Anemometer Laboratory

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OUTLINE

Objective
Theory
Experimental Set Up
Measurements
Results
Discussion
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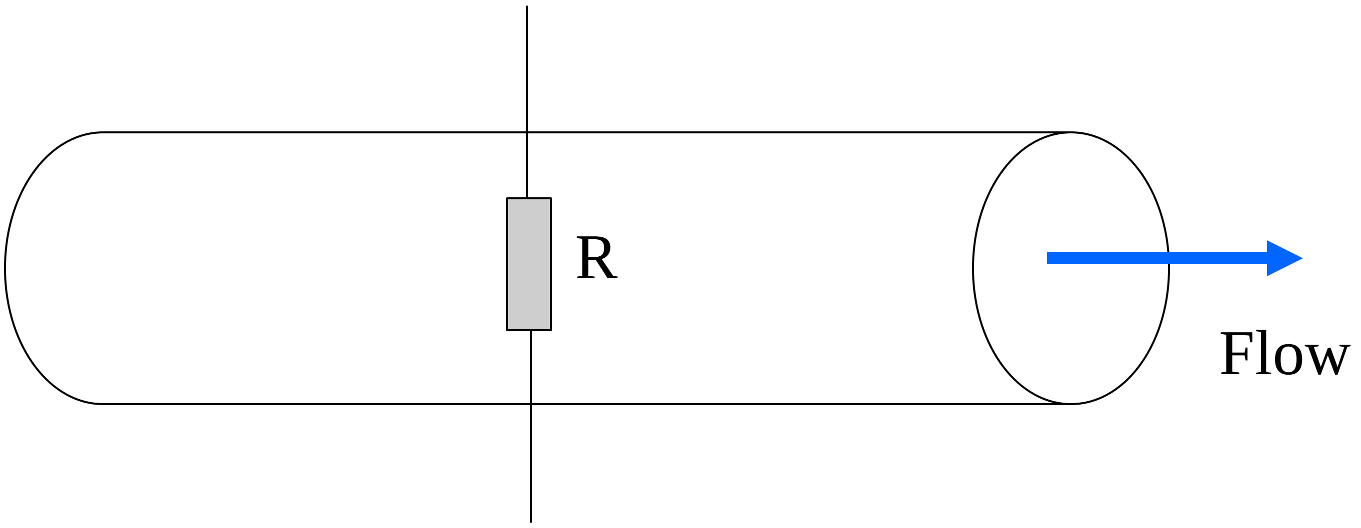
OBJECTIVE

The objective of this laboratory experiment is to build a Thermo-anemometer flow sensor, show that it works, and take measurements to experimentally determine; transfer function, calibration, span, resolution and frequency response.



THEORY

A resistor is heated and placed in fluid flow. Flow causes the temperature of the resistor to change and the temperature change causes a change in mobility that causes a change in the value of the resistance. The change in resistance is related to the value of the air flow, the specific heat of the fluid and the physical parameters of the resistor and the air flow chamber.

Units of flow:
sccm = standard cubic cm per min.
Slm = standard liter per min.

THEORY:

There are many biomedical applications in which it is necessary to measure the flow rate of a fluid, including artificial respirators and drug delivery systems. A common method of measuring the flow rate of a fluid is hot-wire anemometry. When electrical current passes through a resistive element, power is dissipated in that element as heat. This method works on the principle that as a fluid moves over and around that element, the heat will be removed through convection. As long as the fluid temperature and the temperature of the resistive element remain constant, the electrical power dissipated will be equal to the amount of heat removed, as shown in (1).

$$\frac{V^2}{R_s} = \delta(T_s - T_f) \qquad (1)$$

Where V is the voltage across the sensing element, R_s is the resistance of the sensing element, δ is the heat dissipation constant of the resistive element, T_s is the temperature of the resistive sensing element, and T_f is the fluid temperature. The resistance of the resistive sensing element itself depends on its temperature, but in this application we will use feedback to maintain the element at constant resistance (and temperature). The heat transfer coefficient *(δ)* can be calculated according to King's law:

$$\delta = a + bv_f^n \qquad (2)$$

Where a, b, and n are calibration coefficients. The values of a, b and n may be found by a three point calibration at three different known flow rates (v_f). Combining (1) and (2) yields:

$$a + bv_f^n = \frac{V^2}{R_s(T_s - T_f)} = \frac{Power}{(T_s - T_f)} \qquad (3)$$

Solving for v_f yields:

$$v_f = \left(\frac{\left(\frac{Power}{(T_s - T_f)} \right) - a}{b} \right)^{\frac{1}{n}} \qquad (4)$$

This means that for a given resistive element, the fluid velocity (v_f) is a function of the sensor temperature (T_s), fluid temperature (T_f), and power dissipated in the resistive element *(Power)*. If the sensor temperature, fluid temperature, and power dissipated are known, the fluid velocity can be determined.

THEORY QUESTIONS

1. What is the theoretical relationship between resistance and temperature? (derive an equation for some stated assumptions) (hint:mobility)

MICROELECTRONIC ENGINEERING 3/13/2005

CALCULATION OF MOBILITY Dr. Lynn Fuller

To use this spreadsheed change the values in the white boxes. The rest of the sheet is protected and should not be changed unless you are sure of the consequences. The calculated results are shown in the purple boxes.

