# Fabrication and Characterization of a Packaged MEMS Gas Flow Sensor

Vee Chee Hwang

**Abstract—A surface micromachined MEMS gas flow sensor has been fabricated and tested. The fabrication process of the device was presented. The heater glowed red hot when a voltage of 27V was applied if the underlying LTO was completely etched away. Both the upstream and downstream resistors changed when temperature changed. A proof of concept showing that output voltage changes with gas flow was shown.**

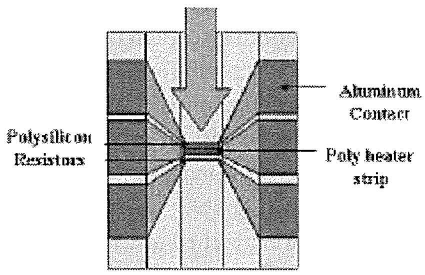
*Index Terms*—**MEMS, LTO.**

## I. INTRODUCTION

Gas flow sensors are required to monitor and control the amount of gas going into wafer fabrication machines such as the Bruce Furnace and the Dry Tech Quad. The resistance differential gas flow sensor uses the principle that the gas flow will change the temperature of the resistors, hence their resistance values. A heater strip is used to cause a temperature difference between the upstream and downstream resistors. The sensor will be manufactured on the surface of a 5mm by 5mm silicon chip and does not require special fabrication tools.

The gas flow sensor consists of a heater strip and 2 resistors that act as temperature sensors (one upstream and one down stream) shown in *Fig 1*. *Fig 2* shows the cross-section of the gas flow sensor. The heater strip and the resistors are suspended to prevent temperature loss to the substrate. A tube is attached to direct the gas to flow across the 2 resistors and heater. When there is no gas flow, the resistors will be at the same temperature and there will be no change in the resistors values. When there is gas flow, the down stream resistor will be at a higher temperature, causing an increase in the resistance value of that resistor, and the upstream resistor will be at a lower temperature, causing a decrease in the resistance value of that resistor.

Fig. 1. Top view of senor




By connecting the 2 resistors of the gas flow sensor to a Wheatstone bridge or potential divider (+6V to -6V) circuit and measuring the output voltage, the gas flow speed can be characterized. A constant heater circuit will be required to supply constant power to the heater so that the heater would not be cooled by the flowing gas.

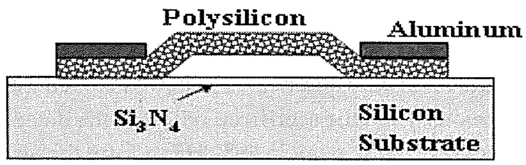



Fig. 2. Cross-sectional view of sensor

## II. DESIGN AND FABRICATION

3 lithography mask layers were used to fabricate the gas flow sensor. There are 16 different designs in the 2nd level mask and the masks were designed by students of EMCR890 (MEMS) in spring 2003. The length of the heater (800 um) and resistor (700 um) are identical for all designs. However, the width of the heater and resistor, and the gap between them varies. A list of some of the gas flow sensor design is shown in *Table 1*.

Table 1
Gas Flow Design Parameters

| Design | Gap | Width (heater) | Width (resistor) |
|---|---|---|---|
| 1 | 10 um | 100 um | 10 um |
| 2 | 10 um | 50 um | 20um |
| 3 | 8 um | 100 um | 10 um |

| | | | |
|---|---|---|---|
| 4 | 6 um | 50 um | 50 um |
| 5 | 6 um | 50 um | 20 um |
| 6 | 4 um | 100 um | 10 um |

A 4-inch silicon wafer was used to fabricate the devices. The quality of the wafer does not matter since a layer of insulating nitride will be deposited on top of the silicon substrate, and the substrate will not be used during device operation. Reclaim wafers, which were used to check the coating uniformity of the coater track, were used to manufacture the gas flow sensors.

After a RCA (Radio Cooperation of America) clean, a 3500A of silicon nitride was deposited on top of the silicon substrate using Low Pressure Chemical Vapor Deposition (LPCVD). This layer serves as an insulating anchor point for the two resistors and heater strip. Next, a 3um sacrificial low thermal oxide (LTO) was deposited. This sacrificial oxide will create the suspended resistors and heater strip once it is etched away at the last processing step. The first level lithography was performed on a g-line stepper. Unwanted LTO were etched away to form the release layer for the heater and resistors. A 2um LPCVD polysilicon layer was deposited and doped with N-250 spin on dopant. This layer will eventually become the two resistors and heater. 7500A of aluminum was sputtered. This aluminum will protect the underlying polysilicon during polysilicon etch, and will form the contact pads for the probes during electrical test.

