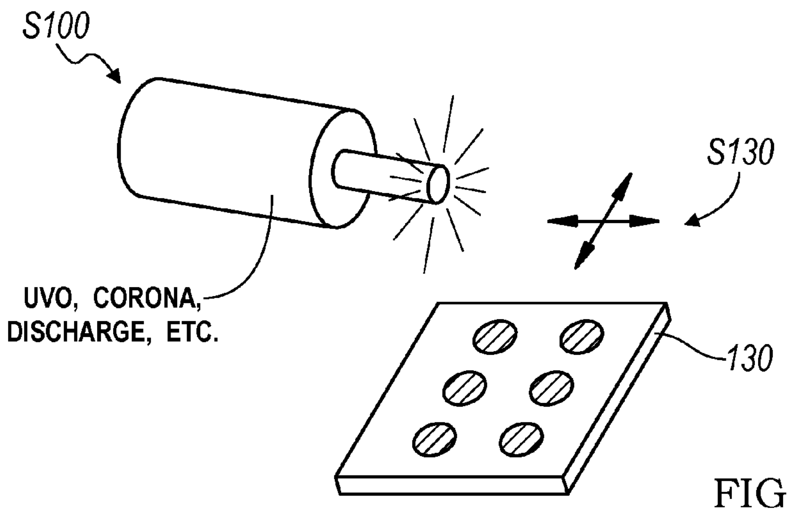


FIG. 6C

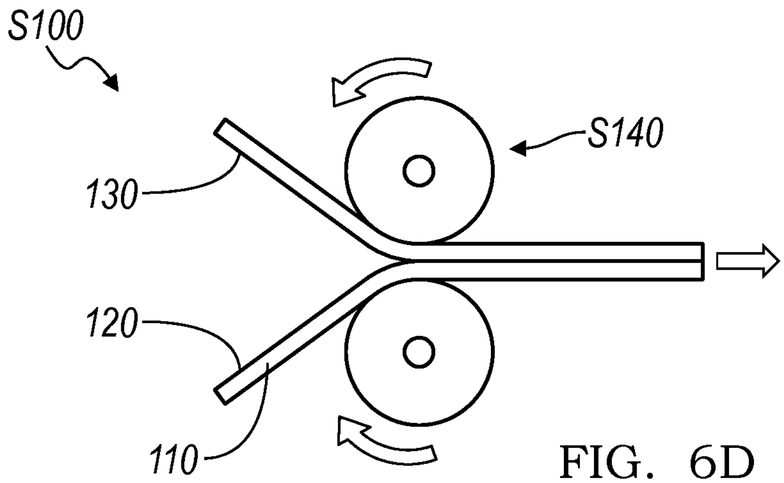

S100
S140
130
120
110

FIG. 6D

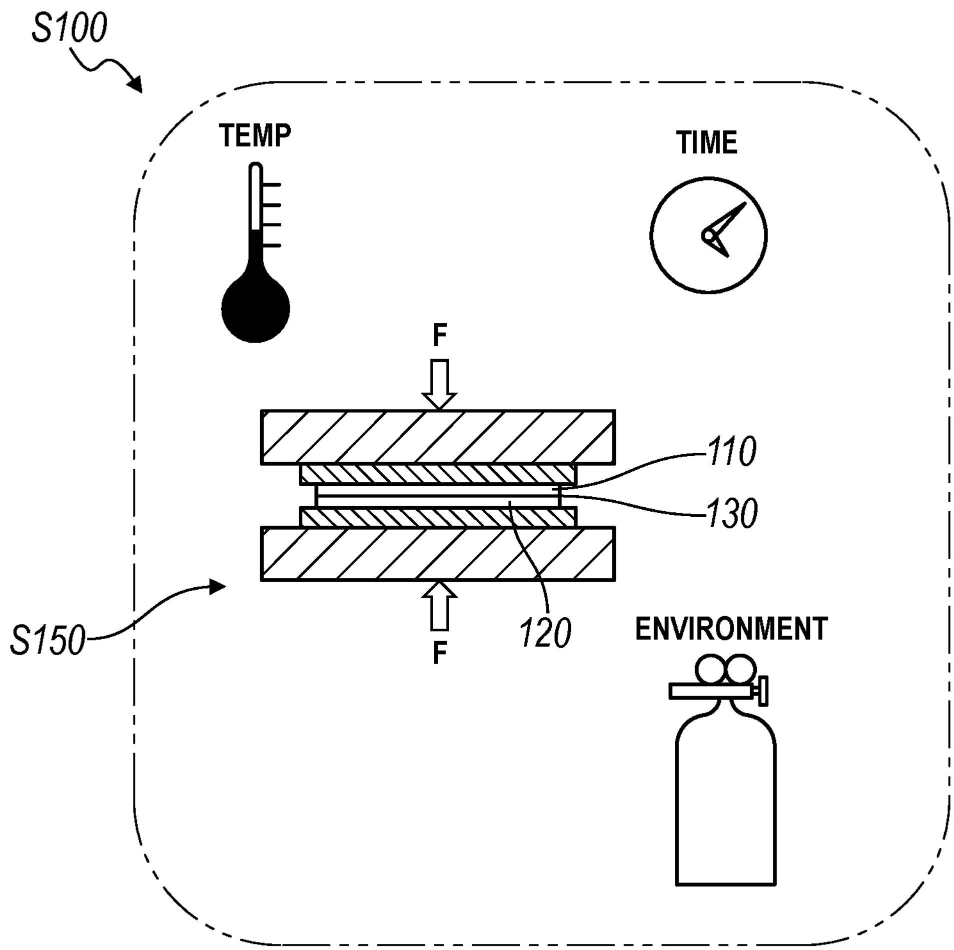

S100
TEMP
TIME
F
110
130
S150
120
F
ENVIRONMENT

FIG. 6E

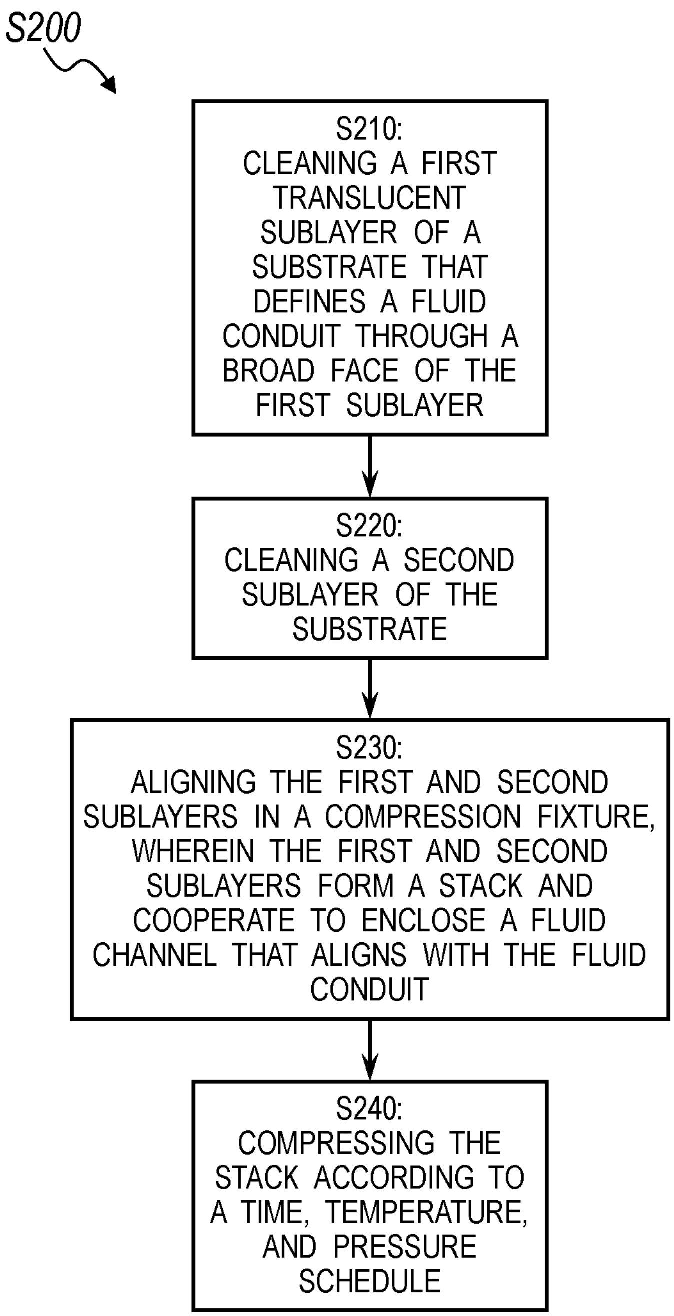

S200
S210:
CLEANING A FIRST TRANSLUCENT SUBLAYER OF A SUBSTRATE THAT DEFINES A FLUID CONDUIT THROUGH A BROAD FACE OF THE FIRST SUBLAYER
S220:
CLEANING A SECOND SUBLAYER OF THE SUBSTRATE
S230:
ALIGNING THE FIRST AND SECOND SUBLAYERS IN A COMPRESSION FIXTURE, WHEREIN THE FIRST AND SECOND SUBLAYERS FORM A STACK AND COOPERATE TO ENCLOSE A FLUID CHANNEL THAT ALIGNS WITH THE FLUID CONDUIT
S240:
COMPRESSING THE STACK ACCORDING TO A TIME, TEMPERATURE, AND PRESSURE SCHEDULE

