

Novel Coplanar Capacitive Force Sensor for Biomedical Applications: a Preliminary Study

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Abstract. Nowadays the world of sensors is gaining a primary importance in the electronics field, thanks to the boom of the smartphones and IoT market. Capacitive sensors are widely involved in the most of applications, from the biomedical to the gaming industry, and they can sense a wide variety of physical quantities. In this work we focused on force sensing capacitive sensors, trying to mix two of the most in-fashion markets, sensors and polymers. Polymers industry is constantly growing and, by the constant synthesis of new bio-based molecules, it will quickly enter the most of the technology markets. We made a soft capacitive force sensor, by inserting a coplanar capacitor in a polymeric wafer structure. The involved technology is derived from the touch-sensing technique, usually involved in appliances' user interfaces. This sensor is easy to make and cheap, and it was tested with a force of 1 N. It is waterproof and non-sensitive to moisture variation in the outer environment. It shown a sensitivity of 172 fF/N, with a resolution of 80 mN. As it is only a preliminary study, more investigations are needed in order to obtain a deeper characterization versus different environment conditions and with higher force stimuli. It will be also relevant to evaluate the behavior of the sensor by using different polymers.

Keywords: force sensor, coplanar capacitive sensor, biomedical.

1 Introduction

1.1 State of the art

Knowing force or pressure level is a key feature in many applications, from the manufacturing to the biomedical, through the gaming to the smartphones. A well knowing of this physical quantity has a fundamental relevance in many fields, it can help the success of a surgery as well as improving the gaming experience of a player. The ways to obtain this information are many. Sensors employ different physical principles for this purpose, capacitance, piezo resistance, diffraction and many others. Piezoresistive sensors were the most used but, for their temperature-dependent response and a lower resolution, their getting supersede by capacitive sensors. Furthermore, capacitive touch-

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sensors are making their fortune because of their wide application in consumer electronics. Capacitive sensors technology is growing also in accordance to the great progress of the polymer industry. The continuous introduction of new bio-based polymers is pushing the sensors' industry to another level, adding lot of new possibilities, starting from biology. For example, for intraocular pressure measuring (IOP) [1], graspers for surgery [2], robot assisted single cell microinjection [3], as human tactile receptors simulators[4] and many others. They are also used in the manufacturing field as next generation contact detection for prevent operators' injuries, for example, when working with co-op robots.

They are also more involved in consumer fields, as gaming, gesture recognition and augmented reality controls [5].

Standard capacitive sensors inherit their working principle from their structure, force sensing capability is directly related to their 3D assembly. Nowadays the making of 3D structures is not that difficult as it was 10 years ago, thanks to the rapid improvement of the additive manufacturing techniques [6][7][8]. This however requires a 3D printer capable to deposit layers with high dimensional precision on all the 3 axes, that requires a high-level printer which is very expensive.

Additive manufacturing is not the only technique for making non-planar structures. Also screen printing can be involved for this kind of purpose, but it requires expensive machines and a complicated process [9].

1.2 Coplanar Capacitors

This research aims at moving towards less difficult processes, reducing the method complexity and then, the most important, the overall costs. How to obtain the same capacitive sensors performance, without using their peculiar 3D structure? Again, the consumer electronics market drives the choice. Since around 2007 we are facing a proper boom of the touch-sensing technologies, in all the fields in which a human-machine interface (HMI) is needed. The touch sensing technique is based on different physical principles which could consider, variations of resistance, capacitance, SAW (surface acoustic waves) path perturbations and many more [10]. In the early designs these interfaces were made with resistive touch panels. Unfortunately, they were sensitive to temperature variations and not very accurate. There was also a problem in the dimension of the minimum feature size. Later, capacitive touch screens replaced resistive because of their lower cost, independence from temperature variations and accuracy/sensitivity. It was also easier to make the sensing matrix thicker to improve the spatial resolution. Nowadays this technology reached its maturity thanks to the wide employment in the consumer and manufacturing markets, with also the addition of different features as force touch or 3D touch. These additional features permit to obtain a value of the applied force but are very complex to implement.