CONSTANTS	VARIABLES			CHOICES	
Tn = T/300 : 1.30					1=yes, 0=no
	Temp=	390	°K	n-type	1
	N total	1.00E+18	cm-3	p-type	0
				<100>	

Kamins, Muller and Chan; 3rd Ed., 2003, pg 33

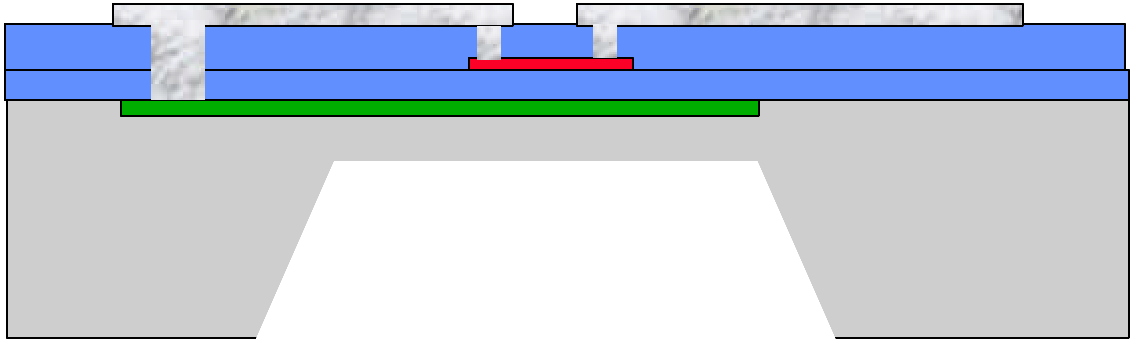
mobility= 141 cm2/(V-sec)

2. What is the theoretical relationship between flow and temperature?

EXPERIMENTAL SET UP QUESTIONS

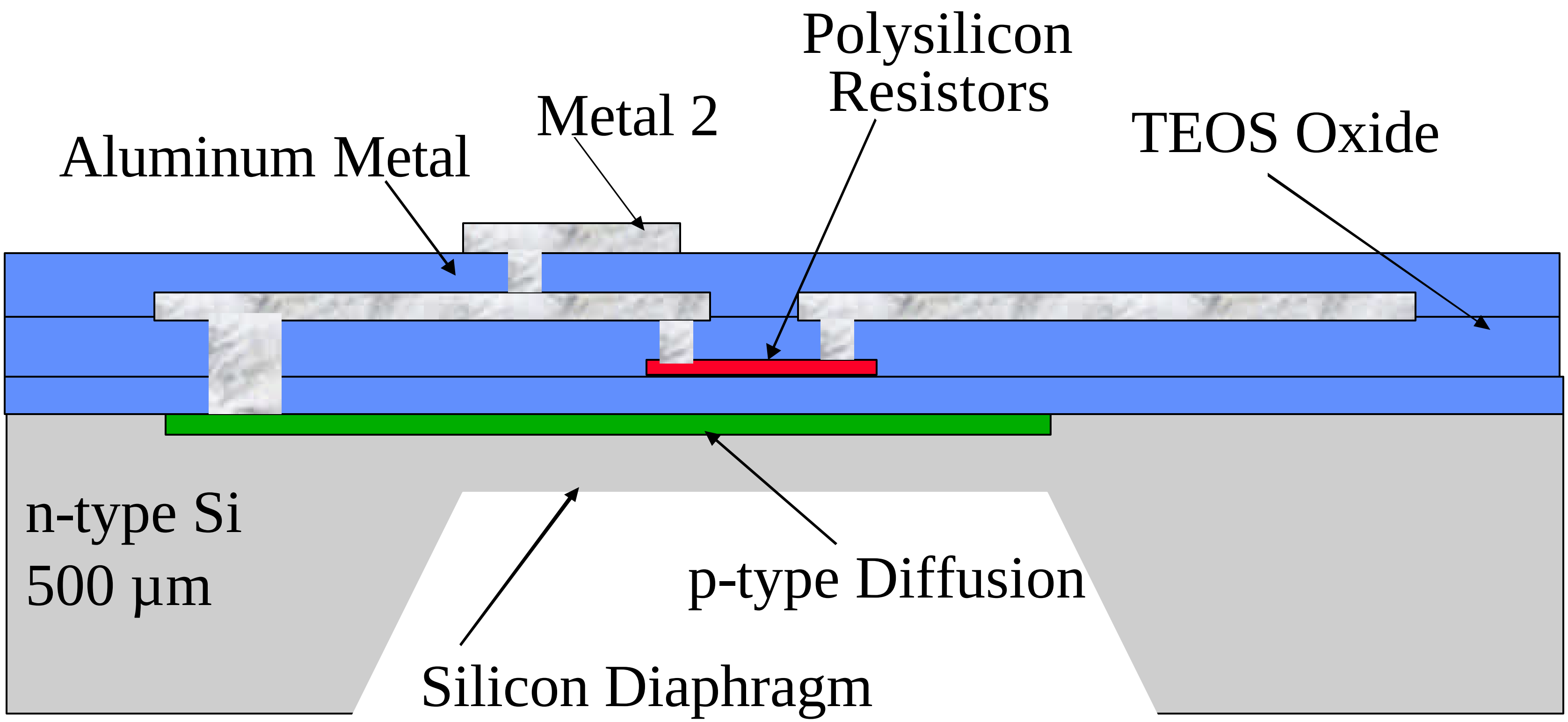
1. How is the anemometer resistor heated?

