EE688
Silicon Membrane Thermal Actuator

Ivan Puchades

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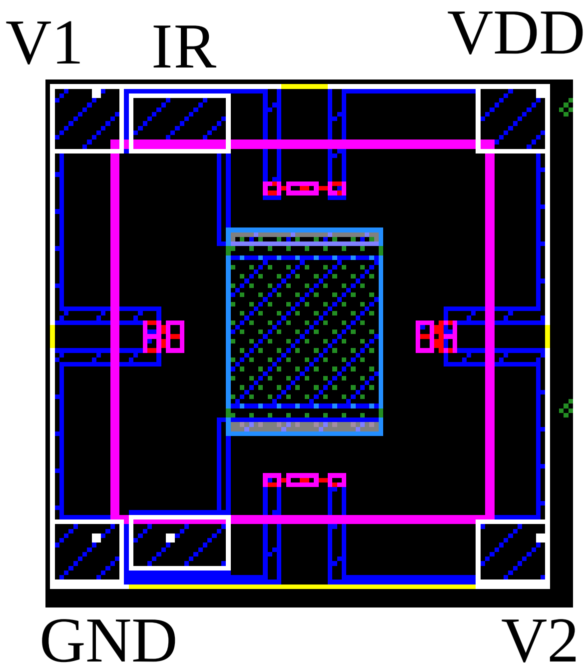
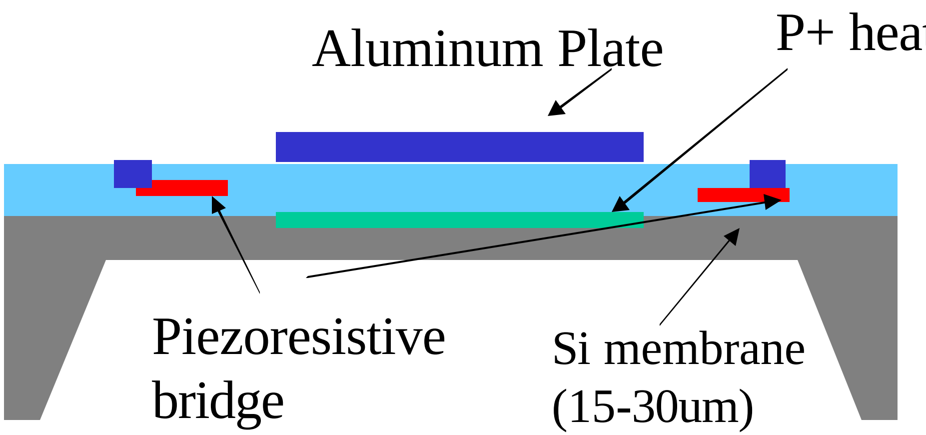
Proposed: Electro-thermal MEMS Viscometer



- In-situ P+ Si heater (joule heating).
- In-situ poly-silicon piezoresistor bridge to monitor membrane deflection

