Full-Body Silicon Medical Tweezers for Cancerous Tissue Detection and Characterization

Connie Wu
Electrical Engineering and Finance, University of Pennsylvania

NNIN REU Site: Cornell NanoScale Science and Technology Facility, Cornell University, Ithaca, NY
NNIN REU Principal Investigator: Prof. Amit Lal, Electrical and Computer Engineering, Cornell University
NNIN REU Mentor: Po-Cheng Chen, Electrical and Computer Engineering, Cornell University
Contact: wuconnie@seas.upenn.edu, amit.lal@cornell.edu, pc445@cornell.edu

Abstract:

We designed and created the first prototype of a full-body silicon surgical tool for detecting and characterizing cancerous tissue. From literature, it had been shown that tissue elasticity and electrical permittivity have been promising non-optical markers for identifying cancerous tissue [1]. Because of the advantages of micro-fabrication technology, a full body silicon device in a tweezer structure was designed and employed with numerous sensors. Strain gauges were used for tissue elasticity by monitoring the insertion force, and the platinum wires were designed for tissue permittivity measurements. Additionally, the platinum electrodes have the capability of electrical physiology signal measurements. Strain gauge resistivity measurements were performed to verify the performance of the tweezers and feasibility for future medical applications.

Introduction:

If a surgeon were to staple bad tissue into the affected site during a colon anastomosis, there is a high chance of intestinal leakage and subsequent high risk for the patient. Our goal is to design a medical tool that can help surgeons distinguish abnormal tissue from normal tissue. The full body silicon tweezer with several different sensors on it can provide assistance for the doctor during operation. The tweezer structure is easily accessible to surgeons, and since the body is constructed from a continuous piece of silicon, it allows for flexibility in integrating sensors and CMOS circuitry for more function, such as wireless transmission of measured signal.

Experimental Procedure and Process:

The device structure was designed using L-Edit and Matlab code that can automatically generate Caltech Intermediate Format (CIF) files with parameter alteration capability. The structural parameters included the hinge radius, hinge thickness, leg length, leg thickness, hinge beginning angle, hinge ending angle, and inter-probe distance.

The first prototype design had a hinge radius of 8000 μm, leg length of 4 cm, thickness at the hinge of 400 μm, and leg thickness of 1000 μm. The tweezers were laser cut for structural testing, during which it was verified the tweezers inter-probe distance could deform at least 5000 μm.

In a COMSOL simulation, it was found that the point of maximum stress at 80.7 MPa was at the apex of the hinge, while the normal stress fracture of silicon was around 1-3 GPa. Four probes were placed on each leg of the tweezers and finger holders were placed along the mid-section of the legs. Each probe had a Wheatstone bridge strain gauge at the cantilever junction. In the eight probes, the strain gauges resistors were realized with LPCVD polysilicon implanted with boron at a dose of 2×10^{15} ions/cm^2 at 100 keV. The sheet resistance of polysilicon was ~ 185 ohms/□. The resistors were electrically contacted with aluminum alloy (Al + 1% silicon) metal lines. Insulating PECVD nitride was deposited, followed by platinum evaporation to define electrical recording sites and permittivity sensors. The device layers are depicted in Figure 1.

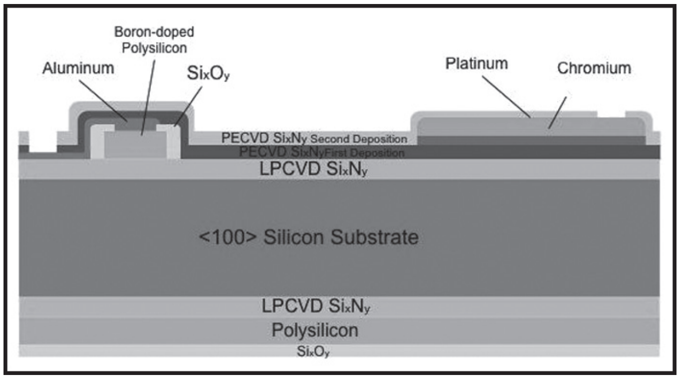

Figure 1: Fabrication layers of the tweezers.

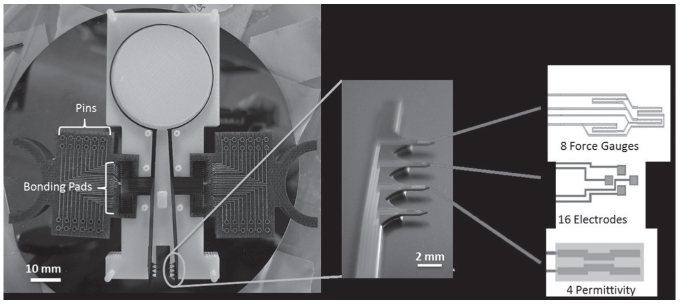

Figure 2: Assembled tweezer device with holder.

