New Types of Haptic Sensors for Robotic Applications

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Summary: We show the fabrication and the first measurement results of a new type of pressure force sensor respectively. The concept of the sensor is a fluidic channel with a rigid walls and a deflectable membrane as top cover. On the ground of the channel are four gold electrodes and a electrical conductive fluid is filled in the channel. The impedance is permanently measured between the electrodes and is proportional to the thickness of the fluidic channel above. When a force is applied to the membrane it will deflect and thus chance the diameter, respectively the shape of the channel, which will chance the measured impedance.

Keywords: Haptic Device, Polymer, Micromachining.

1. Introduction

Robots or robotic systems are becoming more and more important in our lives. Their tasks reach from discrete duties, such a single welding process to very complex measuring task with device interactions. It is even more critical to guarantee a safe human-robot interaction. For a safe interaction the robots needs sensors: Sensors to recognise its surroundings and sensors and actuators to interact with its surroundings.

One main task over the last years is the will to give the robot a sensitive touch especially at its “hands”. With this the robot will be able to grip soft or brittle objects without damaging them. In fact the robot will be able to use just the right force to grip a subject and he will recognise with his sensors whether it is wet or dry, slippery or sharp, heavy or lightweight.

As multifunctional as the sensing tasks are, the different used sensors respectively sensorial principals there are available today. In [1] the main used principles are compared with each other and reviewed. The first group of used sensors are the 3D force sensor arrays like they are used by Kim et al. [2] or by Sohgawa et al. [3]. Kim et al use strain gauges and receive a change in the resistance from 1,84 kOhms to 1,76 kOhms at a change of force from 0 to 2 N. Sohgawa used flexible cantilevers and thus the piezoresistive effect. They received an output voltage of 6 mV at a normal stress of 100 kPa.

The second group, 3D force sensors that are not in an array, primary use piezoresistors with similar sensitivity like the ones in the first group. Noda et al. [4] for example measure in a very low force range from 0,05 N to 3 N. These sensors are not in an array, but on special places on the robot. This is useful for moving and driving the robot.

The third group consist of pressure sensors in an array. This is also the group with the most different sensor approaches. They reach from strain gauges by Kim et al [5], over conductive polymer by Yu et.al. [6] and conductive elastomers by Cheng et al [7], to optical systems by Corley et. Al. [8]. They usually cover only a small pressure domain up to 650 kPa by Cheng et al. [7]. The big exception is the work by Wettels et. al. [9], who use a conductive fluid. This fluid is incompressible and so they reach a pressure range from 0,01 to 40 N, which is the highest range so far documented.

The last group, the pressure/normal force sensors not in an array use optical sensors like Heo [10] or Manunza [11] who used organic field effect transistors (OFETs). With these sensors they measure the force or pressure in the low N or kPa range, respectively.

The spatial resolution of all these sensors reach from 0,4 mm to 10 mm or no spatial resolution in the case of single sensors.

In this work a sensor is developed, which has an average spatial resolution, a high pressure/force range and a good independency to the environment. The goal is to use this array at normal room temperature and standard pressure as well as form underwater robotics with several hundreds of bar ambient pressure and temperatures slightly above zero degree. Going on from these characteristics the sensor was designed to use a deformable body filled with in incompressible medium. The chosen medium is an electrolyte, thus water with ions, and the corresponding sensor principle is basically a change in impedance due to the change in shape (see Figure 1).

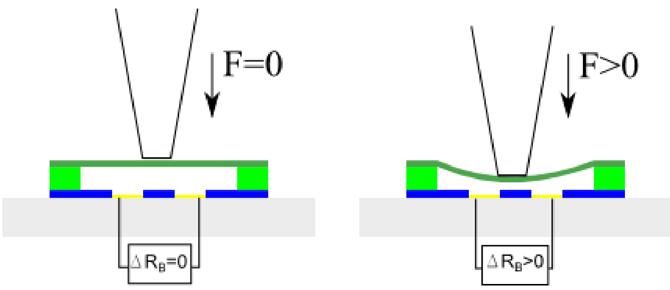

Figure 1. The sensor principle as schematic: Without an applied force, the change in the resistor R_B is 0. When a certain force is applied, the membrane deflects and a change in the resistance between the gold electrodes can be measured.