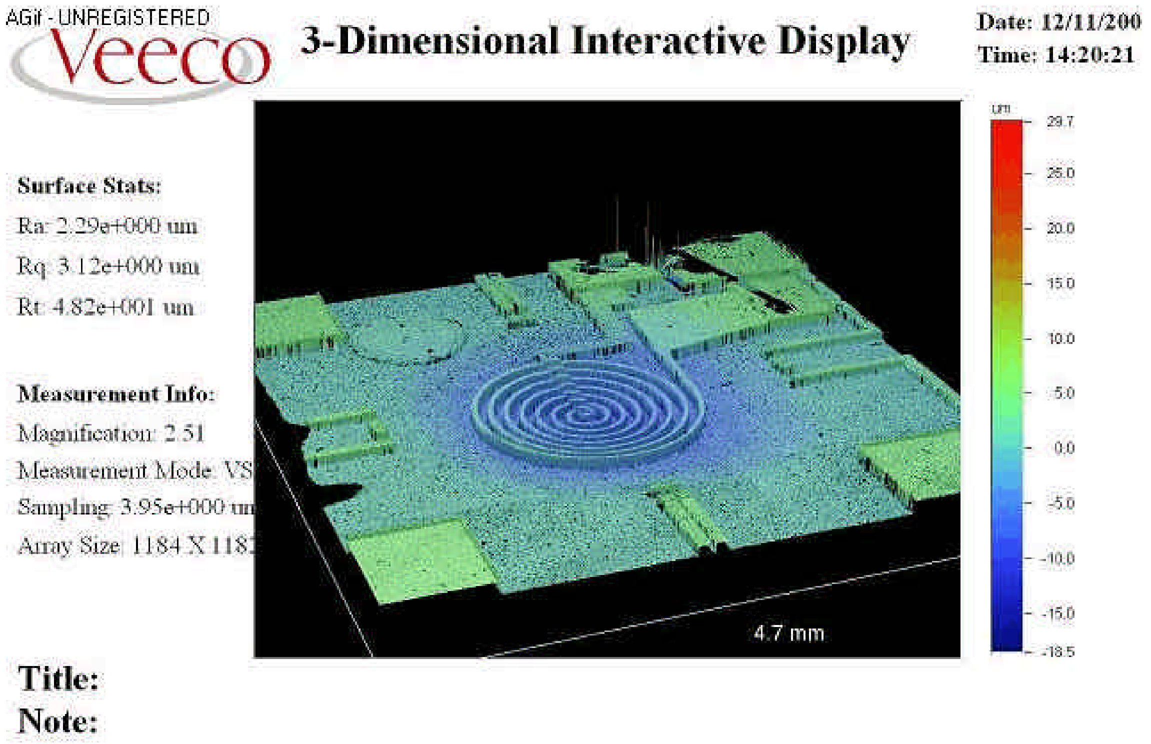
  Vout=V2-V1

- Vertical displacement due to thermal coefficient of expansion difference between Si/SiO_2 and Al (bimetallic effect)
- Viscosity of liquid opposes movement of membrane