2nd Level lithography was performed and the aluminum and polysilicon was etched away to form the 2 resistors and heater. After the polysilicon etch, a short test was conducted using a multimeter to check if polysilicon was completed removed. 3rd Level lithography was performed and the aluminum on top of the suspended resistors and heater strip was etched away. The wafers were diced and the sacrificial oxide on the diced gas flow sensor was etched away in 49% HF to form the air-bridge effect. The photoresist was removed in acetone and the device was ready for electrical test. *Fig 3* shows the cross-sectional view of the processing steps. *Fig 4* shows a photo of a finished gas flow sensor.

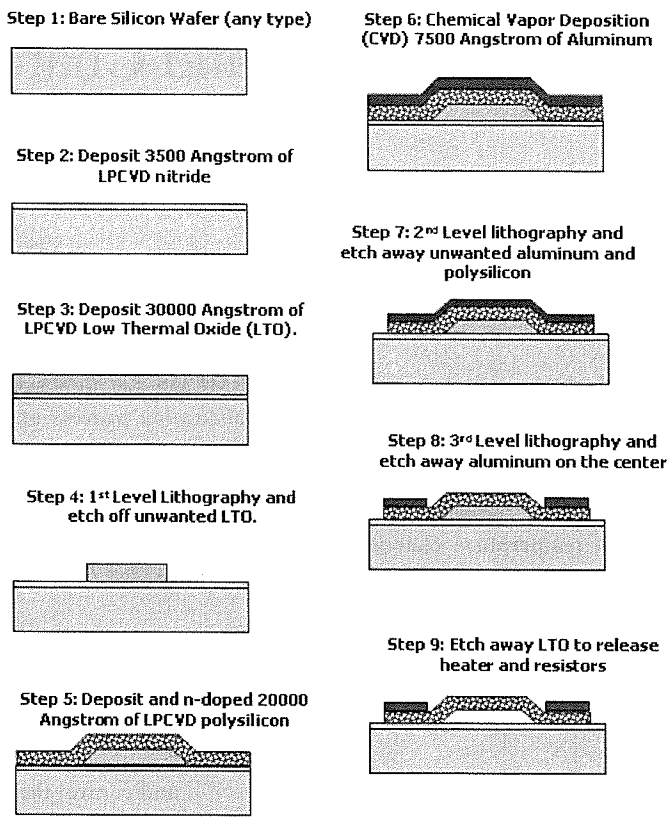



Fig. 3. Processing steps

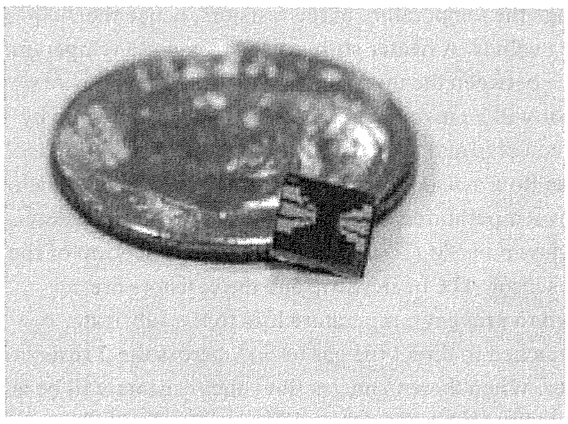


Fig. 4. Gas flow sensor on a dime

## III. RESULTS

A cross-sectional Scanning Electron Microscope (SEM) picture shown in *Fig 5* was taken to check for the release of the heater and 2 resistors after the 49% HF etch. A multimeter was used to measure the resistance across the heater and 2 resistors after the release. The aluminum contact pads were unintentionally etched away during the air-bridge formation due to undercutting. However, electrical test could still be conducted on the underlying polysilicon.

