MEMS Resistor Laboratory

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3-13-2013 Resistor_lab.ppt

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OUTLINE

Objective
Theory
Experimental Set Up
Measurements
Results
Discussion
References
Lab Instructors Notes

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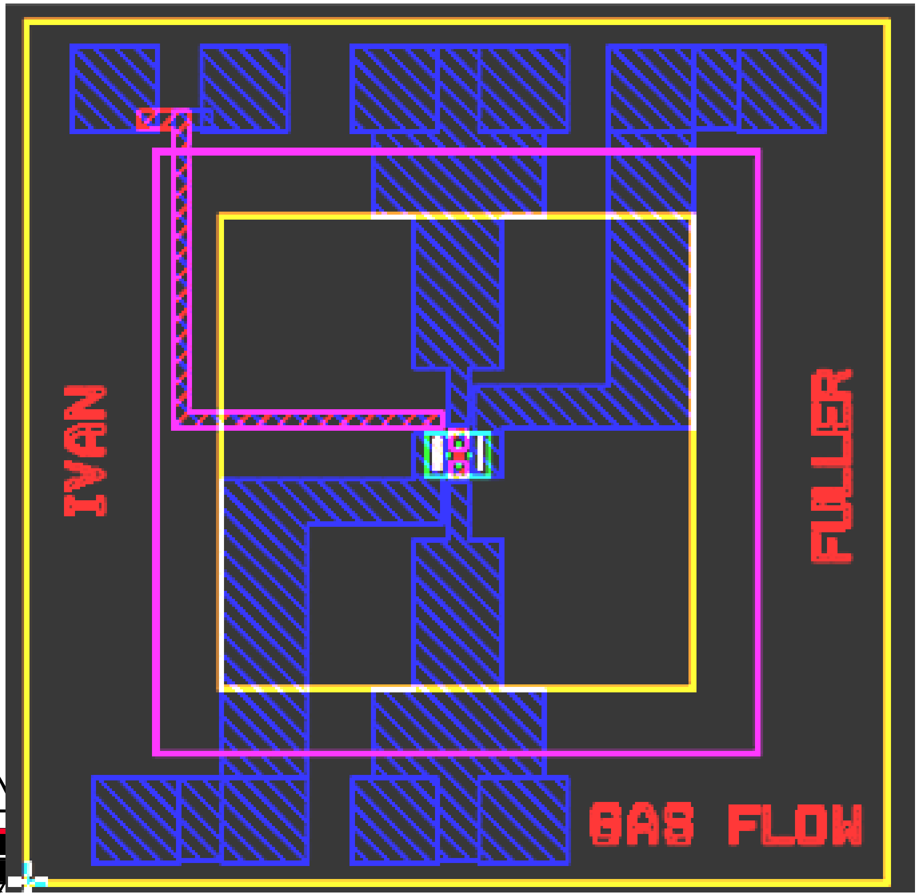
OBJECTIVE

The objective of this lab is to investigate integrated MEMS resistors and their applications as heaters, sensors and actuators.



4000x4000 chip
2200x2200 diaphragm

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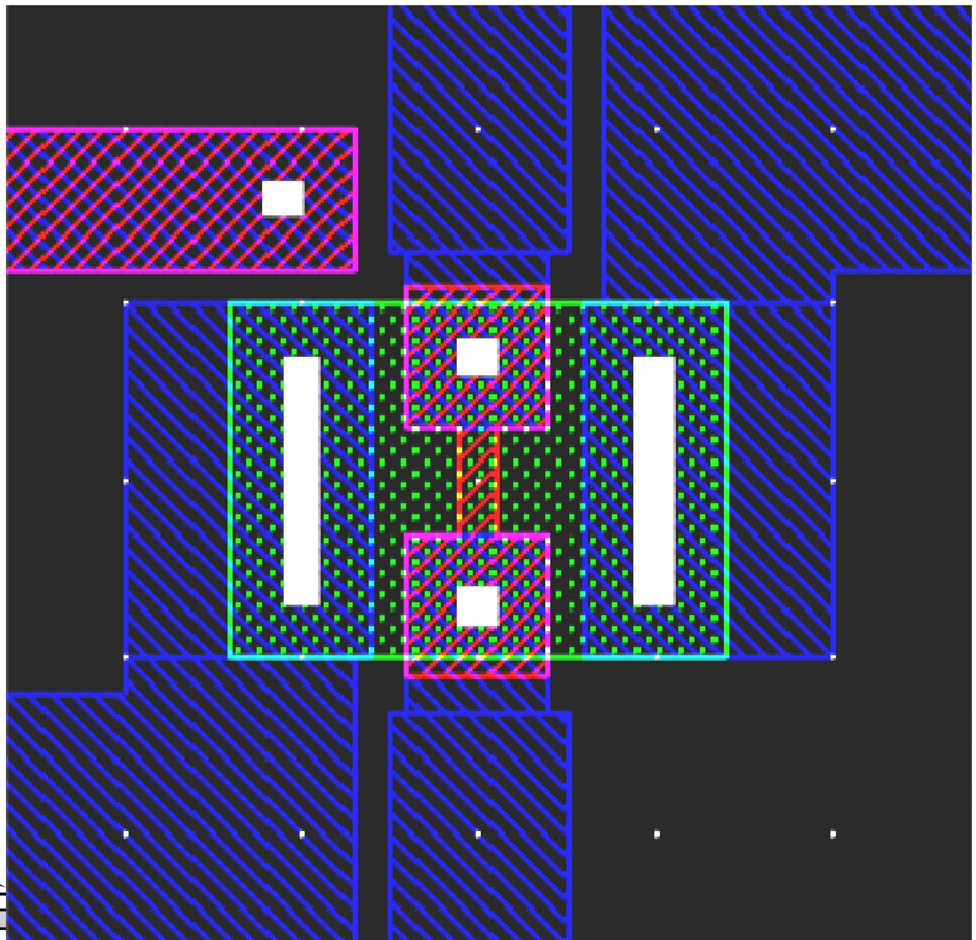
CLOSE UP OF RESISTORS AND THERMOCOUPLE