2. What physical properties of the resistor design are important for a good sensor?



3. We expect the resistance to only change by a small amount. Lets come up with a simple but sensitive measurement technique.

BACKSIDE ETCHED BULK MICROMACHINED POLYSILICON RESISTOR GAS FLOW SENSOR

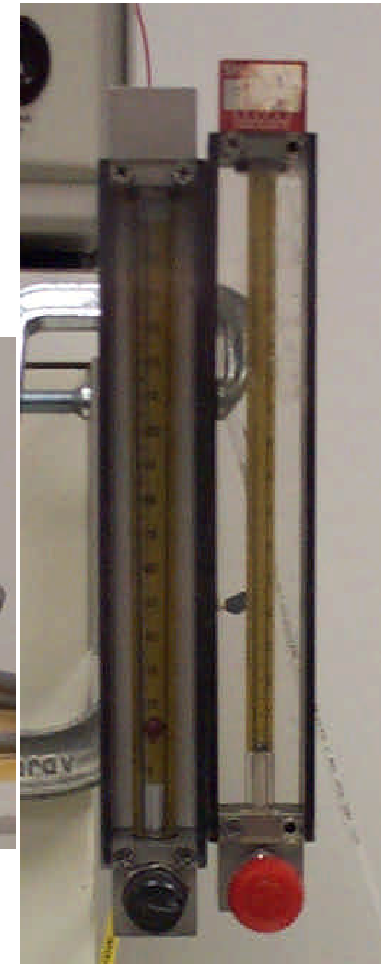


EXPERIMENTAL SETUP

1. How can we control the flow?

2. How can we calibrate the flow?

MFC



Rotometer

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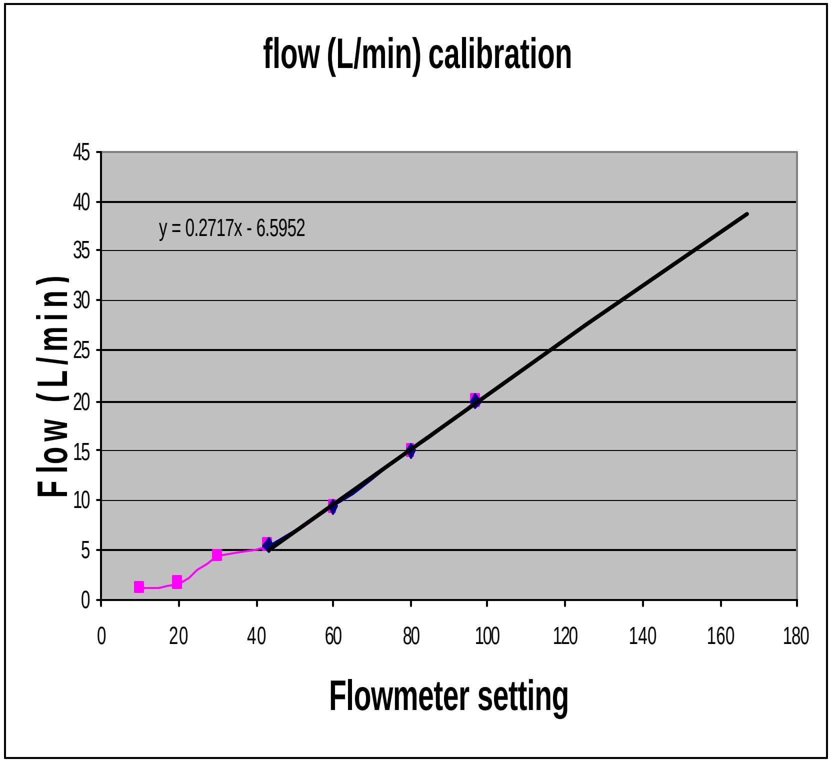
- Dr. Pearson calibrated the airflow gauge on the bench by finding the amount of time it took to displace 2L of water in an upside down beaker. Manufacturers data sheet for Sapphire Ball gives 28.6 SLM full scale (marked as 150 on the gauge)

