



## Review of Different Tactile Sensors Using Piezoresistivity Mechanism

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### Abstract

This paper is a brief review of different tactile sensors based on piezo-resistive mechanism developed in recent times. The topics which are briefly covered are crystalline silicon-based sensors, flexible graphene based sensors, Carbon Nano Tubes (CNT) based flexible sensors, patterned PDMS thin film and self-healing materials for sensors.

**Keywords:** Mechanical; Bio-medical; Graphene sensors; Transistor

### Introduction

The word "Tactile" has Latin origins from word *tactilis* which means perceptible by touch. Thus, in mechanical terms it can be said as: "response on touch", i.e. by applying pressure. Development of tactile sensors for various applications in Robotics, Bio-medical, Display technologies etc. is necessary. Tactile sensors are based on three main mechanisms that are piezo resistivity, capacitance and optical. The working of piezo resistive mechanism is simple: when pressure is applied the resistance changes in the material. Therefore, change in electrical resistance is directly proportional to pressure applied. The change in electrical resistance is due to change in structure of material. The resistance change is thus dependent on both geometry and resistivity and can be expressed as  $\Delta R/R = (1+\nu)\Delta r/r$ , where  $\nu$  and  $r$  are Poisson's ratio and strain, respectively [1].

### Different Types of Tactile Sensors

#### Crystalline silicon based sensors

Tactile sensors based on crystalline silicon take inputs of pressure or strain and convert them to electrical signals. These sensors work with piezo resistivity mechanism. These tactile sensors require arrays of piezo resistors. The fabrication process involves perforated silicon sheet (Figure 1) [2]. Single crystalline silicon is used for making the sensor array. The piezo resistors are embedded into the perforations. Single side silicon bulk micromachining technique is used for putting the n-type crystalline silicon membranes. The embedded piezo resistors are p-type. This doping allows electric charge to flow in a direction. The silicon bulk has a constant resistance whereas piezo resistor has variable resistance depending on the load applied on it. Therefore, both these resistances form a voltage divider which as a result gives electric signal proportional to pressure applied on the surface of the sensor. The complete array is then covered by elastic cover membrane made with materials like rubber. This elastic membrane transfers pressure to the functioning mechanism [2].

#### Flexible graphene based sensors

Flexible graphene-based strain sensors based on piezo resistivity mechanism can also be used for making tactile sensors. These are high performance sensors as graphene is a very special material with properties like ultra-high mobility, and transparency [3]. To fabricate these flexible graphene sensors, laser scribing is used. Graphene oxide films are laser scribed with precision. The change in resistance of graphene is linear to applied strain. Moreover, thin cracks appear on the surface of the graphene film when strain is applied.

There may be following reasons for change in resistance:

1. Change in area of overlap between the graphene layers
2. Tunneling effect between the graphene sheets which changes the resistance exponentially.
3. Change in band gap due to deformation may also cause change in resistance.
4. Over connecting of graphene flakes [3].

Sliding of graphene sheets takes place and the area of overlap changes which causes change in resistance along with cracking of graphene film as shown above in Figure 2 enables the piezo resistance effect [3]. Hence graphene micro ribbons can be laser scribed and used as tactile or strain sensing devices.

#### Carbon nanotubes based sensors flexible sensors

The graphene based, and silicon based sensors are found to be good, but they have limited range of sensing strain. The Multiwalled Carbon Nanotubes (MWCNT) is used to make strain sensors with higher range. They can be used for tactile sensing purposes with higher strain sensing capacity. Thus providing more range.

MWCNTs are sandwiched between layers of natural rubber which acts like an elastic cover. Reference [4] compared the strain limit of MWCNT based sensor and graphene based sensor, both fabricated by the same procedure. The MWCNT based sensor had relatively higher measurable strain limit than graphene based sensor. This is mainly due to smaller size of CNT.

#### Patterned PDMS thin films

Polydimethylsiloxane (PDMS) is used in many electronic applications due its properties of viscoelasticity, flexibility and bio compatibility. Thick PDMS layers can be used easily as they are completely elastic. Whereas when it comes to using PDMS as thin films some problems me crop up such as: creep, increased relaxation time of PDMS after application of load, lesser relaxation time leads to increased sensor reset time.