For resolving this fabrication difficulty, we tried to mix the coplanar capacitor solution with polymers.

First of all is necessary to explain how a coplanar capacitor work.

Think about standard parallel plates capacitor, the electric field is confined between the two plates and a minimum part of it will leak out because of the fringing effect.

Putting the plates on the same plane, we deform the area in which the electric field is confined, and we shape it as a “U”. A basic schematic representation is depicted in Fig. 1.

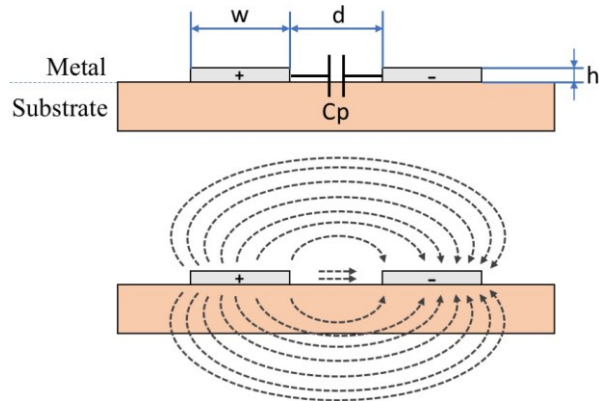


Fig. 1. Basic coplanar capacitor principle.

Because it is very difficult to quantify the fringing effects, we should impose that the standard path of the field lines will be curved. There is a better and deeper explanation of this principle in [11]. These capacitors are then characterized by a dual side field. This particular feature will be an advantage or not based on the application. In this case this kind of behavior is un-wanted. The way to remove this effect is to add a ground plane on the opposite side of the plates. This method also helps to increase the low intrinsic capacitance value adding to the original C_p the capacitance of the ground plane.

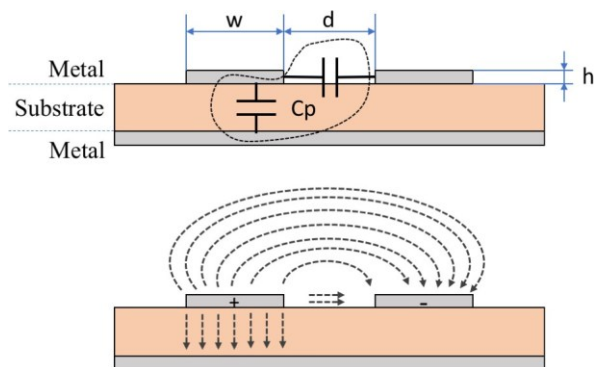


Fig. 2. Coplanar capacitor with the addition of the ground plane. This helps to increase the intrinsic capacitance value.

A coplanar capacitor, for its nature, senses the variation in the surrounding environment. Approaching it with the fingers, it will measure a sensible variation in the capacitance value. What happens if the capacitance variation will be linked to the distance from the capacitor by a well-known amount? How can we relate the variation of the distance q in Fig. 3 to the total capacitance seen at the capacitor heads?

