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(54) DYNAMIC TACTILE INTERFACE

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(60) Provisional application No. 61/871,081, filed on Aug. 28, 2013.

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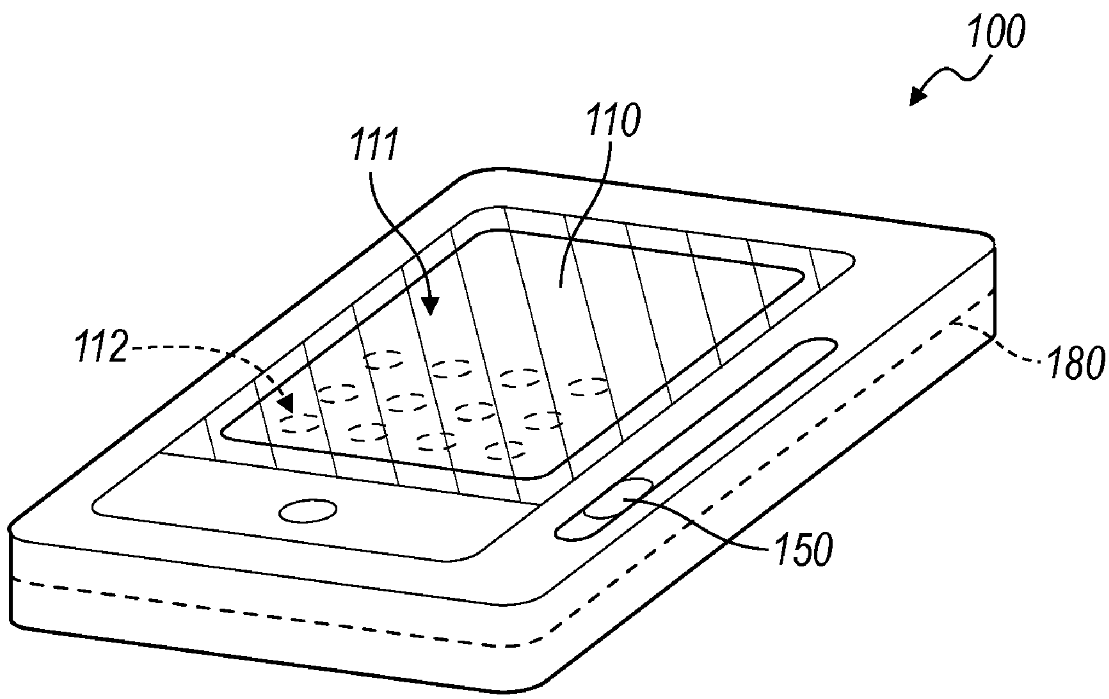
(57) **ABSTRACT**

One variation of a dynamic tactile interface for a computing device includes: a tactile layer defining a peripheral region and a deformable region adjacent the peripheral region; a substrate including a transparent base material exhibiting a first optical dispersion characteristic, coupled to the tactile layer at the peripheral region, defining a fluid conduit adjacent the peripheral region and a fluid channel fluidly coupled to the fluid conduit; a volume of transparent fluid contained within the fluid channel and the fluid conduit and exhibiting a second optical dispersion characteristic different from the first optical dispersion characteristic; a volume of particulate contained within the transparent base material of the substrate, biased around the fluid conduit, and exhibiting a third optical dispersion characteristic different from the first optical dispersion characteristic; and a displacement device displacing fluid into the fluid channel to transition the deformable region from a retracted setting into an expanded setting.