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For the specific application of electronic skin, use of PDMS thin films is important. Therefore, to reduce the effect of all the disadvantages of PDMS thin films micro structured PDMS thin films are used.

Fabrication of micro structures is a costly process involving use silicon molds. The process of fabrication is explained in Figure 3.

Different patterns such as pyramidal can be formed by this process. The microstructure gives increased surface area. The microstructure formed is shown in Figure 4.

A transistor based sensor can be made after the PDMS is laminated to the rubrene crystal [5]. Another and much cheaper method of fabrication is suggested by use of silk to make micro structures as shown in Figure 5 [6].

The microstructure of silk is imprinted on the PDMS thin film like weaves of clothes each micro structure resembling a stitch. Two such layers are prepared, and a thin layer of CNT web is deposited on the micro structured side. The layers are then kept face to face and joined together. Silver paste on sides acts like electrodes. Higher sensitivity is observed for micro structured PDMS thin film [6]. This process in relatively cheaper than using silicon molds with similar sensitivity.

### Self-healing materials for tactile sensors

Many methods have been developed for making self-healing materials to be used in sensors, which include: thermally reversible materials that on cracking can be healed by exposing it to changed temperature, which in turn diffuses and fixes the bonds. Another method is by using organic solvents, these solvents are applied on cracked or damaged surfaces. It reacts with the surface and re-joins the broken bonds. Furthermore, an autonomous method of self-healing was developed by micro-capsulation of organic solvents which would rupture if any damage is caused and would again react with broken bonds to fix the material [7].

All these materials have some drawback such as external factors, semi-autonomous healing, etc. Another method of self-healing was developed by using supra molecule and micro nickel particles.

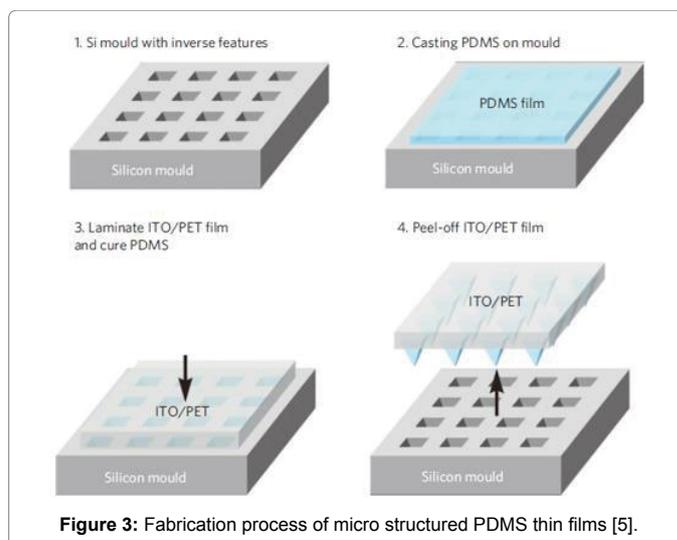


Figure 3: Fabrication process of micro structured PDMS thin films [5].

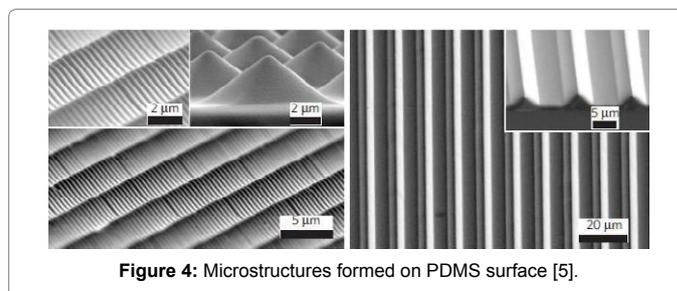


Figure 4: Microstructures formed on PDMS surface [5].