Aluminum – N+ Poly Thermocouple

Green P+ Diffused Resistor
200 um wide x 180 um long

Red N+ Polysilicon Resistor
60 um x 20 um
+ 30 to contact so L/W ~ 6

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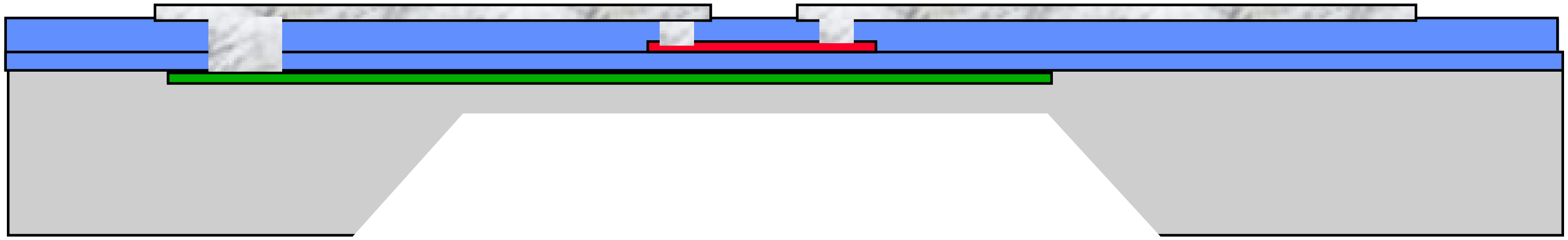
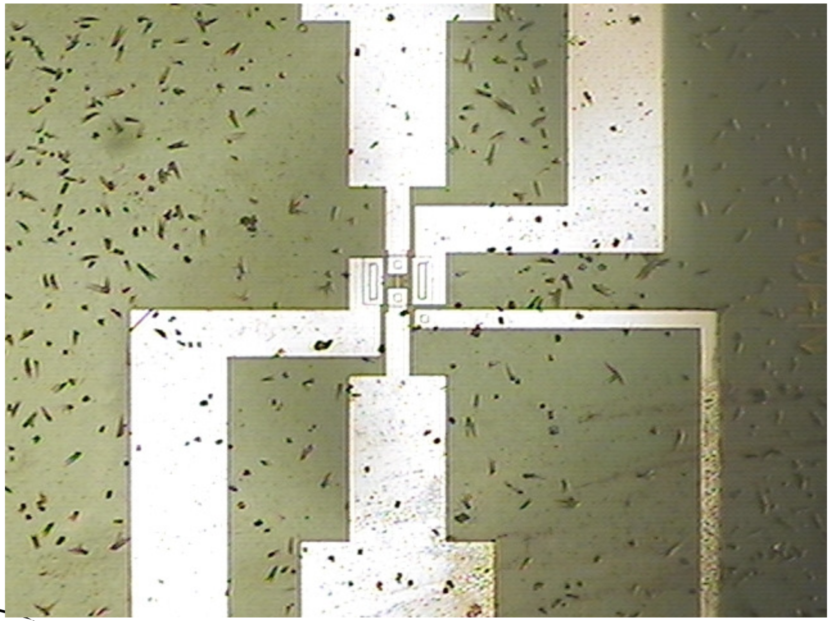
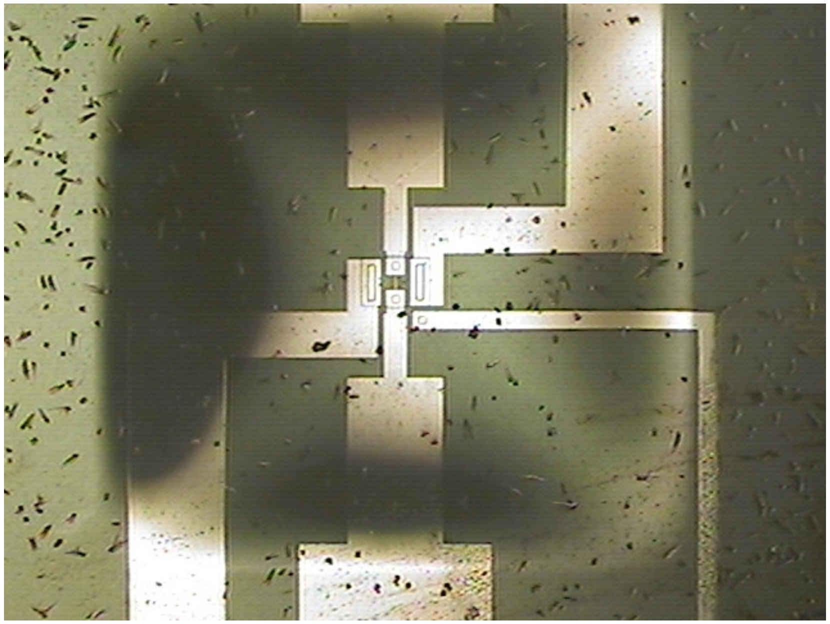
RESISTORS ON THIN DIAPHRAGM







With Vacuum Chuck On

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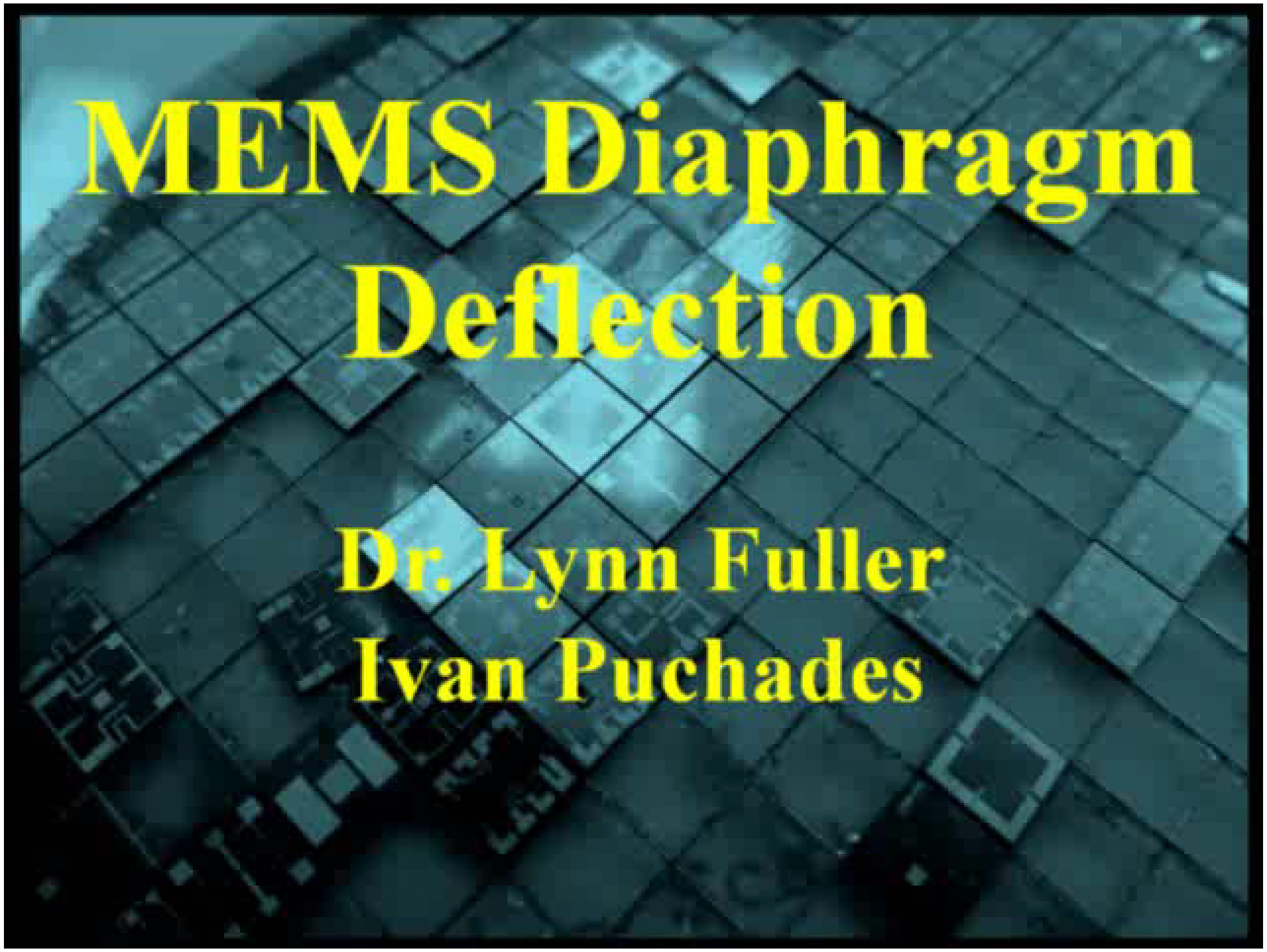
MOVIE OF DIAPHRAGM DEFLECTION



