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Surface texture change on-demand and microfluidic devices based on thickness mode actuation of dielectric elastomer actuators (DEAs)

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ABSTRACT

Tactile feedback devices and microfluidic devices have huge significance in strengthening the area of robotics, human machine interaction and low cost healthcare. Dielectric Elastomer Actuators (DEAs) are an attractive alternative for both the areas; offering the advantage of low cost and simplistic fabrication in addition to the high actuation strains. The in-plane deformations produced by the DEAs can be used to produce out-of-plane deformations by what is known as the thickness mode actuation of DEAs. The thickness mode actuation is achieved by adhering a soft passive layer to the DEA. This enables a wide area of applications in tactile applications without the need of complex systems and multiple actuators.

But the thickness mode actuation has not been explored enough to understand how the deformations can be improved without altering the material properties; which is often accompanied with increased cost and a trade off with other closely associated material properties. We have shown the effect of dimensions of active region and non-active region in manipulating the out-of-plane deformation. Making use of this, we have been able to demonstrate large area devices and complex patterns on the passive top layer for the surface texture change on-demand applications. We have also been able to demonstrate on-demand microfluidic channels and micro-chambers without the need of actually fabricating the channels; which is a cost incurring and cumbersome process.

Keywords: Electroactive polymers, Dielectric elastomer actuators, Thickness mode actuation of DEAs, Tactile feedback, Microfluidics.

1. INTRODUCTION AND MOTIVATION

There is a great emphasis on novel technologies for improving human-machine interaction through tactile feedback and haptics. [1] The interest in the field of haptics and tactile information is driven by a plethora of applications; imparting a

sense of touch to the robots, immersive user experience in virtual and augmented reality, refreshable braille displays for the visually challenged and improving the haptics in touch-sensitive products like smartphones and display screens. [2] Tactile feedback allows for superior identification and sorting; the feel of touch is able to resolve incoming data five times faster than visual sorting. [3] Our sense of touch is remarkably adept at identifying different textures by swiping across a surface. [4] These texture changes can be perceived from a range of physical attributes like variations in friction (moist to dry, sticky to slippery), hardness (soft and hard), temperature (cold and warm) and roughness (unevenness and smoothness). [5] Over the years, a lot of research has been done into the technologies to enable tactile feedback and enhance the user experience during user-machine interaction. Few of these technologies have also started finding their feet commercially in the global market; TESLATOUGH creates a tactile sensation on the screen by electrovibration [6], Lateral force fields create a feeling of depth by changing the properties of ongoing horizontal vibrations [7], AIREAL hits user's hand with air vortexes for a force sensation in virtual environments [8], and Braille Kindle [9] work on the principle of microfluidics. However, most of these technologies create the tactile sensation by simulation of the senses rather than creating actual topographical changes on the surface.

Microfluidics promises a huge potential in low cost, point of care diagnostics; making medical services accessible to a larger population in low resource settings. [10] They offer the advantage of efficient use of samples by making use of micro-volumes of reagents and samples. [10] Conventional microfluidics, capable of complex processing of fluids and integration of advanced analytical techniques, requires patterning of individualized chambers and flow channels inside the PDMS membrane. Several techniques have been successfully demonstrated for this purpose; membrane sandwich technique making use of photolithography and replica molding [11], femtosecond laser pulsing followed with chemical etching [12] and high-brightness diode-pumped Nd:YAG laser direct write method [13] to mention a few. Most of these techniques are quite complex and lack on demand adaptability with the requirements of the environment.

Dielectric elastomer actuators (DEAs), under the family of electroactive polymers provide an attractive alternative for both the scenarios mentioned above. DEAs provide large actuation strains, and work on the principle of Maxwell stresses. [14] The architecture is essentially of that of a capacitor, where a soft, insulating, elastomeric layer is sandwiched between compliant electrodes. [15] Under the influence of an electric field, the elastomer layer stretches out, providing the actuation. [15] DEAs have been investigated for tactile applications as well; coupled with mechanical components [16, 17], coupled with fluidic systems [18] and in vibrational actuation mode with pulse-width, amplitude and frequency modulations [19,20]. However, these systems are single, separate actuators and to generate topographical deformations over large area poses a difficult challenge for them; as assembling large arrays of discrete actuators is prohibitive in terms of cost, actuator density and fabrication complexity. [21] Thickness mode actuation of DEAs provides a solution to this complexity. [21, 22] A mechanically coupled soft layer to DEA produces surface deformations. [21]

Here we study the effect of dimensions of the active region and the non-active region on the surface deformation and show the proportional and inversely proportional relationship, respectively. We also demonstrate large area devices with an area of 15 cm X 14 cm, having 7 individual pixels and 2 different surface patterns. We also show the ability of this mode of actuation to achieve complex patterns with ease. This can enable complex tactile devices; increasing the capability and complexity of these devices. We have also been able to achieve on-demand micro-chambers and flow channels for microfluidic devices, from a smooth polymer membrane. This can eliminate the need for complex fabrication processes, which are employed currently.

