Fabrication of MEMS Using Cheap Substrates

Ryan Gaudreau

Engineering Science, Stony Brook University

NNIN REU Site: Howard Nanoscale Science and Engineering Facility, Howard University, Washington, DC
NNIN REU Principal Investigator: Dr. Gary L. Harris, Electrical Engineering, Howard University
NNIN REU Mentor: Dr. William L. Rose, Electrical Engineering, Howard University
Contact: ryan.gaudreau@yahoo.com, gharries@msrce.howard.edu, wbullrose@gmail.com

Abstract:

The objective of this project was to create microelectromechanical systems (MEMS) using paper as the substrate and piezoresistive carbon ink to create a device that was sensitive to force. The idea behind this approach was to minimize cost and maximize ease of production. To achieve our objective, we used a paper cantilever design to correlate the relationship between force and change in resistance of the device, and subsequently the relationship between current and applied force. Our results showed a linear relationship. The next part of the project required us to apply this relationship to create a useful device. We opted on creating a microphone made from paper and the piezoresistive material. This was based on the fact that the relationship between force and resistance would facilitate the modulation of current in much the same way as the moving coil in a magnetic field in a conventional microphone. We were able to successfully accomplish our goals after several designs were tested and optimized.

Introduction:

Microelectromechanical systems (MEMS) are becoming increasingly popular. MEMS are used today in many fields, from biotechnology, medicine, communications, to inertial sensing [1]. In an attempt to decrease cost and time of production, paper-based MEMS are now being researched as a cheap alternative [2]. A paper MEMS device does not require a clean room, takes less than an hour to make, and cost only cents to produce. These attributes make them very attractive.

Our project sought to use a piezoresistive material on a paper substrate in order to create a practical device. Our project was divided into two parts. The first part sought to examine the relationship between force and change of resistance/current on the piezoresistive material, and then in the second part, apply this in a practical way. We decided we could use the properties of the device to build a paper microphone.

Fabrication and Experimental Procedure:

The first part of our experimental procedure required us to design paper MEMS to test and correlate the relationship between force and resistance of the piezoresistive material. To do this we used the drawing software Corel Draw X5 to design cantilever systems. We then used an Epilog Helix Laser to cut the devices out. Carbon-based piezoresistive paint was applied to the device and allowed to dry, followed by a silver based conductive paint. A Wheatstone bridge was constructed on a breadboard to precisely measure the resistance of our device.

The MEMS was fixed onto a mounting device that slowly lowered the cantilever of the MEMS onto a precision balance, applying a measurable force. Applying force to the cantilever put force on the piezoresistor, therefore changing its resistance and causing current to flow through the ammeter. The adjustable resistor was then manipulated until the current read zero. The resistance of the adjustable resistor could then be read using a multi meter. Using the equation for a Wheatstone bridge, the resistance for the MEMS could be found and thus correlated to force.

We tested several single cantilevers and double cantilever designs applying the force and varied distance from the piezoresistive material (Figure 1). We were thus able to establish a relationship between the force and resistance, and consequently, current.

For the second phase of our procedure, we used the same fabrication process as above to design and cut out our piezoresistive paper microphone. We tested several designs to first create a working microphone and then to optimize it. A basic microphone circuit was made using a capacitor, resistor, the paper microphone, a signal wire to connect to a speaker, and a ground wire. The setup consisted of fastening the samples to a rigid cardboard frame. Once attached, the samples were tapped and spoken into to test their effectiveness.

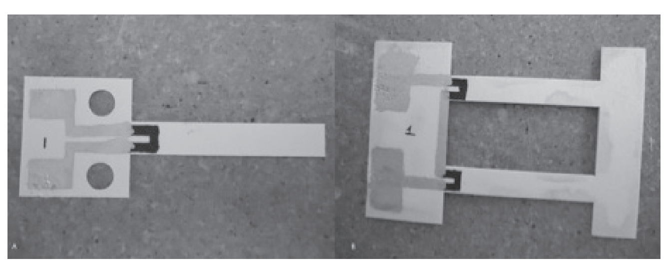
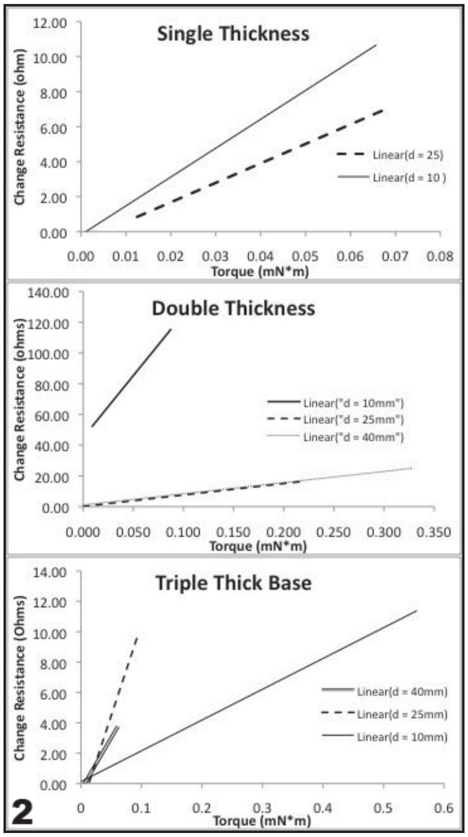