FIG. 7

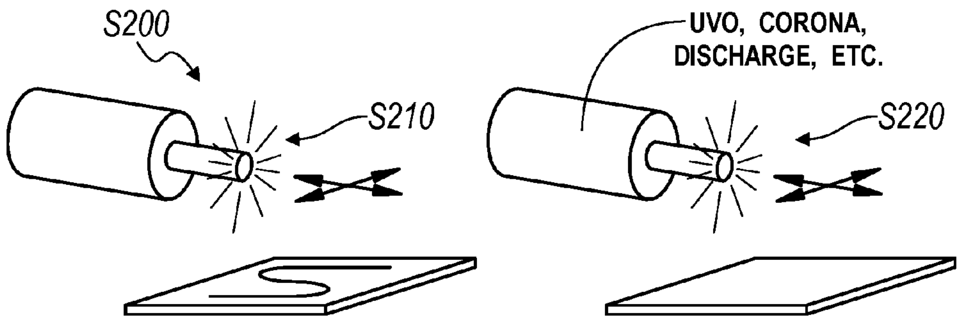


FIG. 8A

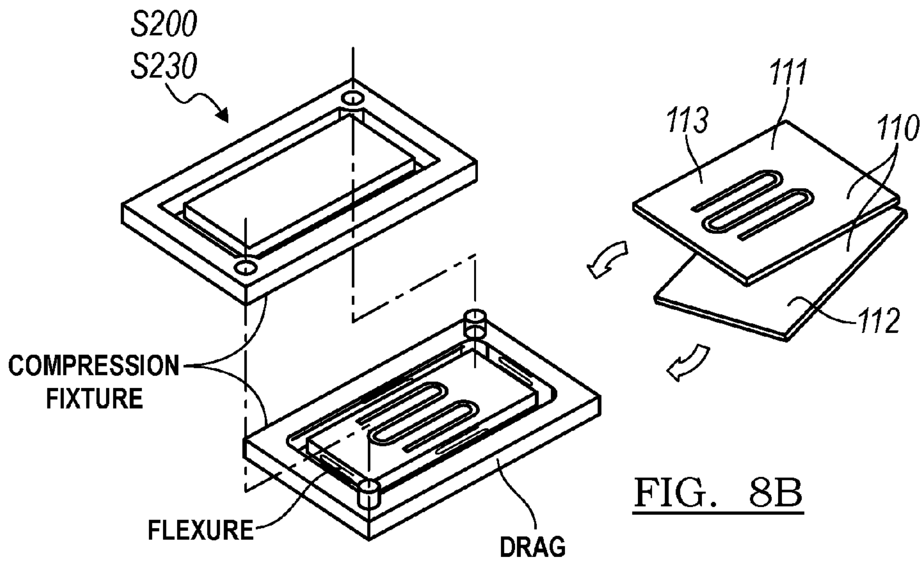


FIG. 8B

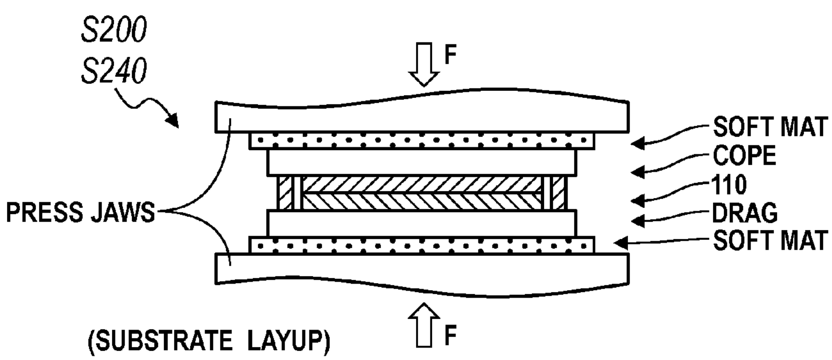


FIG. 8C

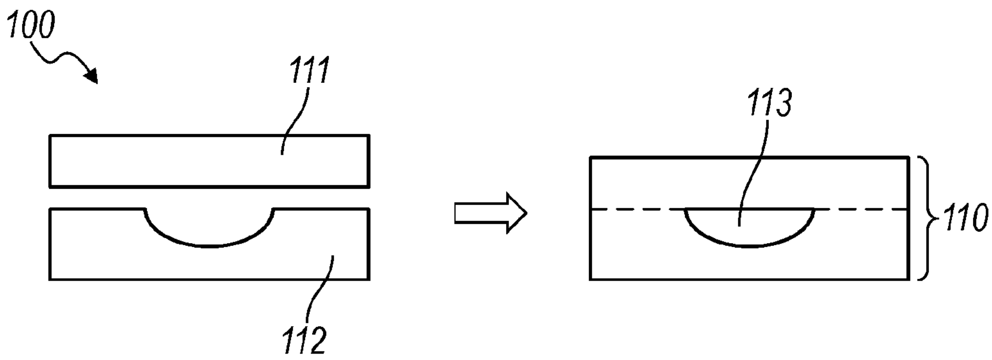


FIG. 9A

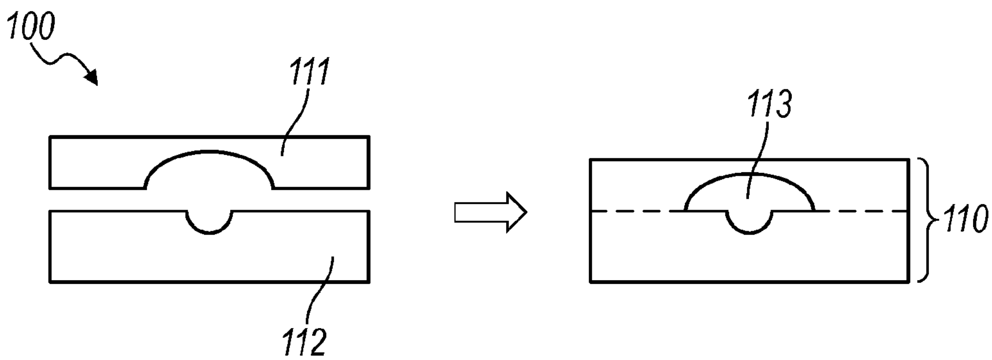


FIG. 9B

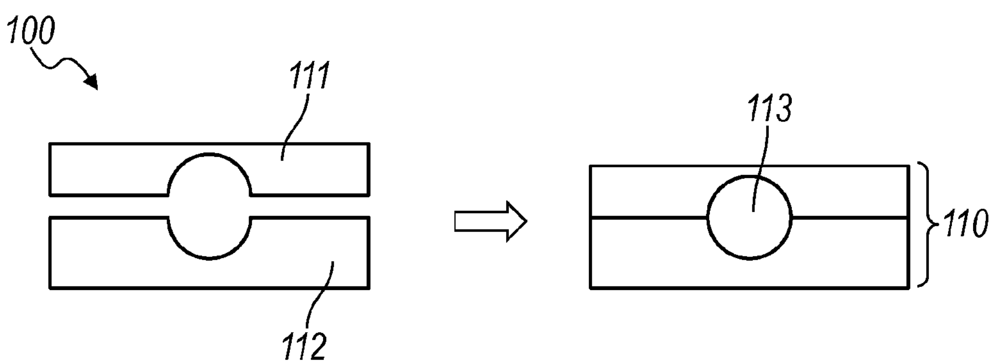


FIG. 9C

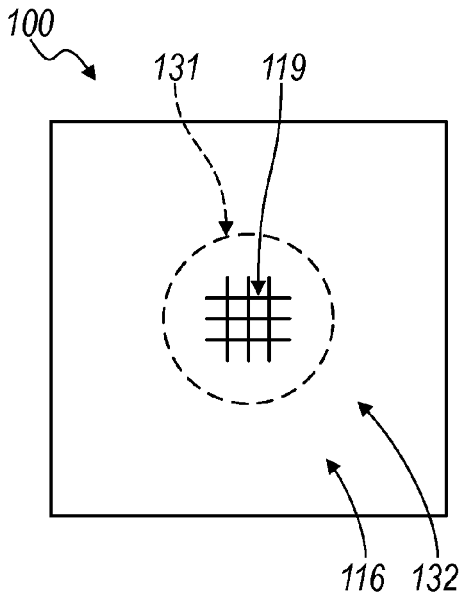


FIG. 10A

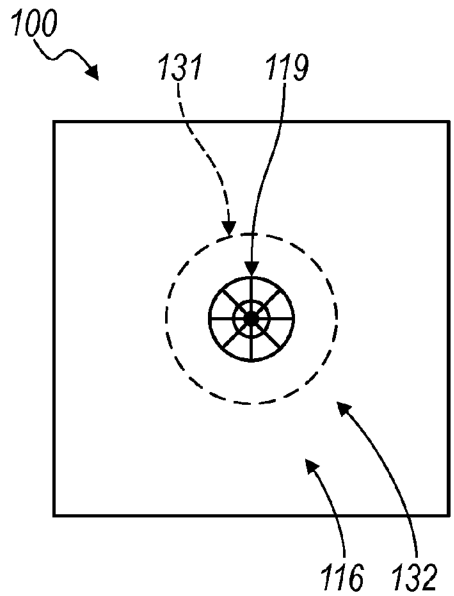


FIG. 10B

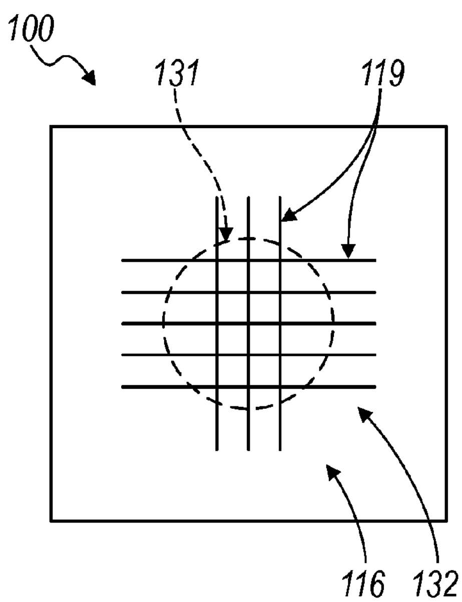


FIG. 10C

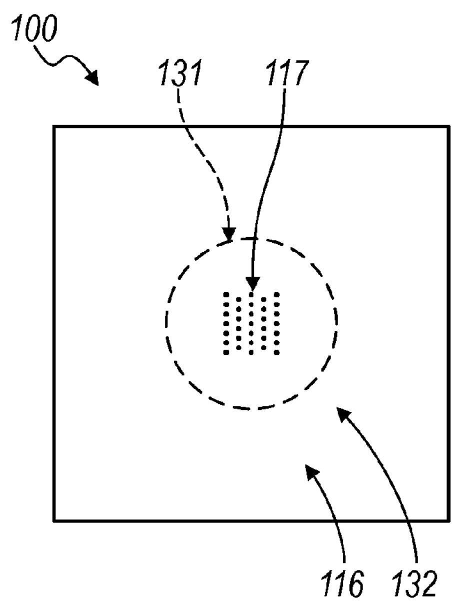


FIG. 10D

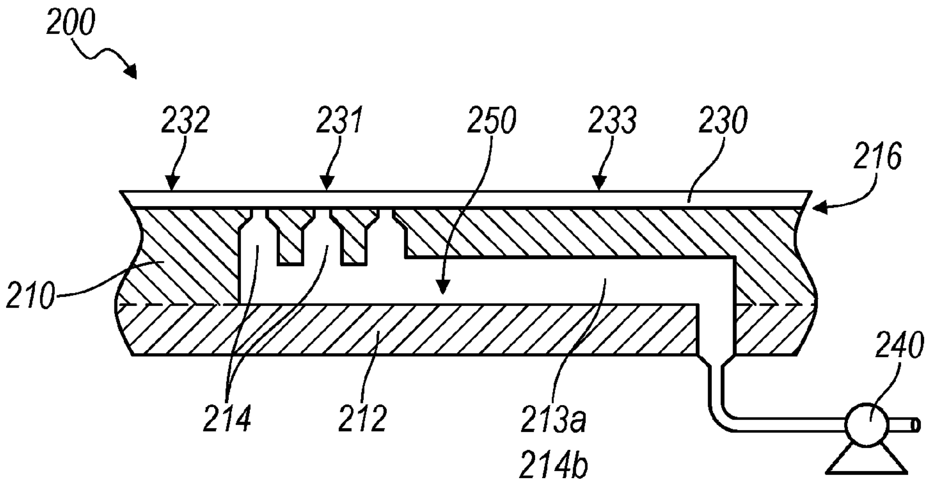


FIG. 11A

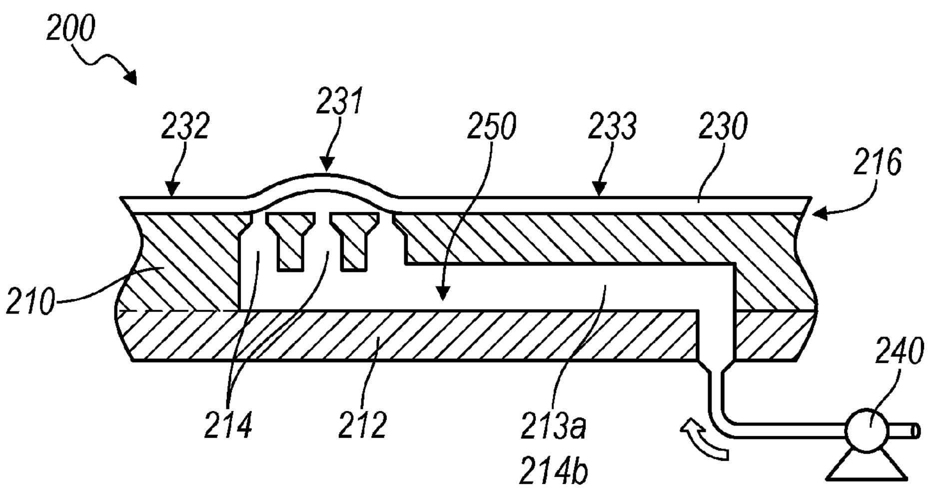


FIG. 11B

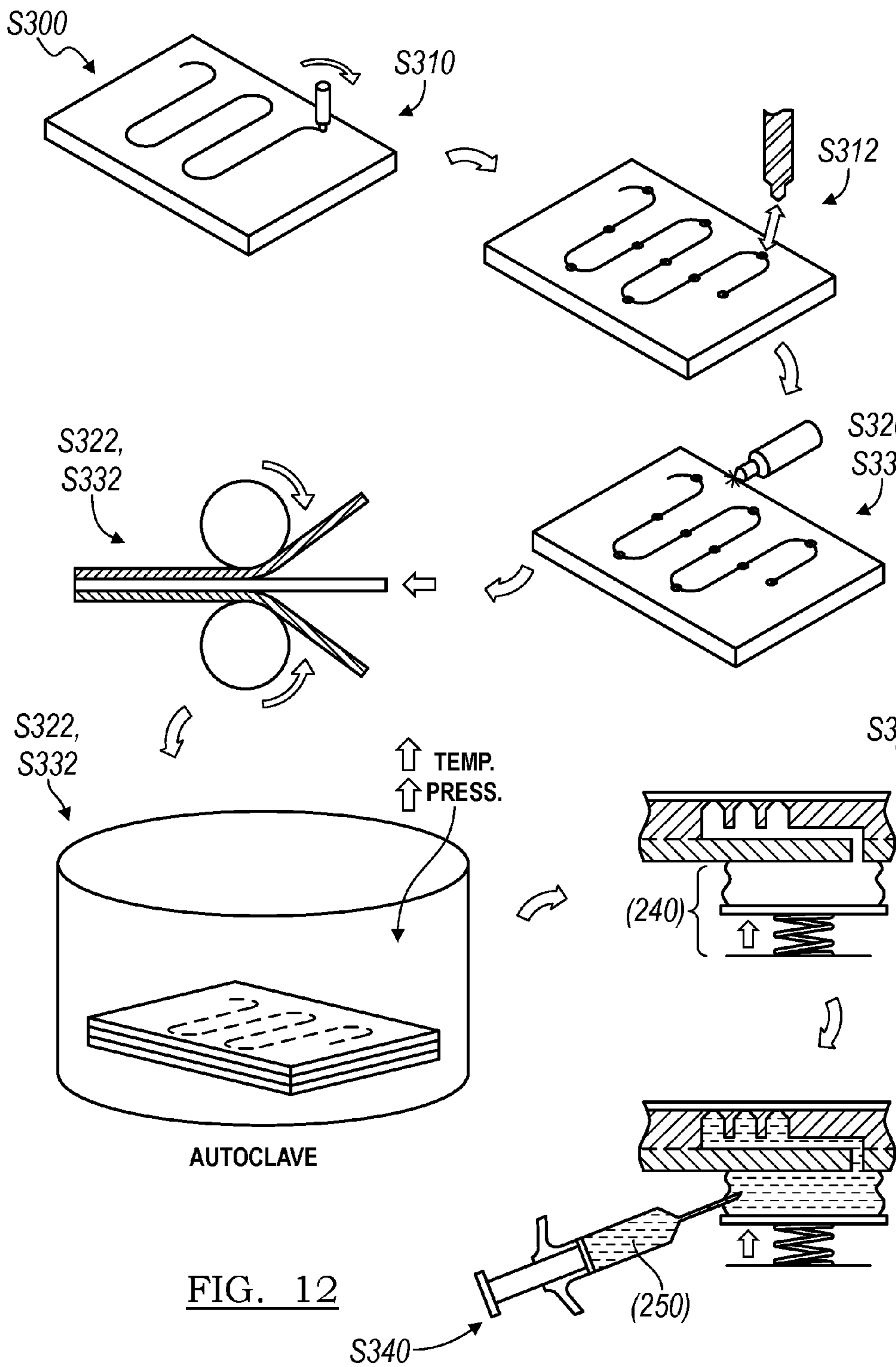

S300
S310
S312
S322,
S332
S320,
S330
S322,
S332
TEMP.
PRESS.
S342
(240)
AUTOCLAVE
(250)
S340

FIG. 12

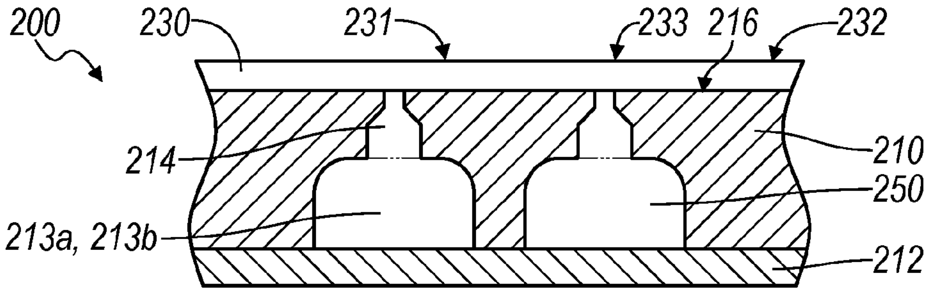


FIG. 13A

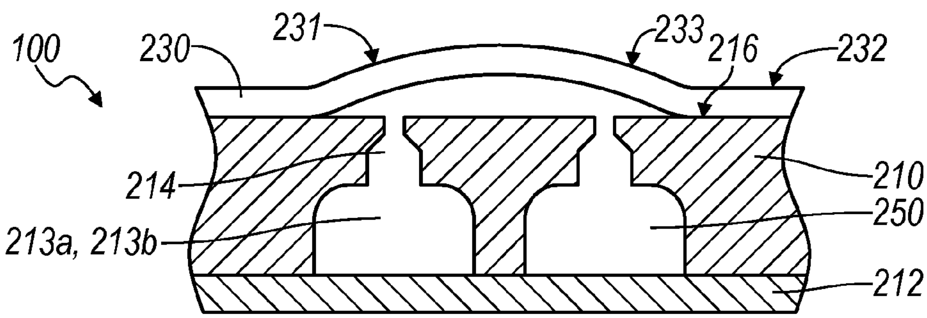


FIG. 13B

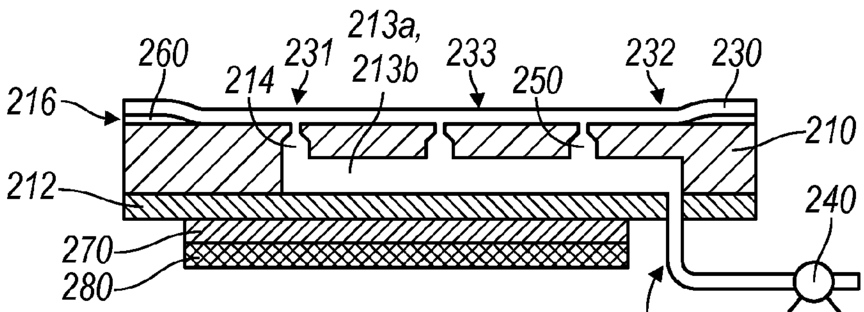


FIG. 14A

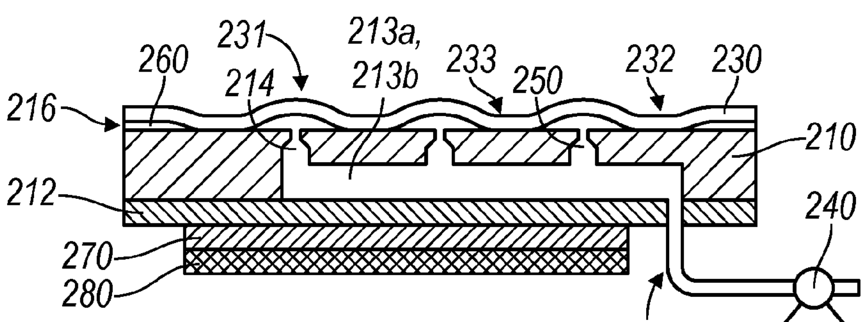


FIG. 14B

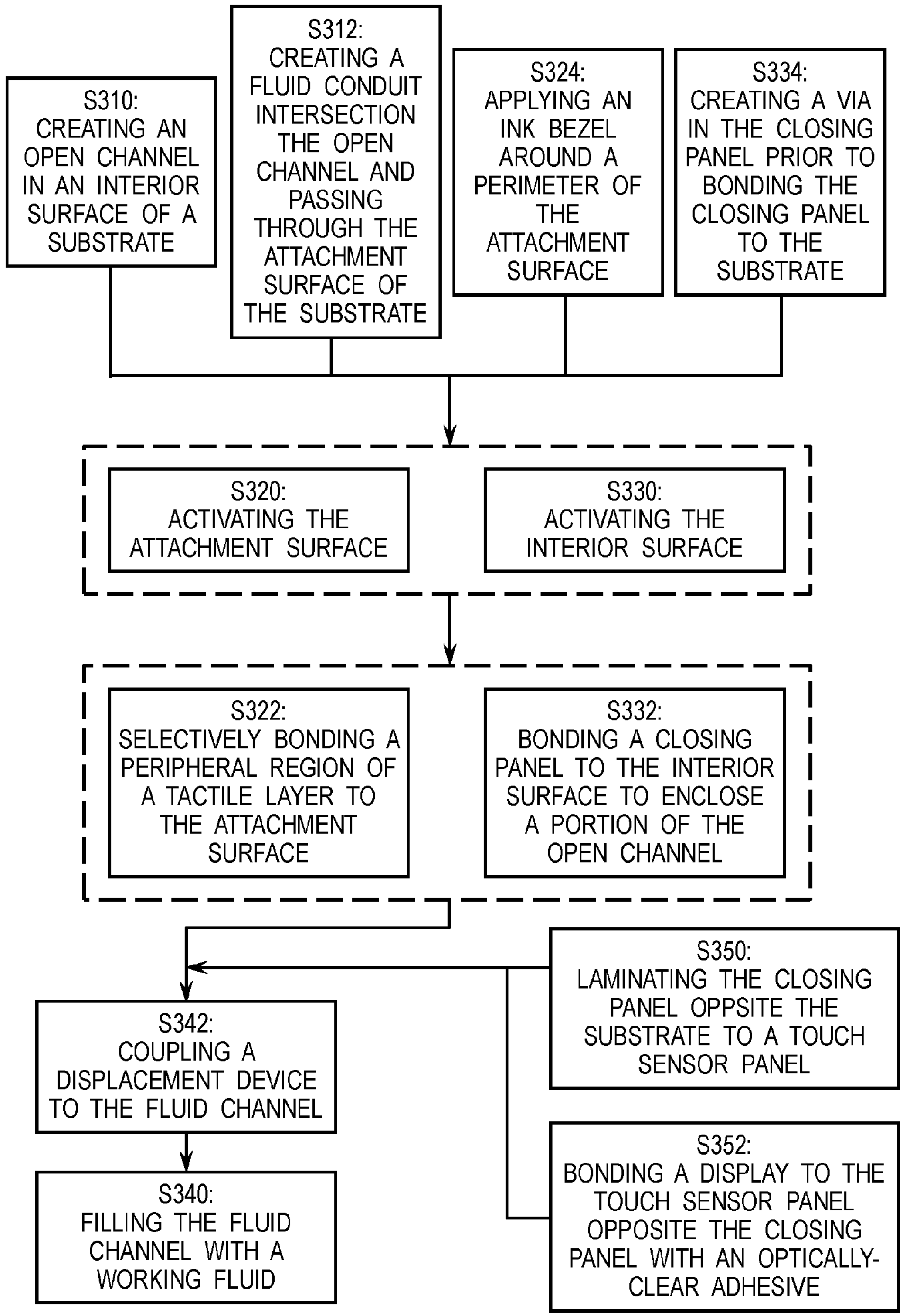

S310:
CREATING AN OPEN CHANNEL IN AN INTERIOR SURFACE OF A SUBSTRATE
S312:
CREATING A FLUID CONDUIT INTERSECTION THE OPEN CHANNEL AND PASSING THROUGH THE ATTACHMENT SURFACE OF THE SUBSTRATE
S324:
APPLYING AN INK BEZEL AROUND A PERIMETER OF THE ATTACHMENT SURFACE
S334:
CREATING A VIA IN THE CLOSING PANEL PRIOR TO BONDING THE CLOSING PANEL TO THE SUBSTRATE
