MEMS Resistor Laboratory

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3-13-2013 Resistor_lab.ppt
Resistor Lab

OUTLINE

Objective
Theory
Experimental Set Up
Measurements
Results
Discussion
References
Lab Instructors Notes
The objective of this lab is to investigate integrated MEMS resistors and their applications as heaters, sensors and actuators.

4000x4000 chip
2200x2200 diaphragm
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
RESISTORS ON THIN DIAPHRAGM

With Vacuum Chuck On
MOVIE OF DIAPHRAGM DEFLECTION

MEMS Diaphragm Deflection

Dr. Lynn Fuller
Ivan Puchades

movie click to play
MOBILE OF PROBE STATION SET UP

Probe Station Set Up

movie click to play
DATA COLLECTION AND RESISTANCE VALUE

movie click to play

movie click to play
MEASURED RESISTANCE

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

Slope = 4.69 m

Slope = 2.49 m
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.

\[ \Delta V = \alpha_1 (T_{\text{cold}} - T_{\text{hot}}) + \alpha_2 (T_{\text{hot}} - T_{\text{cold}}) = (\alpha_1 - \alpha_2)(T_{\text{hot}} - T_{\text{cold}}) \]

Where \( \alpha_1 \) and \( \alpha_2 \) 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

<table>
<thead>
<tr>
<th>Material</th>
<th>( \Delta V/K )</th>
<th>( \mu V/K )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bi</td>
<td>-73.4</td>
<td>7.4</td>
</tr>
<tr>
<td>Ni</td>
<td>-14.8</td>
<td>7.6</td>
</tr>
<tr>
<td>Pa</td>
<td>-5.7</td>
<td>7.6</td>
</tr>
<tr>
<td>Pt</td>
<td>0</td>
<td>7.8</td>
</tr>
<tr>
<td>Ta</td>
<td>3.3</td>
<td>11.2</td>
</tr>
<tr>
<td>Al</td>
<td>4.2</td>
<td>14.5</td>
</tr>
<tr>
<td>Sn</td>
<td>4.2</td>
<td>n-poly (30 ( \Omega/cm ))</td>
</tr>
<tr>
<td>Mg</td>
<td>4.4</td>
<td>n-poly (2600 ( \Omega/cm ))</td>
</tr>
<tr>
<td>Ir</td>
<td>6.5</td>
<td>p-poly (400 ( \Omega/cm ))</td>
</tr>
</tbody>
</table>

Note: The sheet resistance is given for the 0.38-\( \mu \)m-thick polysilicon film. Polysilicon is an attractive material for the fabrication of thermocouples and thermopiles because of its large Seebeck coefficient.
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

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

Thickness ~ 30 um
# THERMAL PROPERTIES OF SOME MATERIALS

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

1 watt = 0.239 cal/sec
### COLLECT DATA VERSUS HEATER VOLTAGE

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

Calculations:  
\[ P = I \times V \]  
\[ \text{Temp} = 25°C + \frac{\text{TC voltage}}{(\alpha_1 - \alpha_2)} \]
RESISTOR TEMPERATURE RESPONSE

Heat provided by 10V on Poly Resistor

R, L, W, xj do not change with light, \( \mu_n \) and \( \mu_p \) 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).

\[
R = \rho \frac{L}{W x_j} \quad \text{ohms}
\]
\[
\rho = \frac{1}{q \mu_n n + q \mu_p p}
\]
CALCULATION OF RESISTANCE

### Calculation of Mobility of Single Crystal Silicon

<table>
<thead>
<tr>
<th>CONSTANTS</th>
<th>VARIABLES</th>
<th>CHOICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_n = T/300 )</td>
<td>( T = 342 )°K</td>
<td>( n)-type 0, ( p)-type 1</td>
</tr>
<tr>
<td>Concentration from Dose / thickness, ( N = \frac{\text{Dose}}{t} = 6.33 \times 10^7 ) cm(^{-3})</td>
<td>( \mu = 129 ) cm(^2)(V-sec)</td>
<td></td>
</tr>
</tbody>
</table>

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

### Calculation of Resistance

- Length is the drawn length
- Width is the drawn width
- Thickness is known if poly, or \( X_j \) from Diffusion.xls if doped by c

| Implanter setting if doped by ion implant or from Diffusion.xls if doped by c | \( \text{Dose} = 1.9 \times 10^{14} \) /cm\(^2\) |
| Poly? | \( \text{Yes} = 1 \), No = 0 |
| Resistance/poly grain boundary | 0.9 ohm |

### Calculation of Resistance

- Average Doping = \( \text{Dose} / \text{Thickness} = 6.33 \times 10^7 \) atoms/cm\(^3\)
- Mobility, \( \mu = 129 \) cm\(^2\)(V-sec)
- q = 1.6e-19 coulomb / ion
- \( \text{Rhos} = \text{sheet resistance} = \frac{1}{(q \mu \text{Dose})} = 254 \) ohms/sq
- \( \text{Rho} = \text{bulk resistivity} = 85 \) ohm-cm
- \( R = \frac{\text{Rho} L}{W \mu} = 229 \) ohms
- \( R = \frac{\text{Rhos} L}{W} = 254 \) 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
## TEMPERATURE CALIBRATION DATA

<table>
<thead>
<tr>
<th>Oven Temperature °C</th>
<th>Poly Resistance Ohms</th>
<th>Diffused Resistance Ohms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured</td>
<td>Calculated</td>
</tr>
<tr>
<td>30</td>
<td>394</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>394</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>394</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>395</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>395</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>395</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>395</td>
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<td>65</td>
<td>395</td>
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<td>70</td>
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<td>75</td>
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</tr>
<tr>
<td>80</td>
<td>396</td>
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</tr>
<tr>
<td>85</td>
<td>396</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>397</td>
<td></td>
</tr>
<tr>
<td>95</td>
<td>397</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>397</td>
<td></td>
</tr>
</tbody>
</table>
Supply heater voltage from a signal generator and try to evaluate the speed of response of the diaphragm movement.

\[ V_{cc} = 15V \]

**Diagram:**

- SIGNAL GENERATOR
- **Input:** Vin
- **Output:** Vcc = 15V
- **Heater**
- **Transistor**: 2N3904

**Text:**

- Rochester Institute of Technology
- Microelectronic Engineering

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SEE IT MOVE – HEAR IT

movie click to play

movie click to play

movie click to play
REFERENCES

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