2. THICKNESS MODE ACTUATION OF DEAS

Thickness mode actuation is one of the configurations of DEAs, which enables out of the plane deformation from 2 dimensional patterning of electrodes. [21] By coupling an intrinsically soft, elastomeric, passive layer on top of DEA mechanically, the deformations produced in the active layer can be harnessed to produce 3-D deformations. [21, 22] The

mechanism for thickness mode actuation is illustrated in figure 1. Upon application of voltage, the sandwiched elastomeric layer experiences compressive Maxwell stresses, which squeezes the elastomer forcing it to thin down and stretching the active region (figure 1 (a)). At the same time, the non-active region experiences a shear stress, because of the actuation in the active region (figure 1 (b)). By placing a soft elastomeric layer on top, these stresses can be harnessed to produce out-of-the-plane deformations (figure 1 (c)). The soft layer above the active region reduces in thickness and the soft layer above the non-active region bulges out.

Figure 1. (a) Schematic (front view) showing the compressive Maxwell stresses that the elastomeric film sandwiched between compliant electrodes experiences when electric field is applied. (b) Schematic (top view) showing the shear stress that the elastomer (in non-active regions) between adjacent electrodes experiences. (c) The combination of these mechanisms enables out of plane deformation in thickness mode actuation. The smooth surface has surface deformations when electric field is applied.

3. EXPERIMENTAL SETUP

Acrylic elastomer (3M, VHB 4905) was used for the active elastomeric layer, carbon powder (Sigma-Aldrich, CAS Number 7782-42-5) for patterning compliant electrodes, electrical connections were made by copper tape and polydimethylsiloxane (PDMS) (Dow Corning, Sylgard 184, 50 Shore A hardness) as the soft passive layer. The acrylic elastomer was pre-stretched on a rigid frame, 300 % biaxially, and carbon electrodes were patterned on both the sides by brushing. Figure 2 shows the schematic of electrode patterning used for device fabrication, illustrating the nomenclature to be followed later in the discussion section. The DEA device was transferred on a rigid substrate and held together by adhesion of acrylic tape with the substrate, reinforced by the scotch tape. A 1 mm thick layer of PDMS was cured on the top of the device. Voltage was applied to the device for actuation by using a DC voltage supply (Aim-TTi, MX100TP), stepped up using a transformer (XP Power, CB101). The vertical deformations were measured using a surface profilometer (Alpha-Step IQ). All the surface deformations were measured at 6 kV.

Figure 2. Schematic showing the electrode patterning for device fabrication.

For flow channel and micro-chamber experiments, the PDMS surface was treated with plasma (Harrick Plasma) to make the surface hydrophilic.

4. VARIATION OF SURFACE DEFORMATION WITH VARIATION IN DIMENSIONS OF ACTIVE AND NON-ACTIVE REGIONS

It has been mentioned that the surface deformation in thickness mode actuation of DEAs depends on a range of factors like elastic modulus of active and passive layer, thickness of the active and passive layer and dimensions of electrode and non-electrode regions of the device. [21] We have studied here the effect of the dimensions of the active and non-active region on the surface deformations produced in the region. As already mentioned above, the stresses produced in the active and the non-active region of the device enable the out-of-plane deformations on the soft passive layer. For observing the effect of the dimension of active region on the surface deformation produced, we had kept the width of non-active region fixed at 5 mm. The width of the active region was varied at 6 mm, 8 mm and 10 mm. The length of both the regions was kept similar for simplification. As seen in figure 3 (a), the surface deformations vary proportionally with the width of the active region. As the width of the active region was increased, the surface deformations increase. The surface deformation for 6 mm width was observed as nearly 250 microns, which increases to ~280 microns for 8 mm width and goes up to 363 microns for 10 mm width. The scans for 3 different device widths has been shown in figure 3 (b). The surface deformations tend to take a parabolic profile, as clearly seen from the figure.

Figure 3. (a) Increase in vertical deformation with increasing the width of the active region. (b) Surface profile scans for 3 different device widths. The nomenclature in the figure is: A stands for active region, N stands for non-active region and the number denotes the width. All the dimensions are in mm.