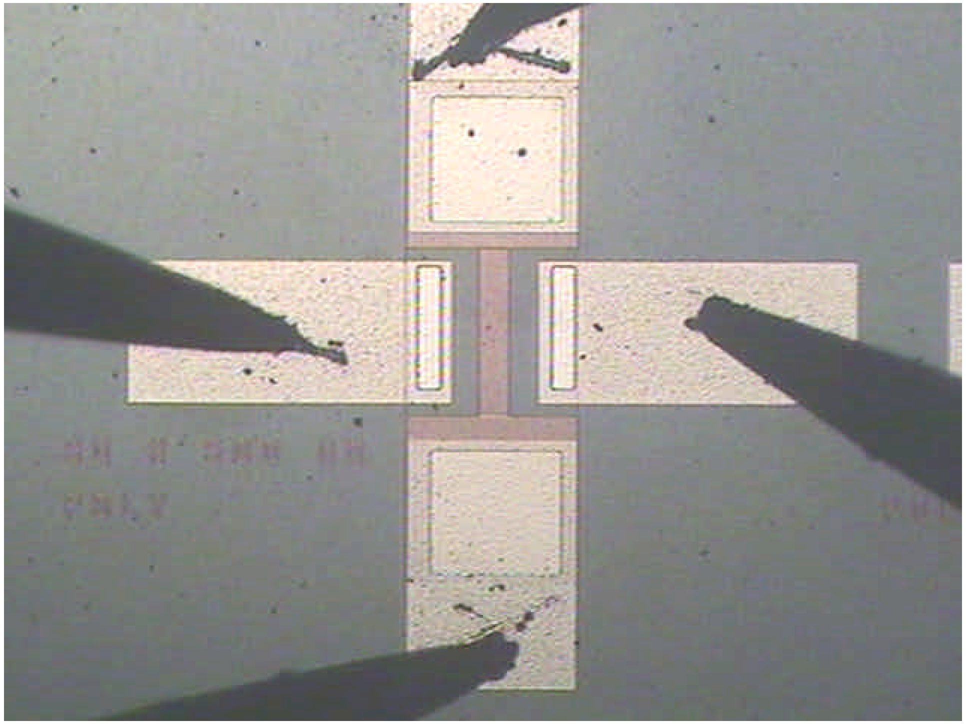
mL	time	setting	flow (mL/s)	SLPM
2000	100	10	20	1.2
2000	75	20	26.66666667	1.6
2000	28	30	71.42857143	4.285714
2000	22	43	90.90909091	5.454545
2000	13	60	153.8461538	9.230769
2000	8	80	250	15
2000	6	97	333.3333333	20
		120		26
		140		31
		150		34



MEASUREMENTS

Transfer Function (Output voltage vs flow in sccm)
Calibration
Span
Resolution
Frequency Response

MEMS RESISTOR AND HEATER OVER DIAPHRAGM



Polysilicon Resistor on oxide over a p-type diffused resistor in n-type substrate.

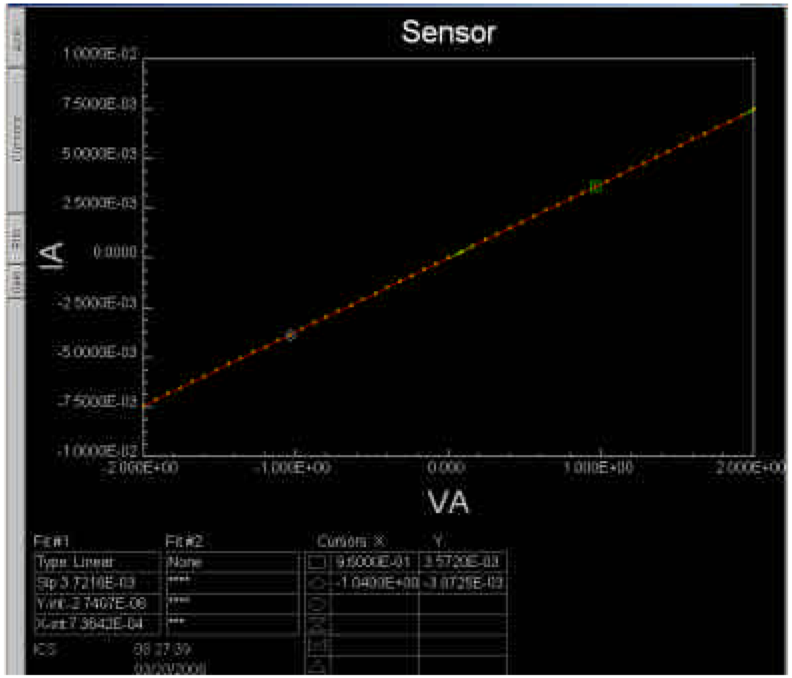
Poly sheet Rho ~ 40ohm/sq
L=500µm, W=90µm

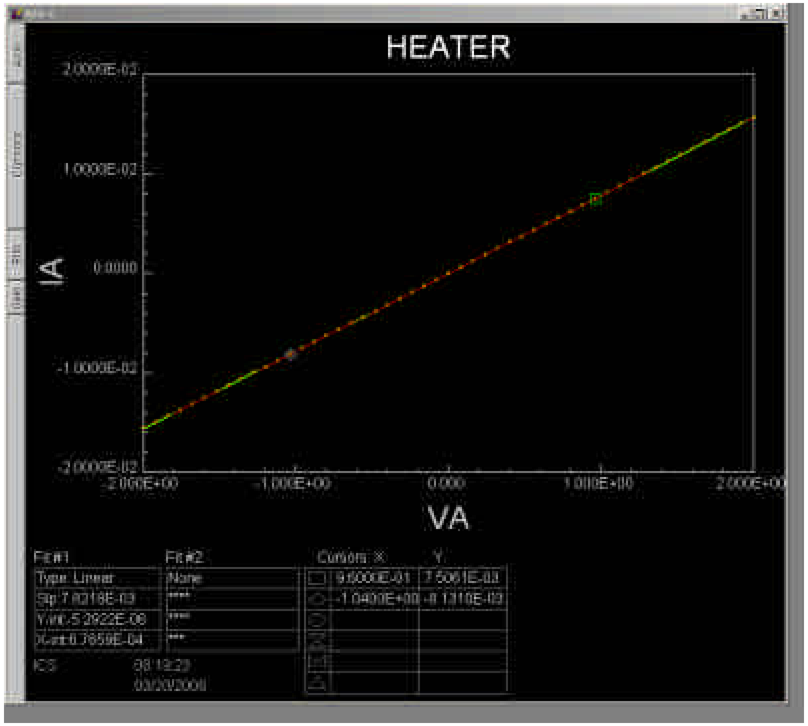
Diffusion sheet Rho~110ohm/sq
L=W=400µm

BASIC MEASUREMENTS

1. Calculate Rpoly, Measure Rpoly
2. Calculate Rdiff, Measure Rdiff
3. Calculate mobility at room T and 100°C for doping 1E19
4. Calculate power in heater if 10 volts applied
5. Calculate temperature of heater with 10 volts applied
6. Measure change in poly resistor when heated by heater
7. Measure time response for poly resistor sensor / heater on/off