movie click to play

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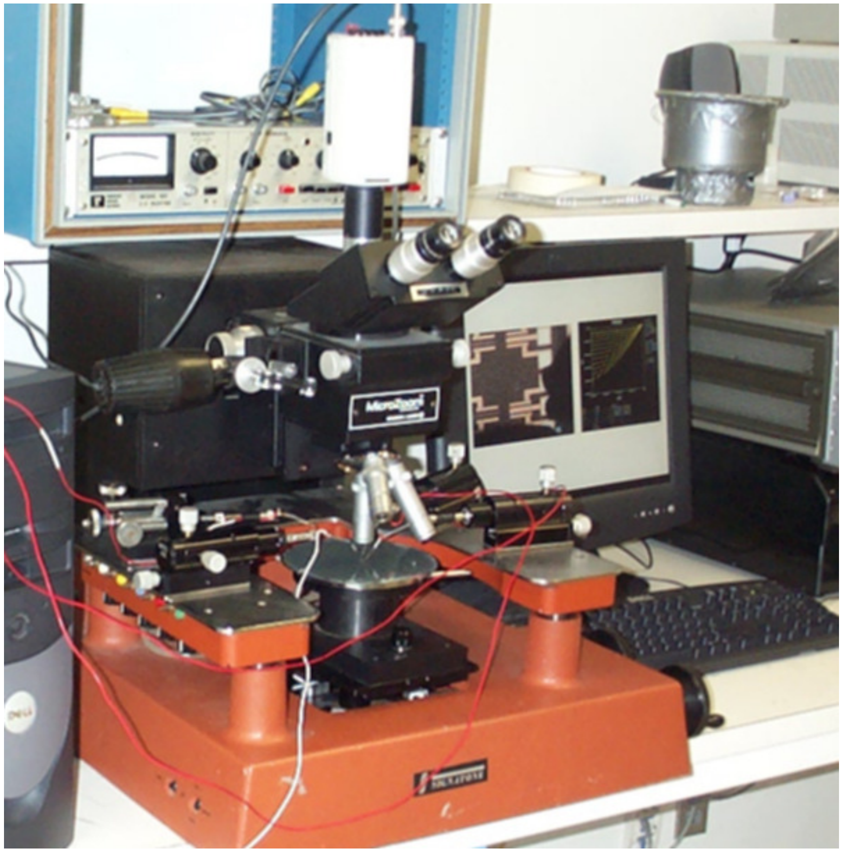
MOVIE OF PROBE STATION SET UP



Probe Station Set Up

movie click to play

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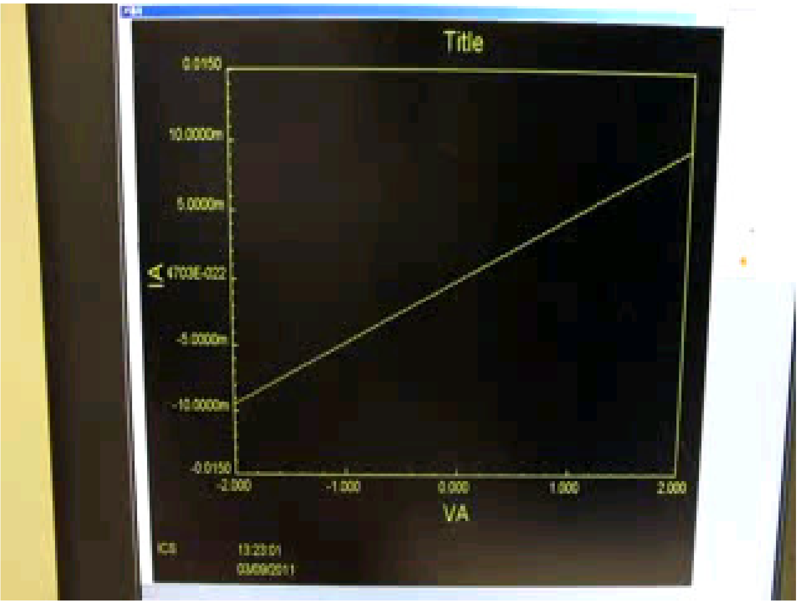
DATA COLLECTION AND RESISTANCE VALUE