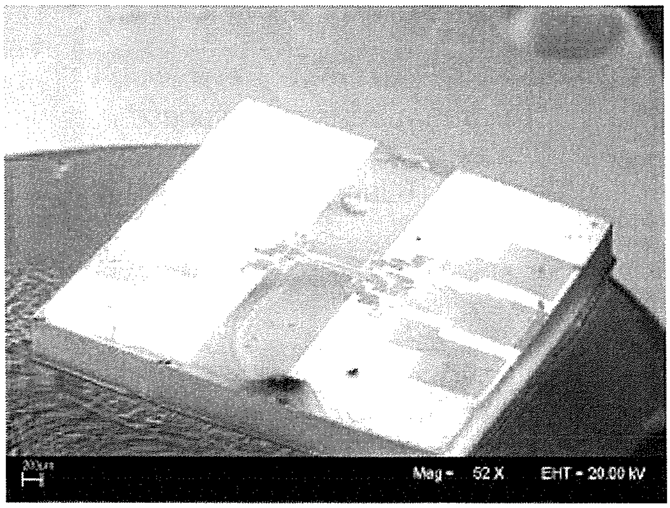



Fig. 5. Cross SEM photo showing air-bridge formation

After the heater and resistors were released, the structural integrity test was conducted on the device be blowing air across the gas flow sensor. It was observed that gas flow sensors with a resistor width of 10um suffered from poor structural ruggedness as shown in *Fig 6.* Gas flow sensors with a resistor width of 20um had a good structural integrity as shown in *Fig 7*.

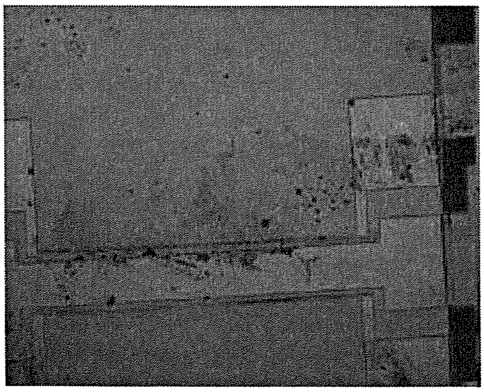


Fig. 6. 10um wide resistors, showing bending after LTO etch

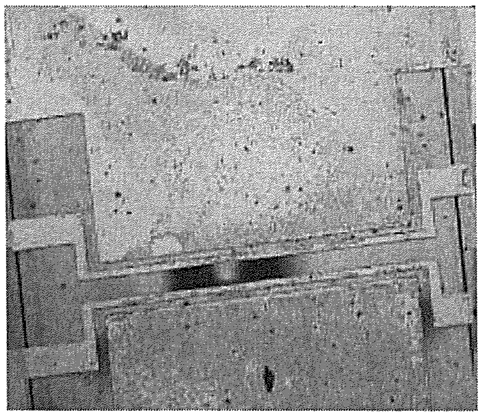


Fig. 7. 20um wide resistors, showing no bending after LTO etch

When a voltage of 27V was applied across the heater, the heater started to glow red hot as shown in *Fig 8*. If the heater is not completed released, the heater will not be red hot since heat will be conducted to the substrate via the LTO, which has a thermal conductivity of $0.014 Wcm^{-1}K^{-1}$. Released heater also caused a bigger change in the resistors values compared to non-released heaters as shown in *Fig 9.* This is because released heaters are hotter and require less voltage to make it hot. However, it is not necessary to make the heater red hot as long as the heater could cause a substantial change in the resistors values.

Fig. 8. 50um wide heater glowing red hot when a voltage of 27V was applied.

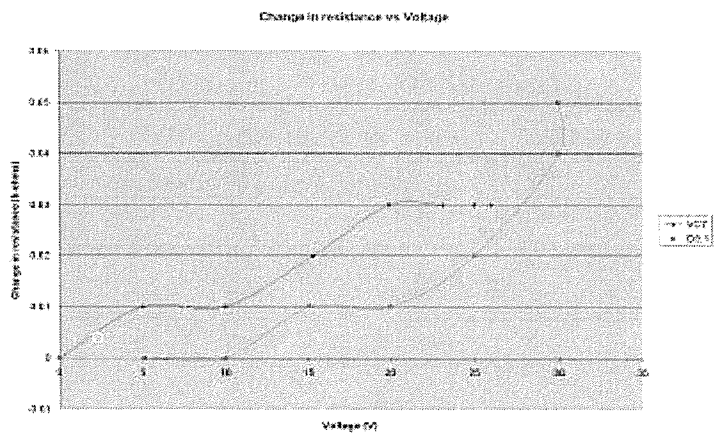



Fig. 9. Device VC7 heater was completed released, while device D9.1 heater was not. This shows that released heater caused a bigger change in the resistor values and required less applied voltage.

*Fig 10* shows the increased in resistors values when a constant voltage of 33V was applied. The resistor value increased by 40 ohms within 15s, and stabilization time for the resistor value was 5 minutes. When a nitrogen flow of 6 lpm was flown, the upstream resistor value decreased by 20ohms over a period of 2 minutes as shown in *Fig 11*. By arranging the upstream and downstream resistors as shown in *Fig 12*, the output voltage can be calculated as shown in (1)

$$Vout = \frac{(R2 - R1)6V}{(R1 + R2)} \quad (1)$$

When there was no gas flow and the heater was on, the resistors values were identical (8.508k-ohms) and the output voltage was zero. When 6 lpm of nitrogen was flowing, the output voltage was 2.83mV. This is shown in table 2.

