Thermally Actuated MEMS Sensors

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Abstract

This report provides an account of internship work on thermally actuated Microelectromechanical resonant mass sensors conducted at the University of Denver Integrated Nanosystems Laboratory over the Summer of 2010.

Microelectromechanical systems are a combination of mechanical systems (Sensors, Actuators) and electronics on a common silicon substrate.

Microelectromechanical resonant sensors have shown high quality factors and have been implemented using batch fabrication techniques to help reduce cost. A high quality factor indicates a low rate of energy loss and is indicative of an efficient sensor.

Energy losses due to friction with the surrounding air as the resonator oscillates are minimized. The sensors will have potential applications in monitoring air quality and will reduce the size and cost currently associated with these devices.

Work on Microelectromechanical resonant mass sensors was conducted under the direction of Dr Siavash Pourkamali and PhD. student Arash Hajjam. They have been developed using batch fabrication techniques and will be used to provide low cost high quality alternatives to presently available technology.

The devices were fabricated on Silicon on Insulator substrates to improve performance. Silicon on Insulator substrates consists of two layers of Silicon separated by an insulating layer. To fabricate the devices, the Silicon substrates were placed into an oven for about 3 hours to grow a thin layer of Silicon oxide on them, a process known as Thermal Oxidation. The wafers were subsequently spin coated with a thin layer of glue and photo resist. The solubility of the photo resist changes when exposed to Ultra Violet light .In this case positive photo resist was used. Positive photo resist becomes more soluble in photo developer after it has been exposed to Ultra Violet light. Photolithography was used to transfer patterns onto the surface of the Silicon Substrate coated with the photo resist. A specially designed mask was aligned with the surface of the substrates using a mask aligner and they were exposed to Ultra Violet light The silicon wafers were then removed and placed into the photo developer solution which removed the parts of the photo resist that were exposed to the light. At this point, each individual substrate was place onto a heater for about twenty minutes, after which the underlying oxide layer was etched using wet etching techniques. The remaining photo developer was then removed and the underlying silicon layer was etched using Deep Reactive Ion Etching. In some cases Reactive Ion Etching was used to remove the oxide layer.

A single resonator consists of four pads connected to a central square mass which acts as a sensing platform. The sensors work by passing a combination of AC and DC current through the upper pads which causes the central mass to vibrate due to thermal expansion of its actuator beams. The resonant frequency of the sensors is given by $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ where k is the stiffness of the device and m is its mass. The measured resonant frequency shift can therefore be used to calculate the change in mass and hence determine the amount of a particular substance on the surface of the device. Mass sensitivities in the order of hundreds of Hz/ng can be calculated.

The Scanning Electron Microscope (SEM) was used to view the device structure. Figure 1.1 shows a SEM view of the sensing platform and thermal actuation beams and Figure 1.2.shows a SEM view of the device structure with particles deposited onto the surface.

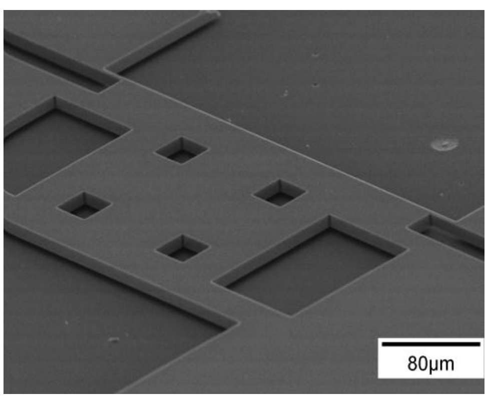


Fig 1.1 SEM view of the mass sensing structure platform and thermal actuation beams

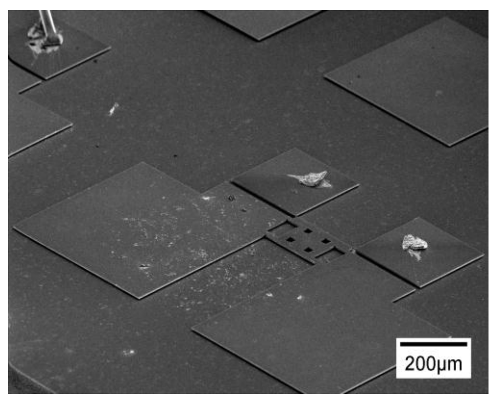


Fig 1.2 SEM view of the device structure after particle deposition

To test the sensors a silicon substrate was placed on a custom made printed circuit board and connections to the upper pads of a device were made with a wire bonder. The PCB was then placed into a custom made aerosol deposition system. A vacuum pump was used to facilitate testing at low pressure. The PCB was connected to a power supply, network analyzer and digital multi meter and aerosol particles were then delivered onto the surface of the device Fig 1.3 and Fig 1.4 shows the SEM view of the sensor after the deposition of aerosol particles.