movie click to play



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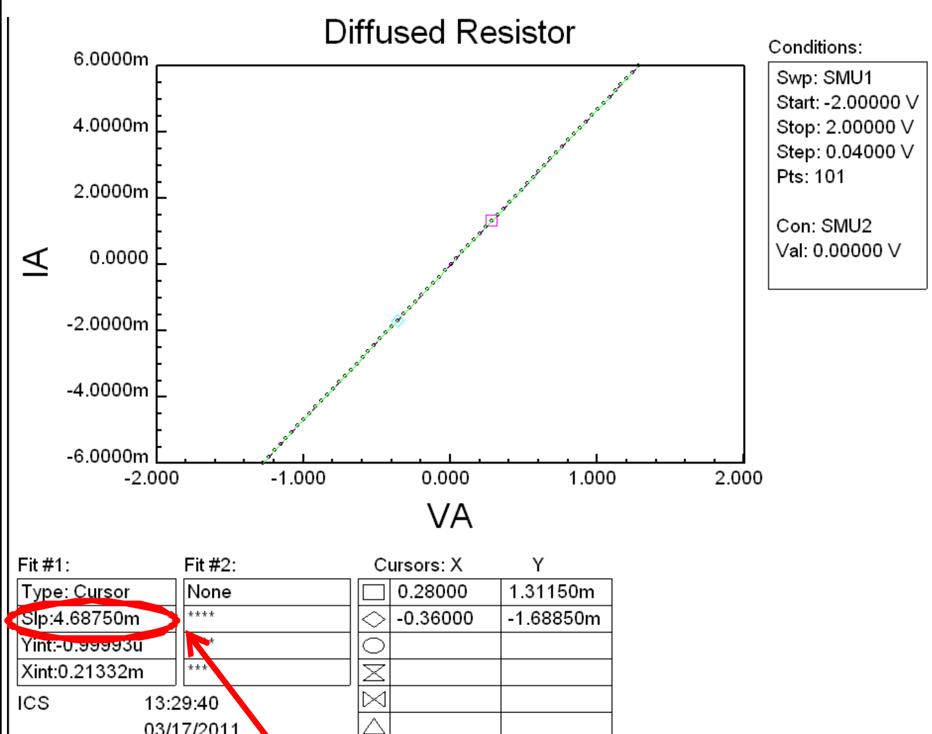
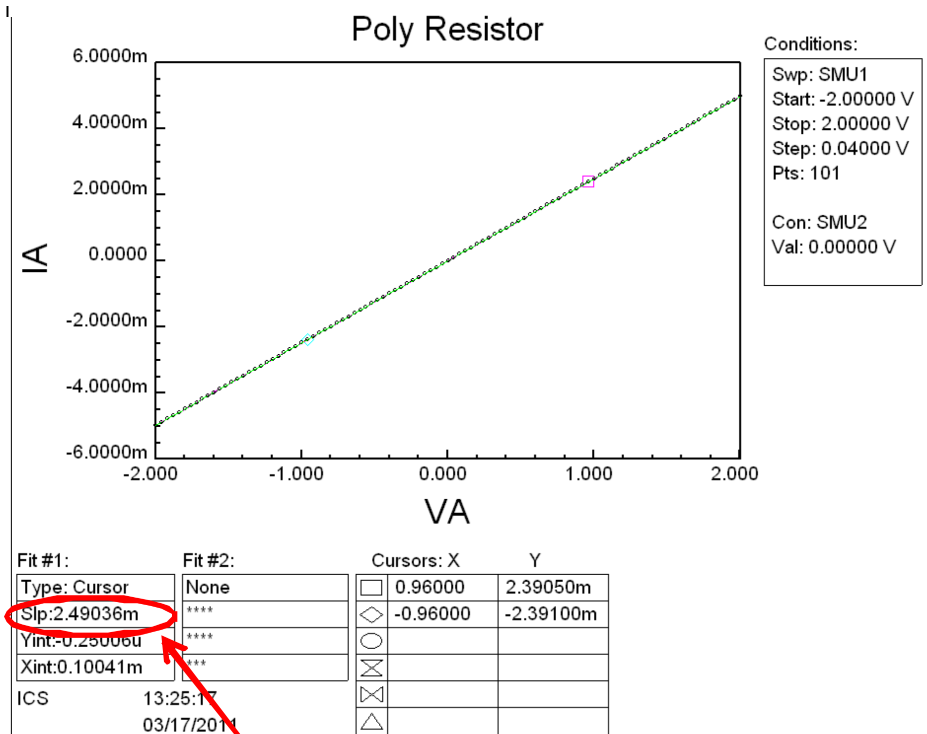
MEASURED RESISTANCE

Measure resistance of the heater and the sensor using the HP-4145 Semiconductor Parameter Analyzer and calculate the sheet resistance.





Slope = 4.69m

Slope = 2.49m

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CALCULATIONS

Using the data on the previous page calculate
R = 1 / slope
For both diffused and poly resistors.

Calculate Rhos
R = Rhos L/W
For both diffused and poly resistors.

SEEBECK EFFECT

When two dissimilar conductors are connected together a voltage may be generated if the junction is at a temperature different from the temperature at the other end of the conductors (cold junction) This is the principal behind the thermocouple and is called the Seebeck effect.

$$\Delta V = \alpha_1(T_{cold}-T_{hot}) + \alpha_2 (T_{hot}-T_{cold})=(\alpha_1-\alpha_2)(T_{hot}-T_{cold})$$

Where α_1 and α_2 are the Seebeck coefficients for materials 1 and 2

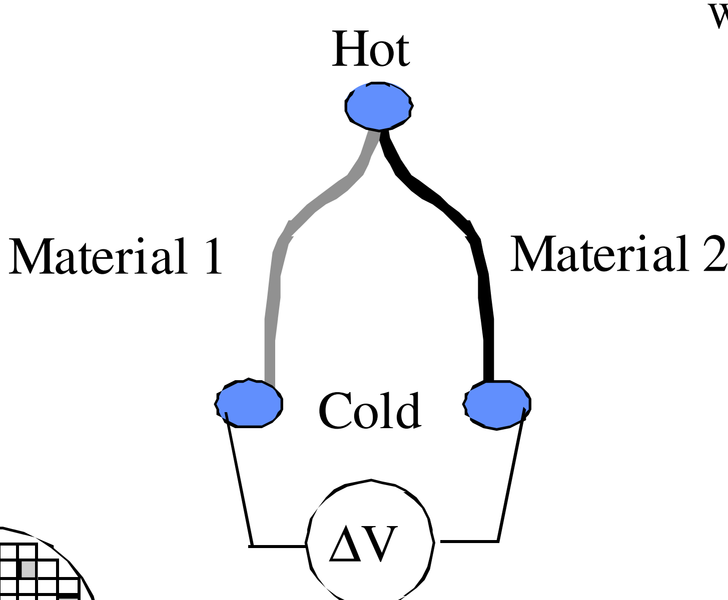

Table 2.6 The Seebeck Coefficients Relative to Platinum for Selected Metals and for *n*- and *p*-Type Polysilicon

	μV/K		μV/K
Bi	−73.4	Ag	7.4
Ni	−14.8	Cu	7.6
Pa	−5.7	Zn	7.6
Pt	0	Au	7.8
Ta	3.3	W	11.2
Al	4.2	Mo	14.5
Sn	4.2	*n*-poly (30 Ω/□)	−100
Mg	4.4	*n*-poly (2600 Ω/□)	−450
Ir	6.5	*p*-poly (400 Ω/□)	270

Note: The sheet resistance is given for the 0.38-μm-thick polysilicon films. Polysilicon is an attractive material for the fabrication of thermocouples and thermopiles because of its large Seebeck coefficient.