2. Sensor fabrication

2.1. The fabrication of the "lower" sensor-cell

The fabrication process starts with a single side polished silicon wafer, 525 µm thick. For a later used filling process cavities are etched with a deep reactive ion etching (DRIE) process into the wafer with a depth of 350 µm. After that an oxidation takes place to isolate the later systems from one another. This silicon-oxide layer is 100 nm thick. The next step is the realization of gold electrodes. Therefore a 150 nm thick gold layer is sputtered on a 15 nm thick chromium layer, which serves as an adhesive layer for the gold. This is structured via a gold-etch-plus (a cyanide gold etchant) and an alkaline chromium etchant.

Table 1. Configuration of different EPOCITE-Resin resists.

EPICOTE-type	EPICOTE-part	γ-part	Salt part	Film thickness
1001	10	1	5,39	Up to 10 µm
1002	10	1	5,39	20-63 µm
1002	10	1	8,00	9-16 µm
1004	10	1	5,39	Up to 100 µm

The next functional layers are all made of a negative resist, described by Pai [12]. For all following experiments the rsist is composed out of three different EPICOTE resins, gamma-butyrolactone as a solvent and trialylsulfonium hexaflouroatimontae salts as a photosensitive component. Table 1 show the different mixing parameters used.

The wafer needs to be conditioned in a barrel etcher for 30 seconds in oxygen plasma which promotes the adhesion of the 1002F resin. It is spun onto the wafer for a homogeneous layer of about 20 µm thicknesses (parameters shown in Table 2. It is structured via UV and developed by MR DEV 600 developer. After development it is heat treated for 1 hour at 80°C to stabilize the resin.

Table 2. Process parameters for EPOCITE Resin-layers.

Type	Step	Acc.	Speed	Time
		[rpm^2]	[rpm]	[s]
1002F				
	1	15	500	20
	2	10	4500	45
	3	15	300	5
1004F				
	1	15	500	20
	2	15	1150	45
	3	15	300	5

The resin layer is structured in a way that the area above the structured electrodes is not covered (see Figure 2 A). The next step is the realization of the fluidic chamber and channel. Therefore the wafer is again prepared in oxygen plasma for 30 seconds. After that the next resin layer is spun with a thickness of 100 µm of 1004F resin with the parameters shown in Table 2 and receive an intermediate result like show in Figure 2 B.

2.2. Fabrication of the cover membrane layer

The processing of the covering layer starts on a second separated wafer. After oxidation a layer of E 8015 dry resist is laminated on the wafer. The dry resist is 38 µm thick and has a protection layer of polyester on the upper and lower side. The downside polyester is striped of during the lamination process while the upper side a left on the dry resist. The resist is flood exposed and serves together with the polyester layer as an intermediate layer for the further processing. Onto this layer the next resin layer is spun on. This is going to be the covering layer so the thickness of this one is about 20 µm. This layer is heat treated like in a softbake but not jet exposed.

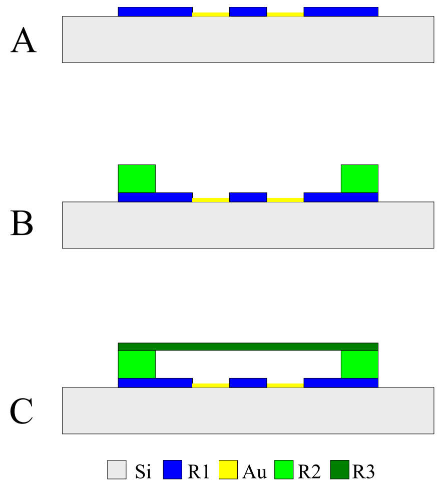

Figure 2. Main process steps for the sensor fabrication:
A: Oxidized silicon wafer with chromium/gold electrodes buried in the first EPOCITE resin layer (R1).
B: second EPICOTE resin layer (R2) to form the fluidic sensor chamber.
C: Cover membrane out of the third EPICOTE resin (R3), which has been transferred from the handling wafer.