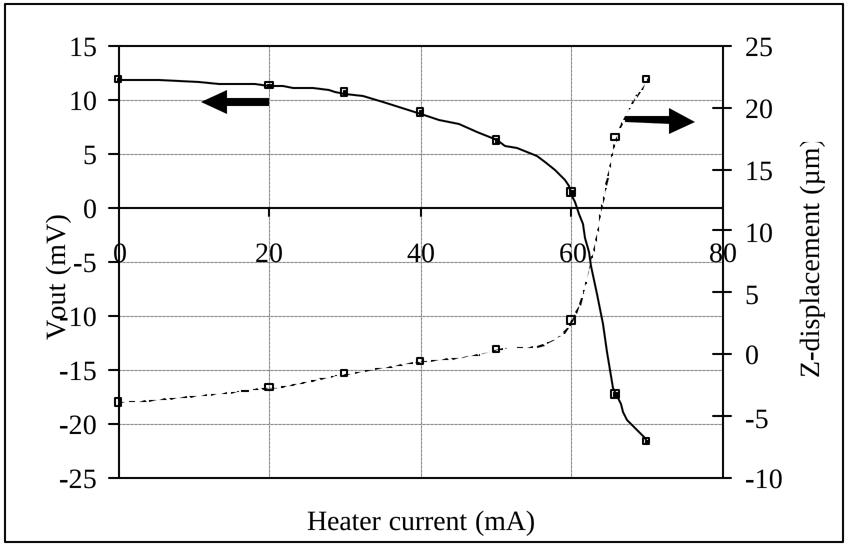
Vertical Displacement Calibration

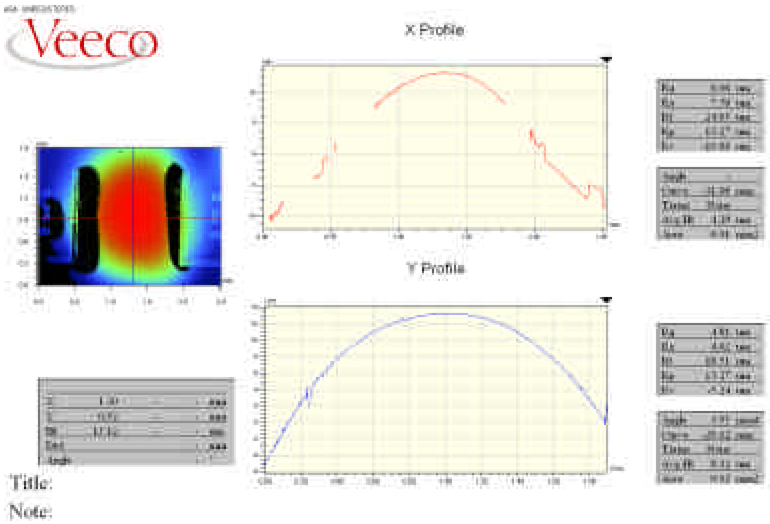
- Veeco Wyko White Light Interferometer
- Measure z-displacement and Vout=V2-V1