Nadim Maluf, Kirt Williams, An Introduction to Microelectromechanical Systems Engineering, 2nd Ed. 2004

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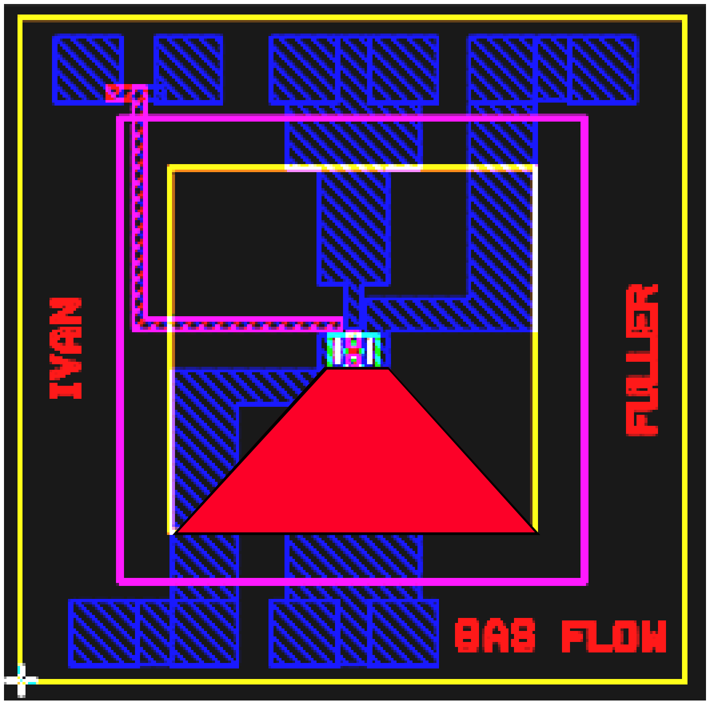
THERMAL RESISTANCE

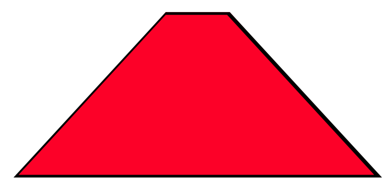


Rth = 1/C L/Area

where

C=thermal conductivity
L= length of thermal path between heater and ambient
Area = cross sectional area of the path to ambient

200um



2200 um

Thickness ~ 30 um

Rth ~ 1/1.5 1000/(500x30) = 444°C/watt
but 4 paths in parallel gives ~ 111 °C/watt

THERMAL PROPERTIES OF SOME MATERIALS

	MP °C	Coefficient of Thermal Expansion ppm/°C	Thermal Conductivity w/cmK	Specific Heat cal/gm°C
Diamond		1.0	20	
Single Crystal Silicon	1412	2.33	1.5	
Poly Silicon	1412	2.33	1.5	
Silicon Dioxide	1700	0.55	0.014	
Silicon Nitride	1900	0.8	0.185	
Aluminum	660	22	2.36	0.215
Nickel	1453	13.5	0.90	0.107
Chrome	1890	5.1	0.90	0.03
Copper	1357	16.1	3.98	0.092
Gold	1062	14.2	0.032	
Tungsten	3370	4.5	1.78	
Titanium	1660	8.9	0.17	
Tantalum	2996	6.5	0.54	
Air			0.00026	0.24
Water	0		0.0061	1.00

1 watt = 0.239 cal/sec

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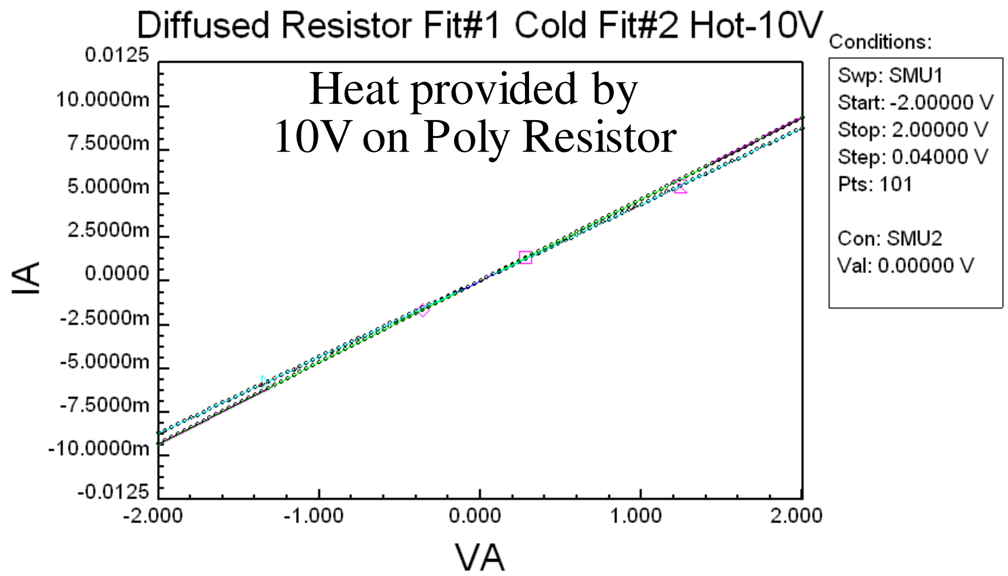
COLLECT DATA VERSUS HEATER VOLTAGE

Heater Voltage, V	Heater Current, I mA	Poly Heater Power W	Poly Heater Resistance Ohms	TC Voltage V mV	Temp. from TC Voltage °C	Diffused Sensor Resistance, ohms
0	0		-	.001		207
2	5			.067		210
4	10			.237		214
6	15			.517		218
8	20			1.006		220
10	25			1.690		230
12	30			2.580		340
14	35			3.500		255

