

environment. It should be noted that the present invention may combine piezoelectric elements, cantilever-spring, and/or SMA to achieve a specific haptic sensation.

[0039] FIG. 5(a) is a side view diagram of an interface device 500 illustrating an array of haptic cells 502 with thermal fluid pockets 504 in accordance with one embodiment of the present invention. Device 500 includes an insulated layer 506, a haptic layer 512, and a display 508. While the top surface of insulated layer 506 is capable of receiving inputs from a user, the bottom surface of insulated layer 506 is placed adjacent to the top surface of haptic layer 512. The bottom surface of haptic layer 512 is placed adjacent to display 508, wherein haptic layer 512 and insulated layer 506 may be substantially transparent thereby objects or images displayed in display 508 can be seen through haptic layer 512 and insulated layer 506. It should be noted that display 508 is not a necessary component in order for the interface device to function.

[0040] Haptic layer 512, in one embodiment, includes a grid of fluid filled cells 502, which further includes at least one thermal fluid pocket 504 and an associated activating cell 510. It should be noted that each of fluid filled cells 502 can include multiple thermal fluid pockets 504 and associated activating cells 510. In another embodiment, a fluid filled cell 502 includes multiple associated or shared activating cells 510 thereby initiating a different activating cell generates a different haptic sensation(s).

[0041] Activating cell 510, in one embodiment, is a heater, which is capable of heating an associated thermal fluid pocket 504. Various electrical, optical, and mechanical techniques relating to heating technology can be used to fabricate activating cells 510. For example, various electrically controlled resistors can be used for activating cells 510, wherein resistors can be implanted in haptic layer 512 during the fabrication. Alternatively, optical stimulators such as infrared lasers can be used as activating cells 510 to heat up thermal fluid pockets 504. Optical stimulator, for example, can be mounted at the edge of the interface device. It should be noted that activating cells 510 can be any types of optical or radioactive stimulator as long as it can perform the function of a heating device. Activating cells 510 may also use rear mounted thermal stimulators, which are similar technologies like hot plasma displays such as are commonly found in flat panel plasma televisions.

[0042] Device 500 further includes a set of control wires, not shown in FIG. 5(a), wherein each of activating cells 510 is coupled to at least one pair of wires. The wires are configured to transmit activating/deactivating control signals, which are used to drive activating cells 510. It should be noted that each of fluid filled cells 502 is addressable using signals from wires or wireless networks. Display 508, in one aspect, can be a flat panel display or a flexible display. In an alternative embodiment, the physical location of display 508 is exchangeable with haptic layer 512. Also, thermal fluid pockets 504, in one embodiment, can be activated by a piezoelectric grid.

[0043] Thermal fluid pockets 504, in one embodiment, include fluid with physical properties of low specific heat and high thermal expansion. Examples of this fluid include glycerin, ethyl alcohol, or the like. Thermal fluid pockets 504 are capable of producing multiple localized strains in response to multiple touches received by insulated layer 506. Each localized strain is created by a heated thermal fluid pocket 504 wherein the heat is generated by an associated activating cell

510. In one embodiment, a thermal fluid pocket 504 changes its physical shape in accordance with the temperature of the fluid in the pocket. In another embodiment, fluid filled cell 502 has an active cooling system, which is used to restore the expanded shape of thermal fluid pocket 504 to its original shape after it is deactivated. The control of fluid temperature affects haptic bandwidth. Rapid rising of fluid temperature and fast heat dissipation of fluid enhance haptic bandwidth of thermal fluid packets.

[0044] The physical size of each fluid cell 502 can also affect the performance of the cell for generating haptic sensation(s). For example, if the size of fluid cell 504 is smaller than  $\frac{1}{2}$  fingertip, the performance of cell 504 enhances because smaller cell permits rapid heat dissipation as well as quick temperature rising of fluid in the cell. In another embodiment, thermal plastic pockets filled with plastic fluid are used in place of thermal fluid pockets 504 filled with thermally sensitive fluid to enhance the haptic effects. Using thermal plastic pockets filled with plastic-like fluid can produce high thermal plastic strain. For example, a type of plastic fluid is polyethylene. Thermal plastic pockets can also provide different and unique haptic sensations to the user. In another embodiment, some exotic fluids such as electrorheological and/or magnetorheological fluid can be used in place of thermal fluid in thermal fluid pockets 504. Thermal fluid pockets 504 filled with electrorheological fluid can be stimulated by a local or remote electrical field, while thermal fluid pockets 504 filled with magnetorheological fluid can be stimulated by a local or remote magnetic field.

[0045] FIG. 5(b) is a side view diagram for an interface device 550 illustrating an array of haptic cells 502 using thermal fluid pockets 554 in accordance with one embodiment of the present invention. Device 550 also shows an activated thermal fluid pocket 554 and an activated activating cell 560. During the operation, thermal fluid pocket 554 increases its physical volume (or size) from its original state 556 to expanded thermal fluid pocket 554 when activating cell 560 is activated. When activating cell 560 is activated, it provides heat 562 to thermal fluid pocket 554 or 556 to expand the size of thermal fluid pocket 554 or 556. Due to the expansion of thermal fluid pocket 554, a localized portion 552 of insulated layer 506 is created. As soon as the temperature of the fluid in the thermal fluid pocket 554 cools down, the size of thermal fluid pocket 554 returns to its original state 556. The change of size between original size of a thermal fluid pocket 556 and expanded size of thermal fluid pocket 554 generates a haptic effect. It should be noted that activating cell 560 could be an electric heater or an optical heater such as an infrared simulator.

[0046] FIG. 6(a) is a side view diagram of an interface device 600 illustrating an array of MEMS pumps 602 in accordance with one embodiment of the present invention. Diagram 600 includes an insulated layer 606 and a haptic layer 612. While the top surface of insulated layer 606 is configured to receive a touch or touches from a user, the bottom surface of insulated layer 606 is placed adjacent to the top surface of haptic layer 612. The bottom surface of haptic layer 612 is, in one embodiment, placed adjacent to a display (not shown in FIG. 6(a)), wherein haptic layer 612 and insulated layer 606 may be substantially transparent thereby objects or images displayed in the display can be seen through haptic layer 612 and insulated layer 606. It should be noted that display is not a necessary component in order for the interface device to function.