•Images at 0, 50, 100, 150, 200 and 250m A

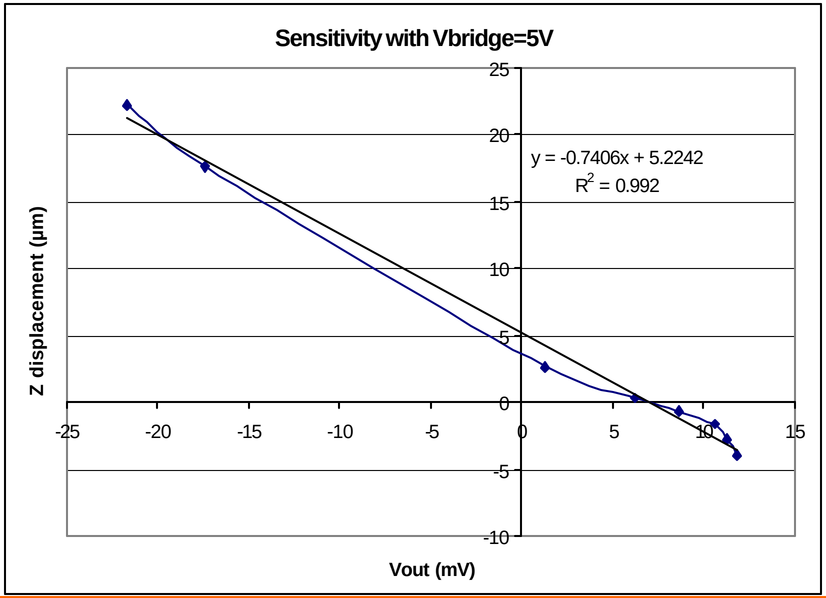
Vertical Displacement Calibration



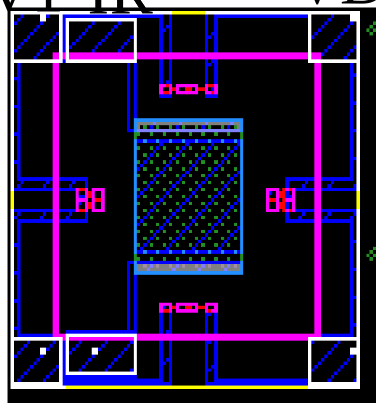


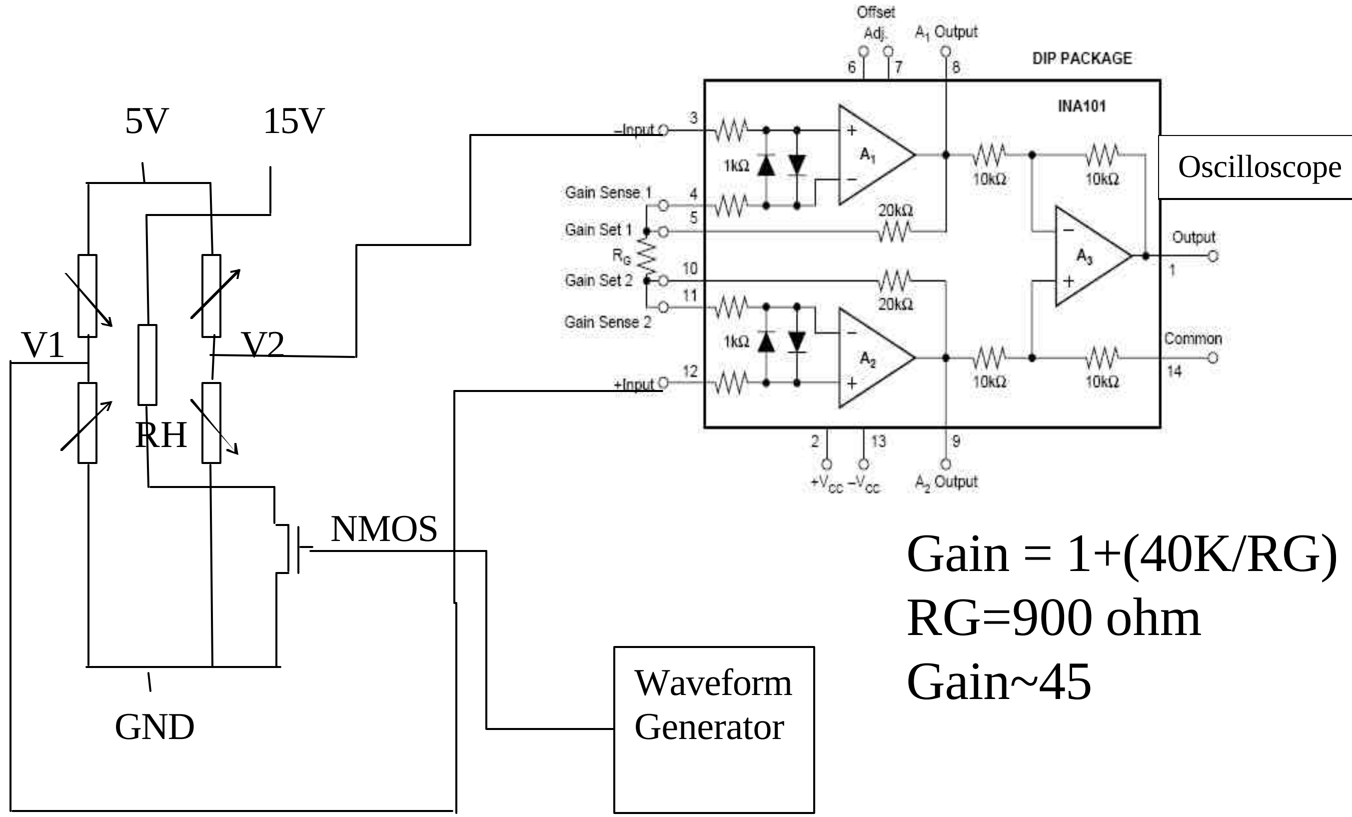
Sensitivity = 0.148 µm/mV/V

Example,
If Vbridge=5V and ? Vout=10mV,
Then,
? Z= (5V*10mV*0.148µm/mV/V) = **7.4µm**



Dynamic Measurement





Gain = 1+(40K/RG)

RG=900 ohm

Gain~45

- Thermal heater RH is pulsed with NMOS transistor to obtain needed current.
- Vout voltage is amplified with Instrumentation amplifier INA101 with a gain of 45.