Calculations: $P = I\,V$

$Temp = 25°C + \text{TC voltage} / (\alpha 1 - \alpha 2)$

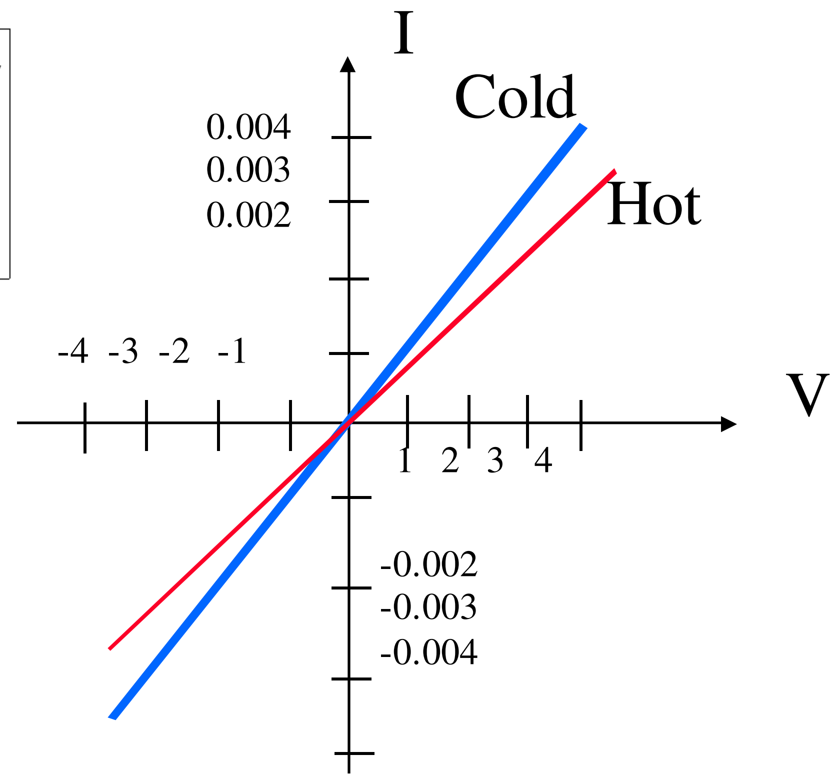
RESISTOR TEMPERATURE RESPONSE



Fit #1:	Fit #2:
Type: Cursor	Type: Cursor
Slp:4.68750m	Slp:4.36871m
Yint:-0.99993	Yint:3.69883u
Xint:0.21332m	Xint:-0.84666m

Cursors:	X	Y
□	0.28000	1.31150m
◇	-0.36000	-1.68850m
○		
⧖	1.24000	5.42090m
⋈	-1.32000	-5.76300m
△		

ICS 13:33:47 03/17/2011



Slope = 4.37m

Slope = 4.69m

$R = \rho L/(W\ xj)$ ohms

$\rho = 1/(q\mu_n n + q\mu_p p)$

L,W,xj do not change with light, µn and µp does not change with light but can change with temperature, n and p does not change much in heavy doped semiconductors (that is, n and p is determined by doping)

CALCULATION OF RESISTANCE

Calculation of Mobility of Single Crystal Silicon

CONSTANTS	VARIABLES			CHOICES	
Tn = T/300 1.14					1=yes, 0=no
	Temp=	342	°K	n-type	0
	Concentration from Dose / thickness, N = Dose/t =	6.33E+17	cm-3	p-type	1
Kamins, Muller and Chan; 3rd Ed., 2003, pg 33					
	mobility = µ =	129	cm2/(V-sec)		

Calculation of Resistance

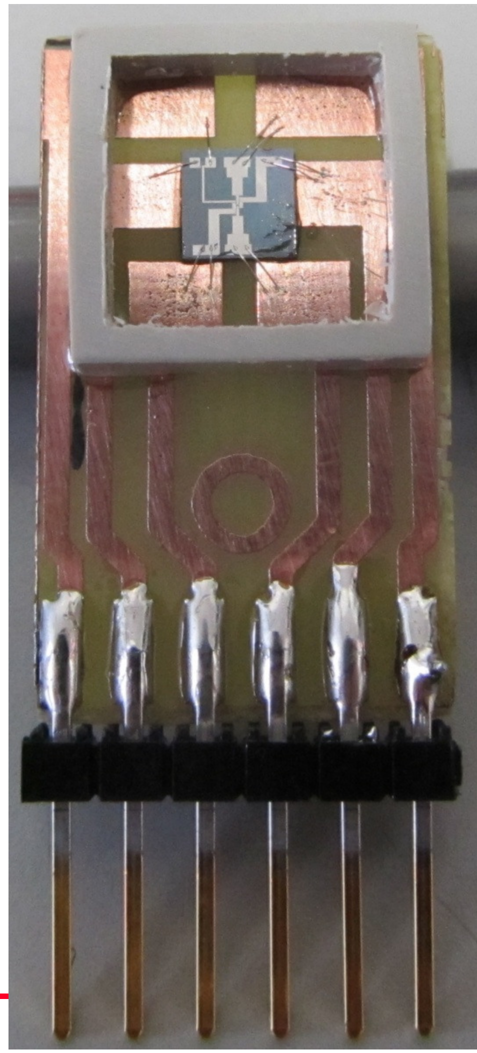
L ength is the drawn length	Length, L =	180	µm
Width is the drawn width	Width, W =	200	µm
Thickness is known if poly, or Xj from Diffusion.XLS	Thickness, t =	3	µm
Implanter setting if doped by ion implant or from Diffusion.xls if doped by c	Dose =	1.90E+14	/cm2
	Poly ?	0	Yes=1 , No =0
	resistance/poly grain boundary	0.9	ohm

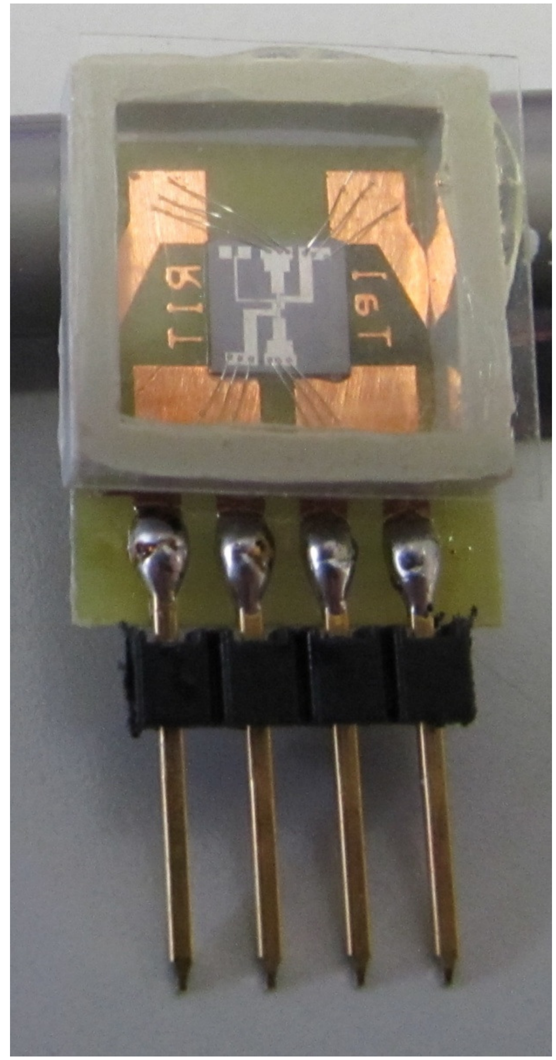
Calculation of Resistance

	approximate number of grain boundaries in path = L / t =	60	
	Average Doping = Dose/Thickness =	6.33E+17	atoms/cm3
	Mobility, µ =	129	cm2/v-sec
q = 1.6e-19 coulomb / ion	Rhos = sheet resistance =1/(q µ Dose) =	254	ohms/sq
	Rho = bulk resistivity =	85	ohm-cm
R = Rho L / W / t	Resistance =	229	ohms
R = Rhos L / W	If Poly the effective sheet resistance =	254	ohms/sq