Figure 1: Single and double arm cantilever design.



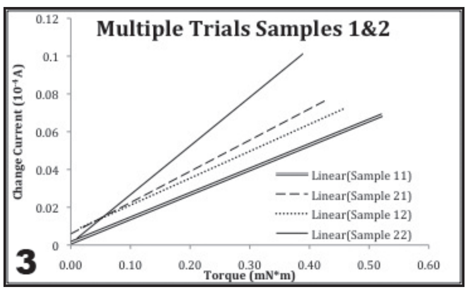


Figure 2, top: Graphs of torque vs. resistance for single arm cantilever for different thicknesses of the cantilever.

Figure 3, bottom: Double arm cantilever trials testing two samples' change of current vs. torque.

Results and Conclusions:

The results from tests done on the single cantilever system showed a linear relationship between force and resistance within our testing range. We found that making contact with the cantilever closer to the base gave the most linear reading, greatest range, and highest resolution. It was found that increasing the base stiffness increased the resolution and gave a more linear reading, but not by a significant amount. When we doubled the thickness of the entire MEMS, there was significant improvement in force range, and linear readings were observed at all tested distances (Figure 2). Upon testing the double arm cantilever, we found that a double thickness design of this model also provided the greatest range and sensitivity. This model was using force as a function of both current and resistance, and linear results were found for both. Figure 3 shows the results for the change of current vs. force test.

We were able to design and construct a paper piezoresistive microphone. Many designs were tested in order to optimize the device and produce the desired results. At first, only taps could be faintly heard through a speaker. We optimized our design even further and then connected to an amplifier. We were then able to clearly distinguish words, proving that the principle works. Upon further design modifications, the microphone was able to transmit music clearly (Figure 4). Further areas of research on this idea would be to condense the sound, diminish background noise, and decrease the size.

Acknowledgements:

I would like to thank Dr. Gary L. Harris and Dr. William L Rose, as well as the rest of the research group at Howard University. I am also thankful to the National Nanotechnology Infrastructure Network Research Experience for Undergraduates (NNIN REU) Program, and the National Science Foundation.

References:

[1] www.memsnet.org

[2] Xinyu, L., et al., "Paper-based Piezoresistive MEMS sensors"; Lab/Chip, 2011, p2189-2196.

[3] www.sensorland.com

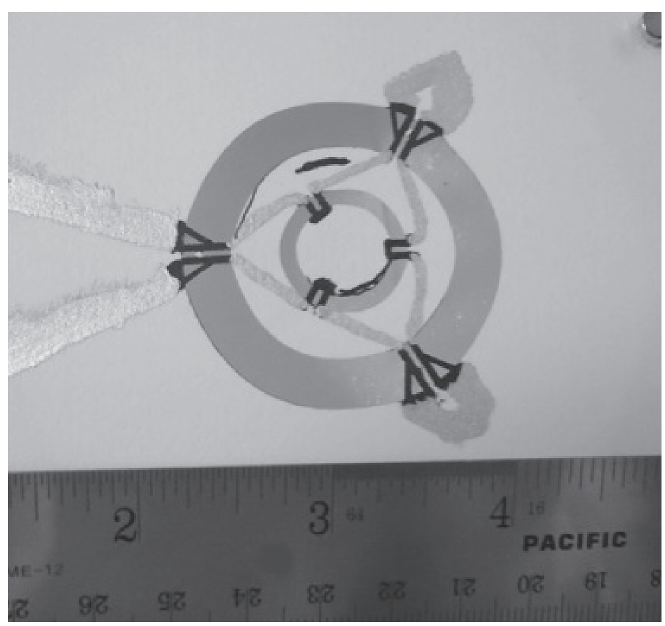


Figure 4: Final working model of the paper microphone.