For studying the effect of the dimension of non-active region on the surface deformation produced, we had kept the width of active region fixed at 8 mm. The width of the non-active region was varied from 5 mm, 6 mm and 8 mm. The length of both the regions was again kept similar for simplification. It can be seen in figure 4 (a) that the surface deformation has an inversely proportional relationship with the width of the non-active region. As the width of the non-active region was increased, the surface deformations decrease. Deformation of ~ 280 microns was seen for 5 mm width, which reduced to ~ 265 microns for 6 mm width and went down to ~ 200 microns for 8 mm width. The scans for 3 different device widths has been shown in figure 4 (b).

Figure 4. (a) Decrease in vertical deformation with increasing the width of the non-active region. (b) Surface profile scans for 3 different device widths. The nomenclature is similar to the one explained before.

Comparing the variations in surface deformation by width of active and non-active region and analyzing the data (figure 5), we can observe an interesting pattern. For a fixed width of non-active region, as we keep increasing the width of the active region, the change in deformation per unit change in width increases as well. Similarly, for a fixed width of active region, the change in deformation per unit change in width decrease when the width if further decreased.

Figure 5. (a) Comparison of the effect of change in width of active region and non-active region on the surface deformation.

5. SURFACE TEXTURE CHANGE FOR TACTILE FEEDBACK

Thickness mode actuation of DEAs can be used for tactile feedback devices. The advantages for using such a configuration has already been discussed. We have demonstrated here large area tactile touchpads (15cm X 14 cm) with 7 individual pixels and 2 different patterns. These patterns represent the tactile information that has to be conveyed through the surface texture change. As seen from figure 6 (a) and figure 6 (b), upon actuation, the smooth surface deforms to creates patterns in 7 different locations. The relationship derived between the width of active region and the width of non-active region with respect to surface deformations help us design these patterns so as to convey different tactile information to the user. The simplistic 2 D patterning to produce complex surface deformations has also been demonstrated in our work. From a smooth surface as seen in figure 6 (c), the complex patterns appear on the surface upon applying voltage as observed in figure 6 (d). This can enable complex tactile information to be conveyed to the user. The individual pixels can be patterned to have 7 different patterns and can be actuated individually as well.

Figure 6. Large area tactile touchpad with 7 pixels transforms from a smooth surface (a) to predetermined surface patterns (b) upon application of voltage. Smooth surface in (c) deformed by application of voltage to produce complex and irregular surface patterns in (d).

6. FLOW CHANNELS AND MICRO-CHAMBERS

The thickness mode actuation can also be manipulated to create micro-chambers and flow channels for microfluidic chips and devices. These micro-chambers can hold micro-liters of sample. As mentioned earlier, the fabrication of these chambers and channels require sophisticated techniques like soft lithography and laser etching. However, the thickness mode actuation enables the chambers and flow channels to be created on unpatterned PDMS membranes by appropriate patterning of electrodes. The transition from smooth surface to micro-chambers and channels has been shown in figure 7. The added advantage that this configuration lends to microfluidic devices is that the dimension of the micro-channels and micro-chambers can be altered on the applied electric field as well. Figure 7 (a) and (d) shows the smooth PDMS surface of both the micro-chamber and flow channel device respectively; and the actuated state can be seen in figure 7 (b) and (e). 20 microliters of blue ink were dropped in each of the chambers; to demonstrate the capability of the devices to keep the fluids in the chambers separate from each other, without allowing them to mix with each other.

Figure 7. (a) Smooth surface of PDMS membrane cured on top of DEA device. (b) Actuation by application of voltage, surface of the PDMS deforms to create micro-chambers. The region is highlighted with a red circle. (c) Blue ink inside the micro-chambers. It shows that the boundary of the micro-chambers is well-defined and do not allow the mixing of fluids in different chambers. Unactuated smooth surface of PDMS membrane (d) forms flow channels (e) for fluid flow upon application of voltage.

7. CONCLUSION AND FUTURE WORK

We have been able to show a proportional relationship between the width of active region and the surface deformation; and an inversely proportional relation between the width of non-active region and the surface deformation. We have been able to demonstrate large area devices (15 cm X 14 cm) with 7 individual pixels and 2 different patterns. Complex 3-D surface patterns has also been demonstrated using thickness mode actuation of DEAs. Manipulation of smooth PDMS surface to create micro-chambers and flow channels has also been shown in our work, which can be applied in microfluidic chips and devices, without the need of actual micro-fabrication of PDMS.

Further study will be carried out to incorporate the examined variables in the formula given to predict the surface deformation produced in thickness mode actuation, to enable researchers to simulate the results close to experimental values and better design of devices. Analysis of other independent variables affecting the surface deformation will be

carried out. Integration of these fabricated tactile devices with active functionalities and devices and surfaces will be studied to increase the applicability of this technology and seamless amalgamation with surroundings. Applicability of this technology with existing microfluidic devices will be analyzed as well.