S320:
ACTIVATING THE ATTACHMENT SURFACE
S330:
ACTIVATING THE INTERIOR SURFACE
S322:
SELECTIVELY BONDING A PERIPHERAL REGION OF A TACTILE LAYER TO THE ATTACHMENT SURFACE
S332:
BONDING A CLOSING PANEL TO THE INTERIOR SURFACE TO ENCLOSE A PORTION OF THE OPEN CHANNEL
S350:
LAMINATING THE CLOSING PANEL OPPSITE THE SUBSTRATE TO A TOUCH SENSOR PANEL
S342:
COUPLING A DISPLACEMENT DEVICE TO THE FLUID CHANNEL
S340:
FILLING THE FLUID CHANNEL WITH A WORKING FLUID
S352:
BONDING A DISPLAY TO THE TOUCH SENSOR PANEL OPPOSITE THE CLOSING PANEL WITH AN OPTICALLY-CLEAR ADHESIVE

FIG. 15

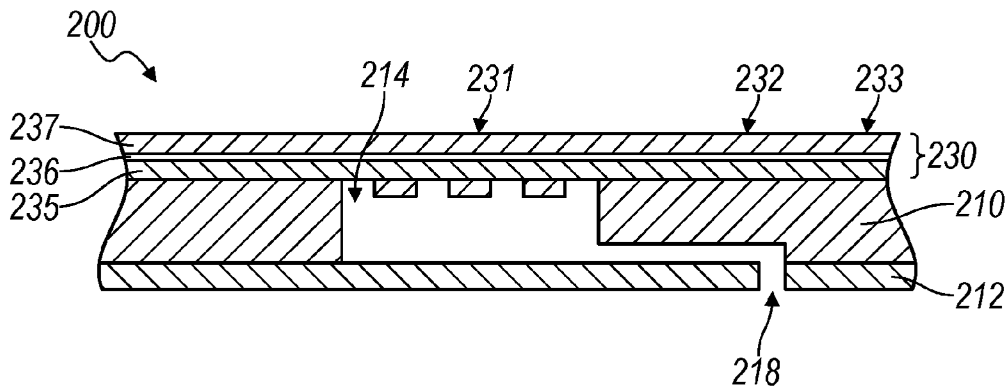


FIG. 16A

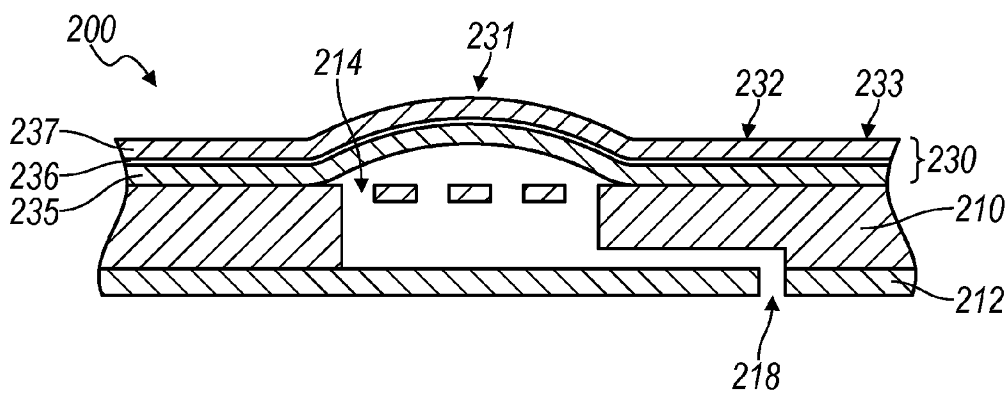


FIG. 16B

DYNAMIC TACTILE INTERFACE AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. application Ser. No. 15/006,744, filed 26 Jan. 2016, which is a continuation of U.S. application Ser. No. 14/035,851, filed on 24 Sep. 2013 and this application claims the benefit of U.S. Provisional Application No. 61/705,053, filed on 24 Sep. 2012, and U.S. Provisional Application No. 61/713,396, filed on 12 Oct. 2012, all of which are incorporated in their entireties by the reference.

TECHNICAL FIELD

[0002] This invention relates generally to the field of touch-sensitive displays, and more specifically to a dynamic tactile interface and methods for touch-sensitive displays.