Fig 1.3 SEM view of particles deposited on the sensing platform

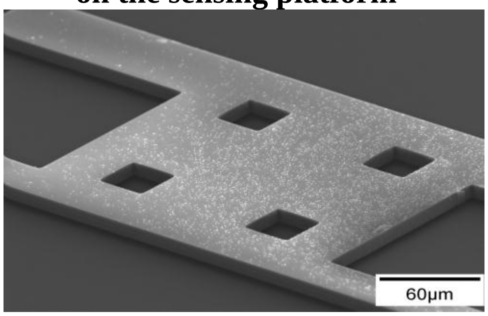
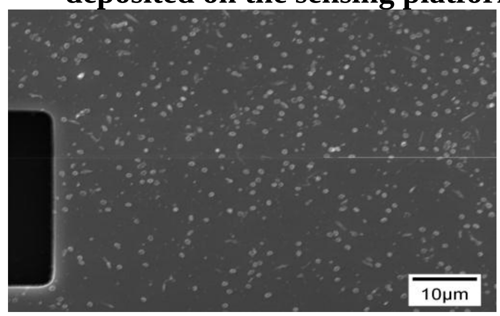


Fig 1.4 SEM view of particles deposited on the sensing platform



The nature of the sensors means they are susceptible to extremes in temperature. The stiffness of the device decreases as temperature increases. This in turn causes the resonant frequency of the device to decrease. To try to compensate for this problem we pursued two methods.

The first method was to implement a simple operational amplifier design which consisted of a voltage divider used as input to the operational amplifier. The operational amplifier was configured as a non inverting amplifier and the voltage divider network consisted of thermistors configured to produce an increase or decrease in current with the changing environmental temperature. The resonators were assumed to act like resistors and they were connected to the output of operational amplifier. The increase/decrease in current at the output of the op amp was used to compensate for the frequency shift due to the increasing temperature. The design was tested extensively to see if it would be a viable method to properly compensate the devices. To carry out these tests the sensors were placed into an oven. They were connected to the custom made PCB. The upper pads of a single device was wire bonded to the PCB. A network analyzer was used to observe and measure the frequency response of the device and a power supply was use to set the voltage bias. We also used a digital millimeter in series with the device to take recordings of the current at each temperature the Table 1.1 shows the result of one such test of using thermistor compensation.

In an effort to minimize power consumption the operational amplifier compensation method was eventually put on hold in favor of the second method “doping the devices”. Similar test were performed on doped devices indeed showed less of a dependence on the environmental temperature. There was a reduction in average frequency shift per degree Celsius. Table 1.2 shows the results of the test using doping as a compensation method.

Table 1.1

Voltage-bias(Volt)	**current(mA)**	**temp(C)**	**frequency(MhZ)**
12.99	6.26	21	7.08402
12.99	6.23	27	7.08162
12.99	6.19	32	7.08072
12.99	6.16	37	7.07942
12.99	6.14	41	7.07812
12.99	6.1	47	7.07632
12.99	6.06	52	7.07542
12.99	6.03	57	7.07432
12.99	5.96	63	7.072455
12.99	5.94	68	7.071555
12.99	5.93	73	7.070755
12.99	5.91	79	7.069155
12.99	5.88	85	7.066855

Table 1.2

Voltage-bias(Volt)	current(mA)	temp(C)	frequency(MhZ)
9.6	4.666	23	20.58421
9.6	4.666	28	20.58436
9.6	4.673	34	20.58481
9.6	4.675	40	20.585
9.6	4.679	45	20.58523
9.6	4.682	50	20.58528
9.6	4.684	55	20.58534
9.6	4.687	60	20.58553
9.6	4.694	65	20.58583
9.6	4.696	71	20.58617
9.6	4.703	76	20.5869
9.6	4.71	80	20.58707

In retrospect the internship helped me decide on a focus for my graduate studies. It provided me with the opportunity to see some of the concepts I have been taught in classes put together to implement a Micro system. For the most part it met my expectations. I would recommend a similar Research internship to students considering graduate school as it really does give a glimpse of what it may be like. In the future I would like to continue my work in developing Mirco/Nanosystems.

References

Amir Rahafroz,, Arash Hajjam , Siavash Pourkamli “Fabrication and Characterization of Resonant Aerosol Particle Mass Sensors”, Denver, CO, USA

Arash Hajjam, Amir Rahfrooz, Siavash Pourkamail, “Thermally actuated low Impedance MEMS Resonators for Mass Sensing Applications”, Denver, CO, USA,