Due to the flood exposure of the dry resist in the beginning, it is now very easy to strip the polyester layer together with the resin layer of the second handling wafer and to laminate it onto the first wafer. Together with the polyester foil it is stable enough to bridge the gap in the fluidic chamber or the channel, respectively. This layer can now be structured via a UV mask, just like the layers before. After the UV exposition the stack is baked in a conventional oven at 80°C for 60 minutes. Then the polyester layer can be deducted from the resin and the resin layer can be developed. The result is an overstretching membrane cover for the chamber or channel, respectively (see Figure 2 C)

2.3 Filling up the channels

The next step is to fill up the channel with an electrical resistive fluid. For a faster and better filling process, 13 single cells are connected with a fluidic channel, so that they are in a row (detail in Figure 3). Previous to the first cell, there is a filling area under which are the DRIE etched holes. These areas are also past the last cell. The conductive liquid is filled into a syringe with a small injection needle. The resin layer is punctuated in the area of the first DRIE etched holes and after the last cell. The liquid is now pushed out of the needle into the DRIE holes and thus into the fluidic channel. Due to the pressure and due to the capillary effect the whole cell row will be filled up with the liquid. After the filling, the needle is removed and the holes in the resin layer are closed. It is essential, that the filling is bubble free; otherwise the measurement would be corrupted.

3. Measurement

3.1. Setup

For the measurement an unbalanced Wien bridge with oscillator frequency of 5 kHz and a voltage of 5 Vpp is used. For signal recording and later analysis a NI-USB-6229 data acquisition device (a multichannel A/D converter) controlled by a LabVIEW program is connected to the cells via wire bonding.

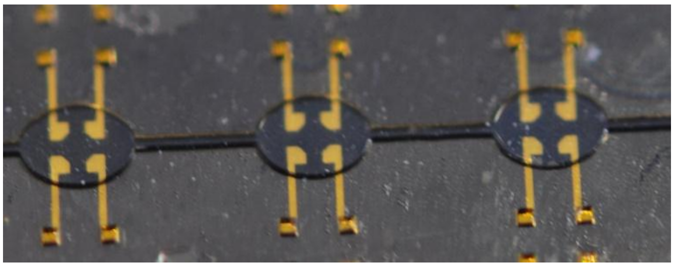

Figure 3. Three sensor cells connected through a micro-fluidic channel.

A solid cage with a holding for a controllable piezo actor (PI-601.1SL [13]) was constructed. This actor is mechanically connected to a solid indenter, which is placed shortly above the cover membrane of the device under test. With the actor the membrane is deflected reproducibly with a certain track and with a certain frequency. By deflecting the membrane the profile of the area of the chamber above the electrodes is chanced. This leads to a change in the measured impedance between two electrodes and is used as the sensor output signal.

The results of the first measurement are shown in Figure 4: At the beginning the membrane is not deflected and the normal bridging voltage is about 875 mV. Then the actor is operated to deflect the membrane. The track is 90 µm and the bridging voltage get up to 938 mV. After one second the actor is moved to its initial position and the single falls back to 875 mV. This is repeated several hundred times and the lift in the bridging voltage stays the same.

The presented measuring results are raw data only, thus neither electrical amplification nor filtering is yet implemented. In a later state the use of those will even enhance the results.

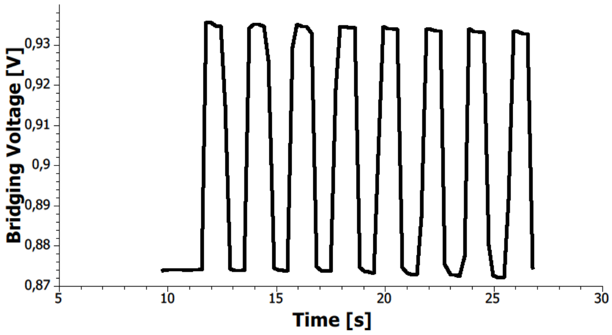

Figure 4. First measured sensor signals. Shown is the voltage from the used Wien-bridge which is not harmonised on purpose.

4. Conclusion

This paper describes the manufacturing process and characterization of a novel pressure/force sensor fabricated in EPICOTE-resin. The measure principle utilizes the change in electrical resistance between electrodes, evoked by a deformation of a liquid filled chamber. The changes in resistance measured with an unbalanced Wien bridge are found to be reproducible and proportional to the applied force.

Future work will concentrate on adapted electronics, long term stability and further minimization.

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