BRIEF DESCRIPTION OF THE FIGURES

[0003] FIGS. **1**A and **1**B are schematic representations of a first dynamic tactile interface of the invention;

[0004] FIG. **2** is a schematic representation of one variation of the first dynamic tactile interface;

[0005] FIG. **3** is a schematic representation of one variation of the first dynamic tactile interface;

[0006] FIG. **4** is a schematic representation of one variation of the first dynamic tactile interface;

[0007] FIG. **5** is a flowchart representation of a second method of the invention;

[0008] FIGS. **6**A-**6**E are schematic representations of variations of the second method;

[0009] FIG. **7** is a flowchart representation of a first method of one embodiment of the invention;

[0010] FIGS. **8**A, **8**B, and **8**C are schematic representations of variations of the first method;

[0011] FIGS. **9**A, **9**B, and **9**C are schematic representations of variations of the first dynamic tactile interface;

[0012] FIGS. **10**A, **10**B, **10**C, and **10**D are schematic representations of variations of gothe first dynamic tactile interface;

[0013] FIGS. **11**A and **11**B are schematic representations of a second dynamic tactile interface of the invention;

[0014] FIG. **12** is a flowchart representation of a third method of the invention;

[0015] FIGS. **13**A and **13**B are schematic representations of one variation of the second dynamic tactile interface;

[0016] FIGS. **14**A and **14**B are schematic representations of one variation of the second dynamic tactile interface;

[0017] FIG. **15** is a flowchart representation of one variation of the third method; and

[0018] FIGS. **16**A and **16**B are schematic representations of one variation of the second dynamic tactile interface;

DESCRIPTION OF THE EMBODIMENTS

[0019] The following description of the embodiments of the invention is not intended to limit the invention to these embodiments, but rather to enable any person skilled in the art to make and use this invention.

1. First Dynamic Tactile Interface

[0020] As shown in FIGS. **1**A and **1**B, a first dynamic tactile interface **100** includes: a substrate **110**, a tie layer **120**, a tactile layer **130**, and a displacement device **140**. The substrate **110** defines an attachment surface **116**, a support surface **115** continuous with the attachment surface **116**, a fluid channel **113**, and a fluid conduit **114** configured to communicate fluid from the fluid channel **113** through the support surface **115**. The tie layer **120** is deposited onto the attachment surface **116**. The tactile layer **130** includes a peripheral region **132** bonded to the tie layer **120**, includes a deformable region **131** adjacent the support surface **115** and disconnected from the tie layer **120**, and defines a tactile surface **133** opposite the substrate **110**. The displacement device **140** is configured to displace fluid into the fluid channel **113** to transition the deformable region **131** from a retracted setting to an expanded setting, wherein the tactile surface **133** at the deformable region **131** is flush with the tactile surface **133** at the peripheral region **132** in the retracted setting (shown in FIG. **1**A) and is offset from the surface at the peripheral region **132** in the expanded setting (shown in FIG. **1**B).

[0021] Generally, the first dynamic tactile interface **100** can be incorporated or applied over a display and/or over a computing device, such as a smartphone or a tablet, and define one or more deformable regions of a tactile layer that can be selectively expanded and retracted to intermittently provide tactile guidance to a user interacting with the computing device. In one implementation, the first dynamic tactile interface **100** is integrated into a touchscreen of a mobile computing device, and the first dynamic tactile interface **100** can include a set of round or rectangular deformable regions, each deformable region substantially aligned with a key of a virtual keyboard displayed on the mobile computing device. In this implementation, the deformable regions can thus mimic physical hard keys when in the expanded setting, but when the keyboard is not displayed on the mobile computing device, the deformable regions can retract to yield a uniform, flush tactile layer. In this implementation, the first dynamic tactile interface **100** can also include an elongated deformable region that, in the expanded setting, aligns with a virtual 'swipe-to-unlock' input region rendered on the display **180**, and the elongated deformable region in the expanded setting can thus provide tactile guidance to a user unlocking the mobile computing device. The elongated deformable region can subsequently transition into the retracted setting to yield a uniform, flush surface over the display **180**, such as once the mobile computing device is unlocked and the 'swipe-to-unlock' input region is no longer rendered on the display **180**.

[0022] Because the first dynamic tactile interface **100** can be implemented over a display, elements of the first dynamic tactile interface **100**, such as the substrate **110**, the tie layer layer (e.g., a silicon oxide film), and the tactile layer **130**, can be substantially transparent to enable light transmission therethrough. Similarly, features of the first dynamic tactile interface **100**, such as the fluid channel **113**, the fluid conduit **114**, and a drainage hole **117** (described below and shown in FIG. **10**D), can be substantially small and/or of suitable geometries to substantially minimize reflection, refraction, and/or diffraction of light output from the display **180** through the first dynamic tactile interface **100**, thereby limiting optical distortions perceived by a user (e.g., up to a 'just noticeable' difference at a typical viewing distance of twelve inches from the display **180**). The substrate **110**, the silicon oxide layer, the tactile layer **130**, fluid, and/or other components of the first dynamic tactile interface **100** can also be of similar indices of refraction (e.g., at an average wavelength of light in the visible spectrum) or can share similar chromatic dispersion or other optical properties.

[0023] The substrate **110** of the first dynamic tactile interface **100** defines the fluid channel **113** that is connected to the fluid conduit **114**, wherein the fluid conduit **114** is configured to communicate fluid from the fluid channel **113** through the attachment surface **116**. The substrate **110** can be substantially planar and substantially rigid and therefore can retain the peripheral region **132** of the tactile layer **130** in substantially planar form in and between the expanded and retracted settings. However, the substrate **110** can be of any other form, such as curvilinear, convex, or concave, and the substrate **110** can also be flexible.

[0024] The substrate **110** can be of acrylic (Poly(methyl methacrylate) or PMMA) such that the substrate **110** is substantially translucent. However, the substrate **110** can alternatively be surface-treated or chemically-altered PMMA, glass, chemically-strengthened alkali-aluminosilicate glass, polycarbonate, acrylic, polyvinyl chloride (PVC), glycol-modified polyethylene terephthalate (PETG), polyurethane, a silicone-based elastomer, or any other suitable translucent or transparent material or combination thereof. Alternatively, the substrate **110** can be opaque, such as for arrangement over an off-screen region of a mobile computing device. The substrate **110** can also be of various different materials. For example, the substrate **110** can include a glass base sublayer bonded to a fluid channel and fluid conduit formed of PMMA. The substrate **110** can also be of a material exhibiting adequate adhesion properties with tie layer (e.g., a silicon oxide film) such that the tie layer **120** deposited onto the attachment surface **116** can function to retain the peripheral region **132** of the tactile layer **130** against the substrate **110** despite the position of the deformable region **131** or the fluid pressure between the substrate **110** and the deformable region **131**. For example, adhesion the tie layer and the substrate and between the tie layer and the tactile layer can be enhanced with surface treatments, such as described below. The tie layer can also include a multiple layers and/or include a thin metallic layer a few angstroms thick.

[0025] The fluid channel **113** can be a blind channel defined within the substrate **110**. In one variation of the first dynamic tactile interface **100** shown in FIGS. **1A** and **1B**, the substrate **110** includes a first sublayer **111** and a second sublayer **112** that, when joined, cooperate to define and to enclose the fluid channel **113**. The first sublayer **111** can define the attachment surface **116**, and the fluid conduit **114** can pass through the first sublayer **111** to the attachment surface **116**. In this variation, the first and second sublayers, can be of the same or similar materials, such as PMMA for both sublayers or surface-treated PMMA for the first sublayer **111** and standard PMMA for the second sublayer **112**.

[0026] The fluid channel **113** can be one of a set of fluid channels that communicate fluid to one or more fluid conduits of the deformable region **131**. Fluid channels in the set of fluids channels can also intersect, such as in the vicinity of the deformable region **131**. Implementation of multiple channels feeding fluid to the deformable region **131** can increase flow rate to or from the deformable region **131**, thus yielding faster transitions between retracted and expanded settings. This can additionally or alternatively enable implementation of fluid channels of smaller cross-sectional areas, which may be less visible to a user. Multiple fluid channels can be incorporated into a system configured to independently expand one or more deformable regions simultaneously.

[0027] As shown in FIG. **9A**, the fluid channel **113** can be created by forming (or cutting, stamping, casting, etc.) an open channel in the first sublayer **111** of the substrate **110** and then enclosing the channel with a second sublayer **112** (without a channel feature) to form the enclosed fluid channel and the substrate **110**. Alternatively, as shown in FIGS. **9A** and **9B**, the substrate can include two sublayers, including a first sublayer **111** defining an upper open channel section and including a second sublayer **112** defining a lower open channel that cooperates with the upper open channel to define the fluid channel **113** when the first and second sublayers **111**,**112** are aligned and joined. For example, each sublayer can include a semi-circular open channel, wherein, when bonded together, the sublayers form an enclosed fluid channel with a circular cross-section, as shown in FIG. **9C**. Because small cross-sections may affect fluid flow rate through the fluid channel **113**, this fluid channel geometry may enable higher flow rates than other cross-sections. However, the substrate **110** can define a fluid channel of any suitable cross-section, such as square, rectangular, circular, semi-circular, ovular, etc.

[0028] In one example implementation, the fluid channel **113** and the fluid conduit **114** are cut into the first sublayer **111** opposite the attachment surface **116** via conventional machining. The first and second sublayers, can then be treated and surface activated in ultraviolet ozone for a specified period of time (e.g., several minutes), as shown in FIG. **8A**. The first and second sublayers, can then be stacked in alignment on a compression fixture (shown in FIG. **8B**) and compressed according to a time, temperature, and pressure schedule (shown in FIG. **8C**), such as one hour at 300 psi of compression at a temperature of 50° C. The stack can also be compressed according to an environment schedule throughout a portion or all of the compression cycle, such as an environment that is dry argon, wet hydrogen (i.e., hydrogen mixed with small quantities of air or water), or vacuum (e.g., 10^-6 Torr). The stack can additionally or alternatively be laminated in a compression machine (e.g., with rollers) that bonds the layers of the stack by applying pressure and/or heat across portions of the stack over time.

[0029] The first dynamic tactile interface **100** can also include multiple substrates, each defining one or more fluid channels and vias, such as shown and described in U.S. patent application Ser. No. 12/652,704, filed on 5 Jan. 2010, which is incorporated in its entirety by this reference. In this implementation, substrates can be stacked with vias in alignment to enable communication of fluid across multiple substrate layers, and the stack of substrates can then be bonded according to any of the foregoing or forthcoming methods or techniques.

[0030] The compression fixture implemented in the foregoing example implementation can be a two-part fixture including a cope side and a drag side. Each of the cope and drag sides can include a bonding surface and a support surface that supports the bonding surface via one or more flexures, as shown in FIG. **8**. In this example implementation, the sheet materials that define the substrate **110** and the tactile layer **130** can extend beyond the compression portions of the compression fixture (e.g., beyond the flexure), which can reduce distortion of the substrate **110** and tactile layer proximal the boundary of the compression portions of the compression fixture. Furthermore, alignment features integral with the sheet materials that define the substrate **110** and the tactile layer **130** can be arranged beyond the portions of the materials within the compression portions of the compression fixture. Each side of the compression fixture also can include a recess with geometry, form, and width correlating with and/or substantially similar to that of the fluid channel **113** such the stack can be set between the cope and drag plates and compressed without collapsing the fluid channel **113**. The cope and/or drag plates can also include locating features that align the stack with the recess. Furthermore, the drag side can include at least one male locating feature, and the cope side can include at least one female locating feature such that the halves of the compression fixture can be repeatably aligned.

[0031] In the foregoing example implementation, the first sublayer of the substrate **110** can include an open valley opposite the attachment surface **116**, wherein the open valley substantially defines the fluid channel **113** when the first and second sublayers are joined. The first sublayer **111** also can include at least one through-bore that passes from a portion of the fluid channel **113** to the attachment surface **116** such that the fluid channel **113** and fluid conduit can be formed in the first sublayer **111** substantially simultaneously and/or in the same manufacturing setup. However, in this or other manufacturing implementations, the fluid channel **113** and/or fluid conduit can be created in the substrate **110** (e.g., in the second sublayer **112** and/or in the first sublayer **111**) via any suitable manufacturing technique, such as by etching, drilling, punching, stamping, molding, casting, etching, bulk micromachining, or any other suitable manufacturing process. Furthermore, the first and second sublayers, can be cleaned, treated, and/or activated via any other process, or combination of processes, such as via low-temperature heating in a vacuum, via etching, or via a solvent wipe. The stack can also be compressed according to any other time, temperature, pressure, and/or environment schedule. Following assembly, the stack can be further post-annealed, such as by heating the stack according to a particular time, temperature, and/or environment schedule to modify the crystalline (e.g., grain) structure with the layers of the stack.

[0032] Therefore, as shown in FIG. **7**, a first method S**100** for enclosing a fluid channel **113** within a substrate **110** includes: cleaning a first translucent sublayer of the substrate **110** that defines a fluid conduit **114** through a broad face of the first sublayer **111** as shown in FIG. **8**A as Block S**110**; cleaning a second sublayer **112** of the substrate **110** as shown in FIG. **8**B as Block S**120**; aligning the first and second sublayers **111**, **112** in a compression fixture, wherein the first and second sublayers **111**, **112** form a stack and cooperate to enclose the fluid channel **113** that aligns with the fluid conduit **114** as shown in FIG. **8**C as Block S**130**; and compressing the stack according to a time, temperature, and pressure schedule as shown in FIG. **8**D as Block S**140**.

[0033] The first method S**100** can be implemented to join the first and second sublayers **111**, **112** of the substrate **110** of the first dynamic tactile interface **100**, as described above. The first method S**100** can therefore also include curing the sublayer stack according to a time, temperature, pressure, and environment schedule. However, the first method S**100** can include any other procedure implemented in any other way to enclose the fluid channel **113** within the substrate **110**.