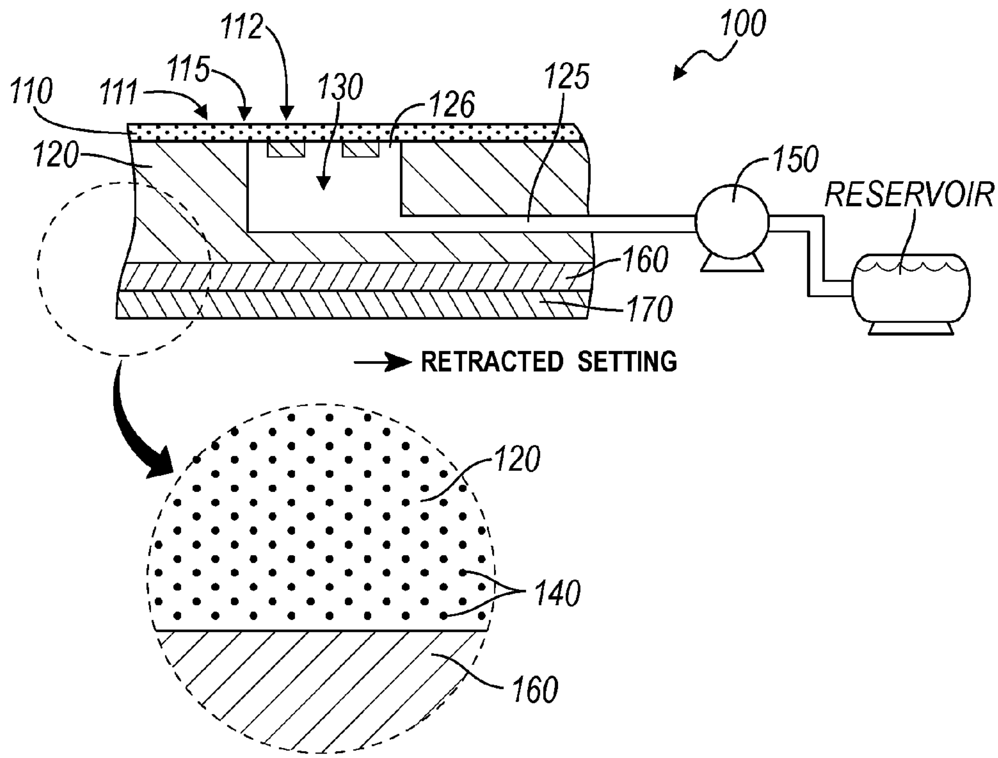

100
112
115
110
111
130
126
125
120
150
RESERVOIR
160
170
RETRACTED SETTING
120
140
160

FIG. 1A

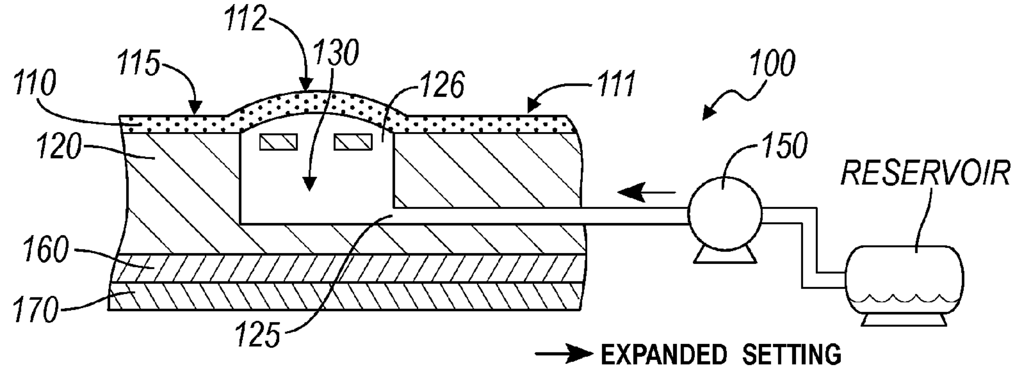

112
130
115
126
111
100
110
120
150
RESERVOIR
160
170
125
EXPANDED SETTING

FIG. 1B

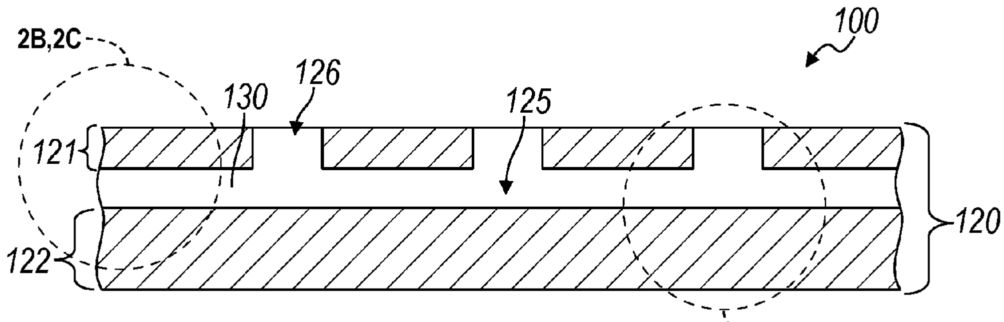


FIG. 2A

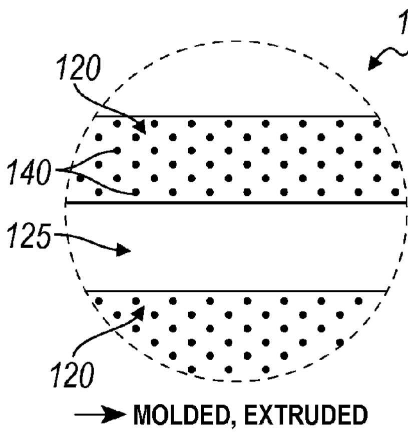


FIG. 2B

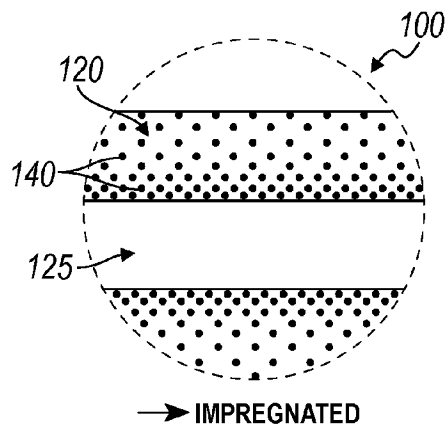


FIG. 2C

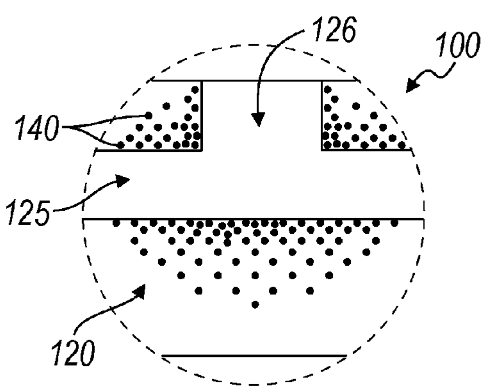


FIG. 2D

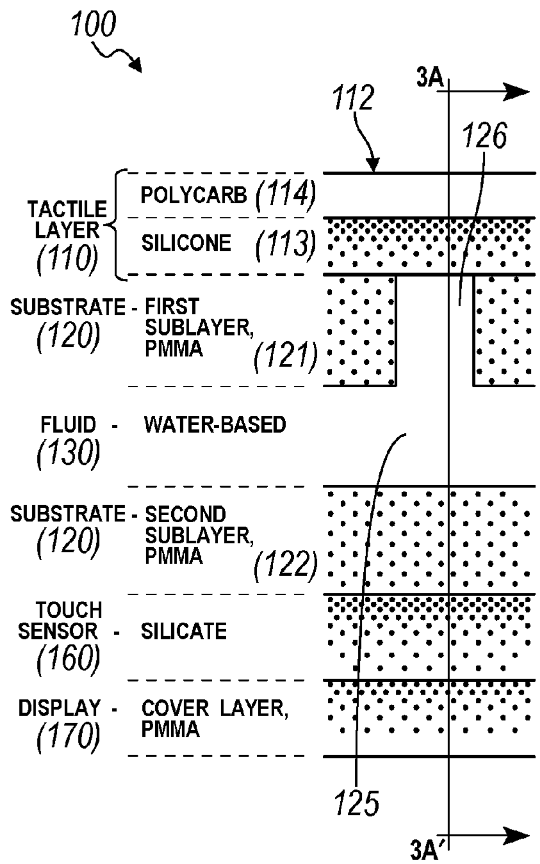

100
3A
112
126
TACTILE LAYER (110)
POLYCARB (114)
SILICONE (113)
SUBSTRATE - FIRST SUBLAYER, PMMA (121)
(120)
FLUID - WATER-BASED
(130)
SUBSTRATE - SECOND SUBLAYER, PMMA (122)
(120)
TOUCH SENSOR - SILICATE
(160)
DISPLAY - COVER LAYER, PMMA
(170)
125
3A'

FIG. 3A

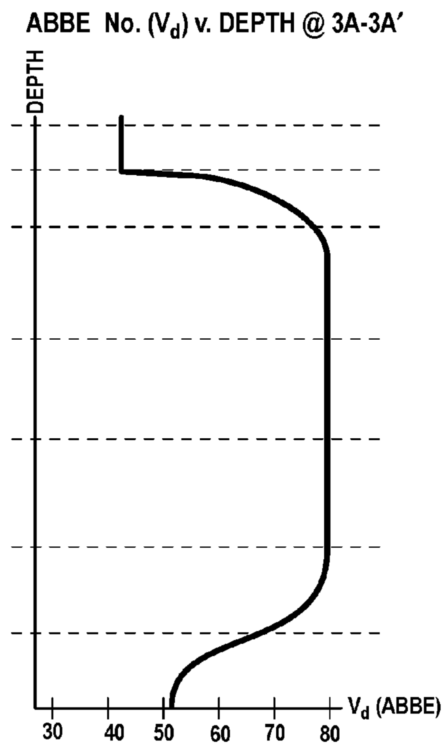

ABBE No. (V_d) v. DEPTH @ 3A-3A'
DEPTH
V_d (ABBE)
30
40
50
60
70
80

FIG. 3B

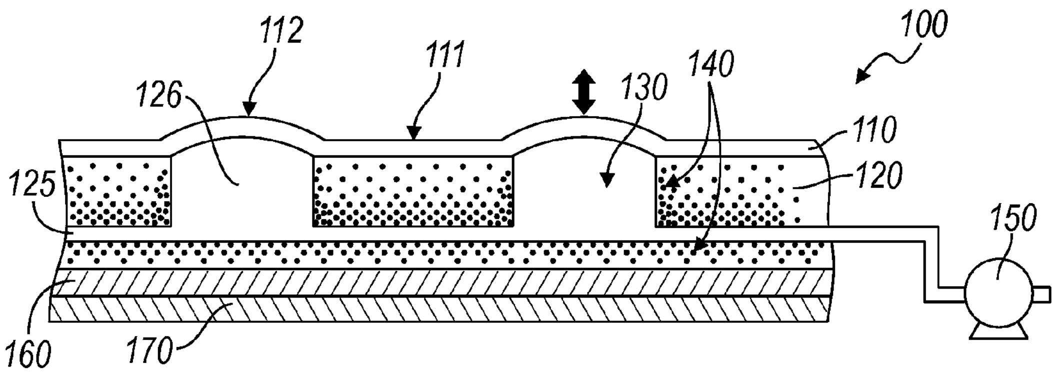

100
112
111
140
126
130
110
125
120
150
160
170

FIG. 4

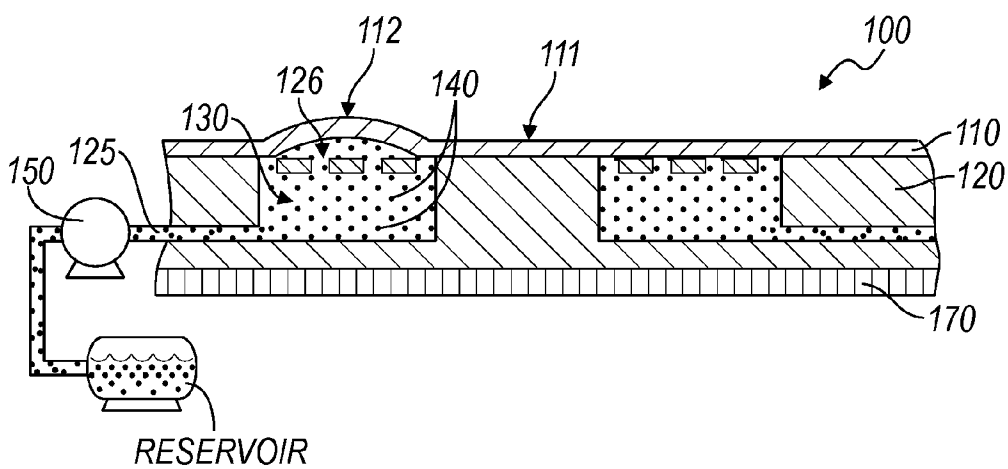

112
111
100
126
140
130
110
125
150
120
170
RESERVOIR

FIG. 5

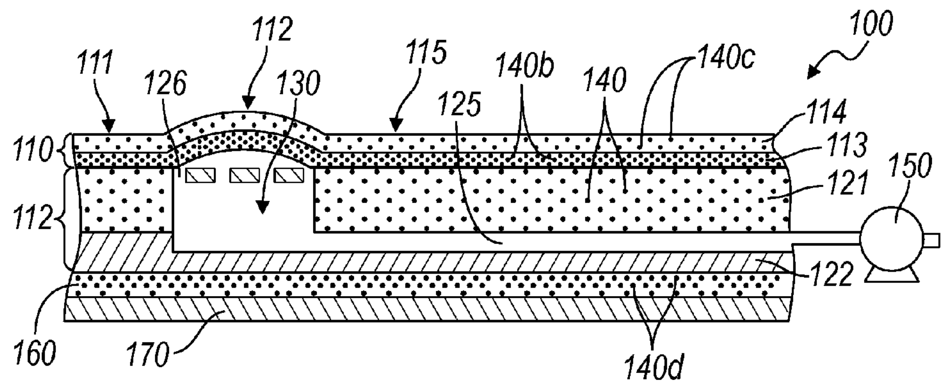

100
112
111
126
130
115
140b
140
140c
114
125
113
110
150
121
112
122
160
170
140d

