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Fabrication of a Flexible Tactile Sensor with Micro-Pillar Array

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Abstract

The tactile sensors are primarily used to measure the contact area and normal pressure of contacting two solids. The common deficiencies of the current tactile sensors are flexibility, adaptation to contacting bodies, normal and lateral resolution. In order to overcome these limitations, this work presents the fabrication of polymer meso and micro scale pillar arrays of integrated tactile sensor mimicking the adhesion mechanism found in geckos. The tactile sensor primarily consists of two layers which are a polymer micro-pillar array and a thin supporting backing layer of piezoelectric polymer with patterned electrodes. The sensitivity of the tactile sensor is measured to be 21.1 mV/N according to the best fit line to the experimental data's.

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Keywords: Tactile sensor; piezoelectric polymer;gecko

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1. Introduction

The tactile sensor is an array of touch sensors that converts normal mechanical force to an electrical signal. It consists of many touch sensors (tactels) that is formed preferably in a grid fashion. The output of the tactels can give a pressure map of the contacting bodies when the electrical signals are swept using a special electronics. Until now, various physical mechanism of sensing for a touch sensor are proposed such as optical , magnetic, capacitive , resistive , ultrasonic and piezoelectric. Of them, the ones to be employed the most commonly for the commercial applications

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are the piezoresistive and capacitive sensors, wherein the force magnitude is quantified in relation with the change in the various electrical signals.

The tactile sensors are primarily used to estimate the contact area and pressure of contacting two solids and placed in between them. The estimation starts with the measurement of the electrical signals which turns out the total force measurement where the contact area is estimated using the spatial distribution. The pressure distribution would finally can be revealed by knowing the distinct average calibrated force values with the estimated contact area. Therefore, the quality of the pressure measurement is associated with the spatial and vertical resolution. The common deficiencies of the tactile sensors are flexibility, adaptation to contacting bodies, low normal and lateral resolution and large area sensing. In present, the commercial flexible tactile sensor devices employ a thin film composite. These thin film sensors generally have a dielectric, piezoelectric or piezoresistive layer that is coated with a thin layer of metal on both sides. Although, these sensors holds some degree of flexibility, they have a little rough surface adaptation properties. Moreover, the vertical sensitivity and full measurement span of the sensors can only be changed with physical and/or material properties of the active sensing layer. Because of the exceptional characteristics, our fingers usually taken as a role model for the tactile sensor research. Our touch of sense with the fingers depends on billions of receptors located in our dermis, which permit high-resolution tactile feeling down to 40 μm and the viscoelastic nature of our skin similar to a soft elastomer gives high adaption to any surface [1,2]. Therefore, the basic requirements of the tactile sensor that would be useful in robotic and minimally invasive surgery operations that mimics the human hand are roughness adaptation, high sensitivity and ability to give high resolution pressure mappings. In recent works, bump shape structures is included on the top layer of the sensor to get higher sensitivity from the tactile sensor which results transmitting the applied force more uniformly [3,4,5,6,7].

The adhesion mechanism of geckos to any surface has taken great attention from the scientific community due to their repeatable and superior adhesion, roughness adaptation and self-cleaning properties [8,9,10]. The synthetic pillar array that is integrated to the tactile sensors may be a solution to some of the deficiency of the current tactile sensors. This work presents the fabrication of polymer micro-pillar arrays of integrated tactile sensor mimicking the adhesion mechanism found in geckos. The tactile sensor primarily consists of two layers which are micro-pillar array and a thin supporting backing layer of piezoelectric polymer (polyvinylidenedifluoride (PVDF)) with patterned electrodes. A finite element method (FEM) is performed in order to understand the effect of elastomer patterning on the force transmission and stress deployment in the vertical and lateral directions to the sensor as shown in Figure 1. The stress variation in the lateral and vertical direction is more uniform than the pillar case as one compares with the film. Therefore, the load is transferred equally to the active sensing layer. Also, the compliance of the pillars with respect to film is more pronounced leading to larger strains. It is expected that the total enhancement due to the equal load sharing of the distributed pillars can be represented as an additive decoupling of each contribution. Overall, patterning the elastomer would increase the stress concentration which turns out an amplified voltage output from the tactile sensor. In addition to the sensitivity enhancement, the compliance of the patterned elastomer is expected to have favorable influence on the detrimental effect of the surface roughness which limits the resolution of the tactile sensor.