[0034] As shown in FIGS. **1** and **4**, the substrate **110** can further define a support surface **115** adjacent the deformable region **131**, wherein the support surface **115** defines a hard stop for the tactile layer **130** that resists inward deformation of the deformable region **131** due to an input on the tactile surface **133**. The support surface **115** can further be in-plane with the attachment surface **116** proximal the peripheral region **132** such that the support surface **115** resists inward deformation of the deformable region **131** past the plane of the peripheral region **132**, though the support surface **115** can be of any other geometry or form. The fluid conduit **114** can pass through the support surface **115** such that the fluid conduit **114** can communicate fluid from the fluid channel **113** to the interior surface of the tactile layer **130** to transition the deformable region **131** between settings.

[0035] The fluid channel **113** can be defined as an elongated recess of constant cross-section and depth through the substrate **110**. The cross-section of the fluid channel **113** can be rectilinear, though the cross-section of the fluid channel **113** can alternatively be circular, semi-circular, curvilinear, ovular, triangular, trapezoidal, elliptical, or any other suitable cross-section. The fluid channel **113** also can include a series of orthogonal linear segments that meet at arcuate or filleted sections (shown in FIG. **3**) to form a serpentine path configured to communicate fluid to a plurality of adjacent deformable regions separated by peripheral regions. The substrate **110** can also define the fluid channel **113** that is of varying cross section along its length, such as varying width, constant-width with oscillating profile along the length of the fluid channel **113**, or a sinusoidal, waveform, or 'squiggle' oscillating profile. The cross-section (e.g., geometry, height, width, etc.) of the fluid channel **113** (and/or fluid conduit) can be tailored for particular speed and/or pressure of fluid flow at one or more particular regions along the length of the fluid channel **113**. Furthermore, the substrate **110** can also define the fluid channel **113** that is an open channel or a sunk (e.g., buried) channel, or the substrate **110** can define the fluid channel **113** in any other suitable way. However, the fluid channel **113** can be of any other constant or varying depth, any other constant or varying cross-section, linear or non-linear path, linear or non-linear profile, or of any other geometry, profile, form, or path.

[0036] The fluid conduit **114** can be circular in cross-section and normal to the attachment surface **116** or of any other profile and/or cross-section. The fluid conduit **114** can also be one in a set of fluid conduits paired with the deformable region **131**, wherein the set of fluid conduits cooperate to direct fluid between the fluid channel **113** and the interior surface of the tactile layer **130**. Furthermore, the cross-sectional area of the fluid conduit **114** at the attachment surface **116** can be less than the cross-sectional area of the fluid channel **113** at the junction with the fluid conduit **114**, such as shown in FIGS. **11**A and **11**B. However, the fluid conduit **114** can be of any other form, geometry, or profile.

[0037] The substrate **110** can further define one or more drainage holes **117** fluidly coupled to the fluid conduit **114** and to the fluid channel **113**. The drainage holes **117** can be in fluid communication with the back surface of the deformable region **131** and adjacent the fluid conduit **114**. For example, the fluid conduit **114** can define an outlet substantially proximal the center of the deformable region **131** and the drainage hole **117** can define a fluid inlet substantially proximal and within the boundary of the deformable region **131**, and the outlet of the drainage hole **117** can be coupled to the fluid channel **113** to communicate fluid back into the fluid channel **113**. Furthermore, the cross-section of the drainage holes **117** can be substantially smaller than the cross-section of the fluid conduit **114** such that the fluid conduit **114** defines a primary fluid path to communicate fluid toward and away from the back surface of the deformable region **131**. The drainage hole **117** can thus function to permit additional fluid, trapped under the deformable button during a transition to the retracted setting, to passively escape a fluid cavity between the substrate **110** and the back surface of the deformable region **131**. This can enable more complete drainage of fluid from the cavity and thus a more predictable and/or consistent form of the deformable region **131** in the retracted setting. Generally, the fluid can be actively pumped into and/or out of the fluid cavity via the fluid conduit **114** to transition the deformable region **131** between expanded and retracted settings, and fluid can passively move out of the cavity via the drainage holes **117** to improve efficacy of transitions into the retracted setting. However, the drainage hole **117** can additionally or alternatively be coupled to a drainage source that actively draws fluid out of the fluid cavity to actively retract the deformable region **131**, though the drainage hole **117** can function in any other suitable way.

[0038] As shown in FIGS. **10**A-**10**C, the attachment surface **116** can also define one or more grooves **119** that provide additional paths for fluid to flow into or out of the fluid conduit **114** and/or drainage holes **117** during a transition between the retracted and expanded settings. Like the drainage hole **117**, grooves **119** can assist removal of fluid from the fluid cavity and thus prevent fluid from being trapped between the tactile layer **130** and the substrate **110**. The grooves **119** can be shallow, deep, narrow, wide, or of any other constant or varying cross-section or geometry and can also feature microtexturing or other suitable surface treatment or profile. The grooves **119** can extend only over the portion of the substrate **110** adjacent the deformable region **131** (shown in FIGS. **10**A and **10**B) or into the peripheral region **132** (shown in FIG. **10**C). The substrate **110** can define multiple grooves, such as grooves that intersect across the portion of the substrate **110** adjacent the deformable region **131** of the tactile layer **130**, such as in a checkerboard pattern (shown in FIGS. **10**A and **10**C), a pattern of radiating lines and concentric circles (shown in FIG. **10**B), or randomly arranged linear or nonlinear grooves. The back surface of the tactile layer **130** can also define ridges that align with and substantially dip into or fill the groove(s) in the retracted setting. Alternatively, the back surface of the tactile layer **130** can define one or more grooves, and the attachment surface **116** can also define one or more ridges that align with and fill one or more grooves in the tactile layer **130** in the retracted setting.

[0039] The form, profile, surface finish, and/or geometry of the fluid conduit **114** and the fluid channel **113** can be selected to limit optical distortion of an image transmitted through the substrate **110**, such as scattering, diffraction, refraction, or reflection. These variables can also be tailored to inhibit unwanted back-reflection of impinging light, such as from an external light source or the sun. Furthermore, these variables can also be tailored to limit directional or preferential light scattering in a particular direction in favor of even distribution of light scattering or refraction through the substrate **110** and the tactile layer **130**. The fluid channel **113** and fluid conduit can further include concave or convex fillets of constant or varying radii at any edge, corner, or apex such that unwanted optical distortion, such as scattering, reflection, refraction, and/or diffraction, can be minimized at such features. Additionally or alternatively, the fluid channel **113** and/or fluid conduit can be of a substantially small cross-sectional area that reduces light scattering at a fluid-substrate boundary or interface. The fluid channel **113**, fluid conduit, and tactile layer can also be substantially clean before the first dynamic tactile interface **100** is filled with fluid in order to promote wetting and/or to minimize nucleation sites (e.g., for bubbles) throughout the fluid path(s) within the first dynamic tactile interface **100**. Air can also be evacuated from the fluid channel **113**, fluid conduit, and tactile layer can also be prior to filling the first dynamic tactile interface **100** with fluid. The fluid channel **113** and/or fluid conduit can also be hydrophobic or hydrophilic. The geometry and/or the minimal cross-sectional area of the fluid conduit **114** and the fluid channel **113** can render the fluid conduit **114** and the fluid channel **113** substantially optically imperceptible to a user. The geometry and/or the minimal cross-sectional area of the fluid conduit **114** and the fluid channel **113** can also limit optical distortion through the substrate **110** to less than a just noticeable difference, such as at a typical working distance of twelve inches between the tactile surface **133** and an eye of a user. Generally, the geometry and/or minimal cross-sectional area of the fluid paths can yield the benefit of limiting optical abnormalities of the first dynamic tactile interface **100** below a just noticeable difference.

[0040] The tie layer **120** of the first dynamic tactile interface **100** is deposited on the attachment surface **116**. The tie layer **120** can function as an activatable adherent that chemically and/or mechanically bonds the substrate **110** to the tactile layer **130**. For example, the tie layer **120** can include a silicone oxide film applied to the attachment surface **116** of the substrate **110** via a chemical vapor deposition process, as shown in FIG. **6**A. Alternatively, the tie layer **120** can be applied via sputtering, plasma polymerization, mechanical application via a rolling drum, or any other suitable process that yields a silicon oxide film of substantially even thickness across the attachment surface **116**. The thickness of the tie layer **120** can be sufficiently thin such that a person interacting with the dynamic tactile interface **100** finds difficulty in distinguishing the tie layer **120** by sight and/or by feel. For example, the tie layer **120** can be less than one micrometer (1 μm) in thickness.

[0041] The tie layer **120** can be selectively applied to the attachment surface **116**. In one example implementation, prior to application of the film, a weighted (or magnetized) shield is placed over the portion of the attachment surface **116**, the shield covering a particular area that will be adjacent to the deformable region **131**, wherein the shield prevents deposition of silicon oxide over the substrate **110** at the particular area. In another example implementation, prior to application of the film, a sticker-type mask is selectively adhered to the attachment surface **116**, specifically at portions that will be aligned with deformable regions of the tactile layer **130**. Alternatively, the tie layer **120** can be applied across the attachment surface **116** and subsequently selectively removed, such as through laser ablation or plasma etching. However, the tie layer **120** can be (selectively) applied in any other way, can be of any other thickness, and can also or alternatively be applied to the interior surface of the tactile layer **130**.

[0042] In other variations of the first dynamic tactile interface **100**, a different material, such as urethane, polyurethane, epoxy, silicone, titanium, gold, primer, adhesives, an adhesive monomer layer, or any other suitable material or combination of materials enabling adhesion between the tactile layer **130** and the substrate **110**, is used in place of silicon oxide to create the film that joins the tactile layer **130** and the substrate **110**. In yet other variations of the first dynamic tactile interface **100**, the silicone oxide layer is excluded entirely and the substrate **110** is bonded or coupled directly to the tactile layer **130**.

[0043] The tactile layer **130** of the first dynamic tactile interface **100** defines the peripheral region **132** that is bonded to the tie layer **120** and the deformable region **131** that is adjacent the deformable region **131**, adjacent the fluid conduit **114**, and disconnected from the tie layer **120**. The tactile layer **130** also defines the tactile surface **133** opposite the substrate **110**. The tactile layer **130** can be of a flexible and/or elastic material that is translucent or transparent, such as polyethylene terephthalate (PET), polycarbonate (PC), silicone, or urethane. However, the tactile layer **130** can be any other substantially transparent material.

[0044] As shown in FIG. **1**A, the tactile layer **130** can include two sublayers, including an outer sublayer and a buffer backing. The outer sublayer can be substantially rigid and durable to resist scratching and can be bonded to the tie layer **120** via the buffer backing. In one example, the outer sublayer is a more rigid material such as polycarbonate or PET (polyethylene terephthalate), and the buffer backing is substantially more extensible, has a lower modulus, and is more elastic, such as silicone. The tactile layer **130** is operable between the expanded and retracted settings, wherein the outer sublayer deforms between settings and the buffer backing substantially absorbs deformation of the tactile layer **130** proximal a deformation boundary around the deformable region **131**. Because the outer sublayer can be a substantially transparent polymer, repeated transitions between the expanded and retracted settings can result in crazing or drawing near the deformation boundary, which can reduce optical clarity near the circumference of the deformable region **131** and/or result in plastic deformation of the tactile layer **130** over time. However, the buffer backing can soften or cushion the transition region of the outer sublayer at the border between the deformable and deformable regions. Generally, the buffer backing can stretch in a direction of deformation (e.g., outward) when the tactile layer **130** is expanded to absorb sharp deformation of the outer sublayer between settings. Therefore, the tactile layer **130** that includes an outer sublayer and a buffer backing can exhibit improved scratch-resistance and a glass-like tactile feel at the tactile surface **133** while maintaining optical clarity at deformation boundaries throughout repeated transitions between expanded and retracted settings. The tactile layer **130** that includes multiple (e.g., two) sublayers can also enable strain due to application of force on the tactile layer **130** to preferentially manifest in the softer (i.e. buffer) sublayer and rather than the harder (outer) sublayer, which can permit less extensible, more durable layers to be used as the outer sublayer of the tactile layer **130**.

[0045] The tactile layer **130** can be of uniform composition across the deformable and peripheral regions. However, the tactile layer **130** can be selectively flexible or elastic. For example, materials arranged at the deformable region **131** can be substantially flexible or elastic and materials arranged at the peripheral region **132** can be substantially less flexible or less elastic. The tactile layer **130** can also be of uniform thickness, such as less than one millimeter (1 mm) across the deformable and peripheral regions. However, the tactile layer **130** can alternatively be of non-uniform thickness. For example, the tactile layer **130** can be thinner at the deformable region **131** than at the peripheral region **132** to increase flexibility at the deformable region **131**. In another example, the tactile layer **130** can be thicker at the deformable region **131** than at the peripheral region **132** such that the tactile surface **133** of deformable region defines a lip or edge on the tactile surface **133**. In a further example, the tactile layer **130** can be thicker at the deformable region **131** than at the peripheral region **132** such that the deformable region **131** extends into a recess on the interior surface of the substrate **110** adjacent the fluid conduit **114**, wherein the recess includes the support surface **115** that supports the extension of the deformable region **131** to prevent inward deformation of the deformable region **131** in the retracted setting due to an input on the tactile surface **133**. In still another example, the interior surface of the tactile layer **130** can include a valley that at least partially defines the fluid channel **113** when the tactile layer **130** is bonded to the substrate **110**. However, the tactile layer **130** can be of any other form or geometry.