FIG. 6

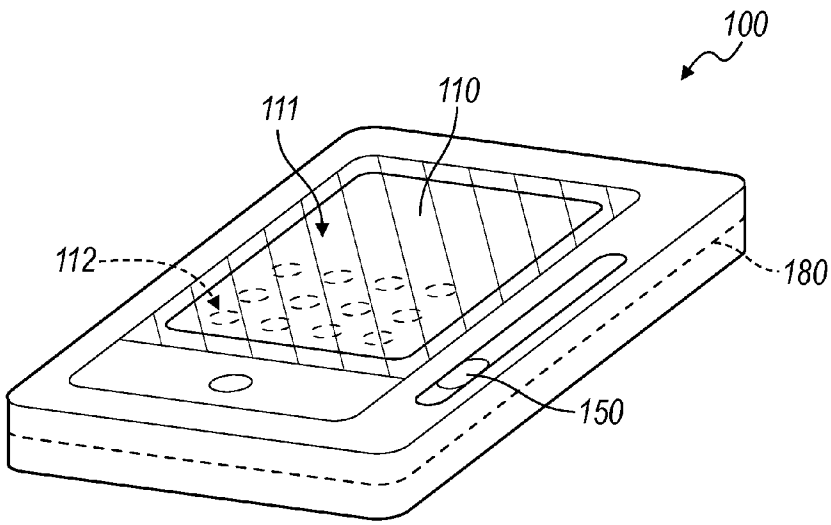

100
110
111
112
180
150

FIG. 7

DYNAMIC TACTILE INTERFACE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 14/471,842, filed 28 Aug. 2014, which claims the benefit of U.S. Provisional Application No. 61/871,081, filed on 28 Aug. 2013, both of which are incorporated in their entirety by this reference.

[0002] This application is related to U.S. patent application Ser. No. 11/969,848, filed on 4 Jan. 2008, Ser. No. 12/319,334, filed on 5 Jan. 2009, Ser. No. 12/497,622, filed on 3 Jan. 2009, Ser. No. 12/652,704, filed on 5 Jan. 2010, Ser. No. 12/830,430, filed on 5 Jul. 2010, and Ser. No. 14/035,851, filed on 24 Sep. 2013, which are incorporated in their entireties by this reference.

TECHNICAL FIELD

[0003] This invention relates generally to the field of touch-sensitive displays, and more specifically to a dynamic tactile interface for a touch-sensitive display.

BRIEF DESCRIPTION OF THE FIGURES

[0004] FIGS. **1**A and **1**B are schematic representations of a dynamic tactile interface of one embodiment of the invention;

[0005] FIGS. **2**A-**2**D are schematic representations of variations of the dynamic tactile interface;

[0006] FIGS. **3**A and **3**B is a graphical representation of one variation of the dynamic tactile interface;

[0007] FIG. **4** is a schematic representation of one variation of the dynamic tactile interface;

[0008] FIG. **5** is a schematic representation of one variation of the dynamic tactile interface;

[0009] FIG. **6** is a schematic representation of one variation of the dynamic tactile interface; and

[0010] FIG. **7** is a schematic representation of one variation of the dynamic tactile interface.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0011] The following description of the preferred embodiment of the invention is not intended to limit the invention to these preferred embodiments, but rather to enable any person skilled in the art to make and use this invention.

1. Dynamic Tactile Interface

[0012] As shown in FIG. **4**, a dynamic tactile interface **100** includes: a tactile layer **110** defining a peripheral region **111** and a deformable region **112** adjacent the peripheral region **111**; a substrate **120** including a transparent base material exhibiting a first optical dispersion characteristic, coupled to the tactile layer **110** at the peripheral region **111**, defining a fluid conduit **126** adjacent the peripheral region **111**, and defining a fluid channel **125** fluidly coupled to the fluid conduit **126**; a volume of transparent fluid **130** contained within the fluid channel **125** and the fluid conduit **126**, the volume of transparent fluid **130** exhibiting a second optical dispersion characteristic different from the first optical dispersion characteristic; a volume of particulate **140** contained within the transparent base material of the substrate **120** and biased around the fluid conduit **126**, the volume of particulate **140** exhibiting a third optical dispersion characteristic different from the first optical dispersion characteristic; and a displacement device **150** displacing fluid into the fluid channel **125** to transition the deformable region **112** from a retracted setting (shown in FIG. **1**B) into an expanded setting (shown in FIG. **1**A), the deformable region **112** defining a formation tactilely distinguishable from the peripheral region **111** in the expanded setting.

[0013] As shown in FIG. **5**, one variation of the dynamic tactile interface **100** includes: a tactile layer **110** defining a peripheral region **111** and a deformable region **112** adjacent the peripheral region **111**; a substrate including a transparent material exhibiting a first thermal expansion coefficient, coupled to the tactile layer **110** at the peripheral region **111**, defining a fluid conduit adjacent the peripheral region **111**, and defining a fluid channel fluidly coupled to the fluid conduit **126**; a volume of transparent fluid **130** contained within the fluid channel **125** and the fluid conduit **126**, the volume of transparent fluid **130** exhibiting a second thermal expansion coefficient greater than the first thermal expansion coefficient; a volume of particulate commingled with the volume of transparent fluid **130** and exhibiting a third thermal expansion coefficient less than the second thermal expansion coefficient; and a displacement device **150** displacing a fluid into the fluid channel **125** to transition the deformable region **112** from a retracted setting into an expanded setting, the deformable region **112** defining a formation tactilely distinguishable from the peripheral region **111** in the expanded setting.

[0014] As shown in FIG. **6**, one variation of the dynamic tactile interface **100** includes: a tactile layer **110** defining a peripheral region **111** and a deformable region **112** adjacent the peripheral region **111**, the tactile layer **110** including a first transparent material exhibiting a first index of refraction; a substrate including a first sublayer **121** and a second sublayer, the first sublayer **121** coupled to the tactile layer **110** at the peripheral region **111**, the second sublayer adjacent the first sublayer **121** opposite the tactile layer **110** and including a second transparent material of a second index of refraction, the substrate **120** defining a fluid conduit adjacent the peripheral region **111** and a fluid channel fluidly coupled to the fluid conduit **126**; a volume of particulate **140** arranged within the first sublayer **121**, the volume of particulate **140** and the first sublayer **121** cooperating to exhibit a bulk index of refraction between the first index of refraction and the second index of refraction for a particular wavelength of light in the visible spectrum; a volume of transparent fluid **130** contained within the fluid channel **125** and the fluid conduit **126**; and a displacement device **150** displacing fluid into the fluid channel **125** to transition the deformable region **112** from a retracted setting into an expanded setting, the deformable region **112** defining a formation tactilely distinguishable from the peripheral region **111** in the expanded setting.

[0015] The dynamic tactile interface **100** can further include a display coupled to the substrate **120** opposite the tactile layer **110** and displaying an image of a key substantially aligned with the deformable region **112** and/or a touch sensor **160** coupled to the substrate **120** and outputting a signal corresponding to an input on a tactile surface **115** of the tactile layer **110** adjacent the deformable region **112**. The dynamic tactile interface **100** can also include a housing **180** that transiently engages a mobile computing device and transiently retains the substrate **120** over a digital display **170** of the mobile computing device.

2. Applications

[0016] Generally, the dynamic tactile interface **100** can be implemented within or in conjunction with a computing device to provide tactile guidance to a user entering input selections through a touchscreen or other illuminated surface of the computing device. In particular the dynamic tactile interface **100** defines one or more deformable regions of a tactile layer **110** that can be selectively expanded and retracted to intermittently provide tactile guidance to a user interacting with the computing device. In one implementation, the dynamic tactile interface **100** is integrated into or applied over a touchscreen of a mobile computing device, such as a smartphone or a tablet. For example, the dynamic tactile interface **100** can include a set of round or rectangular deformable regions, wherein each deformable region **112** is substantially aligned with a virtual key of a virtual keyboard rendered on the a display integrated into the mobile computing device, and wherein each deformable region **112** in the set mimics a physical hard key when in an expanded setting. However, in this example, when the virtual keyboard is not rendered on the display **170** of the mobile computing device, the dynamic tactile interface **100** can retract the set of deformable regions to yield a substantially uniform (e.g., flush) tactile surface **115** yielding reduced optical distortion of an image rendered on the display **170**. In another example, the dynamic tactile interface **100** can include an elongated deformable region **112** aligned with a virtual 'swipe-to-unlock' input region rendered on the display **170** such that, when in the expanded setting, the elongated deformable region **112** provides tactile guidance for a user entering an unlock gesture into the mobile computing device. Once the mobile computing device is unlocked responsive to the swipe gesture suitably aligned with the virtual input region, the dynamic tactile interface **100** can transition the elongated deformable region **112** back to the retracted setting to yield a uniform surface over the display **170**.