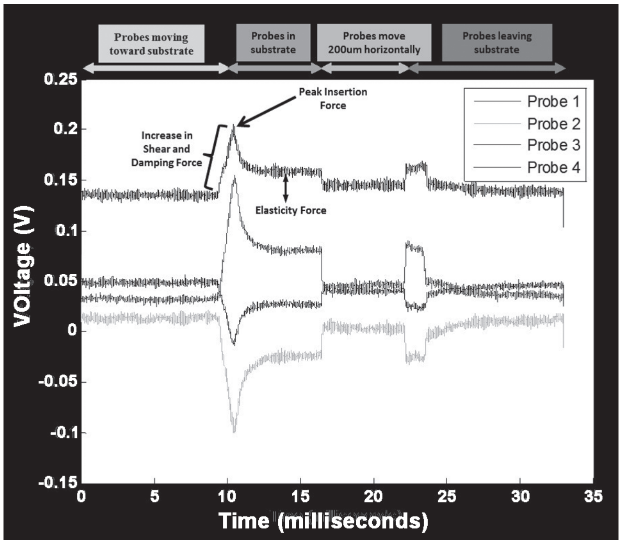

Figure 3: Probe force gauge output at 3000 µm/s insertion speed with horizontal movement of 200 µm.

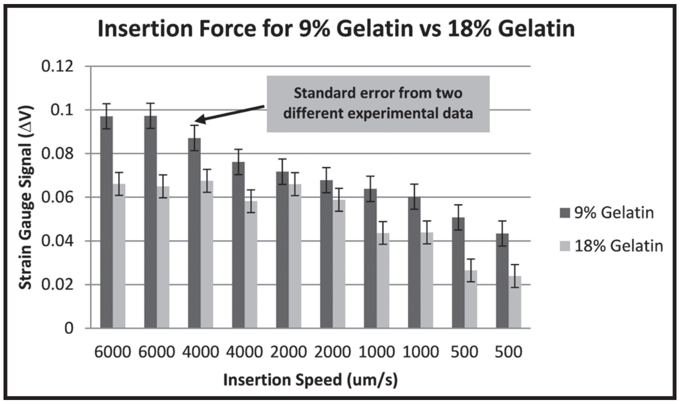

Figure 4: Probe signal from gelatin concentration change.

All of the sensors were connected to the 56 bonding pads located in the finger holders (Figure 2). These bonding pads were wired to a PCB board with pins for testing. The strain gauge pins were connected to a differential amplifier with a gain of 200 that transmitted probe voltage signals to LabView.

Results and Conclusions:

The full body silicon medical tweezers included eight strain gauges, four sets of platinum wires and sixteen platinum electrodes (Figure 2). To test the spring constant of the tweezers, one leg of the tweezers was fixed while the other was displaced horizontally. COMSOL estimated that the spring constant would be around 2 N/m while the empirical result yielded a spring constant was 9 N/m. To test the strain gauge signals, four probes were positioned 8608 μm vertically above 6% gelatin mixture and preset to a 6000 μm/s insertion speed for the control experiment. To get the insertion force signal, we calculated the difference between the signal levels from before the probe is inserted into the gelatin and after it penetrates the sample surface (Figure 3).

Four parameters were altered: insertion speed, insertion height, insertion direction, and gelatin concentration. The results from the experiments indicated that insertion force increased with insertion speed by ~ 15% for every 1000 μm/s increase in speed. Insertion height was found to be negligible when insertion speed was controlled. Whereas the insertion direction in which the substrate was normal to the force gauge had a larger signal change than when the probe tip was normal to the substrate.

An increase of gelatin concentration from 9% to 18% decreased the insertion force by an average of 28% (Figure 4). The strain gauge data profile showed some promising indicators for tissue properties such as a peak for initial insertion force, a second level of height for the tissue elasticity force, and a low reading for when the probe had left the tissue.

Future Work:

Next, we will create a case for the tweezers so that the structure can be durable during surgical usage. Furthermore, more tests will be conducted on healthy tissue versus cancerous tissue to better characterize the force gauge readings. Also, to more comprehensively characterize the tissue samples, the electrodes and capacitors will also be tested and calibrated for usage.

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References:

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[2] P.-C. Chen. "Ultrasonic Neural Probe for Real Time Electromechanical Histology of Neural Interfaces," (Hilton Head 2012).