[0046] The tactile surface **133** of the tactile layer **130** can be substantially smooth to the touch. Alternatively, the tactile surface **133** can include a matte, textured, or patterned surface. For example, a matte surface may reduce glare from reflected light and yield beneficial light transmission and light scattering properties at the tactile surface **133**. A matte finish can also be applied on top of the tactile surface **133**, such as before the tactile layer **130** is bonded to the substrate **110** or before sublayers of the tactile layer **130** are joined. A matte finish or texture can also be applied to the tactile surface **133** during a bonding process to join the tactile layer **130** to the substrate **110** or to join sublayers of the tactile layer **130**. For example, a heated matte-patterned roller can be passed over the tactile surface **133** or a smooth heated roller can press a matte-patterned sheet over the tactile layer **130**, either of which can impress a matte pattern into the tactile surface **133**. However, other patterns or surface features can be additionally or alternatively applied to the tactile surface **133**, another sublayer or surface of the tactile layer **130**, other surface or sublayer of the substrate **110**, etc. Furthermore, a pattern or finish can be applied to any one or more layers, sublayers, or surfaces of the first dynamic tactile interface **100** in any other suitable way.

[0047] The tactile layer **130** can be bonded to the substrate **110** via the tie layer **120**, which can retain the tactile layer **130** to the substrate **110** via a mechanical bond by enabling crystalline grain growth across a boundary between the tie layer **120** and the adjacent interior surface of the tactile layer **130**. Alternatively, the tie layer **120** can retain the tactile layer **130** against the substrate **110** via covalent bonds, wherein the tie layer **120** bonds covalently with the tactile layer **130** while being retained by the underlying substrate. However, the tie layer **120** can retain the tactile layer **130** to the substrate **110** via entanglement of polymer strands between layers, hydrogen bonds, Van der Walls bonds, or any other suitable type of chemical or mechanical bond or attachment.

[0048] In one variation of the first dynamic tactile interface **100**, the tie layer **120**, previously deposited on the attachment surface **116** (shown in FIG. **6**A), is pre-treated with a corona treatment (e.g., air plasma treatment). The corona treatment can improve the surface energy and create reactive species of the tie layer **120** in preparation for bonding with the tactile layer **130**. The interior surface of the tactile layer **130** can be masked at the deformable region **131**, as shown in FIG. **6**B, and then pre-treated with a corona treatment and/or cleaned in ultraviolet ozone, as shown in FIG. **6**C. At least one of these processes can prepare the interior surface of the tactile layer **130** for bonding at exposed areas only, which can include the peripheral region **132** and exclude the deformable region **131** such that the deformable region **131** remains disconnected from the substrate **110** via the tie layer **120**. The tactile layer **130** and the tie layer **120** can then be stacked, aligned, and laminated. The stack can be laminated by passing the stack through a set of rollers, as shown in FIG. **6**D and then cured according to a time, temperature, pressure, and environment schedule, as shown in FIG. **6**E, such as at 30 psi for two hours at room temperature in a dry nitrogen environment. The stack can then be trimmed to size.

[0049] The curing schedule can define application of temperature and pressure the tactile layer **130** and silicone oxide film over time to yield a substantially adequate bond therebetween. The curing schedule can also improve the bond between the substrate **110** and the tie layer **120**. The bond between the tie layer **120** and the substrate **110** and/or the tactile layer **130** can be a macroscopic mechanical bond, such as a diffusion bond defined by cross-boundary grain growth such that the tie layer **120** and at least one of the substrate **110** and the tactile layer **130** appear as a singular structure substantially proximal a boundary. Additionally or alternatively, the bond between the tie layer **120** and the substrate **110** and/or the tactile layer **130** can be a chemical bond. For example, atoms or molecules on a first side of a boundary combine with atoms or molecules on a second side of the boundary to form a third material proximal the boundary. The third material can exhibit adequate adhesion to the parent materials on each side of the boundary, as well as adequate cohesion between molecules within the third material to retain the peripheral region **132** of the tactile layer **130** to the attachment surface **116** of the substrate **110**. Furthermore, the curing schedule can include curing in an inert environment, such as nitrogen or argon, to minimize contamination of the bond, which can negatively affect the strength of the bond and/or the optical clarity of the substrate **110** and tactile layer stack. However, the bond between the tie layer **120** and at least one of the substrate **110** and the tactile layer **130** can be any other type of bond or combination of types of bonds and can be achieved in any other way.

[0050] In the foregoing variation of the first dynamic tactile interface **100**, the tie layer **120** can also or alternatively be selectively pre-treated to ensure joining at the peripheral region **132** and not at the deformable region **131**, such by applying a mask or shield over select portions of the tie layer **120** prior to treatment. The tie layer **120** can also be treated via other techniques, such as ultraviolet ozone treatment, low-pressure plasma, corona discharge, etching, flame treatment, or solvent wipe. Any of these treatments can additionally or alternatively be applied to the interior surface of the tactile layer **130** prior to lamination to ensure select adherence between the tactile layer **130** and the substrate **110** via the tie layer **120**. Similarly, an anti-stick or bond-inhibitor coating can be applied to areas of the back surface of the tactile layer **130** and/or to the tie layer **120** in areas corresponding to the deformable region **131**. Furthermore, the tactile layer **130** can be selectively bonded to the tie layer **120** via "masked" or selective irradiation or heating during a bonding or laminating process.

[0051] The tactile layer **130** and substrate can include alignment features, such as print markers (e.g., "+" or "−" marks) at two or more corners of each of the tactile layer **130** and the substrate **110** to aid manual alignment or automated alignment via machine vision. Alternatively, the substrate **110** and the tactile layer **130** can be supplied as sheets in separate rolls that are merged as they enter a set of laminator rollers. The set of rollers can be a pair or rollers into which the substrate **110** and tactile layer stack is fed, or the substrate **110** and tactile layer stack can be laminated between a static flat plate and a single roller or laminated between two faces in a press. One or more rollers or press faces can be heated, such as with an induction heating coil or with a quartz heating rod, to boost bond temperature, which can increase bond strength, improve optical clarity, and/or reduce cure time for the stack.

[0052] Therefore, as shown in FIG. **5**, a second method S**200** for bonding a tactile layer **130** to a substrate **110** can include: depositing a tie layer **120** onto an outer broad face of the substrate **110** as shown in FIG. **6**A as Block S**210**; masking an inner broad face of the tactile layer **130** at a deformable region **131** as shown in FIG. **6**B as Block S**230**; activating the inner broad face of the tactile layer **130** at an peripheral region **132** as shown in FIG. **6**C as Block S**212**; laminating the inner broad face of the tactile layer **130** to the outer broad face of the substrate **110** to form a tactile layer **130** and substrate **110** stack as shown in FIG. **6**D as Block S**250**; and curing the tactile layer **130** and substrate **110** stack under pressure as shown in FIG. **6**E as Block S**240**.

[0053] The second method S**200** can be implemented to bond the tactile layer **130** and the substrate **110** of the user interface **100**, as described above. The second method S**200** can further include cleaning or activating the tie layer **120**, such as with a corona treatment, ultraviolet ozone treatment, low-pressure plasma, corona discharge, etching, flame treatment, or solvent wipe, as described above. The second method S**200** can also include masking a portion of the outer broad face of the substrate **110** that is aligned with the deformable region **131** of the tactile layer **130** in the tactile layer **130** and substrate **110** stack. The second method S**200** can therefore further include removing the mask from the inner broad face of the tactile layer **130** and/or from the outer broad face of the substrate **110**. However, the second method S**200** can include any other procedure implemented in any other way to bond the tactile layer **130** to the substrate **110**.

[0054] However, the substrate **110** and tactile layer stack can be assembled and/or bonded according to any other technique or process.

[0055] The displacement device **140** of the first dynamic tactile interface Dm is coupled to the fluid channel **113** and is configured to displace fluid through the fluid channel **113** to transition the deformable region **131** from the retracted setting to the expanded setting. Generally, the displacement device **140** can actively displace fluid through the fluid channel **113** and the fluid conduit **114** to outwardly expand the deformable region **131** to transition the deformable region **131** from the retracted setting to the expanded setting. Furthermore, the displacement device **140** can actively remove fluid from the fluid channel **113** and the fluid conduit **114** to inwardly retract the deformable region **131** to transition the deformable region **131** from the expanded setting to the retracted setting. The displacement device **140** can also transition the deformable region **131** to one or more intermediate positions or height settings between the expanded and retracted settings. In the retracted setting, the tactile surface **133** at the deformable region **131** can be in-plane or aligned with the tactile surface **133** at the peripheral region **132**. However, in the retracted setting, the deformable region **131** can be positioned at any other height relative the peripheral region **132**. In the expanded setting, the tactile surface **133** at the deformable region **131** can be elevated above the tactile surface **133** at the peripheral region **132** such that the expanded setting is tactilely distinguishable from the retracted setting at the tactile surface **133**. However, the deformable region **131** can be positioned at any other height relative the peripheral region **132** in the expanded setting.

[0056] The displacement device **140** can be an electrically-driven positive-displacement pump, such as a rotary, reciprocating, linear, or peristaltic pump powered by an electric motor. Alternatively, the displacement device **140** can be an electroosmotic pump, a magnetorheological pump, a microfluidic pump, a manually-powered pump, such as powered though a manual input provided by the user, or any other suitable device configured to displace fluid through the fluid channel **113** and the fluid conduit **114** to transition the deformable regions between settings, such as described in U.S. Provisional Patent Application No. 61/727,083, filed on 15 Nov. 2012, which is incorporated in its entirety by this reference.

[0057] As described above and shown in FIG. **2**, one variation of the first dynamic tactile interface **100** further includes a touch sensor **170** configured to detect an input at the tactile surface **133**. The touch sensor **170** can be a capacitive touch sensor, a resistive touch sensor, an optical touch sensor, a fluid pressure sensor, an acoustic touch sensor, or any other suitable type of sensor. The touch sensor **170** can include a plurality of sensors configured to detect an input at particular regions across the tactile surface **133**, including at the deformable region **131**. However, the touch sensor **170** can be of any other type, include any other feature or component, and can be patterned across the first dynamic tactile interface **100** in any other way. The touch sensor **170** can be arranged between a display **180** and the substrate **110**, as shown in FIG. **2**. Alternatively, the display **180** can be a touch display incorporating the touch sensor **170**. A portion of the touch sensor **170** can also be coupled to the fluid channel **113**, coupled to the fluid conduit **114**, or arranged within the substrate **110**, such as above or below the fluid channel **113**. A portion of the touch sensor **170** can also be arranged within the tactile layer **130**. However, all or a portion of the touch sensor **170** can be arranged in any other way within the first dynamic tactile interface **100**.

[0058] One variation of the first dynamic tactile interface **100** incorporates a plurality of deformable regions, each paired with a fluid conduit fluidly coupled to at least one fluid channel, as shown in FIG. **3**. In this variation, the first dynamic tactile interface **100** can also include one or more displacement devices coupled to the one or more fluid channels, wherein the displacement devices displace fluid through the one or more fluid channels to transition one or more deformable regions between retracted and expanded settings at any given time. In this variation, the deformable regions can define input keys of a QWERTY keyboard when in the expanded setting. Furthermore, the display **180** can output an image aligned with each deformable region, wherein each image is indicative of an input key associated with each deformable region (e.g., SHIFT, 'a,' 'g,' or '8'). In this variation, when the deformable regions are in the expanded setting, a processor coupled to the touch sensor **170** can identify an input on the tactile surface **133** that substantially inwardly deforms a deformable region as an input request for the input key, whereas the processor can identify an input on the tactile surface **133** that does not substantially inwardly deform the deformable region **131** as a second type of input that is not a request for the input key. However, the first dynamic tactile interface **100** can include any other components arranged in any other way to achieve any other function.

[0059] In another variation of the first dynamic tactile interface **100**, the substrate **110** is physically coextensive with at least one of the display **180** and the touch sensor **170**. In this variation, the fluid channel **113** is formed in the interior surface of the tactile layer **130** or is otherwise substantially defined on or within the tactile layer **130**. In this variation, the tactile layer **130** is bonded to the substrate **110** at the peripheral region **132**, wherein the substrate **110** rigidly retains the peripheral region **132** during setting transitions of the deformable region **131**. However, the first dynamic tactile interface **100** can be of any other form and include any other suitable component, film, or layer.

[0060] One variation of the first dynamic tactile interface **100** is incorporated into an electronic device. The electronic device can be any of an automotive console, a desktop computer, a laptop computer, a tablet computer, a television, a radio, a desk phone, a mobile phone, a personal data assistant (PDA), a personal navigation device, a personal media player, a camera, a watch, a gaming controller, a light switch or lighting control box, cooking equipment, or any other suitable electronic device.

2. Second Dynamic Tactile Interface **200**

[0061] As shown in FIGS. **11**A and **11**B, a second dynamic tactile interface **200** includes: a substrate **210** including a first transparent material and defining an attachment surface **216**, an open channel **213**A opposite the attachment surface **216**, and a fluid conduit **214** intersecting the open channel **213**A and passing through the attachment surface **216**; a tactile layer **230** including a second transparent material and defining a tactile surface **233**, a peripheral region **232** bonded to the attachment surface **216** opposite the tactile surface **233**, and a deformable region **231** adjacent fluid conduit **214** and disconnected from the attachment surface **216**; a closing panel **212** bonded to the substrate **210** opposite the attachment surface **216** and enclosing the open channel **213**A to define a fluid channel **213**B; a working fluid **250**; and a displacement device **240** configured to displace the working fluid **250** into the fluid channel **213**B and through fluid conduit **214** to transition the deformable region **231** from a retracted setting to an expanded setting, the deformable region **231** flush with the peripheral region **232**

in the retracted setting (shown in FIG. **11**A) and offset from the peripheral region **232** in the expanded setting (shown in FIG. **11**B).