MEASURED HEATER AND RESISTOR VALUES





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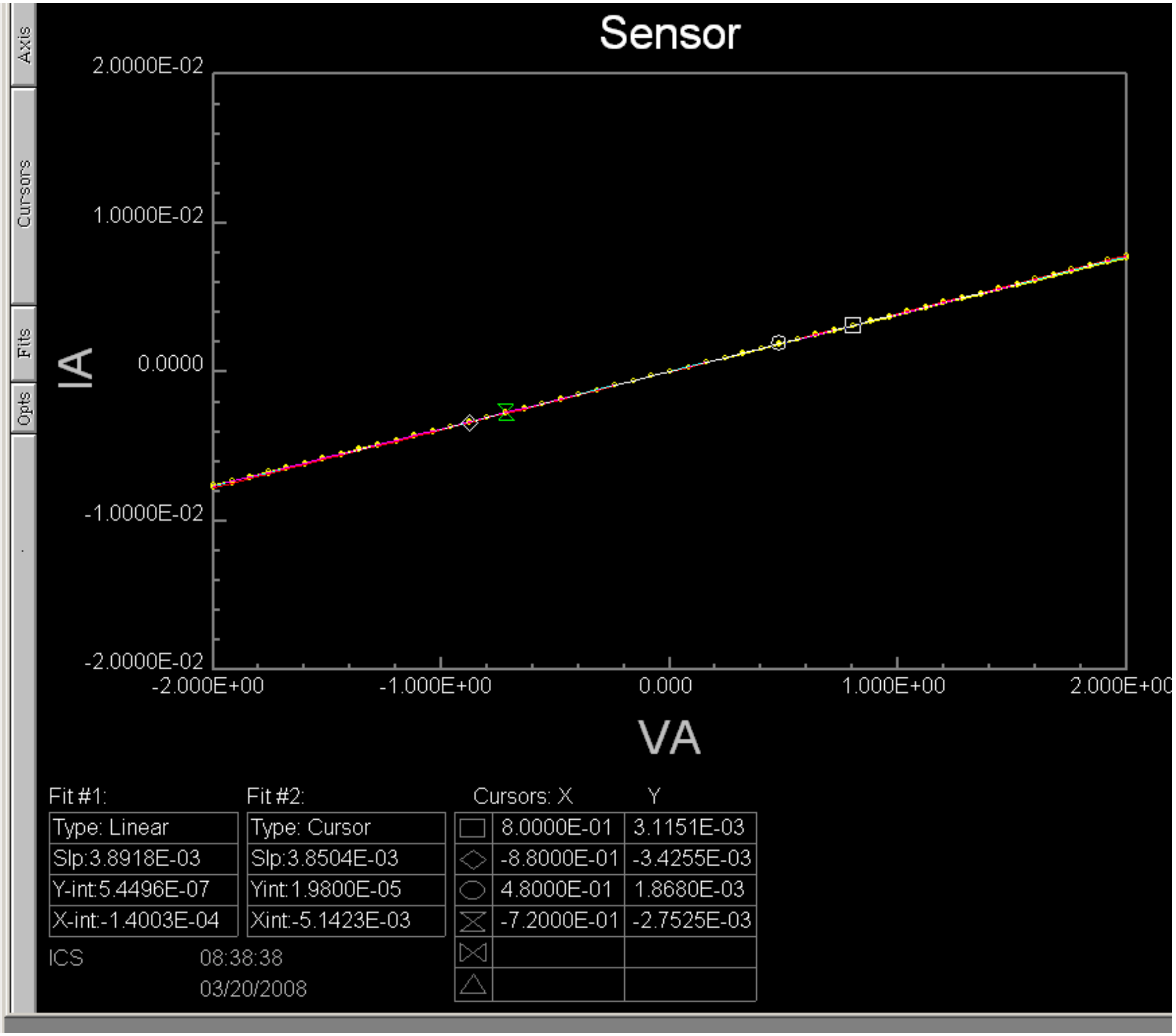
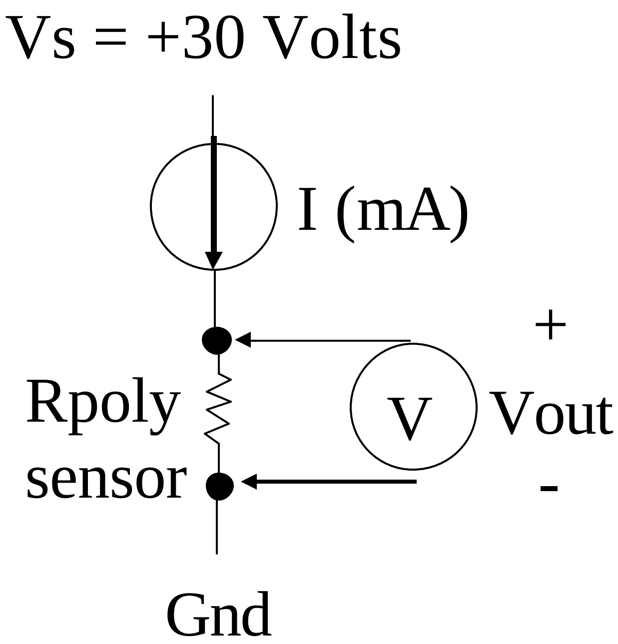
HEATING WITH SOLDER IRON