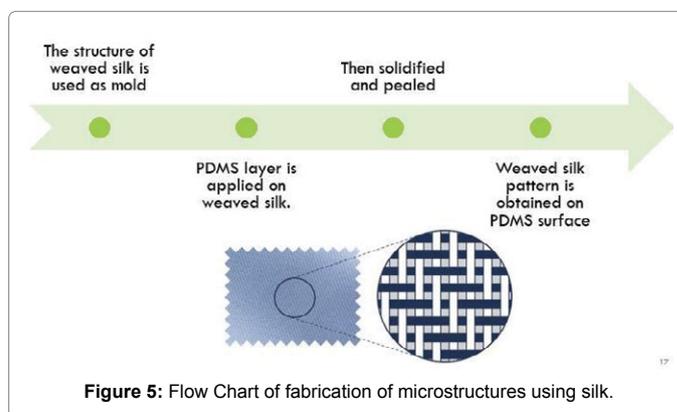


Figure 5: Flow Chart of fabrication of microstructures using silk.

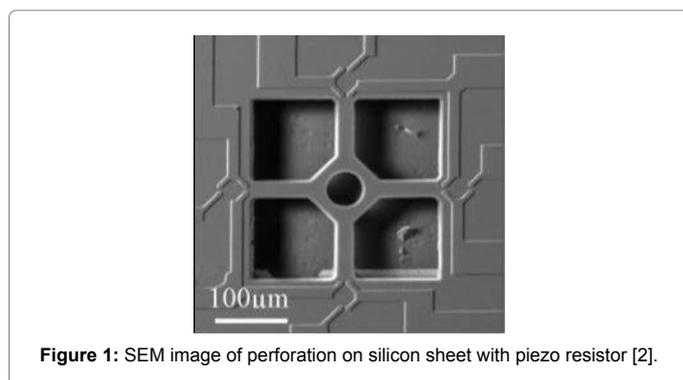


Figure 1: SEM image of perforation on silicon sheet with piezo resistor [2].

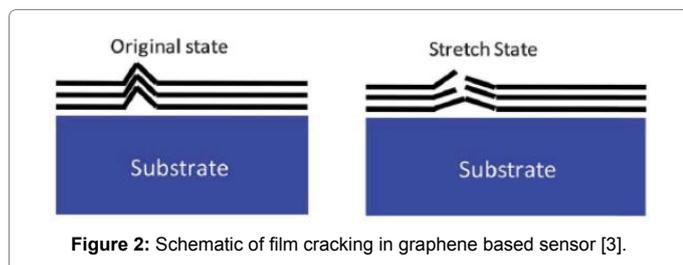
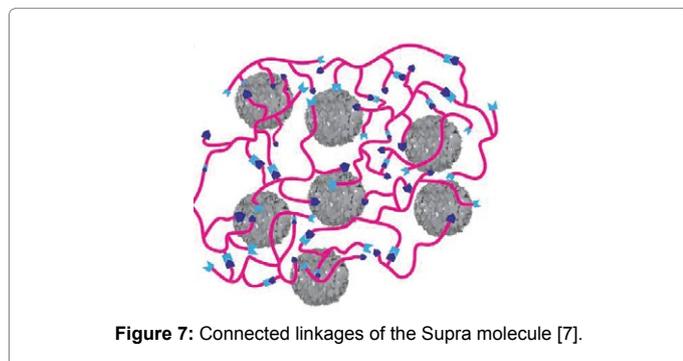
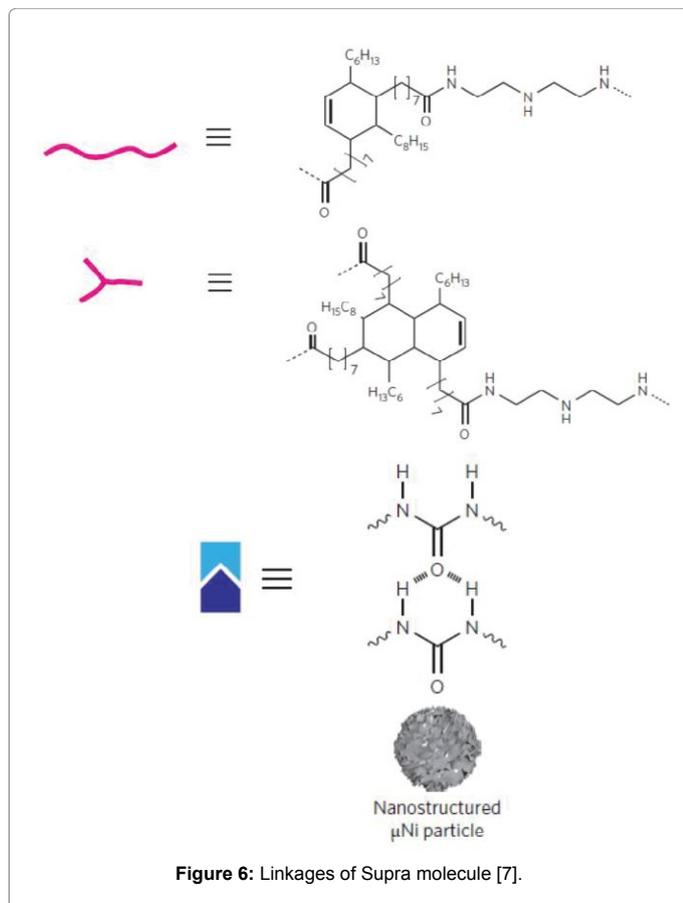