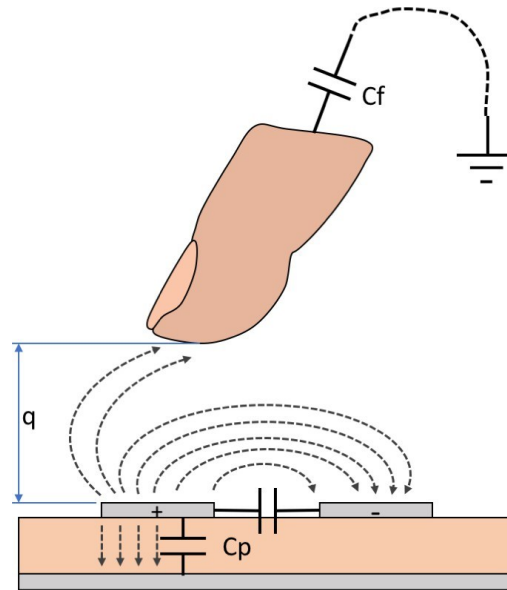


Fig. 3. Coplanar capacitor measure when approaching with a finger

The solution will be the insertion of something with a fixed elastic coefficient, with a low shape memory. Polymer industry comes to help us. With the insertion of a polymeric layer between the finger and the capacitor, we can link the capacitance variation to the applied force.

2 Sensor fabrication and preliminary tests

2.1 Sensor fabrication process

The sensor is fully biocompatible and suitable for biomedical environments in a wide variety of fields of application. It is shaped as an interdigitated spiral, as shown in Fig. 4, with a maximum radius of 8.5 mm in order to increase its sensitivity to the applied force. The sensor is made as a wafer of four different layers, two externals made by ethylene vinyl acetate (EVA) for the enclosure, a central made by poly vinyl siloxane (PVS) and the polyimide flexible layer with the copper plates.

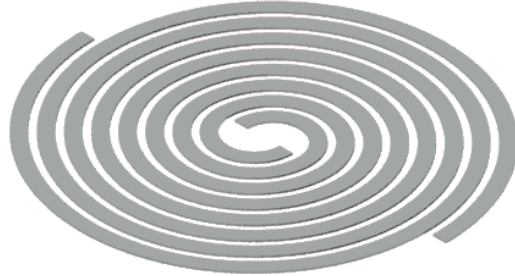


Fig. 4. Coplanar capacitor spiral design. The outer diameter is 8.5 mm, the path width is 0.203 mm separated by a 0.1778 mm gap to each other.

The structure is fabricated through a thermoforming process. A sensor representation is shown in Fig. 5. The sensing flexible area is 130 μm thick and the total height of the sensor is more or less 4.25 mm.

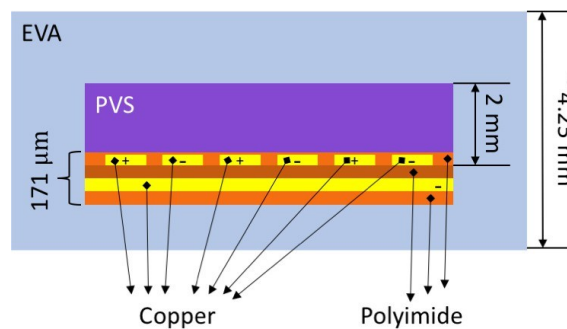


Fig. 5. A section of the sensor. The thicknesses are, copper 35 μm , polyimide 25 μm , PVS 2 mm and EVA 4.25 mm. EVA's starting thickness is 1.5 mm, but after the thermoforming process it lowers its width of the 25%.

The PCB design of the sensing part is made to prevent the interaction of the environments to both sides, making it sensitive only to a one-side force application.

2.2 Sensor preliminary test

Once the first prototypes have been built, shown in Fig. 6, they have been tested with an INSTRON® 3366 machine attached to an HP4194A impedance analyzer. In Fig. 7 are then reported trials results over time and a first capacitance over force characterization in Fig. 8. The sensor reported a sensitivity of 172 fF/N, a resolution of 80 mN and low zero drift, in the order of the units of fF. There is also a hysteresis in the order of 20 fF. These parameters are obtained through a first order linearization with a $R^2 = 0.9798$. In Fig. 7 are reported three different runs of the test, Test1 and Test2 are obtained keeping the INSTRON tip in the center of the sensor, Test3 is indeed obtained

moving it on the edge of the sensing area. There is a lowering in the sensitivity of the sensors, making it also sensitive to the position of the force application. This could be employed also for tracking the position of the force application point. Further investigations are now needed in order to achieve a more accurate sensor characterization.