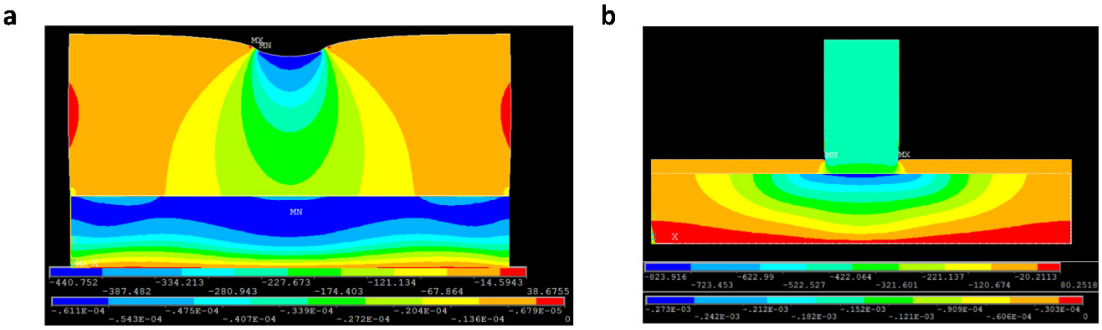

Fig. 1. The combined results of stress and voltage output: (a) film (b) single pillar. The upper bars are the stress colors and bottom bars are the voltage colors for each case.

2. Fabrication

The vertical pillar integrated tactile sensor is fabricated on a commercially available PVDF film using the additive methods of lithographic and flexible electronic techniques as illustrated on Figure 1. The dimensions and layout of the pillars are designed according to the mechanical failure theories such as buckling and lateral collapse of the pillars [4]. The tactile sensor includes an elastomer pillar array with aspect ratio of $h_{pillar}/D=1$ (25 µm height and diameter), patterned silver electrode layer of 12 µm thickness, a 40 µm thick PVDF film, a 142 µm polyester film (Mylar DS2) for the carrier and approximately 15 µm layer of pressure sensitive adhesive layer. The fabrication process begin with spin coating the plain silicon (Si) wafer with the SU8-2025 negative photoresist at 3000 rpm, which determines the height of the pillars. Following a soft bake step, the whole wafer is exposed to the ultraviolet light using a high resolution chromium mask in order to get the holes that defines the diameter of the pillars (Figure 2.b). After the proper post exposure bake, the wafer is developed in the SU-8 developer for 5 minutes to get the master template which follow a perfluorination step to decrease the surface energy of the mold as outlined by Greiner *et al.* [11]. A polydimethylsiloxane (PDMS) solution is spin coated on the master template at 1000 rpm for 10 minutes, degassed under vacuum and let it cured the whole structure at 50 C^{o} overnight (Figure 2.c). Note that the PDMS backing layer thickness is measured as 24 µm using a profilometer. At this stage, it is not possible to remove the pillars without damaging the template and the pillars itself. In the meantime, a four by four silver electrodes are patterned on the top of the commercially available PVDF (polled and stretched) using a screen printing technique (Figure 3.a). Also, plain electrode, which serves as the ground connection in the sensor, is printed on the other side of the film. After printing the electrodes, it is sintered at 70 C^{o} which is below the Curie temperature of the piezoelectric polymer. PDMS backing layer are treated using a hand-held corona system to increase the surface energy before bonding with the piezoelectric polymer with patterned electrode using an epoxy (Figure 2.d). A plastic carrier made of polyster is attached by screen printing a pressure sensitive adhesive to the top of the metallized PVDF. The whole structure is peeled away from the template where the micro-pillars stays on the top of the structure (Figure 2.g). The micro-pillar integrated tactile sensor have flexible layers except the metal electrodes at the piezoelectric layer. A crimp style connector is attached to the each of the electrodes after the fabrication process (Figure 3.b).