[0017] The dynamic tactile interface **100** can alternatively embody an aftermarket device that adds tactile functionality to an existing computing device. For example, the dynamic tactile interface **100** can include a housing **180** (shown in FIG. **7**) that transiently engages an existing (mobile) computing device and transiently retains the substrate **120** over a digital display **170** of the computing device. The displacement device **150** of the dynamic tactile interface **100** can thus be manually or automatically actuated to transition the deformable region(s) **112** of the tactile layer **110** between expanded and retracted settings.

[0018] Elements of the dynamic tactile interface **100**, such as the substrate **120** and the tactile layer **110**, can be substantially transparent to enable light transmission from the display **170** to a user, such as described in U.S. patent application Ser. No. 11/969,848, filed on 4 Jan. 2008, Ser. No. 12/319,334, filed on 5 Jan. 2009, Ser. No. 12/497,622, filed on 3 Jan. 2009, and Ser. No. 12/652,704, filed on 5 Jan. 2010, and U.S. Provisional Application No. 61/713,396, filed on 12 Oct. 2012, and 61/841,176, filed 28 Jun. 2013, which are incorporated in their entireties by this reference.

[0019] However, the substrate **120** and the (volume of transparent) fluid can be of different materials and can therefore exhibit different indices of refraction at various wavelengths of light within the visible spectrum (~390 to ~700 nm). For example, the substrate **120** can include a base material of acrylic (PMMA), polycarbonate, silicone, glass (e.g., alkali-aluminosilicate glass), or other transparent material, and the fluid can be water, an alcohol, an oil, or air. As described below, the substrate **120** defines a fluid channel and a fluid conduit through which fluid is communicated to the back surface of the tactile layer no at the deformable region **112** to transition the deformable region **112** into the expanded setting, and the fluid channel **125** and the fluid conduit **126** may therefore contain fluid throughout various (e.g., all) periods of operation the dynamic tactile interface **100**. An acute change in refractive index, optical dispersion, or other optical property may therefore occur at a junction (or "interface") between the disparate materials of the fluid **130** and the substrate **120**—such as at a wall of the fluid channel **125** or at a wall of the fluid conduit **126**—such that light output from a display below the substrate **120** (i.e., adjacent the substrate **120** opposite the tactile layer no) to reflect internally back toward the display **170**, thereby reducing a perceived brightness of the display **170** and reducing a maximum angle of off-axis viewing of the display **170** through the substrate **120** and the tactile layer no. Similarly, this junction between disparate materials can cause various wavelengths of light output from the display **170** to refract (i.e., "bend") through the junction at different angles (i.e., as a function of wavelength), thereby yielding local chromatic dispersion of a portion of an image output from the display **170** adjacent the junction.

[0020] In one example, the fluid **130** and the substrate **120** are index-matched at a particular wavelength near the center of the visible spectrum (e.g., at approximately 550 nm, in the green light spectrum) but exhibit increasingly different refractive indices at wavelengths further from this particular wavelength in the visible spectrum. In this example, the distinct change in optical dispersion characteristics of the substrate material and the fluid **130** at frequencies of ~400 nm (violet light) and ~750 nm (red light) may thus cause violet lines and red lines to appear (to a user) along an edge of the fluid channel **125** and/or along an edge of the fluid conduit **126**.

[0021] In another example, the fluid **130** and the substrate **120** are index-matched near a lower wavelength end of the visible spectrum, such as near 400 nm, but exhibit increasingly different refractive indices at higher wavelengths of light. In this example, the junction between the fluid **130** and the substrate **120** may cause parallel yellow, orange, and red lines along the fluid channel **125** and/or along the fluid conduit **126** to appear to a user viewing a digital display **170** through the substrate **120** and the tactile layer **110**. Therefore, though the fluid **130** and the base material of the substrate **120** may be of similar transparency, optical clarity, and/or index of refraction at one wavelength of light or across a limited range of the visible spectrum, a user may nonetheless perceive optical distortion of an image—rendered on an adjacent digital display **170**—in the form of wavelength-dependent refraction of light (i.e., chromatic dispersion) proximal junctions between disparate materials of the dynamic tactile interface **100**, such as along the fluid channel **125** and/or along the fluid conduit **126**.

[0022] Therefore, particulate can be impregnated or suspended in locally in regions of the base material of the substrate **120**—such as around the fluid channel **125** and/or the fluid conduit **126**—to modify local optical dispersion properties (e.g., variations in refractive index as a function wavelength) of the substrate **120** to better approximate optical dispersion properties of the fluid **130** contained within the fluid channel **125** and the fluid conduit **126**. In particular, particulate can be preferentially impregnated or suspended in the substrate **120** around the fluid channel **125** and/or the fluid conduit **126** such that a bulk optical dispersion characteristic of this portion of the substrate **120** better matches optical dispersion characteristics of the adjacent fluid yields a relatively smoother transition of index of refraction through the substrate **120**, the volume of fluid **130**, and the tactile layer no. For example and as described below, if the fluid **130** is characterized by an Abbe number less than a Abbe number of the substrate **120**, the particulate **140** can be of a metal-oxide (e.g., indium-tin oxide (ITO), titanium oxide (TiO_2), or aluminum oxide (AlO_2)) exhibiting a lower Abbe number (V-number, constringence) than the substrate **120** base material such that the combination of particulate **140** and the base material of the substrate **120** yields an effective (i.e., bulk) Abbe number that better matches the Abbe number of the fluid **130**. Thus, when mixed into, impregnated into, or otherwise added to the base material of the substrate **120**, the particulate can locally modify a bulk chromatic dispersion characteristic of the substrate **120**, thereby smoothing transition of this chromatic dispersion characteristic at the junction between the fluid **130** and the substrate **120** and yielding less chromatic dispersion and internal reflection of light transmitted from the digital display **170** and incident on this junction.

[0023] Generally, the Abbe number of a material quantitatively describes the variation in index of refraction of the material as a function of wavelength. Modifying a bulk (e.g., effective) Abbe number of a material, such as described herein, may therefore indicate a (relative) change in the refractive indices of the material as a function of wavelength. In particular, adjacent materials characterized by substantially similar Abbe numbers may exhibit less chromatic dispersion of light passing there through than for a pair of adjacent materials characterized by substantially dissimilar Abbe numbers. Therefore, by adding particulate to the substrate **120** to modify the effective Abbe number of the substrate **120**—and more specifically the effective refractive indices of the substrate **120** as a function of wavelength—the junction between the substrate **120** and the fluid **130** may yield less chromatic dispersion of light incident thereon, thereby yielding less perceived optical distortion of this light. Abbe numbers of base materials and bulk Abbe numbers of combinations of base material and particulate combinations are thus described herein to indicate wavelength-dependent refractive indices of a base material or combination of materials.

[0024] Furthermore, lateral junctions between elements of different materials—and therefore different optical properties—within and around the dynamic tactile interface **100** can also yield internal reflection and refraction of light transmitted therethrough. For example, junctions between the substrate **120** and the tactile layer **110**, between adjacent sublayers of the substrate **120**, between adjacent sublayers of the tactile layer **110**, between the tactile layer **110** and ambient air, and/or between the substrate **120** and a display, touch sensor **160**, or touchscreen, etc. can yield optic aberrations and reduced image brightness due to discrete changes in materials across these junctions. Particulate can therefore be mixed, impregnated, or otherwise added to various layers and/or sublayers of elements of the dynamic tactile interface **100** to smooth changes in optical properties across junctions between these layers and sublayers. In particular, particulate can be incorporated into various layers and/or sublayers of the dynamic tactile interface **100** at substantially uniform densities at constant depth through the layers and sublayers and varying densities dependent on depth to yield substantially smooth transitions in index of refraction, chromatic dispersion, and/or other optical property throughout the thickness of the dynamic tactile interface **100**.

[0025] Particulate can also be incorporated (e.g., mixed into, dissolved into, suspended in) the volume of fluid **130** to yield a bulk optical property of the fluid **130**/particulate **140** combination that better match that of the substrate **120**. For example, particulate can be mixed into the volume of fluid **130** to better match a bulk coefficient of thermal expansion of the fluid **130**/particulate **140** combination to the coefficient of thermal expansion of the surrounding substrate. Thus, because index of refraction may be dependent on temperature, a change in index of refraction of the fluid **130**/particulate **140** combination with temperature may better track a change in index of refraction of the substrate **120** for a given temperature of the dynamic tactile interface **100**.