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REFERENCES

- [1] Shull P.B., and Damian D. D., “Haptic wearables as sensory replacement, sensory augmentation and trainer – a review”, *J Neuroeng Rehabil*, 12 (59), 13 (2015).
- [2] Skedung L., Arvidsson M., Chung J.Y., Stafford C.M., Berglund B., and Rutland M.W., “Feeling Small: Exploring the Tactile Perception Limits”, *Scientific Reports*, 3, 2617-2622 (2013).
- [3] - Poupyrev I., Maruyama S., and Rekimoto J., “Ambient Touch: Designing Tactile Interfaces for Handheld Devices”, *ACM UIST* (2002).
- [4] Mate C.M., and Carpick R.W., “A sense for touch”, *Nature*, 480, 189-190 (2011).
- [5] Okamoto S., Nagano H. and Yamada Y., “Psychophysical Dimensions of Tactile Perception of Textures”, *IEEE Trans Haptics*, 6 (1), 81-93 (2013).
- [6] - Bau O., Poupyrev I., Israr A., and Harrison C., “TeslaTouch: Electro vibration for Touch Surfaces”, *ACM UIST* (2010).
- [7] – Nidec Corporation, <http://www.nidec.com/en-Global/technology/story/tactile?prt=1> , Last accessed 23/02/2017.
- [8] - Sodhi R., Poupyrev I., Glisson M., and Israr A., “AIREAL: Interactive Tactile Experiences in Free Air”, *ACM SIGGRAPH* (2013).
- [9] - Alexander R., O'Modhrain S., Gillespie R., and Matthew R., "Refreshing Refreshable Braille Displays.," *IEEE Trans Haptics*, 8 (3), 287 – 297 (2015).
- [10] - Whitesides G.M., “The origins and the future of microfluidics”, *Nature*, 442, 368-373 (2003).
- [11] - Anderson J.R., Chiu D.T., Jackman J.R., Cherniavskaya O., McDonald J.C., Wu H., Whitesides S.H., and Whitesides G.M., “Fabrication of Topologically Complex Three-Dimensional Microfluidic Systems in PDMS by Rapid Prototyping”, *Anal. Chem.*, 72 (14), 3158-3164 (2000).
- [12] - Maselli V., Osellamea R., Cerullo G., Ramponi R., and Laporta P., “Fabrication of long microchannels with circular cross section using astigmatically shaped femtosecond laser pulses and chemical etching”, *Appl. Phys. Lett.*, 88, 191107 (2006).

- [13] - Lim D., Kamotani Y., Cho B., Mazumder J., and Takayama S., "Fabrication of microfluidic mixers and artificial vasculatures using a high-brightness diode-pumped Nd:YAG laser direct write method", *Lab Chip*, 3, 318-323 (2003).
- [14] - Bar-Cohen Y., "Electro-active polymers: current capabilities and challenges", *Proc. SPIE* 4695, 2002.
- [15] - Pelrine R., Kornbluh R., Pei Q., and Joseph J., "High-Speed Electrically Actuated Elastomers with Strain Greater Than 100%", *Science*, 287, 836 – 839 (2000).
- [16] - Phung H., Nguyen C.T., Nguyen T.D., Lee C., Kim U., Lee D., Nam J., Moon H., Koo J.C., and Choi H.R., "Tactile display with rigid coupling based on soft actuator", *Meccanica*, 50, 2825–2837 (2015).
- [17] - R. Heydt and S. Chhokar, Refreshable Braille display based on electroactive polymers, *Proc. Int'l Display Res. Conf. P7.5*, 2003.
- [18] - Carpi F., Frediani G., Tarantino S., and Rossi D.D., "Millimetre-scale bubble-like dielectric elastomer actuators", *Polym. Int.*, 59, 407-414 (2010).
- [19] - Matysek M., Lotz P., and Schlaak H.F., "Tactile Display with Dielectric Multilayer Elastomer Actuators", *Proc. SPIE* 7287, 2009.
- [20] - Matysek M., Lotz P., Flittner K., and Schlaak H.F., "Vibrotactile Display for mobile applications based on dielectric elastomer stack actuators", *Proc. SPIE* 7642, 2010.
- [21] - Prahlad H., Pelrine R., Kornbluh R., Guggenberg P.V., Chhokar S., Eckerle J., Rosenthal M., and Bonwit N., "Programmable Surface Deformation: Thickness-Mode Electroactive Polymer Actuators and Their Applications", *Proc. SPIE* 5759, 2005.
- [22] - Yun S., Park S., Park B., Park S.K., Prahlad H., Guggenberg P.V. & Kyung K., "Polymer-Based Flexible Visuo-Haptic Display", *IEEE/ASME Trans. Mechatronics*, 19 (4), 1463-1469 (2014).