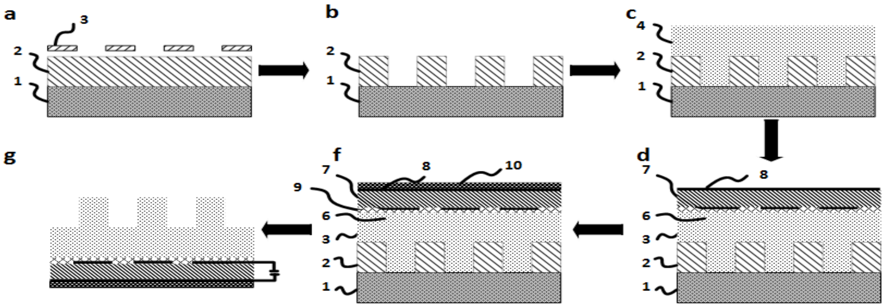

Fig. 2. An illustration for the manufacturing steps of the micro-pillar integrated tactile sensor.

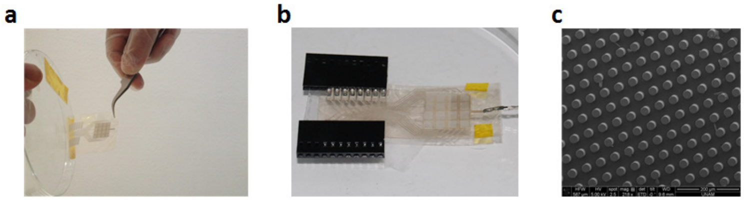

Fig. 3. (a) Screen printed patterned electrodes on the PVDF film, (b) an image of the tactile sensor, (c) scanning electron microscopy (SEM) image of the pillars on the top of the sensor.

3. Experimental Results and Discussion

In the experiments, a custom-build characterization setup is utilized to test the dynamic performance of the sensor (Figure 4.a). The setup consists of a PZT stack actuator, a reference loadcell, a hemispherical glass or flat punch, a linear stage, charge amplifiers and a data acquisition system where the actuators are controlled through a software based on LabVIEW. Initially, a preload of 1.75 mN which is well below the limit for the buckling of the pillars, is applied to the sensor. Then, the stack actuator gives different displacements to the tactile sensor with 1 Hz frequency, which is in compression through the reference load cell with the aid of the tip (Figure 4.b). Then, the actuator is driven by different voltage values to get diverse preloads on the sensor. As the peak to peak force value increases, the voltage output of the sensor trace the input in a linear manner (Figure 4.c). The sensitivity of the sensor is found to be 21.1 mV/N according to the best fit line to the data.

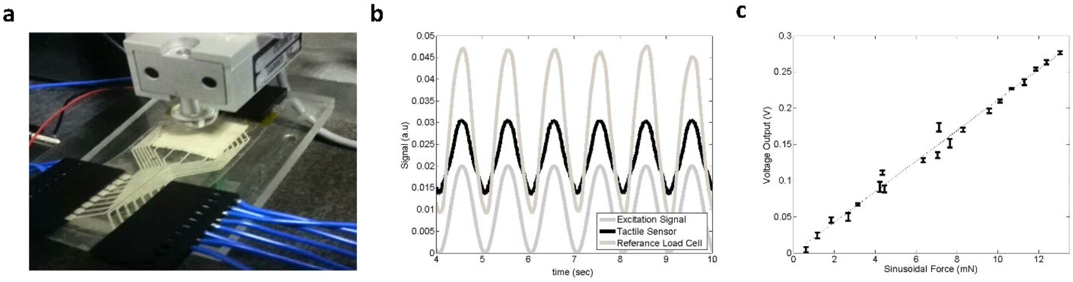

Fig. 4. (a) A close-up view of the experimental setup, (b) sample voltage output in a.u.; (c) sensitivity of the sensor.

4. Conclusion

In this study, a micro-pillar integrated tactile sensor is fabricated and tested. In addition to the sensitivity enhancement, the compliance of the patterned elastomer is expected to have favorable influence on the detrimental effect of the surface roughness on the resolution of the tactile sensor. Future work includes characterization of the sensor for the adhesion repeatability on different surface roughness substrates and comparison with the thin film counterparts. Also, a scanning circuit will be developed to get the pressure mapping of the contact area.

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