[0026] One or more of the foregoing variations can be implemented within the dynamic tactile interface **100** to improve optical clarity and reduce optical aberrations (e.g., internal reflection, refraction, diffraction, etc.) within the dynamic tactile interface **100**. For example, multiple volumes of similar or dissimilar particulate can be incorporated into the substrate **120** (e.g., shown as particulate **140** in FIG. **6**), the tactile layer no (e.g., shown as particulate **140**B and particulate **140**C in FIG. **6**), a sheet of a touch sensor **160** (e.g., as shown particulate **140**D in FIG. **6**), and/or the volume of fluid **130** (e.g., as particulate **140** in FIG. **5**), etc. to reduce chromatic dispersion across lateral material junctions, to reduce refraction and internal reflection across horizontal area junctions (i.e., between layers and sublayers), and to reduce changes in optical performance of the dynamic tactile interface **100** with changes in ambient and/or operating temperatures.

3. Particulate

[0027] The volume of particulate **140** exhibits an optical property distinct from an optical property of a base material of the dynamic tactile interface **100** that contains the volume of particulate **140**, and the volume of particulate **140** cooperates with the base material that contains it to exhibit a different, controlled bulk optical property. In particular, the volume of particulate **140** functions to locally or globally modify a bulk optical property of a base material containing it to yield smoother transitions in the optical property (e.g., index of refraction, chromatic dispersion, Abbe number, etc.) between adjacent materials of the dynamic tactile interface **100**, such as between fluid-substrate junctions, substrate-tactile layer **110** junctions, etc.

[0028] In one implementation, the transparent base material of the substrate **120** exhibits a first optical dispersion characteristic; the volume of fluid **130** exhibits a second optical dispersion characteristic; and the volume of particulate **140** exhibits a third optical dispersion characteristic different from the first optical dispersion characteristic, is contained within the transparent base material, and cooperates with the base material to exhibit a bulk optical dispersion characteristic nearer (i.e., that better approximates) the second optical dispersion characteristic of the volume of fluid **130** than the base material of the substrate **120** alone. In this implementation, the particulate can be biased (e.g., preferentially impregnated) around the fluid conduit **126**, as described below, to locally modify the bulk optical dispersion characteristic of the substrate **120** around the fluid channel **125** and/or the fluid conduit **126** and to yield a substantially smooth transition back to the first optical dispersion characteristic in the remaining volume of the substrate **120**. For example, the transparent base material of the substrate **120** can be characterized by a first constringence value; the volume of transparent fluid **130** can be characterized by a second constringence value less than the first constringence value; and particulate in the volume of particulate **140** can be characterized by a third constringence value less than the second constringence value. In this example, a portion of the substrate **120** and a portion of the volume of particulate **140** impregnated into the substrate **120** proximal a surface of the fluid conduit **126** can thus cooperate to exhibit a fourth constringence value approximating the second constringence value of the fluid **130**.

[0029] Furthermore, in the foregoing implementation, an amount of particulate added to the substrate material (e.g., in suspension) can be set to achieve a target bulk refractive index of the substrate **120** for a particular wavelength of light, such as to mimic a refractive index of the fluid **130** at the particular wavelength of light. Similarly, the amount of particulate added to the substrate material can be selected to achieve a target shift in a refractive index-wavelength curve characterizing the substrate **120** to better match a refractive index-wavelength curve characterizing the fluid **130**. Thus, in this implementation, particulate can be preferentially incorporated into the substrate **120** to smooth lateral transitions in one or more optical properties proximal junctions between various base materials.

[0030] In one variation, the tactile layer no exhibits a first index of refraction; the substrate **120** includes a first sublayer **121** and a second sublayer **122** that cooperate to define and enclose the fluid channel **125**; the first sublayer **121** coupled to the tactile layer no at the peripheral region **111**; and the second sublayer **122** adjacent the first sublayer **121** opposite the tactile layer **110** and including a second transparent material of a second index of refraction, as shown in FIG. **6**. In this variation, the volume of particulate **140** is interspersed throughout the first sublayer **121** and cooperates with the first sublayer **121** to exhibit a bulk index of refraction between the first index of refraction and the second index of refraction. In this variation, the volume of particulate **140** can be impregnated in the first sublayer **121** at a density (or concentration) varying with depth through the first sublayer **121** (shown in FIG. **2**C), and a first portion of the volume of particulate **140** and the first sublayer **121** adjacent the tactile layer no can thus cooperate to exhibit a bulk index of refraction approximating the first index of refraction of the tactile layer no. A second portion of the volume of particulate **140** and the first sublayer **121** adjacent the second sublayer **122** can thus cooperate to exhibit a bulk index of refraction approximating the second index of refraction of the second sublayer **122** of the substrate **120**. Thus, in this variation, particulate can be incorporated into the substrate **120** (and/or the tactile layer **110**, etc.) to smooth transitions in one or more optical properties proximal junctions between various base materials through the depth of the dynamic tactile interface **100**.

[0031] As in the foregoing implementation and variation, the volume of particulate **140** can include indium-tin oxide (ITO) particulate, titanium oxide (TiO_2) particulate, aluminum oxide (AlO_2) particulate, highly-porous silica, or particulate of any other material (e.g., metal oxide) that is substantially transparent or translucent. The volume of particulate **140** can include nanoparticles (i.e., particulate sized between one and one hundred nanometers) and can include particulate of any suitable size range, such as 2-80 nm or 51-55 nm. However, the particulate can be of any other suitable material, size, range of sizes, etc. !

[0032] In yet another variation, the substrate **120** exhibits a first thermal expansion coefficient; the volume of transparent fluid **130** (contained within the fluid channel **125** and the fluid conduit **126** within the substrate **120**) exhibits a second thermal expansion coefficient greater than the first thermal expansion coefficient; and the volume of (non-agglomerated) particulate is commingled with the volume of transparent fluid **130** and exhibits the third thermal expansion coefficient less than the second thermal expansion coefficient. In this variation, the particulate can exhibit a negative coefficient of thermal expansion such that the bulk thermal expansion coefficient of the volume of fluid **130** (with the particulate mixed or dissolved therein) better approximates the thermal expansion coefficient of the adjacent substrate. Thus, when the temperature of the dynamic tactile interface **100** increases, the substrate **120** and the fluid **130** can expand at similar rates such that a corresponding change in an optical property of the fluid **130** better tracks a change in the optical property of the substrate **120**. For example, the volume of particulate **140** can include cubic zirconium tungstate nanoparticles commingled with the volume of fluid **130** within the fluid channel **125** and the fluid conduit **126**. In this example, a filter can be arranged between the fluid channel **125** and the displacement device **150** to substantially prevent the particulate from exiting the substrate **120** and returning to the displacement device **150** and/or to a connected reservoir.

[0033] Alternatively, the volume of particulate **140** can exhibit a substantially high coefficient of thermal expansion and can be interspersed throughout the substrate **120** such that a bulk coefficient of thermal expansion of the substrate **120** and the volume of particulate **140** better approximates (e.g., approaches) the coefficient of thermal expansion of the volume of fluid **130**. The dynamic tactile interface can also include a first discrete volume of particulate and a second discrete volume of particulate, the first discrete volume of particulate interspersed throughout the fluid to reduce the bulk coefficient of thermal expansion of the volume of fluid **130**, and the second discrete volume of particulate interspersed throughout the substrate to increase the bulk coefficient of thermal expansion of the substrate **120** substantially up to the bulk coefficient of thermal expansion of the volume of fluid **130**.

[0034] The dynamic tactile interface **100** can therefore include one or more discrete volumes of particulate of the same or different material. For example, the dynamic tactile interface **100** can include: a first volume of indium tin oxide nanoparticles interspersed throughout a second sublayer **114** of the tactile layer no in a first density to smooth a transition in index of refraction between the tactile layer **110** and ambient air; a second volume of indium tin oxide nanoparticles interspersed throughout a first sublayer **113** of the tactile layer **110** in a second density to smooth a transition in index of refraction between the substrate **120** below and the tactile layer **110**; a third volume of indium tin oxide nanoparticles preferentially impregnated into the substrate **120** around the fluid channel **125** and the fluid conduit **126** to smooth a transition in index of refraction between the substrate **120** and the fluid **130**; and/or a fourth volume of cubic zirconium tungstate nanoparticles commingled within the volume of fluid **130** within the fluid channel **125** and the fluid conduit **126** to better match a thermal expansion coefficient of the fluid **130** to a thermal expansion coefficient of the substrate **120**.