[0062] As shown in FIG. **12**, a method for manufacturing the second dynamic tactile interface **200** includes: creating an open channel in an interior surface of a substrate including a first transparent material and defining an attachment surface **216** opposite the interior surface in Block S**310**; creating a fluid conduit intersecting the open channel **213**A and passing through the attachment surface **216** of the substrate **210** in Block S**312**; activating the attachment surface **216** in Block S**320**; selectively bonding a peripheral region of a tactile layer to the attachment surface **216** in Block S**322**, the tactile layer **230** including a second transparent material and defining a deformable region disconnected from the attachment surface **216** proximal fluid conduit **214**; activating the interior surface in Block S**330**; bonding a closing panel to the interior surface to enclose a portion of the open channel **213**A to define a fluid channel in Block S**332**; coupling a displacement device to the fluid channel **213**B in Block S**342**; and filling the fluid channel **213**B with a working fluid in Block S**340**.

[0063] Like the first dynamic tactile interface, the second dynamic tactile interface **200** functions to expand and retract one or more deformable regions to intermittently and selectively provide tactile guidance over a touchsensor and/or display of a computing device. For example, second dynamic tactile interface **200** can be implemented in a smartphone, tablet, laptop, PDA, automotive or in-dash console, a desktop computer, a television, a radio, a desk phone, a mobile phone, a personal navigation device, a personal media player, a camera, a watch, a gaming controller, a light switch or lighting control box, cooking equipment, or any other suitable computing or electronic device. The second dynamic tactile interface **200** can also be incorporated in an aftermarket device for a computing device, such as described in U.S. patent application Ser. No. 13/465,772, filed on 7 May 2012, which is incorporated in its entirety by this reference

[0064] The substrate **210** of the second dynamic tactile interface **200** includes a first transparent material and defines an attachment surface **216**, an open channel opposite the attachment surface **216**, and a fluid conduit intersecting the open channel **213**A and passing through the attachment surface **216**. Generally, the substrate **210** functions like the substrate **110** of the first dynamic tactile interface **100** to define an attachment surface **216** that retains a peripheral region of a tactile layer, one or more fluid ports, one or more support members (or support areas) adjacent the fluid ports and deformable regions of the tactile layer **230**, and one or more fluid channels that feed fluid into and out of the fluid channels to transition the deformable regions between expanded and retracted settings. The substrate **210** can be substantially transparent and substantially rigid relative to the tactile layer **230** such that changes in fluid pressure within the fluid channel **213**B are predominantly absorbed by the deformable region **231** of the tactile layer **230**—rather than the substrate **210**—thus yielding controlled expansion and retraction of the deformable region **231** of the tactile layer **230**.

[0065] In one implementation, the substrate **210** is a thermoset resin cast in sheet form, such as polycarbonate or a polycarbonate-hybrid polymer. In this implementation, the substrate **210** can begin as a cast polymer sheet of uniform thickness that is post-machined to create the fluid channel **213**B and fluid conduit **214**. For example, a ball endmill (or endmill of other suitable contour) can be plunged part-way (e.g., through 70% of the thickness of the substrate **210**) into the interior surface of the substrate **210** opposite the attachment surface **216**. In this example, the ball endmill can then be displaced laterally across the interior surface to cut the open channel **213**A of substantially constant depth, as in Block S**310** of the method. A tapered endmill ("taper mill") can then be plunged fully through the substrate **210** normal to the interior surface to create one or more frustoconical bores (i.e., fluid conduits) intersecting the open channel **213**A, as in Block S**312** of the method. The substrate **210** can then be acid-dipped, flame polished, or otherwise processed to reduce or eliminate machining artifacts in the bore(s) and open channel(s). Therefore, in this example, fluid conduit **214** can include a frustoconical section tapering toward the attachment surface **216**, and, once the closing panel **212** is bonded to the interior surface of the substrate **210** to enclose the open channel **213**A and thus define the fluid channel **213**B, the fluid channel **213**B can define a curvilinear cross-section, as shown in FIGS. **13**A and **13**B.

[0066] Alternatively, the substrate **210** can be acrylic, glass, urethane, polyurethane, or of any other substantially transparent, translucent, and/or relatively rigid material. The open channel **213**A and fluid conduit **214** can also be machined (e.g., drilled), stamped, molded, extruded, laser cut, imprinted, or formed in any other way into the substrate **210**, such as described above.

[0067] The substrate **210** can further define a second open channel opposite the attachment surface **216** and parallel to the fluid channel **213**B and a second fluid conduit intersecting the second open channel and passing through the attachment surface **216** adjacent fluid conduit **214** and the deformable region. In this implementation, the substrate **210** can cooperate with the closing panel **212** to enclose the second open channel and thus define a second fluid channel, and the second fluid can also be coupled to the displacement device **240** such that the displacement device **240** can displace the working fluid **250** through both the fluid channel **213**B and the second fluid channel (and fluid conduit **214** and the second fluid conduit) to transition the deformable region **231** from the retracted setting to the expanded setting. In this implementation, fluid can similarly drain back into fluid conduit **214** and the second fluid conduit and then into the fluid channel **213**B and the second fluid channel, respectively, as the deformable region **231** transitions from the expanded setting back into the retracted setting.

[0068] The tactile layer **230** of the second dynamic tactile interface **200** includes a second transparent material and defines a tactile surface, a peripheral region bonded to the attachment surface **216** opposite the tactile surface **233**, and a deformable region adjacent fluid conduit **214** and disconnected from the attachment surface **216**. Generally, the tactile layer **230** functions as an exterior surface of the second dynamic tactile interface **200** (and the computing device) within one or more regions that can be selectively and intermittently deformed to define tactilely-distinguishable formations configured to tactilely guide user input into the computing device. As described above, the tactile layer **230** can be substantially uniform in thickness and composition throughout its thickness and substantially transparent. The tactile layer **230** can also be uniformly elastic and/or flexible relative to the substrate **210** throughout its volume.

Alternatively, the tactile layer **230** can be of varying thickness, optical property, or mechanical property throughout its thickness or volume. For example, the tactile layer **230** can feature a well or recess around a perimeter of the deformable region **231** (inside the peripheral region). The tactile layer **230** can be selectively doped across the deformable region **231** to increase elasticity of the deformable region and/or selectively cross-linked to reduce elasticity across the peripheral region.

[0069] In one implementation, the substrate **210** is formed of a thermoset polymer material (e.g., a polycarbonate-hybrid polymer) of a first elasticity, and the tactile layer **230** is formed of a urethane material of a second elasticity greater than the first elasticity (of the substrate **210** material). In this implementation, the tactile layer **230** and the substrate **210** can be assembled by first cleaning the substrate **210** (e.g., in ultraviolet ozone) and activating the attachment surface **216** of the substrate **210**, as in Block **S320** of the third method. For example, the attachment surface **216** can be treated with nitrogen surface activation to create nitrogen groups (e.g., nitrates, nitrites) along the attachment surface **216** and at a skin depth (e.g., ~5 μm) within the substrate **210**. The attachment surface **216** can then be masked with an area around the fluid port corresponding to the deformable region **231** exposed and a release compound applied across the mask. Alternatively, the release compound can be printed onto the area around the fluid port corresponding to the deformable region, such as with a two-axis printing head, screen printing, stereo lithography, or other printing technique or apparatus. The release compound can be a mold release wax, water, oil, alcohol, or other suitable material. Yet alternatively, the attachment surface **216** can be selectively activated, including a portion of the attachment surface **216** corresponding to the peripheral region **232** and excluding a portion of the attachment surface **216** corresponding to the deformable region.

[0070] In the foregoing implementation, once the attachment surface **216** is activated and/or masked proximal fluid conduit **214** and the tactile layer **230** is cleaned (e.g., in ultraviolet ozone, as described above), the peripheral region **232** of the tactile layer **230** can be selectively bonded to the attachment surface **216** of the substrate **210**, as in Block **S322** of the third method. For example, the substrate **210** and the tactile layer **230** can be laminated together between a set of rollers, as described above, and then placed in an autoclave for a time, temperature, and pressure specified in curing profile. In this example, the substrate **210** and tactile layer stack can be cured in an elevated temperature (e.g., 400° F.) and/or elevated pressure (e.g., 60 psi) environment within the autoclave for a predefined period of time (e.g., one hour), which can cause a bond to grow across the boundary between the substrate **210** and the tactile layer **230** and can reduce the volume of any gas (e.g., air) trapped between the substrate **210** and the tactile layer **230**. The curing process can thus yield a stable bond between the substrate **210** and the tactile layer **230** and can reduce optical aberrations between the substrate **210** and the tactile layer **230** caused by trapped gases therebetween. In particular, as the tactile layer **230** and substrate stack cures, polymer chains within the tactile layer **230** can bond to the nitrogen groups along portions of the attachment surface **216** corresponding to the peripheral region, and the release compound (e.g., working fluid) applied to the attachment surface **216** around fluid conduit **214** can locally retard bonding between the tactile layer **230** and the substrate **210** to yield the deformable region **231** adjacent fluid conduit **214** and disconnected from the attachment surface **216**.

[0071] As shown in FIGS. **14**A and **14**B, one variation of the second dynamic tactile interface **200** includes an ink bezel **260** arranged about a perimeter of the attachment surface **216** between the substrate **210** and the tactile layer **230**. In this variation, the ink bezel **260** can be substantially opaque and thus define an opaque border around the second dynamic tactile interface **200**. For example, the ink bezel **260** can mask (i.e., hide from view) traces and a ribbon connector for a touch sensor coupled to the closing panel **212** opposite the substrate **210**. The ink bezel **260** can also mask a via **218** in the closing panel **212** (shown in FIG. **14**A) that feeds fluid from the displacement device **240** into the fluid channel **213**B, as described below. The ink bezel **260** can be applied along the entire perimeter of the attachment surface **216** or along one or a subset of edges of the attachment surface **216**. The ink bezel **260** can also be of similar or dissimilar width from each edge of the attachment surface **216**. For example, for the second dynamic tactile interface **200** implemented within a smartphone, the ink bezel **260** can be 0.20" wide along the vertical edges of the attachment surface **216** and 0.80" wide along the horizontal edges of the attachment surface **216**.

[0072] One variation of the third method can therefore include applying an ink bezel around a perimeter of the attachment surface **216** in Block **S324**, as shown in FIG. **15**. In the foregoing implementation, the ink bezel **260** can be applied to the attachment surface **216** prior to assembly of the tactile layer **230** over the substrate **210** such that the substrate **210** and the tactile layer **230** cooperate to substantially enclose the ink bezel **260**. For example, once the substrate **210** is cleaned and the attachment surface **216** activated, a black ink in an alcohol or epoxy suspension can be printed or rolled onto the attachment surface **216** in a substantially uniform thickness to yield suitably minimal local light transmission. The tactile layer **230** can then be laminated over the ink and the attachment surface **216** and cured, as described above. In this implementation, which the tactile layer **230**, substrate, and ink bezel stack cures, the ink bezel **260** can flow or deform at its interior edge proximal the junction between the tactile layer **230**, substrate, and ink bezel (e.g., due to elevated temperature in the autoclave) to form a smooth transition between the tactile layer **230**, substrate, and ink bezel, as shown in FIGS. **14**A and **14**B.

[0073] Alternatively, the ink bezel **260** in the form of an uncured black epoxy sheet or a black urethane sheet can be trimmed to size and applied over the attachment surface **216**, applied to the interior surface of the tactile layer **230**, or inserted between the substrate **210** and the tactile layer **230** prior to bonding. Yet alternatively, the ink bezel **260** can be applied to or inserted between the interior surface of the substrate **210** and the closing panel **212** with similar techniques or methods.

[0074] The closing panel **212** of the second dynamic tactile interface **200** is bonded to the substrate **210** opposite the attachment surface **216** and encloses the open channel **213**A to define a fluid channel. The closing panel **212** can be of a material similar to that of the tactile layer **230** such that the closing panel **212** can be bonded to the substrate **210** with a technique or method similar to that described above to bond the tactile layer **230** to the substrate **210**. For example, both the closing panel **212** and the tactile layer **230**

can be of urethane, but the tactile layer **230** can be a urethane material of a higher elasticity (e.g., lower durometer or Shore hardness) than the urethane material of the closing panel **212** such that the tactile layer **230** is more prone to deformable at the deformable region **231** than the closing panel **212** proximal the open channel **213**A when fluid pressure within the fluid channel **213**B changes. The closing panel **212** can also be of a uniform thickness similar to that of the tactile layer **230**. Alternatively, the closing panel **212** can be substantially thick (i.e., thicker than the tactile layer **230**) to resist outward deformation proximal the open channel **213**A when fluid pressure within the fluid channel **213**B increases. Yet alternatively, the closing panel **212** can be substantially thin (i.e., thinner than the tactile layer **230**) to function as an interface layer to close the open channel **213**A and to bond the interior surface of the substrate **210** to a more rigid panel, such as to a capacitive touch panel with a PMMA substrate or to a display with a glass substrate that support the closing panel **212** against deformation when the fluid pressure within the fluid channel **213**B changes. Furthermore, like the tactile layer **230** and the substrate **210**, the closing panel **212** can be substantially transparent to enable light transmission therethrough, such as from a display coupled to the second dynamic tactile interface **200** as described above.

