Characterization of MicroElectroMechanical Systems (MEMS) Flow Channel (May 2009)

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Abstract— MicroElectroMechanical System (MEMS) devices are integrations between mechanical engineering, electrical engineering, and microelectronic engineering. There are many different applications for MEMS such as micro mirrors, pumps, nozzle, and a plethora of sensor types. The Microelectronic engineering department at Rochester Institute of Technology offers a class in MEMS. Within this class, many MEMS applications are further studied and created, one being a gas flow sensor. In 2008, George Manos created a packaging fabrication process for the RIT flow sensor for further future analysis. Along with the use of the package, Dr. Lynn Fuller and Jessica Marks created the tested sensors. Through fluidic and geometrical analysis the flow channel can be modeled such that input pressures can be correlated to channel dimensions and desired flow out of channel. Furthermore, predicted models of varying channel sizes and flow rate were modeled with 2% to 30% error from experimental and modeled results.

Index Terms—**Microelectromechanical devices, Graphical User Interface, Standard cubic centimeters per minute, and Fluid flow.**

I. INTRODUCTION

Micro-Electro-Mechanical Systems are a relatively new technology application. Micro-Electro-Mechanical Systems are actually an expansion of an early technology referred to as micromachining. Micromachining started around 1982 for the purpose of designing and fabricating micromechanical parts such as pressure sensors, accelerometers, flow sensors, etc. [1]

Micromechanical parts are fabricated by using varies etching techniques for selectively etching specific area within the silicon substrates. By doing this selective etch, all that remains are the most wanted geometries. There are two main etching techniques used for micromachining, isotropic and anisotropic.

Micro-Electro-Mechanical System (MEMS) devices are an integration between mechanical engineering, electrical engineering, and microelectronic engineering. The Microelectronic engineering department at Rochester Institute of Technology offers further education about this topic in a MEMS class. During the studies of this class there are projects on some applications in which MEMS devices can be used such as micro mirrors, pumps, nozzle, and a plethora of sensor types. Many MEMS applications are further studied and created, one being a flow sensor.

Currently with this package and the design of the flow sensor the output that the user receives is in voltage. Realistically, flow of any material is not in units of voltage but rather a distance over a time (i.e. standard cubic centimeters per minute, sccm). However, through experimental setup a flow rate can be found along with an input pressure. To insure accurate readings a Matlab Graphical User Interface (GUI) has been created to combine both fluidic and geometrical analysis to ensure proper measurements have occurred. Furthermore, the geometries of the channel can be inputted values within the modeling such that future sensor package and channel designs can be simulated before any creation has occurred.

II. THEORY

The basic flow sensor that has been created here at RIT consists of three resistors, the upstream resistor, the heating resistor, and the downstream resistor, as shown in figure 1.

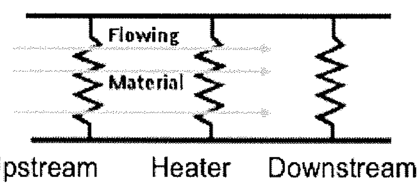

Figure 1: Sensor schematic

As the flow begins the resistance of the upstream resistor reduces and the resistance of the downstream resistor increases. By the given placement of the resistors the output voltage can be calculated such that the device is treated as a voltage divider. This voltage shift therefore is correlated with the flow rate.

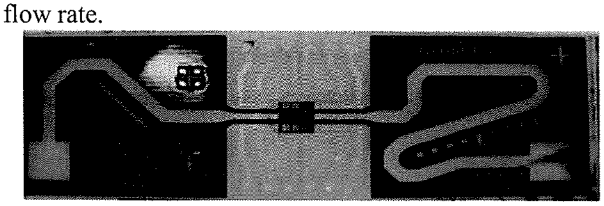

Figure 2: Flow Sensor Package

Figure 2 is the final packaging of the device. The packaging is such that the input flow is carried through a 2mm by 150um channel until the flow reaches the sensor. As shown in figure 3 the channel size directly above the sensor is 1mm by 150um. Therefore through these dimensions and through a combination of geometrical analysis and fluidic analysis the

channel can be modeled.