[0035] In one example implementation, the tactile layer no includes an outer sublayer of polycarbonate base material (constringence V_d=~28, index of refraction n=~1.56) and an inner sublayer of silicone base material (V_d=~18, n=~1.4); the substrate **120** includes two sublayers of PMMA base material (V_d=~52.6, n=~1.5); a touch sensor **160** (described below)—coupled to the substrate **120** opposite the tactile layer **110**—includes a sheet of fused silica base material (V_d=~67, n=~1.45); a cover layer of a display (described below)—coupled to the touch sensor **160** opposite the substrate **120**—includes a layer of PMMA base material (V_d=~52.6, n=~1.5); and the fluid **130** is water-based (V_d=~73, n=~1.35). In this example implementation, base materials of the foregoing components are of the dynamic tactile interface **100** selectively impregnated, extruded, or molded, etc. with various volumes of (the same or different) particulate to yield a stack exhibiting smoothed transitions of bulk (i.e., "effective") optical characteristics (e.g., Abbe number index of refraction, constringence, chromatic dispersion, etc.) through the depth and breadth of the stack. For example, a uniform concentration of particulate can be incorporated into the substrate **120**, such as by co-molding the substrate **120** with particulate in suspension as described below, thereby yielding a substrate of substantially uniform Abbe number—approximating the Abbe number of the fluid **130** (e.g., V_d=~73)—throughout its breadth and depth. Base materials of the touch sensor **160** and the cover layer of the display **170** can also be impregnated with (the same or different type of) particulate such that the touch sensor **160** exhibits Abbe numbers ranging from V_d=~67 to V_d=~73 as a function of depth and such that the cover layer of the display **170** similarly exhibits Abbe numbers ranging from V_d=~56.6 to V_d=~67 as a function of depth. The base materials of the sublayers of the tactile layer **110** can be similarly impregnated with particulate to yield substantially smooth (or relatively smoother) transitions in Abbe numbers from the substrate-tactile layer **110** junction to the tactile layer no-ambient air junction, as shown in FIG. **3**.

[0036] Similar methods or techniques can be applied to a stack with fluid channels, fluid ports, etc. filled with oil (e.g., a silicone oil) or other fluid. However, components within the dynamic tactile interface **100** 'stack' can be of any other material, and one or more volumes of particulate can be added to, mixed in, suspended within, impregnated into, or otherwise incorporated into base materials of components of the dynamic tactile interface **100** to smooth transitions in one or more optical properties throughout the breadth and thickness of the dynamic tactile interface **100**, such as proximal material interfaces within the dynamic tactile interface **100**.

[0037] Furthermore, because the particulate can be of a substantially small average dimension, the particulate may be substantially visually imperceptible to a user at a normal viewing distance (e.g., at a viewing distance of twelve inches from the tactile surface **115** of the tactile layer no), and the particulate can thus yield a substantially minimal increase in optical distortion due to particulate occlusion (and/or diffraction, scattering) throughout the dynamic tactile interface **100** relative to a similar dynamic tactile interface **100** excluding such particulate.

[0038] However, the dynamic tactile interface **100** can include any other volumes of particulate of any other material and size, and the particulate can be arranged in or incorporated into any element of the dynamic tactile interface **100** in any other suitable way and in any other amount or density.

4. Substrate

[0039] The substrate **120** of the dynamic tactile interface **100** is coupled to the tactile layer **110** at the peripheral region **111**, defines the fluid conduit **126** adjacent the peripheral region **111**, and defines the fluid channel **125** fluidly coupled to the fluid conduit **126**. Generally, the substrate **120** functions to define the fluid channel **125** and the fluid conduit **126** such that fluid can be communicated between the displacement device **150** and the deformable region **112** of the tactile layer **110** to transition the deformable region **112** between the retracted and expanded settings. In particular, the substrate **120** cooperates with the displacement device **150** and the tactile layer **110** to define a fluid circuit through which fluid can be displaced to selectively transition the deformable region **112** between the expanded setting and the retracted setting to intermittently form a tactile feature on the tactile surface **115** of the tactile layer **110**.

[0040] As described above and in U.S. patent application Ser. No. 14/035,851, the substrate **120** can include multiple sublayers bonded (or otherwise fastened) together to enclose the fluid channel **125** and to define the fluid conduit **126**. For example, one sublayer of the substrate **120** can define an open channel and a through-bore, and a second sublayer **122** of the substrate **120** can be bonded to a back side of the first sublayer **121** to close the open channel and thus define the fluid channel **125**. However, the substrate **120** can include a singular layer or any other number of sublayers assembled to define the fluid channel **125** and/or the fluid conduit **126**.

[0041] The substrate **120** includes one or more (sub)layers of a transparent base material, such as poly(methyl methacrylate), polycarbonate, glass, polyurethane, or silicone. Particulate can thus be added, mixed, impregnated, or suspended, etc. into the base material of the substrate **120** to modify a bulk optical property or characteristic of the substrate **120**. For example, once incorporated into the substrate **120**, the volume of particulate **140** can function to raise an average refractive index of the substrate **120** (e.g., near 550 nm) while shifting the refractive indices at lower wavelengths and higher wavelengths of light nearer the corresponding refractive indices of the fluid **130** across the visible spectrum. In this example, the substrate **120** base material can be characterized by a first refractive index-wavelength curve, and the fluid **130** can be characterized by a second refractive index-wavelength curve that intersects the first refractive index-wavelength curve at a particular wavelength; inclusion of the particulate in the substrate **120** base material can thus shift the first refractive index-wavelength curve of the substrate **120** nearer to the second refractive index-wavelength curve of the fluid **130**.

[0042] In one implementation, non-agglomerated particulate (e.g., suspended in a solvent) is mixed in solution with uncured polymer (e.g., PMMA, silicone), which is subsequently extruded (or cast) to form a sheet with substantially uniform concentration of particulate throughout its volume, as shown in FIGS. **2**A and **2**B. The sheet can then be cut to size and machined, etched, stamped, wired EDM'd, or laser ablated, etc. to create the fluid channel **125** and/or fluid conduit before assembly with another sheet (of the same or similar material structure) to form the substrate **120**. In a similar implementation in which the particulate is a ceramic capable of withstanding high temperatures, the particulate can be similarly suspended in molten glass (e.g., alkali-aluminosilicate glass), which is then formed into sheet (e.g., over a mercury pool) and cooled to create a glass sheet with substantially uniform distribution of silicate. Non-agglomerated particulate can alternatively be mixed in solution with an uncured polymer, which is then cast in a sublayer mold. The mold form can include a negative fluid channel feature and/or a fluid conduit feature such that, when cured and removed from the mold, the cast substrate includes fluid channel and/or fluid conduit features and can be joined to another cast sublayer to form the substrate **120**.

[0043] Alternatively, the particulate can be impregnated in the base material of the substrate **120**, such as once the substrate **120** with various internal features of the fluid channels, fluid conduits, etc. is fully formed. In one implementation, the substrate **120** base material is bombarded with particulate, such as through sputtering or chemical vapor deposition. In one example of this implementation, the substrate **120** includes a first sublayer **121** and a second sublayer **122**, wherein the first sublayer **121** defines an outer surface and an inner surface, includes an open channel feature in the inner surface, and includes a fluid conduit aligned with the open channel and passing through the first sublayer **121** to the outer surface, and wherein the second sublayer **122** is a planar sheet including a mating surface. Prior to assembly of the inner surface of the first sublayer **121** to the mating surface of the second sublayer **122**, the inner surface of the first sublayer **121** and the mating surface of the second sublayer **122** are impregnated with particulate by a bombardment process, as shown in FIGS. **2**A and **2**C.

[0044] In the foregoing implementation, particulate impregnation by bombardment can yield a non-uniform distribution of particulate within the sublayer, such as with highest concentration of particulate occurring at surfaces nearest a particular target plate (a plate containing particulate for impregnation into the substrate **120** base material). Thus, in the foregoing example, the substrate **120** can feature a highest concentrations of particulate at the inner surface of the first sublayer **121**, the surface(s) of the fluid channel **125** and fluid conduit, and the mating surface of the second sublayer **122**, and concentrations of particulate can reduce linearly, exponentially, or quadratically, etc. with distance from the substrate-fluid interfaces, as shown in FIG. **2**D. In particular, in this example, particulate concentration can be greatest nearest substrate-fluid interfaces but decrease with distance from the substrate-fluid interfaces, and the concentration of particulate at the substrate-fluid interfaces can thus be selected to substantially match the overall refractive index-wavelength curve of the fluid **130**. However, because the particulate may increase (or decrease) the average refractive index of the substrate material, gradual reduction in concentration of particulate from the substrate-fluid interfaces may yield a substantially smooth (rather than stepped) transition to a lower average index of refraction of the tactile layer **110** above. Such gradual reduction of the average index of refraction within the substrate **120** may yield less internal reflection and less refraction than large stepped changes in index of refraction within the substrate **120** or across the substrate **120** and the tactile layer **110**, thus enabling greater viewing angles of the display **170** and greater screen brightness in comparison to an even distribution of particulate through the substrate **120** given a tactile layer **110** of substantially different average index of refraction.

[0045] In a similar example, particulate can be selectively impregnated into the substrate **120**, such as by selectively impregnating the substrate **120** near and around the fluid channel **125** and the fluid conduit **126**, as shown in FIGS. **2**A and **2**D. In one example, the inner surface of the first sublayer **121** of the substrate **120** is masked, leaving the fluid channel **125**, fluid conduit, and an area around the fluid channel **125** (e.g., 2 mm on each side of the fluid channel **125**) exposed. This exposed area of the first sublayer **121** is then impregnated with particulate (e.g., by sputter deposition), and the mask is then removed and the first sublayer **121** assembled over the second sublayer **122**. In this example, the regions of the second sublayer **122** adjacent particulate-impregnated regions of the first sublayer **121** can also be selectively impregnated, such as around the fluid channel **125** through similar methods, thereby smoothing a gradient of refractive indices from the second sublayer **122** through the first sublayer **121**.