Figure 2: Schematic of film cracking in graphene based sensor [3].

Diethylenetriamine (DETA) is the initial oligomer used. Hydrogen bonding is main key to this self-healing method. Hydrogen bonds between the molecules is reversible, therefore whenever the material surface is damaged the reversible bonds are formed again and the material is healed. But healing with only reversible bonding is not sufficient as it takes time is not full proof. Due to this micro nickel particles are introduced to act like binding agent and provide more hydrogen bonds as well as higher surface area. The micro nickel particles are particularly used as they disperse in supra molecule due to reduced phase aggregation, nano-scale corrugated surface provides more area for wetting, and a thin layer of oxide layer on nickel which increases affinity to hydrogen (Figures 6 and 7) [7].

The material formed is highly flexible and takes very little time to self-heal. More development in self-healing is in progress as it is of high importance for increasing the life of the sensors [7].



## Applications of Tactile Sensors

Bio-medical applications such as use of tactile sensors in Electronic Skin (E-Skin). The E-Skin can be used for people with prosthetics. E-Skin can be fabricated on a prosthetic arm of a person. The impulses obtained upon touching the E-skin can be connected to the neural system of the person. This could allow the person to feel the sensation of touch.

Another major field of application is robotics. Industrial as well as humanoid robots need to be calibrated for applying certain amount force while holding an object. Use of tactile sensors would enable robots to decide what amount of force should be applied while picking a specific object.

Use of flexible tactile sensors would enable development of flexible displays and touch surfaces. Flexible human machine interface could be used.

## Conclusion

The review of all these materials and sensors gives a brief insight into development of tactile sensors in recent times. Tactile sensors are going to be used in all those applications where touch is the primary input method. It is necessary to develop cheaper and reliable sensors which can fulfil all the criteria needed in our applications.

## References

1. Yang T, Xie D, Li Z, Zhu H (2017) Recent advances in wearable tactile sensors: Materials, sensing mechanisms, and device performance. *Materials Science and Engineering: R: Reports* 115: 1-37.
2. Vásárhelyi G, Ádám M, Dücső C, Bársony I, Kis A (2008) Tactile sensing arrays—design and processing. *Information and Communications Technology* 22.
3. Tian H, Shu Y, Cui YL, Mi WT, Yang Y, et al. (2014) Scalable fabrication of high-performance and flexible graphene strain sensors. *Nanoscale* 6: 699-705.
4. Tadakaluru S, Thongsuwan W, Singjai P (2014) Stretchable and flexible high-strain sensors made using carbon nanotubes and graphite films on natural rubber. *Sensors* 14: 868-876.
5. Mannsfeld SC, Tee BC, Stoltenberg RM, Chen CVH, Barman S, et al. (2010) Highly sensitive flexible pressure sensors with microstructured rubber dielectric layers. *Nature materials* 9: 859.
6. Wang X, Gu Y, Xiong Z, Cui Z, Zhang T (2014) Silk-molded flexible, ultrasensitive, and highly stable electronic skin for monitoring human physiological signals. *Advanced materials* 26: 1336-1342.
7. Tee BC, Wang C, Allen R, Bao Z (2012) An electrically and mechanically self-healing composite with pressure- and flexion-sensitive properties for electronic skin applications. *Nature nanotechnology* 7: 825.