The following are a series of equations [1] that were manipulated such that the modeling could occur:

$$\left.\frac{\partial N}{\partial t}\right|_{SYSTEM} = \frac{\partial}{\partial t}\int_{C\forall} \eta\rho\, d\forall + \int_{CS} \eta\rho\vec{V}\cdot d\vec{A} \quad (1)$$

Reynolds Transport Theorem

$$0 = \frac{\partial}{\partial t}\int_{C\forall} \rho\, d\forall + \int_{CS} \rho\vec{V}\cdot d\vec{A} \quad (2)$$

Conversation of Mass

$$\sum F_{EXT} = \frac{\partial}{\partial t}\int_{C\forall} \vec{V}\rho\, d\forall + \int_{CS} \vec{V}\rho\vec{V}\cdot d\vec{A} \quad (3)$$

Newton's 2nd Law

$$\frac{P_1}{\rho} + \frac{V_1^2}{2} + gZ_1 = \frac{P_2}{\rho} + \frac{V_2^2}{2} + gZ_2 \quad (4)$$

Bernoulli's Equation

There were simplifications and assumptions that were necessary to accomplish the analysis, such as quasi steady state, which means that although there is constant flow at any given time the area under observation, can be treated as a steady state. Through this assumptions the control volume integral for Reynolds Transport Theorem, Conversation of Mass, and Newton's 2nd Law can drop out for easier calculations.

III. PLANNED PROCEDURE

As mentioned before both a sensor and a package are necessary for the analysis. A fellow student, Jessica Marks, created the sensor earlier this year, which she allowed to be use for the analysis. However, the packaging still needs to be created which through the help of Dr. Fuller could be accomplish.

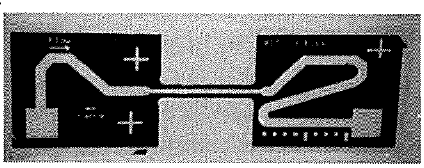

Figure 3: Photoresist pattern for channel formation

Figure 3 is one layer of the photoresist, which is used to create the channel. To achieve the 150um channel height three layers of this resist pattern were used. The process that was used to accomplish this and the whole packaging were Dr. Fuller's PowerPoint and process flows titled *Make Copper Board* and *Imageon Ultra Rapid Dry Film Resist*. Through using these step-by-step PowerPoint slides the package was created.

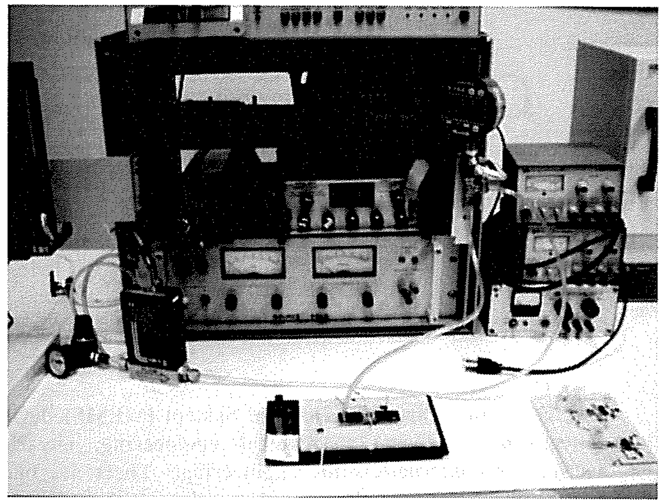

Figure 4: Experimental Setup

Figure 4 here is the experimental setup for testing the device. After the packaging was created, testing was done to verify my modeling simulations. The setup of the experiment was with an air input hose connected to a mass flow controller then through a gage that led to the device. With this setup a desired flow rate dialed into the controller and have a measurable pressure along the channel.

IV. OBSERVATIONS AND RESULTS

In this project the data that needed to be collected was from the experimental setup as mentioned from above. Chart 1 shows the data that was collected.

Flow Controller Reading	Pressure in PSI gage
100	0.635
110	0.7
120	0.76
130	0.83
140	0.89
150	0.965
160	1.035
170	1.1
180	1.17
190	1.24
200	1.32

Chart 1: Experimental Data

The data collection was through increasing the value of the flow rate controller by increments of ten standard cubic centimeters per minute and measuring the necessary input pressure for the channel to achieve the desired flow rate.

Furthermore, this data was placed on a graph such that a graphical comparison of the experimental and simulated results can be accomplished (figure 5).