[0046] In another implementation, the volume of particulate **140** is thoroughly mixed into a volume of uncured base material, and the substrate **120** is then cast from the particulate-base material mixture. As the cast particulate-base material mixture cures, it is exposed to heat, thus causing the particulate to "bloom" or rise to a surface of the casting and thereby yielding a density of particulate within the substrate **120** that varies with depth through the substrate. For example, in this implementation, the volume of particulate **140** can include polyvinylidene fluoride (PVFD) nanoparticles, and the substrate can be of poly(methyl methacrylate) (PMMA). However, a gradient in concentration of particulate can be achieved in the substrate **120** (and/or in the tactile layer no) in any other suitable way.

5. Volume of Fluid

[0047] The volume of transparent fluid **130** is contained within the fluid channel **125** and the fluid conduit **126**. Generally, the volume of transparent is manipulatable by the displacement device **150** to selectively transition the deformable region **112** between the expanded setting and the retracted setting. For example, the displacement device **150** can pump fluid into the fluid channel **125** within the substrate **120** to expand the deformable region **112**, thereby transitioning the deformable region **112** from the retracted setting into the expanded setting, and the displacement device **150** can pump fluid out of the fluid channel **125** to retract the deformable region **112**, thereby transitioning the deformable region **112** from the expanded setting back into the retracted setting

[0048] The volume of fluid **130** can exhibit an optical dispersion characteristic different from the optical dispersion characteristic of the substrate **120** and/or the tactile layer **110**. For example, the tactile layer **110** can exhibit (e.g., be characterized by) a first index of refraction at a particular wavelength (at a particular operating temperature), the substrate **120** can exhibit a second index of refraction at the particular wavelength (and at the particular operating temperature) different from the first index of refraction, and the volume of fluid **130** can exhibit a third index of refraction at the particular wavelength (and at the particular operating temperature) different from the first and second indices of refraction. In another example, the tactile layer **110** can be characterized by a first Abbe number, the substrate **120** can be characterized a second Abbe number different from the first Abbe number, and the volume of fluid **130** can be characterized a third Abbe number different from the first and second Abbe numbers. Particulate can thus be added to the tactile layer **110**, the substrate **120**, and/or the volume of fluid **130** to better match the bulk indices of refraction at a particular wavelength, Abbe numbers, constringence values, optical dispersion characteristics, etc. of materials within the dynamic tactile interface **100**.

[0049] In one implementation, particulate is dispersed into the fluid **130** to modify the bulk Abbe number of the fluid **130** to better match the Abbe number of the substrate **120** and/or the tactile layer no that define boundaries of the fluid **130**. For example, particulate of a suitably small size and of a density approximating that of the fluid **130** can be added to and substantially uniformly mixed into the fluid **130** such that the particulate does not separate from the fluid **130**. The proportion of particulate to fluid can be selected to achieve a target bulk Abbe number in the fluid **130**, such as described above.

[0050] Furthermore, as described above, an optical property of the volume of fluid **130**, the substrate **120**, and/or the tactile layer no can vary with an operating temperature of the dynamic tactile interface **100**. In particular, densities (or concentrations) of the volume of fluid **130**, the substrate **120**, and the tactile layer no can vary with temperature, and index of refraction, Abbe number constringence, chromatic dispersion, and/or other characteristic or property of a material can vary with density. Therefore, particulate can be incorporated into one or more base materials of the dynamic tactile interface **100** to better match coefficients of thermal expansion between adjacent base materials of the dynamic tactile interface **100**.

[0051] Generally, fluids generally exhibit greater positive coefficients of thermal expansion than do solids. Therefore, particulate exhibiting a negative coefficient of thermal expansion (or a coefficient of thermal expansion less than that of the substrate **120**) can thus be added to (e.g., commingled with) the volume of fluid **130** such that a bulk coefficient of thermal expansion of the fluid **130**/particulate **140** better approximates the coefficient of thermal expansion of the substrate **120**. In this implementation, the particulate can exhibit negative thermal expansion within a limited temperature range, such as over an operating temperature range of the dynamic tactile layer **110** and/or a computing device coupled to the dynamic tactile interface **100** (e.g., 0° to 35° C. (32° to 95° F.)). Alternatively, particulate exhibiting a positive coefficient of thermal expansion exceeding a (bulk) coefficient of thermal expansion of the volume of fluid **130** can be incorporated into the substrate **120** such that a bulk coefficient of thermal expansion of the substrate **120**/particulate better approximates the coefficient of thermal expansion of the volume of fluid **130**.

[0052] However, any other type and/or quantity of particulate can be added to or otherwise incorporated into the volume of fluid **130** to better match optical properties of the volume of fluid **130** and an adjacent material of the dynamic tactile interface **100** for a particular wavelength and a particular temperature, over a range of wavelengths, and/or over a range of temperatures.

6. Tactile Layer

[0053] The tactile layer **110** defines the peripheral region **111** and the deformable region **112** adjacent the peripheral region **111**. As described in U.S. application Ser. No. 14/035,851, the tactile layer **110** is attached to the substrate **120** at the peripheral region **111** and is disconnected from the substrate **120** adjacent the fluid conduit **126** such that fluid displaced through the fluid conduit **126** toward the tactile layer **110** outwardly deforms the deformable region **112** of the tactile layer **110**, thereby transitioning the deformable region **112** from the retracted setting (shown in FIG. **1**A) into the expanded setting (shown in FIG. **1**B) to yield a tactilely distinguishable formation at the tactile surface **115**. The tactilely distinguishable formation defined by the deformable region **112** in the expanded setting can be dome-shaped, ridge-shaped, ring-shaped, or of any other suitable form or geometry. When fluid is (actively or passively) released from behind the deformable region **112** of the tactile layer **110**, the deformable region **112** transitions back into the retracted setting (shown in FIG. **1**A).

[0054] In the retracted setting, the deformable region **112** can be flush with the peripheral region **111**. For example, the substrate **120** can define a substantially planar surface across an attachment surface and a support surface that faces the tactile layer **110**, the attachment surface retaining the peripheral region **111** of the tactile layer **110**, and the support surface adjacent and substantially continuous with the attachment surface and supporting the deformable region **112** against substantial inward deformation (e.g., due to an input applied to the tactile surface **115** at the deformable region **112**). In this example, the substrate **120** can define fluid conduit through the support surface, and the attachment surface can retain the peripheral region **111** in substantially planar form. The deformable region **112** can rest on and/or be supported in planar form against the support surface in the retracted setting, and the deformable region **112** can be elevated off of the support surface in the expanded setting. The support surface can thus support the deformable region **112** of the tactile layer **110** against inward deformable passed the plane of the attachment surface.

[0055] The tactile layer **110** can be of a singular material, such as a silicone or polyurethane elastomer, PMMA, or polycarbonate. As described above, the tactile layer **110** can alternatively include sublayers of similar or dissimilar materials. For example, the tactile layer **110** can include a silicone elastomer sublayer adjacent the substrate **120** and a polycarbonate sublayer joined to the silicone elastomer sublayer and defining the tactile surface **115**. As described above, optical properties of the tactile layer **110** can be modified by impregnating, extruding, molding, or otherwise incorporating particulate (e.g., metal oxide nanoparticles) into the layer and/or one or more sublayers of the tactile layer **110**.

[0056] The tactile layer **110** can also be extruded, molded, or impregnated with particulate to yield a different bulk optical property (e.g., constringence value, Abbe number, etc.), such as to better match the (bulk) optical property of the adjacent substrate, the volume fluid, and ambient air. For example, the tactile layer no can include a first sublayer **113** and a second sublayer **114**, the first sublayer **113** coupled to the substrate **120** and exhibiting a first index of refraction, and the second sublayer **114** coupled (e.g., adhered) to the first sublayer **113** and exposed to ambient air, as shown in FIGS. **3** and **6**. In this example, a volume of particulate **140** can be arranged within the second sublayer **114** and cooperate with the second sublayer **114** to exhibit a bulk index of refraction between the first index of refraction of the first sublayer **113** of the tactile layer no and an index of refraction of ambient air, such as for a particular wavelength of light in the visible spectrum at a temperature within an operating temperature range of the computing device. In this example, the volume of particulate **140** can further cooperate with the second sublayer **114** to exhibit a bulk Abbe number between a (bulk) Abbe number of the first sublayer **113** of the tactile layer **110** and an Abbe number of ambient air, such as for a particular temperature within an operating temperature range of the computing device, as described below.

[0057] However, the tactile layer no can be of any other suitable material and can function in any other way to yield a tactilely distinguishable formation at the tactile surface **115**.