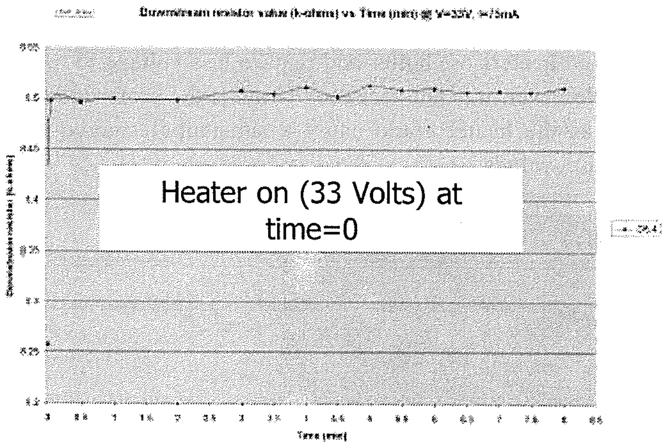



Fig. 10. Resistor stabilization time

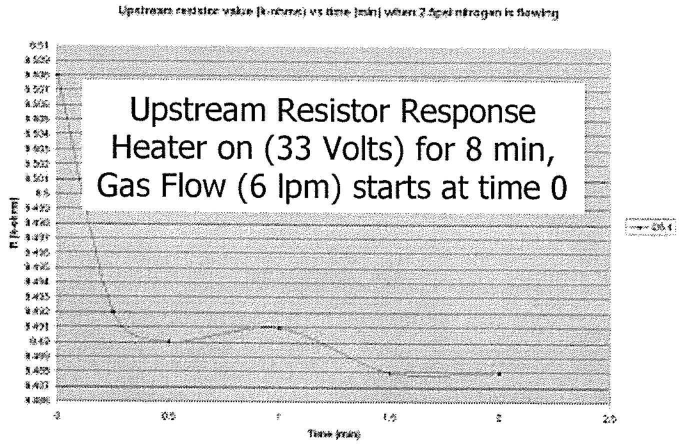



Fig. 11. Upstream resistor response to 6 lpm nitrogen flow

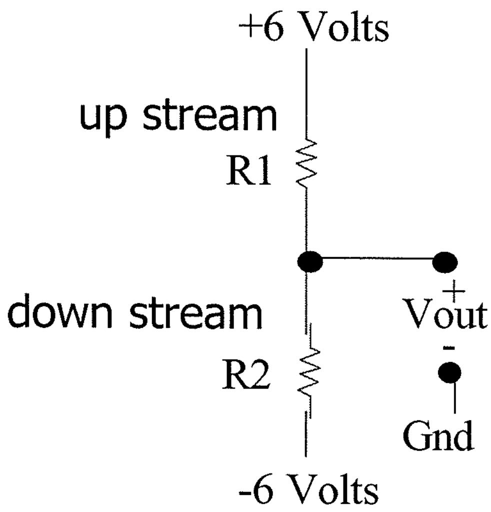



Fig. 12. Potential Divider Circuit to measure change in Vout for different flow rate

Table 2
Calculated output voltage vs Gas flow

| Gas flow | Upstream Resistor | Downstream Resistor | Vout |
|---|---|---|---|
| 0 lpm | 8.508 k-ohms | 8.508 k-ohms | 0 V |
| 6 lpm | 8.488 k-ohms | 8.496 k-ohms | 2.83 mV |

## IV. CONCLUSION

A surfaced micromachined MEMS gas flow sensor has been fabricated and tested. Both the heater and resistors worked

after the LTO was etched away. The heater glowed red hot when a voltage of 27V was applied if the underlying LTO was completely etched away. However, it is not necessary for the heater to become red hot for the gas flow sensor to work. Both the upstream and downstream resistors changed when temperature changed. A proof of concept showing that output voltage changes with gas flow was shown. For more accurate measurements, the gas flow sensor has to be packaged so that detailed testing could be conducted.

## APPENDIX

See Appendix A for detailed processing steps.

## ACKNOWLEDGMENT

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Vee Chee Hwang is from Singapore and has obtained a diploma in Electronics and Computer Engineering from Ngee Ann Polytechinic, Singapore, in 1999. He will be receiving his B.S degree in Microelectronic Engineering and a Minor in Japanese Language from Rochester Institute of Technology in 2004.