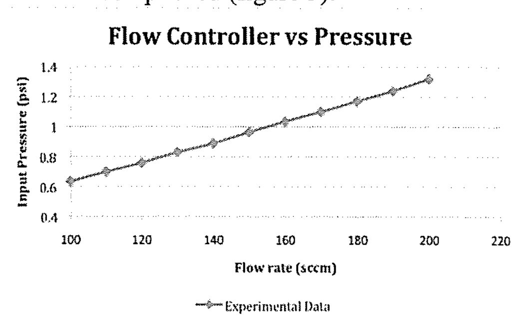

Figure 5: Input pressure versus flow rate for experiment

In addition to the experimental data, a Matlab Graphical User Interface (GUI) was created for analysis and modeling of the channel. Figure 6 shows the GUI that was created for modeling which has a vary of inputs necessary for any modeling to occur and for a pressure input to be calculated to achieve the desired flow rate in the channel.

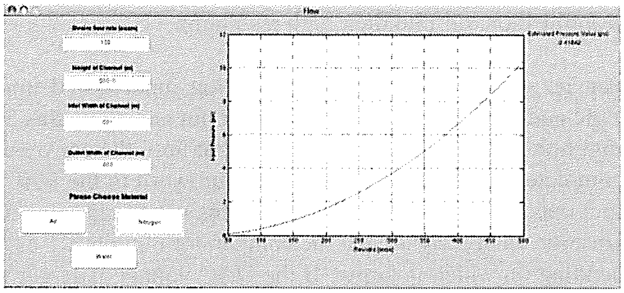

Figure 6: Matlab Graphical User Interface for modeling channel

V. Discussion of Resluts

As mentioned from above both simulated and experimental data was collected and compared as shown in chart 2 and figure 7.

Flow Controller Reading	Pressure in PSI gage	Simulation
100	0.635	0.44281
110	0.7	0.5358
120	0.76	0.63765
130	0.83	0.74835
140	0.89	0.86791
150	0.965	0.99632
160	1.035	1.1336
170	1.1	1.2797
180	1.17	1.4347
190	1.24	1.5985
200	1.32	1.7712

Chart 2: Experimental and Simulated data

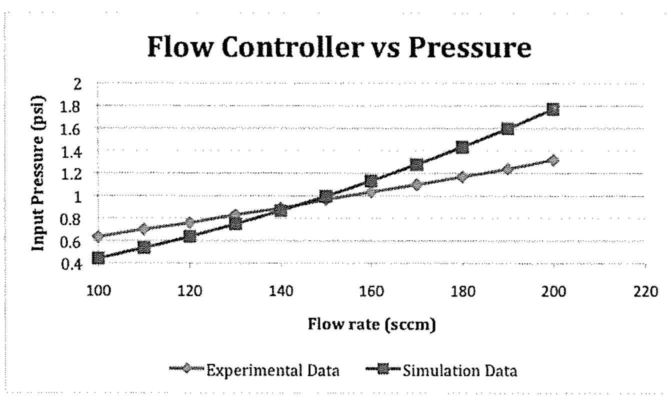

Figure 7: Experimental and Simulated data graph

Figure 7 gives the best comparison between the two results of this project. Although the results are not 100% accurate between the two results the results are close. The results yield a 2% to 30% error along the range of data collected. Furthermore, the Matlab GUI allows scaling of the channel for modeling before creation of the channel.

As mentioned before a variety of inputs are needed from the user in order for modeling to begin. These inputs are desired flow rate, inlet channel width, outlet channel width, channel height, and then the necessary flow material. When running the simulator doubling the inlet and outlet widths effectively decreased the necessary input pressure by eight times the original value for a desired flow rate of 100sccm.

Overall, the experimental and simulated results were successful enough to correlate and ensure that the further modeling could occur. Furthermore, modeling of a channel could occur before any fabrication of devices and packaging.

VI. Conclusion

Although a percent error of 30 is high the modeling is still relatively accurate. For an example, while doing experimental data collection because the simulated and experimental data was so far off, an error in the experimental setup causing such large errors.

Furthermore, this analysis allows modeling of the packaging channel size such that expected results can be found before any fabrication. For an example when running the simulator if the inlet and outlet widths are doubled the necessary pressure to achieve 100 S-C-C-M was decreased my eight times the original value.

After the creation of the simulator and having all results the Matlab GUI into a standalone executable file for future students to use it for such modeling.

Acknowledgment

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References

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