7. Displacement Device

[0058] The displacement device **150** of the dynamic tactile interface **100** displacing fluid into the fluid channel **125** to transition the deformable region **112** from the retracted setting into an expanded setting, the deformable region **112** defining the formation tactilely distinguishable from the peripheral region **111** in the expanded setting. Generally, the displacement device **150** functions to displace fluid into and out of the fluid channel **125** to transition the deformable region **112** between the expanded setting and the retracted setting, respectively. As described above, the deformable region **112** can be substantially flush with the peripheral region **111** in the retracted setting and can be offset above the peripheral region **111** in the expanded setting. The displacement device **150** can therefore manipulate the volume of fluid **130** within the fluid channel **125** and the fluid conduit **126** (e.g., by pumping fluid into and out of the fluid channel **125** and the fluid conduit **126**) to adjust a vertical position of the deformable region **112** above the peripheral region **111**, a firmness of the deformable region **112**, and/or a shape of the deformable region **112**, etc.

[0059] In one variation, the tactile layer **110** further defines a second deformable region **112** adjacent the peripheral region **111**; the substrate **120** defines a second fluid conduit adjacent the second peripheral region **111** and fluidly coupled to the fluid channel **125**; the volume of transparent fluid **130** is further contained within the second fluid conduit; and the displacement device **150** displaces fluid into the fluid channel **125** to transition the deformable region **112** and the second deformable region **112** from the retracted setting into the expanded setting substantially simultaneously. For example, in this variation, the (first) and second deformable regions can function as transient hard keys corresponding to discrete virtual keys of a virtual keyboard rendered on a display coupled to the dynamic tactile interface **100**, and the displacement device **150** can displace fluid into and out of the fluid channel **125** to transition the (first), second, and other deformable regions correspond to the virtual keyboard substantially simultaneously.

[0060] The displacement device **150** can include an electromechanically-actuated pump, an electroosmotic pump, a manually-actuated pump, or any other suitable pump or mechanism suitable for actively displacing fluid into and/or out of the substrate **120**. However, the displacement device **150** can include any other suitable type of device that functions in any other way to transition the deformable region(s) **112** between the expanded and retracted settings.

8. Display

[0061] As shown in FIG. **1A**, one variation of the dynamic tactile interface **100** further includes a display coupled to the substrate **120** opposite the tactile layer **110** and configured to display an image of a key substantially aligned with the deformable region **112**. Generally, the display **170** functions to transmit light in the form of an image through the substrate **120** and the tactile layer **110**. For example, the display **170** can render an image of an alphanumeric input key of a keyboard aligned with the deformable region **112**, thereby indicating an input associated with the deformable region **112**. In this example, when the deformable region **112** is in the expanded setting and the display **170** outputs an image of the alphanumerical character "a", selection of the deformable region **112**—sensed by the touch sensor **160**—can be correlated with selection of the character "a", and the mobile computing device incorporating the dynamic tactile interface **100** can response to the input by adding the character "a" in a text field (e.g., with a SMS text messaging application executing on the mobile computing device). However, the display **170** can function in any other way to display an image of any other type.

[0062] In one implementation, the display **170** of the dynamic tactile interface **100** is coupled (e.g., joined adhered, assembled) to the substrate **120** opposite the tactile layer no. In this implementation, a cover layer of the display **170** can be characterized by a first Abbe number (or first index of refraction) different from a second (bulk) Abbe number characteristic (or second bulk index of refraction) of the substrate **120**. In this implementation, particulate can be molded, impregnated, or other incorporated into the cover layer of the display **170** and/or across a back surface of the substrate **120** such that the (bulk) Abbe number of the cover layer better approximates the (bulk) Abbe number of the substrate **120** across the junction between the cover layer and the substrate **120**, as shown in FIG. **3**. For example, in the implementation above in which the substrate **120** is cast in a polymer with particulate in suspension, the cover layer of the display **170** can be impregnated with particulate across its outer surface to achieve a bulk Abbe number approximating the (bulk) Abbe number of across the adjacent surface of the substrate **120**. In particular, by impregnating the cover layer with particulate, the cover layer and the substrate **120** can cooperate to exhibit a relatively smooth transition from the (bulk) Abbe number of the cover glass to the (bulk) Abbe number of the substrate **120**. Furthermore, volumes of the same or dissimilar particulate can be impregnated at constant or varying densities throughout the remainder of the substrate **120**, throughout the tactile layer **110** (and sublayers), within the volume of fluid **130**, and/or around the fluid channel **125** and fluid conduits, etc. to achieve a substantially smooth gradient of Abbe numbers (i.e., refractive indices as a function of wavelength) throughout the depth of the dynamic tactile interface **100** from the display **170** through the tactile layer **110**, as shown in FIG. **3**, and laterally across the breadth of the dynamic tactile interface **100**.

9. Sensor

[0063] As shown in FIG. **1**A, one variation of the dynamic tactile interface **100** further includes a touch sensor **160** coupled to the substrate **120** and outputting a signal corresponding to an input on the tactile surface **115** adjacent the deformable region **112**. Generally, the touch sensor **160** functions to output a signal corresponding to an input on the tactile surface **115**, such as on the peripheral and/or on the deformable region **112**.

[0064] In one implementation, the touch sensor **160** includes a capacitive, resistive, optical, or other suitable type of touch sensor **160** arranged (i.e., interposed) between the display **170** and the substrate **120**. In this implementation, like the display **170** and/or the substrate **120**, the touch sensor **160** can be impregnated with particulate to yield a substantially smooth Abbe number gradient (or a substantially smooth gradient of any other optical property or characteristic) across a junction between the touch sensor **160** and the substrate **120** and across a junction between the touch sensor **160** and the display **170**. Similarly, the touch sensor **160** can includes a sheet of transparent material exhibiting a first index of refraction different from a second index of refraction of a base material of an adjacent sublayer of the substrate **120**; and a second volume of particulate can be arranged within (e.g., impregnated into) the adjacent sublayer of the substrate **120** and can cooperate with the adjacent sublayer to exhibit a bulk index of refraction approximating the first index of refraction of the sheet of the touch sensor **160** (e.g., for a particular wavelength of light in the visible spectrum).

[0065] In this variation, the display **170** can be coupled to the touch sensor **160** opposite the substrate **120**. Alternatively, the touch sensor **160** can be integrated into the display **170** to form a touchscreen. For example, the display **170** can render an image of a virtual input key substantially aligned with the deformable region **112** in the expanded setting, and the touch sensor **160** can output a signal corresponding to an input on the tactile surface **115** adjacent the deformable region **112**. However, the touch sensor **160** can be arranged at any other depth with the dynamic tactile interface **100** and/or can be incorporated into (e.g., physically coextensive with) any other component of the dynamic tactile interface **100**.

10. Housing

[0066] As shown in FIG. **7**, one variation of the dynamic tactile interface **100** further includes a housing **180** transiently engaging a mobile computing device and transiently retaining the substrate **120** over a digital display **170** of the mobile computing device. Generally, in this variation, the housing **180** functions to transiently couple the dynamic tactile interface **100** over a display (e.g., a touchscreen) of a discrete (mobile) computing device, such as described in U.S. patent application Ser. No. 12/830,430. For example, the dynamic tactile interface **100** can define an aftermarket device that can be installed onto a mobile computing device (e.g., a smartphone, a tablet) to update functionality of the mobile computing device to include transient depiction of physical guides or buttons over a touchscreen of the mobile computing device. In this example, the substrate **120** and tactile layer no can be installed over the touchscreen of the mobile computing device, a manually-actuated displacement device **150** can be arranged along a side of the mobile computing device, and the housing **180** can constrain the substrate **120** and the tactile layer no over the touchscreen and can support the displacement device **150**. However, the housing **18*o*** can be of any other form and function in any other way to transiently couple the dynamic tactile interface **100** to a discrete computing device.

[0067] 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 preferred embodiments of the invention without departing from the scope of this invention as defined in the following claims.

We claim:

1. A dynamic tactile interface for a computing device, comprising:

a tactile layer defining a peripheral region and a deformable region adjacent the peripheral region;

a substrate comprising a transparent base material exhibiting a first optical dispersion characteristic, coupled to the tactile layer at the peripheral region, defining a fluid conduit adjacent the peripheral region, and defining a fluid channel fluidly coupled to the fluid conduit;

a volume of transparent fluid contained within the fluid channel and the fluid conduit, the volume of transparent fluid exhibiting a second optical dispersion characteristic different from the first optical dispersion characteristic;

a volume of particulate contained within the transparent base material of the substrate and biased around the fluid conduit, the volume of particulate exhibiting a third optical dispersion characteristic different from the first optical dispersion characteristic; and

a displacement device displacing fluid into the fluid channel to transition the deformable region from a retracted setting into an expanded setting, the deformable region defining a formation tactilely distinguishable from the peripheral region in the expanded setting.

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