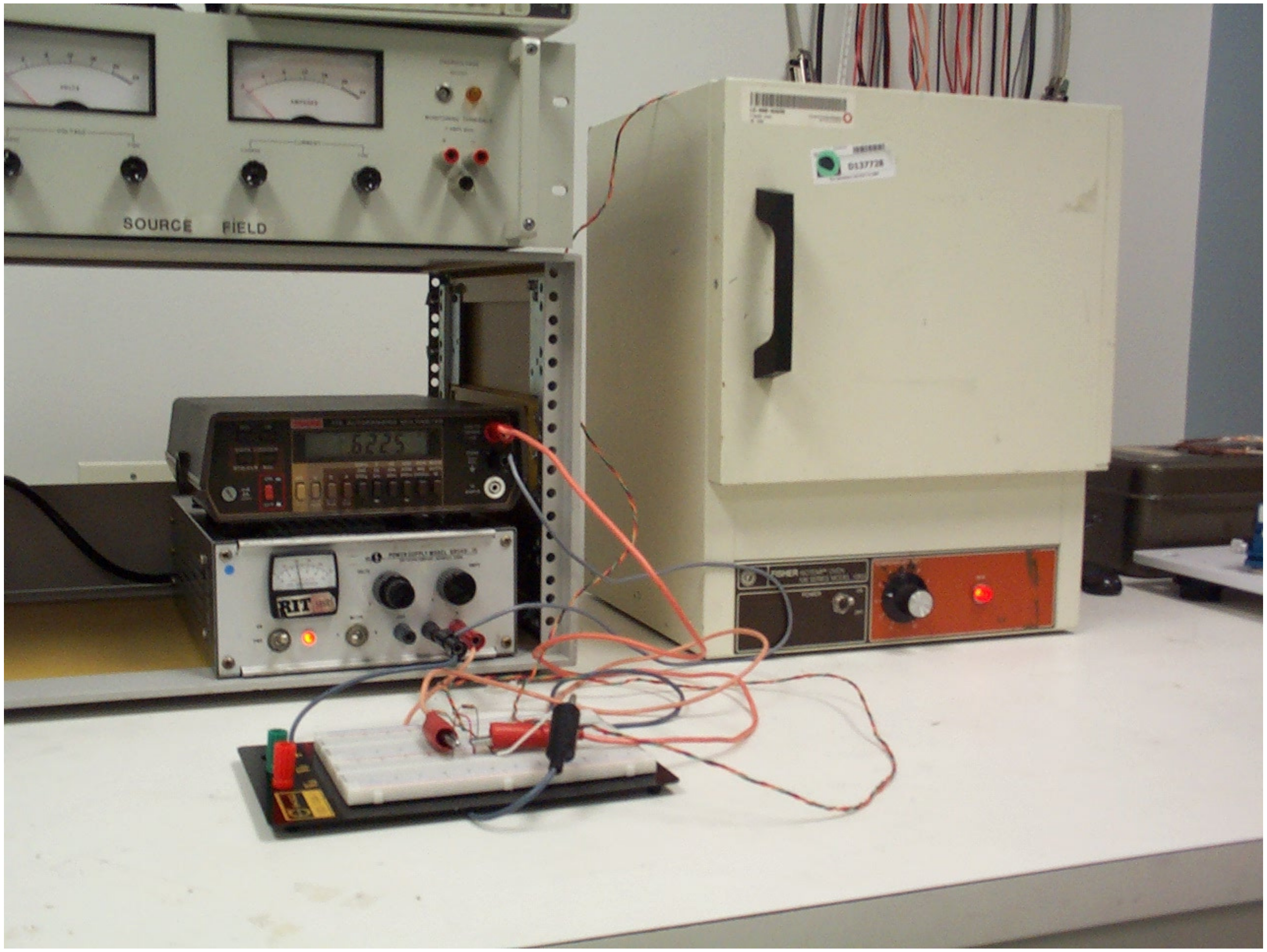
We assume the grain size is equal to the poly film thickness/2. We calculate the number of grains from the length, L, divided by the grain size, t/2. We also assume the grain boundary adds a fixed resistance that is not a function of temperature or doping. The resistance of a grain boundary is found from resistance measurements of poly resistors.

PACKAGED SENSOR CHIPS





RESISTOR VS TEMPERATURE CALIBRATION



Take data for room T up to 100°C

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TEMPERATURE CALIBRATION DATA

Oven Temperature °C	Poly Resistance Ohms		Diffused Resistance Ohms	
	Measured	Calculated	Measured	Calculated
30	394		207	
35	394		209	
40	394		211	
45	395		215	
50	395		218	
55	395		221	
60	395		224	
65	395		227	
70	396		230	
75	396		232	
80	396		235	
85	396		237	
90	397		240	
95	397		243	
100	397		245	

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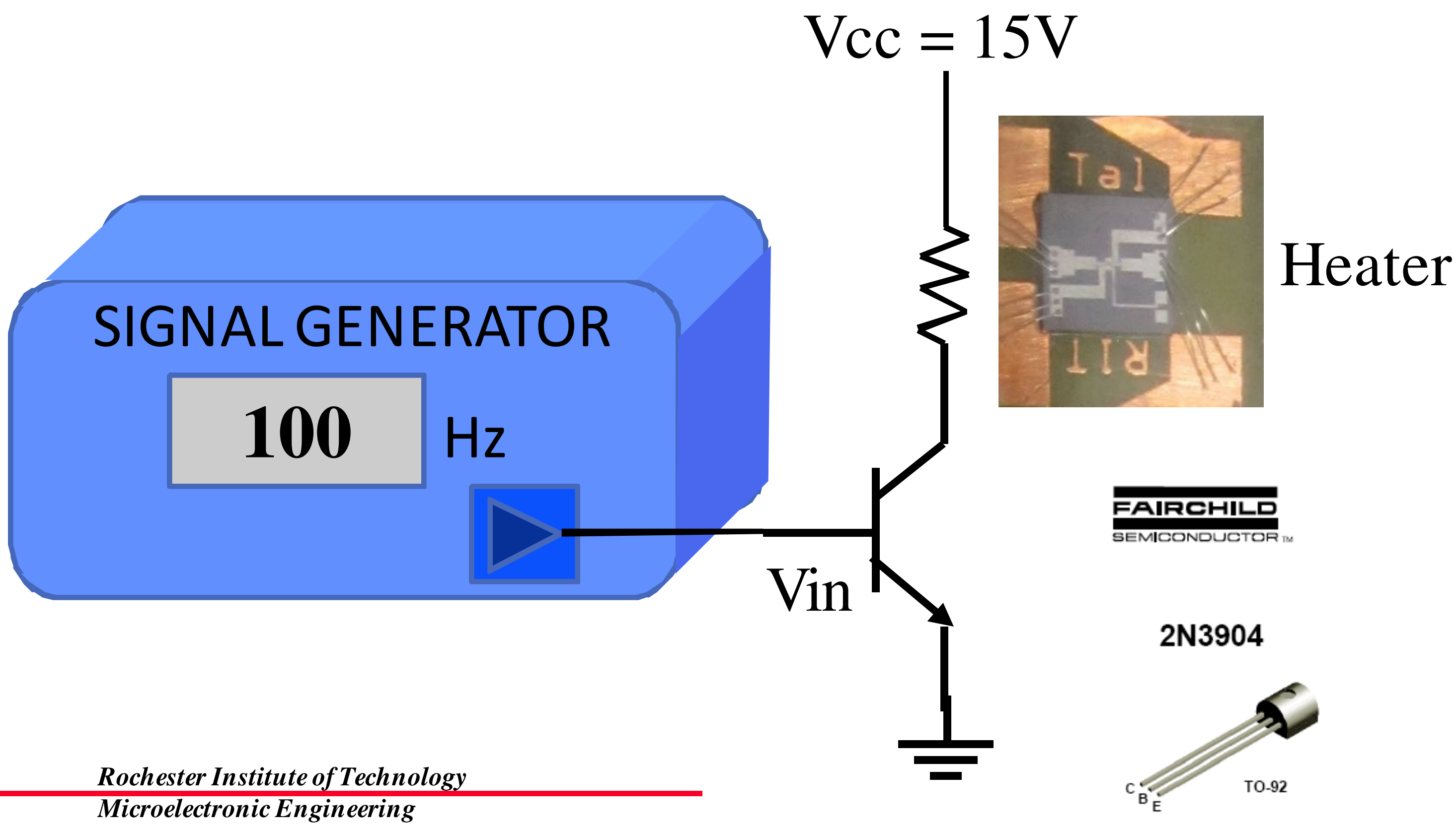
ACTUATOR CHARACTERIZATION