[0075] In the implementation described above in which the substrate **210** is formed of a polycarbonate-hybrid material and the tactile layer **230** is formed of a urethane material of an elasticity greater than that of the substrate **210**, the closing panel **212** can be formed of a urethane material similar to that of the tactile layer **230** but of an elasticity less than that of the tactile layer **230**. In this implementation, the closing panel **212** can be bonded to the substrate **210** with a techniques or methods similar to those described above to bond the tactile layer **230** to the substrate **210**. In particular, the interior surface of the substrate **210** can be cleaned and then activated, as in Block S**330** of the third method. For example, the interior surface can be cleaned in ultraviolet ozone and then treated with nitrogen surface activation as described above. As in Block S**332** of the third method, the closing panel **212** can be similarly cleaned and then laminated to the interior surface of the substrate **210**, such as described above, to enclose a portion of the open channel **213**A, thereby defining the fluid channel **213**B. The substrate **210** and the closing panel **212** can then be cured, such as according to a cure schedule similar to that described above.

[0076] In the foregoing implementation, the interior surface and the attachment surface **216** of the substrate **210** can be prepared for bonding with the tactile layer **230** and the closing panel **212** substantially simultaneously. For example, the interior surface can be cleaned, then the substrate **210** flipped and the attachment surface **216** cleaned. The interior surface can subsequently be activated, then the substrate **210** flipped and the attachment surface **216** activated. The substrate **210** can then be placed between both the tactile layer **230** and the closing panel **212** and the stack laminated (e.g., through a set of rollers) prior to placement in an autoclave for curing. Alternatively, the substrate **210** and the tactile layer **230** can be bonded and cured, and then the substrate **210**-tactile layer stack bonded to the closing panel **212** and cured, or vice versa. However, the tactile layer **230**, substrate, and closing panel (and ink bezel) can be prepped and bonded—and the corresponding Blocks of the third method can be performed—in any other suitable order.

[0077] In one implementation, the closing panel **212** includes a via configured to communicate fluid between the displacement device **240** and the fluid channel **213**B. In the variation of the second dynamic tactile interface **200** that includes the ink bezel **260** between the substrate **210** and the tactile layer **230**, the closing panel **212** can define the via **218** behind the ink bezel **260** such that the via **218** is not optically visible through the tactile layer **230**. In this implementation, the via **218** can be created in the closing panel **212** prior to bonding the closing panel **212** to the substrate **210**, as in Block S**334** of the third method shown in FIG. **15**. For example, the via **218** can be stamped, machined, drilled, etched (e.g., bulk micro-machined), laser cut, or otherwise formed in the closing panel **212**, and the closing panel **212** can then be acid washed, flame polished, or otherwise processed to reduce or eliminates manufacturing artifacts leftover from creation of the via **218**. The closing panel **212** can then be aligned with and bonded to the interior surface of the substrate **210** with the via **218** adjacent the open channel **213**A (i.e., the fluid channel **213**B) such that working fluid can be communicated through the via **218** and into the fluid channel **213**B. Alternatively, the via **218** can be created in the closing panel **212** after the closing panel **212** is bonded to the substrate **210**.

[0078] The second dynamic tactile interface **200** also includes a working fluid. Generally, the displacement device **240** functions to displace the working fluid **250** into the fluid channel **213**B, thereby increasing fluid pressure within the fluid channel **213**B and fluid conduit **214** and thus causing the deformable region **231** of the tactile layer **230** to expand outwardly. The displacement device **240** can also release fluid pressure within the fluid channel **213**B and/or actively pump fluid out of the fluid channel **213**B to enable the deformable region **231** to retract, as described above.

[0079] The working fluid **250** can be substantially transparent, such as exhibiting a refractive index, Abbe number, and/or chromatic dispersion properties similar to those of the substrate **210** in order to limit diffraction, refraction, and reflection of light within the second dynamic tactile interface **200** at interfaces between the working fluid **250** and the substrate **210** (e.g., at a surface of the fluid channel **213**B or at a surface of fluid conduit **214**). For example, the working fluid **250** can be water, an alcohol, or an oil.

[0080] In one implementation, the working fluid **250** is a silicone oil that is substantially incompressible and exhibits low vapor pressure. In this implementation, the base material of the tactile layer **230** can tend to adsorb or "uptake" the working fluid **250**, and the tactile layer **230** can thus incorporate a barrier sublayer **236** that is impermeable to the working fluid **250** to limit working fluid uptake into the tactile layer **230**. For example, the tactile layer **230** can include a first sublayer **235** (bonded to the substrate **210**), a barrier sublayer **236** bonded to the first sublayer **235**, and a second sublayer **237** bonded to the barrier sublayer **236** opposite the first sublayer **235**, as shown in FIGS. **16**A and **16**B. In this example, the first and second sublayer **237***s* can be of the same or similar urethane material, and the barrier sublayer **236** can be nylon, (high-density) polyethylene, or any other suitable plastic that is substantially impermeable to silicone oil. Furthermore, in this example, the barrier sublayer **236** can be substantially thin to enable light transmission through the tactile layer **230** with minimal internal reflection, refraction, or diffraction, and the first sublayer **235** can be substantially thin to minimize a volume of the material over the deformable region **231** that can adsorb the working fluid **250**, as shown in FIG. **16**B. The second sublayer **237** can thus be substantially thicker than the barrier sublayer **236** and/or the first sublayer **235** to yield suitable strength, elasticity, abrasion resistance, etc. to the tactile layer **230** and the tactile surface **233**.

[0081] In the foregoing implementation, the second sublayer **237** can alternatively be of a polymer material different from that of the first sublayer **235**. For example, the first sublayer **235** can be of urethane of a first elasticity, and the second sublayer **237** can be of a polycarbonate-based material of a second elasticity less than the first elasticity. In this example, the first sublayer **235** can thus function as a buffer backing that absorbs sharp deformation of the tactile layer **230** proximal a perimeter of the deformable region, such as described above, and the second layer can yield improved abrasion resistance, gloss or sheen, tactile smoothness, etc. However, the working fluid **250** can be of any other liquid (or gas), and the tactile layer **230** can be of any other number of sublayers of any other material and geometry to limit uptake of working fluid into the tactile layer **230**. However, the tactile layer **230** can be of any other form, any other material, and bonded to the substrate **210** within any other technique or method. The closing panel **212** and the substrate **210** can similarly be of any other suitable material can assembled within the second dynamic tactile interface **200** in any other suitable way.

[0082] The third method can therefore include Block S**340**, which recites filling the fluid channel **213**B with a working fluid in Block S**340**. In one implementation, the closing panel **212** includes a draw port coupled to the fluid channel **213**B at one end of the fluid channel **213**B opposite the via **218**. In this implementation, once the substrate **210**, closing panel, tactile layer, and displacement device are assembled, a valve is connected between an inlet of the displacement device **240** (or connected reservoir) and an external reservoir containing working fluid. With the valve closed, gas (e.g., air) is then evacuated from the fluid channel **213**B through the draw port. Once a threshold vacuum in reached within the fluid channel **213**B, the valve is opened and working fluid is drawn from the external reservoir into the displacement device **240**, through the via **218**, and into the fluid channel **213**B and fluid conduit. Any remaining gas within the second dynamic tactile interface **200** can be subsequently purged by supporting the second dynamic tactile interface **200** vertically with the draw port above the via **218** and displacing a small volume of working fluid into and out of the second dynamic tactile interface **200** to dislodge and draw remaining (air) bubbles out of the second dynamic tactile interface **200** through the draw port. The draw port is finally disconnected from the valve and sealed, and the displacement device **240** (or connected reservoir) is similarly sealed, thus isolating the working fluid **250** in the second dynamic tactile interface **200**. However, Block S**340** can function in any other way to evacuate gas from the fluid channel **213**B, to inject working fluid into the second dynamic tactile interface **200**, and/or to purge any remaining gas from the second dynamic tactile interface **200**.

[0083] As shown in FIGS. **14**A and **14**B, one variation of the second dynamic tactile interface **200** includes a touch sensor **270** configured to output a signal corresponding to an input on the tactile surface **233**. As described above, the touch sensor **270** can be a capacitive touch sensor, a resistive touch sensor, or any other suitable type of sensor arranged on or across a sensor panel.

[0084] In one implementation, the assembled substrate, closing panel, and substrate—hereinafter the "stack"—is bonded to the sensor panel. The third method can therefore include Block S**350**, which recites laminating the closing panel **212** opposite the substrate **210** to a touch sensor panel and curing the closing panel **212** and the touch sensor **270** panel under elevated pressure and elevated temperature, as shown in FIG. **15**. In one example, the sensor panel includes a polymer sheet (e.g., a PMMA or glass sheet) patterned on each side with indium tin oxide (ITO) traces to form a capacitive touch sensor. In this example, an optically-clear adhesive (OCA) can be sprayed or rolled across the closing panel **212** opposite the substrate **210** and/or across a broad face of the sensor panel (and over the ITO traces), and the sensor panel and the stack can be laminated together. Alternatively, a sheet of uncured OCA can be inserted between the stack and the sensor panel. The stack, OCA, and sensor panel can then be cured, such as in an autoclave at a predefined temperature and pressure for a predefined period of time, to adhere the sensor panel to the stack. In this example, the peak temperate of the autoclave during the curing process can be kept substantially below a flow temperature, evaporation temperature, oxidation temperature, etc. of the ITO or other trace, feature, or material within the sensor panel to substantially eliminate potential for damage to the sensor panel during the assembly process. In particular, the substrate **210**, the tactile layer **230**, and the closing panel **212** can be assembled into the stack and cured before the sensor panel in bonded to the stack.

[0085] Alternatively, the closing panel **212** and the sensor panel can be physically coextensive, wherein the sensor panel is bonded directly to the substrate **210**. For example, the touch panel can include a series of ITO traces patterned across each side of a urethane sheet, which is laminated to the substrate **210** and tactile layer assembly and cured in an autoclave at a peak temperate that does not yield substantially distortion or damage to the ITO traces, such as described above. However, the second dynamic tactile interface **200** can include a touch sensor of any other type and can be bonded or coupled to the closing panel **212** and/or substrate in any other suitable way.

[0086] As shown in FIG. **15**, one variation of the second dynamic tactile interface **200** includes a display **280** bonded to the closing panel **212** opposite the tactile layer **230** with an optically-clear adhesive. Generally, the display **280** is configured to render an image of an input key proximal the deformable region, as described above. In one implementation, the display **280** is bonded directly to closing panel, such as by sandwiching a sheet of OCA between the stack and the display **280** and curing the OCA, as described above. One variation of the third method can therefore in include Block S**352**, which recites bonding a display to the touch sensor **270** panel opposite the closing panel **212** with an optically-clear adhesive. In this implementation, the display **280** can be a touchscreen that incorporates both a display and a (touch) sensor. Alternatively, in the variation of the second dynamic tactile interface **200** in which a touch sensor is bonded the closing panel **212**, the display **280** can be bonded to the touch sensor **270** opposite the closing panel **212**, such as by adhering the display **280** to the sensor panel with an OCA. In this implementation, the display **280** can be bonded to the sensor panel after or while the sensor is bonded to the stack. Alternatively, the display **280** and the sensor panel can be assembled and subsequently bonded to the stack, such as described above. However, the second mobile computing device can include any other type of display and/or touch sensor coupled or bonded to the substrate **210**, tactile layer, and/or closing panel in any other suitable way.

[0087] The displacement device **240** of the second dynamic tactile interface **200** is configured to displace the working fluid **250** into the fluid channel **213**B and through fluid conduit **214** to transition the deformable region **231** from a retracted setting to an expanded setting. As described above, the displacement device **240** generally functions to pump fluid into the fluid channel **213**B transition the deformable region **231** from flush with the peripheral region **232** in the retracted setting and to offset from the peripheral region **232** in the expanded setting. In one implementation, the displacement device **240** is coupled to the via **218** in the closing panel **212**, as described above. The third method can therefore include Block S**342**, which recites coupling the displacement device **240** to the via **218**. For example, the displacement device **240** can include a positive displacement pump coupled to the via **218** by a flexible hose extending from the via **218**.

[0088] Alternatively, the displacement device **240** can include a flexible membrane bonded to the closing panel **212** around the via **218** and opposite the substrate **210** to define a reservoir filled with the working fluid **250**. In this implementation, the displacement device **240** can compress the flexible membrane to displace fluid through the via **218** and into the fluid channel **213**B to transition the deformable region **231** into the expanded setting. However, the displacement device **240** can be of any other form and can be fluidly coupled to the fluid channel **213**B in any other suitable way. The displacement device **240** can also transition the deformable region **231** of the tactile layer **230** to any other position above or below the peripheral region **232** of tactile layer.

[0089] However, the second dynamic tactile interface **200** can include any number of displacement devices and can define any number of vias, fluid channels, fluid conduits, valves, and/or deformable regions that can be selectively and intermittently transitioned between retracted and expanded settings to provide tactile guidance over any other suitable computing device. Similarly, the third method can implement any other method or technique to manufacture and assemble the second dynamic tactile interface **200**.

[0090] As a person skilled in the art will recognize from the previous detailed description and from the figures and claims, modifications and changes can be made to the embodiments of the invention without departing from the scope of this invention as defined in the following claims.

I claim:

1. A dynamic tactile interface comprising:

a substrate comprising a first transparent material and defining an attachment surface, an open channel opposite the attachment surface, and a fluid conduit intersecting the open channel and passing through the attachment surface;

a tactile layer comprising a second transparent material and defining a tactile surface, a peripheral region bonded to the attachment surface opposite the tactile surface, and a deformable region adjacent the fluid conduit and disconnected from the attachment surface;

a closing panel bonded to the substrate opposite the attachment surface and enclosing the open channel to define a fluid channel;

a working fluid; and

a displacement device configured to displace the working fluid into the fluid channel and through the fluid conduit to transition the deformable region from a retracted setting to an expanded setting, the deformable region flush with the peripheral region in the retracted setting and offset from the peripheral region in the expanded setting.

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