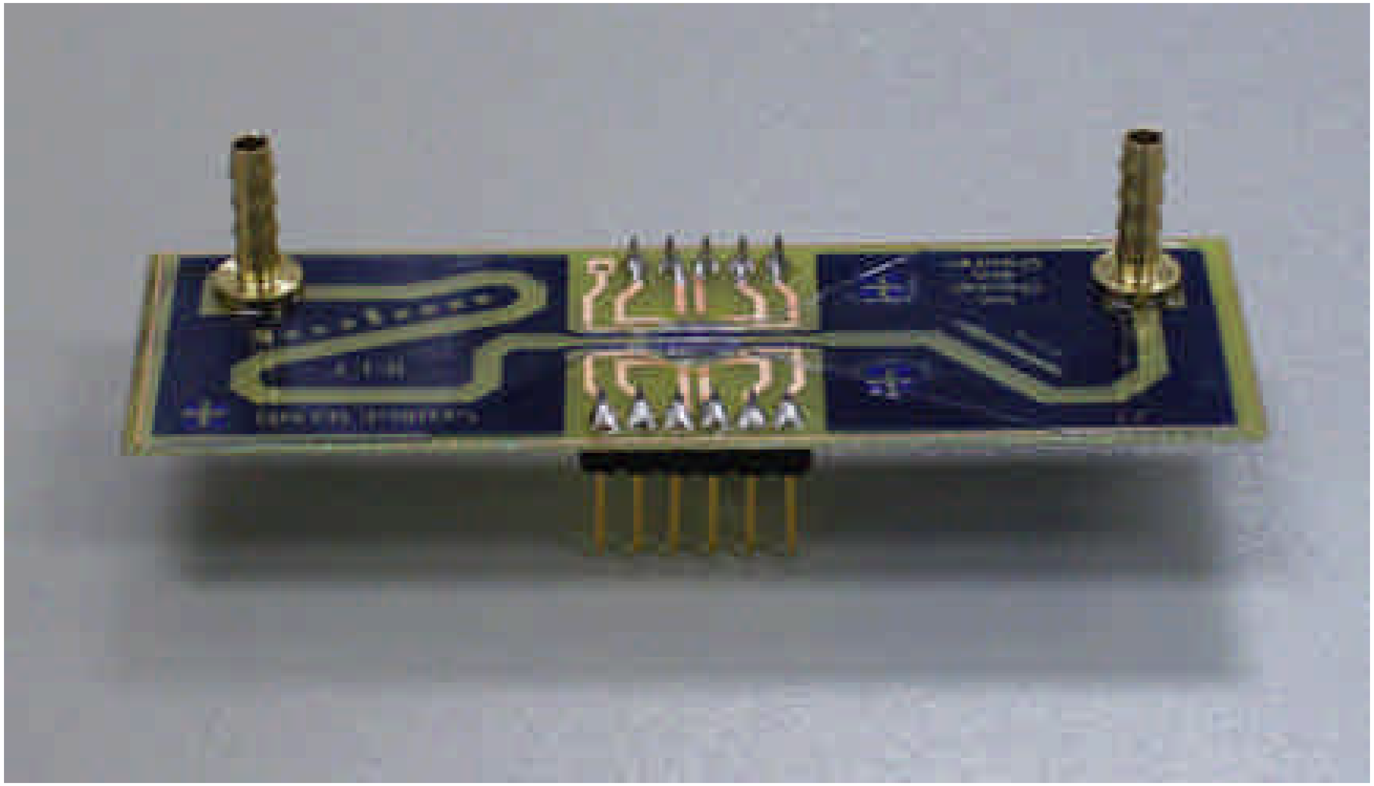


ANEMOMETER MEASUREMENTS

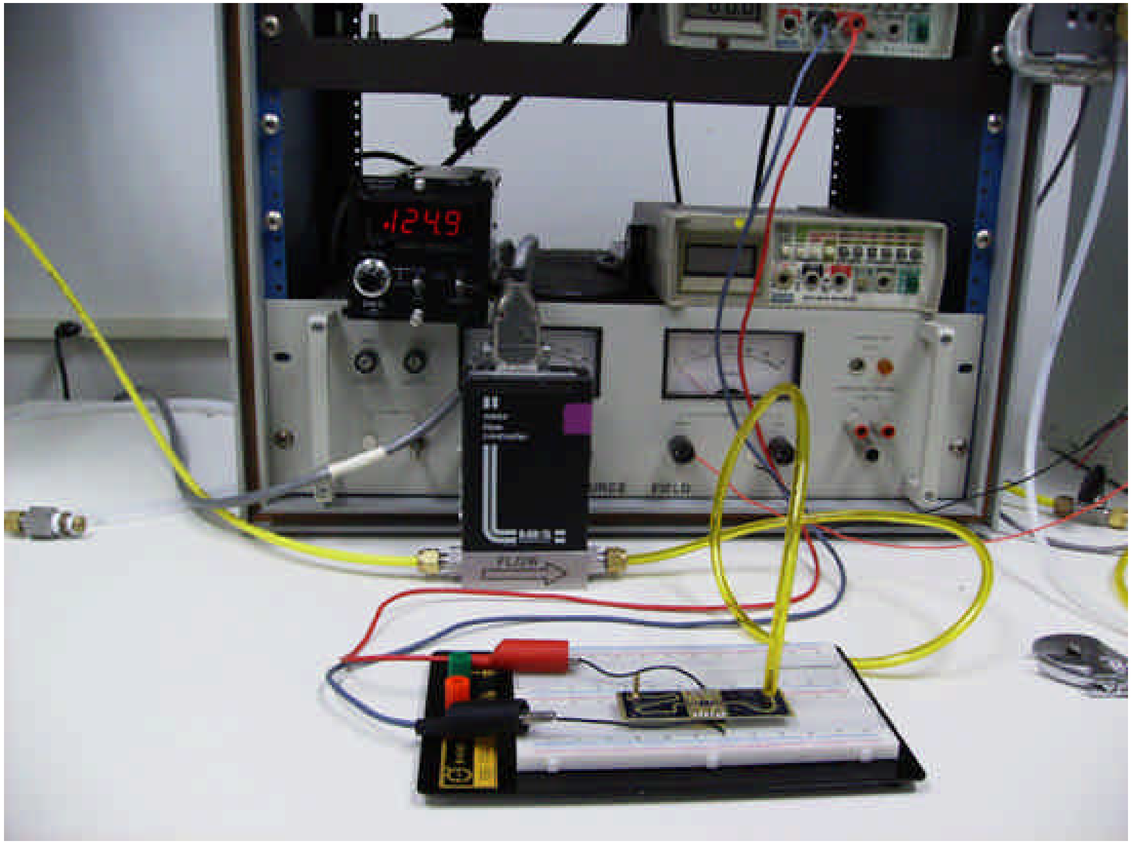
Calculate the current needed to generate ~1 watt in the poly resistor. The poly resistor is self heating and will reach some temperature with no gas flow. The resistance will change if gas flows over the resistor. To measure the response use the simple circuit shown.