Supply heater voltage from a signal generator and try to evaluate the speed of response of the diaphragm movement.



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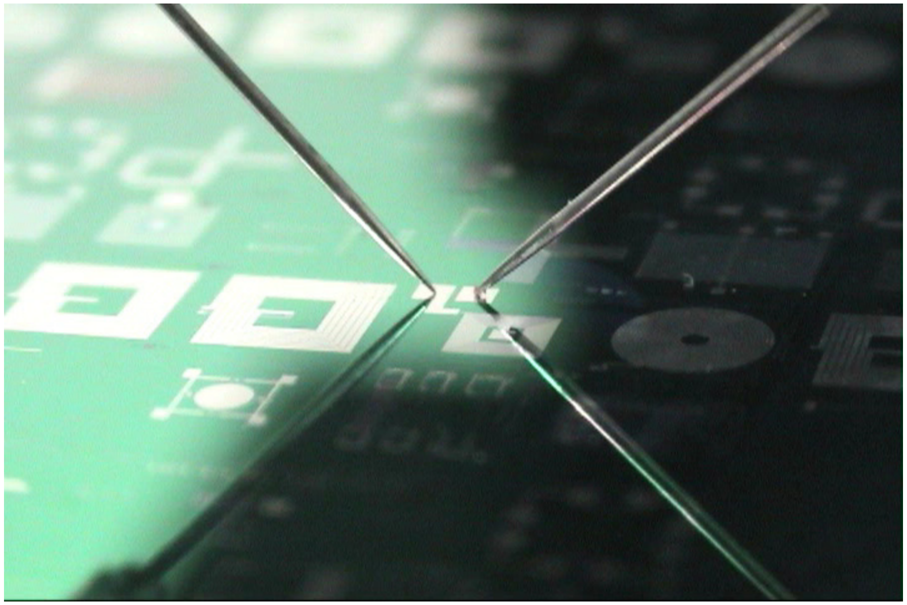
SEE IT MOVE – HEAR IT



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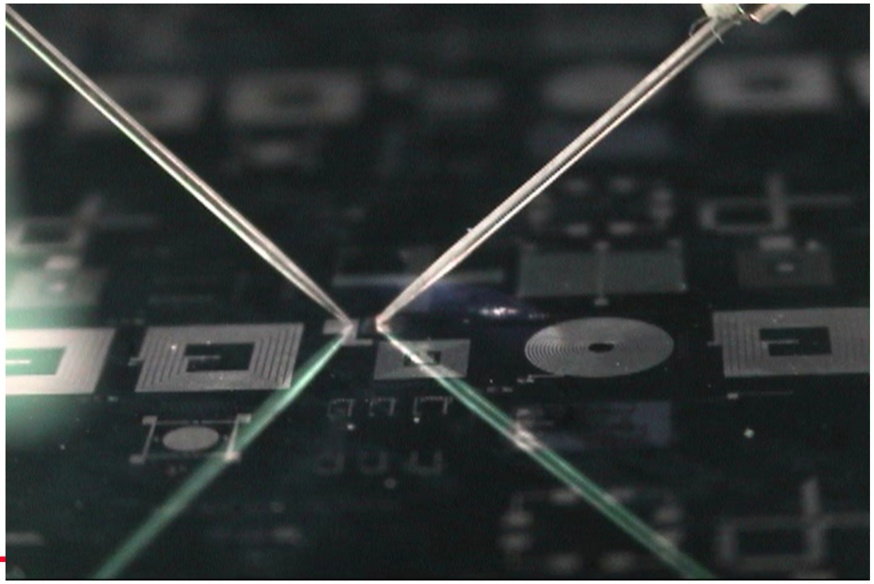

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REFERENCES

1. Handbook of Modern Sensors, Jacob Faraden, Springer
2. Dr. Fuller's webpages, http://people.rit.edu/lffeee

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HOMEWORK

1. Do a more exact calculation of the thermal resistance of the diaphragm shown on page 12.
2. Why can't we calibrate the thermocouple using the oven?
3. Does our data show a square law relationship for temperature vs. voltage to the heater? Why?
4. Plot the data and calculations from page 19. What conclusions can be made?
5. Compare heater and sensor resistance vs. temperature data from page 14 to that from page 19.
6. Discuss the theoretical frequency response of the diaphragm.
7. Write a ~150 word abstract for this lab project.

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INSTRUCTORS CHECK LIST

Show MEMS chip
Take Picture
Apply Vacuum
Take Picture
Measure Heater Resistance using HP4145
Measure Sensor Resistance using HP4145
Measure Sensor Resistance with and without light
Measure Heater Resistor with voltmeter and current meter
Measure Heater I and V at 50 mV applied (no self heating)
Measure Heater I and V at 15 V applied (self heating ~1/4watt)
Take picture of diaphragm deflection due to heating
Take data for table
Take data for Sensor Resistor in oven
Take data for Heater Resistor in oven
Evaluate frequency response of heat driven diaphragm movement

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