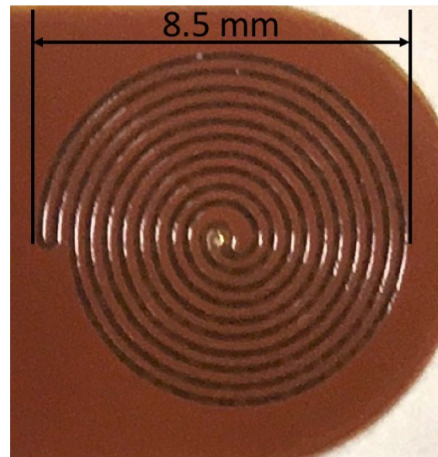


Fig. 6. Flex PCB of the first prototype of the sensor.

3 Conclusions

In this work a coplanar capacitive force sensor had been developed and preliminary tested. The overall system is fabricated by the mixing of two of the most relevant fields in the actual market, capacitive sensors and polymers. It reported a good response in terms of capacitance over force variation and further developments are needed to improve this value. The sensing element is made with standard flexible PCB techniques in order to reduce the production costs. The polymers involved in the process are all bio-compatible and low cost. Finally, the sensor reported a sensitivity of 172 fF/N and a resolution of 80 mN.

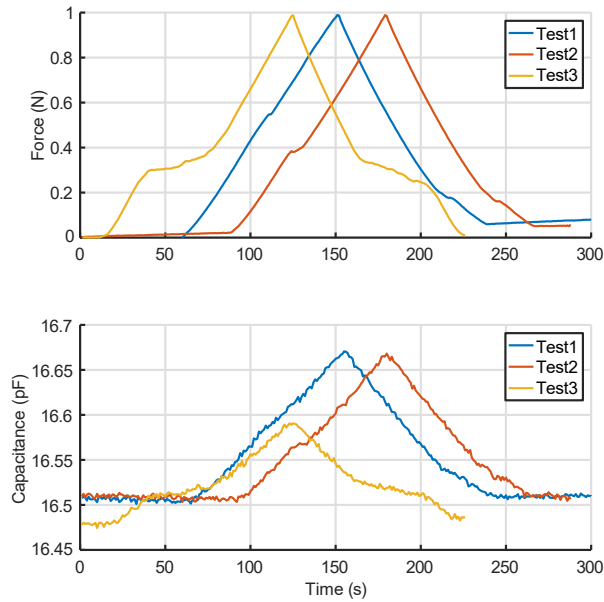


Fig. 7. The INSTRON reading versus time on the top, on the bottom the sensor reading versus time. There are three different tests, Test1 and Test2 are made positioning the test tip in the center, the Test3 is made moving the tip to the outside.

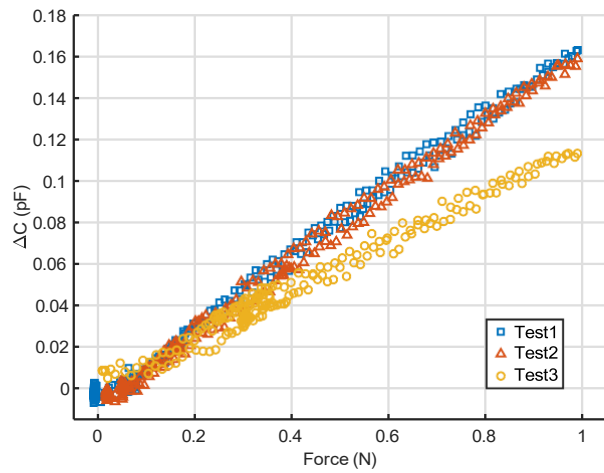


Fig. 8. Capacitance over Force variation. Test3 curve is different by the others because the test tip was moved on the border of the spiral, instead of the center as in Test1 and Test2. There is a decrease in the sensitivity moving from the center.

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