PACKAGE GAS FLOW SENSOR



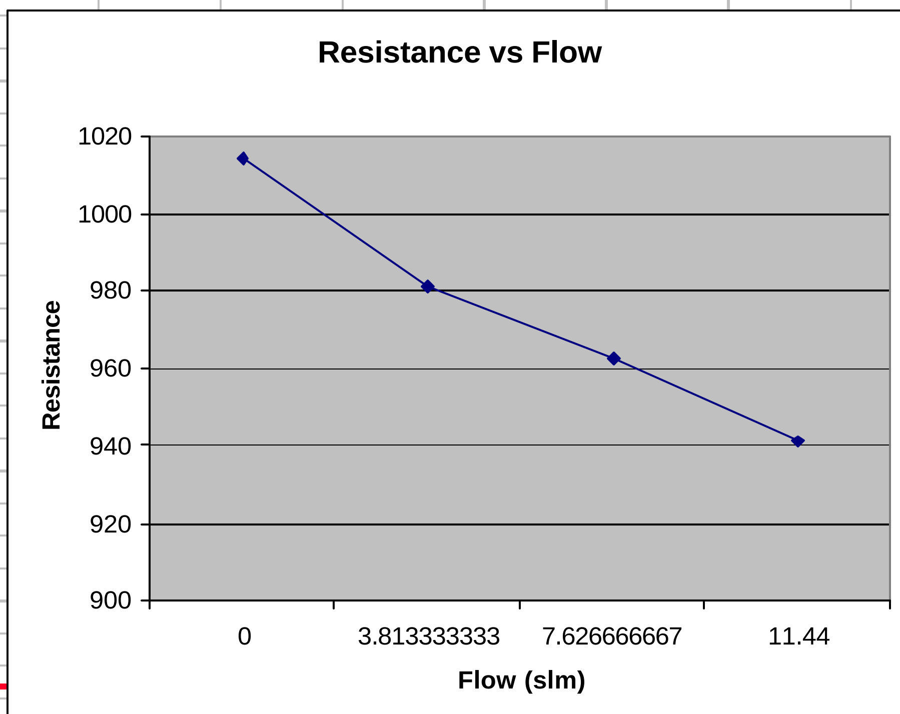
TEST SET UP FOR GAS FLOW SENSOR

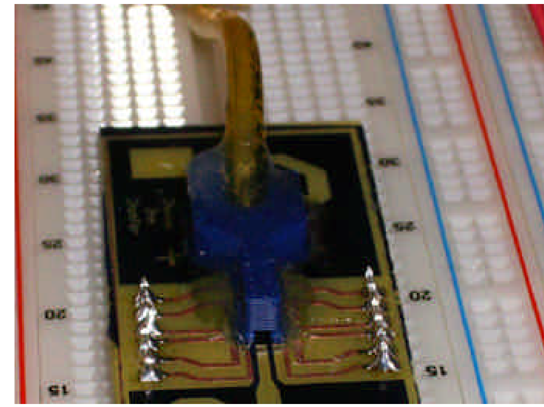


RESULTS FROM PACKAGED SENSOR

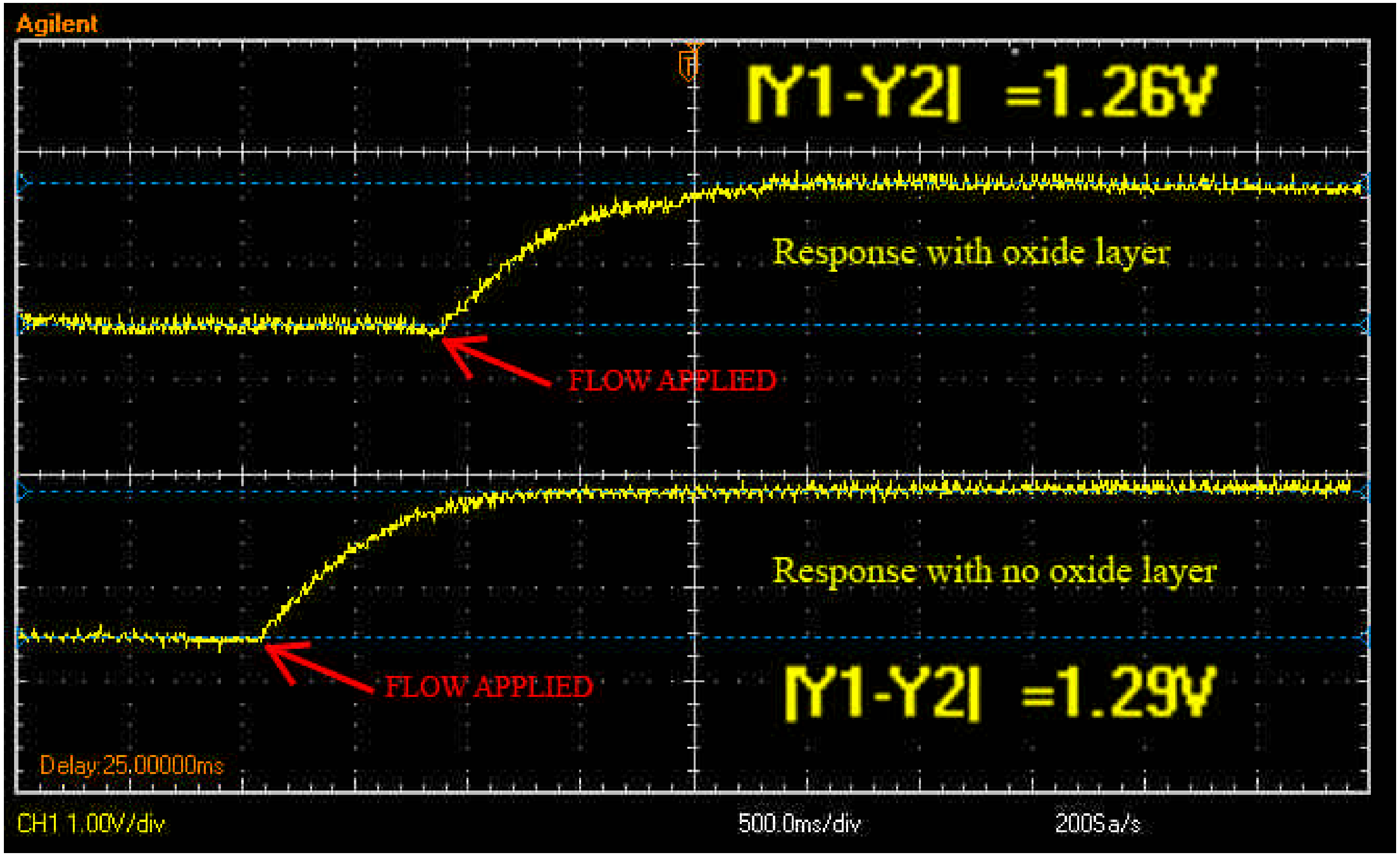
Anemometer Flow Data

Voltage	Current	Power	Resistance	Flow Rate	
Volts	mA	watts	ohms	value (slm)	setting
30.018	29.6	0.888533	1014	0	0
30.018	30.6	0.918551	981	3.813333	20
30.018	31.2	0.936562	962	7.626667	40
30.018	31.9	0.957574	941	11.44	60





STEP RESPONSE



RESULTS

It works!

Calibration was achieved by…..

A plot of output versus flow is shown. An equation for this relationship (transfer function) has been obtained and is given below.

We were able to measure air flows from 0 to xxxx (span) with a resolution of yyyy.

The frequency response was determined by zzzz and is given below in graphical and analytical form.

DISCUSSION

A simple yet effective anemometer was built, calibrated and evaluated. The device performance was investigated and shown to have …… Improvements could be made by ….

REFERENCES

1. Handbook of Modern Sensors, Jacob Faraden, Springer

INSTRUCTORS CHECK LIST

Show MEMS chip
Take a Picture
Measure Heater Resistance using HP4145
Measure Sensor Resistance using HP4145
Measure Sensor Resistance with and without light
Measure Sensor Resistance with voltmeter and current meter
Measure Sensor I and V at 50 mV applied (no self heating)
Measure Sensor I and V at 30 V applied (self heating ~1watt)
Measure Packaged sensor no flow
Measure Packaged sensor with flow, take data at different flows
Measure response to step change in flow
Build electronic constant resistance circuit