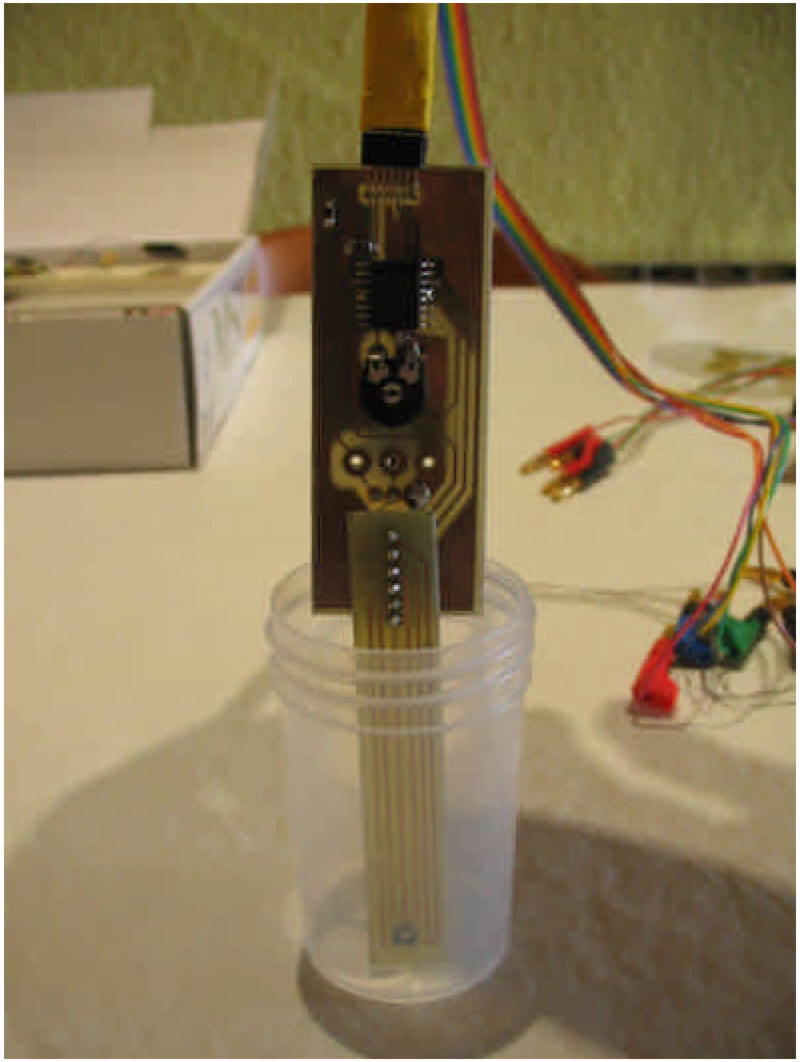
Viscosity sensor testing

Current supply to drive heater actuator to 50mA

Container if filled with oil up to set mark

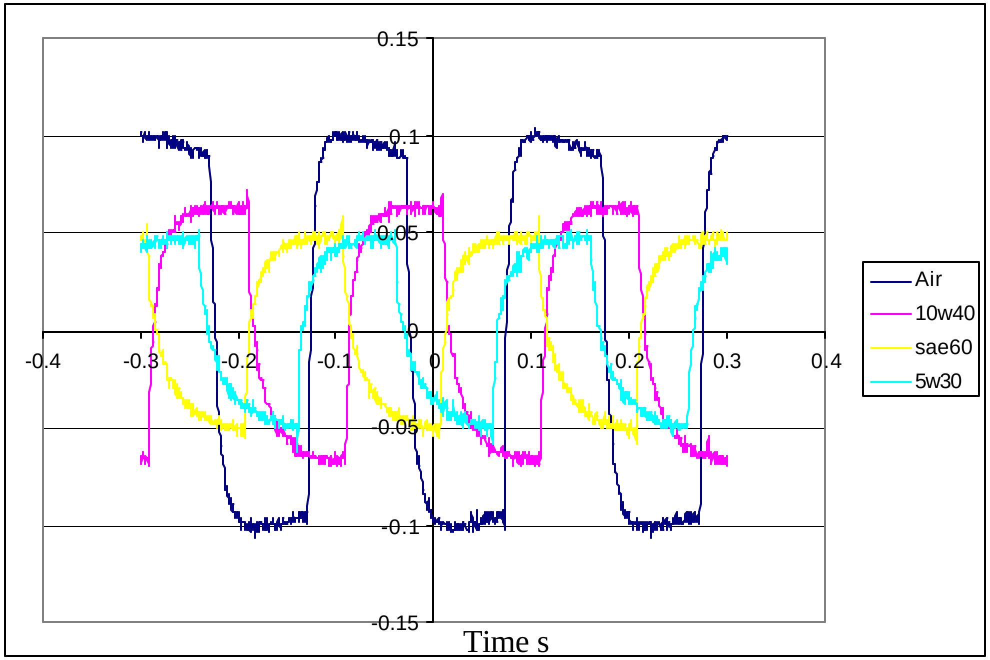
Frequency of driving actuator can be changed

Amplifier can be used to reject common noise and increase signal sensitivity



Typical Measurement

•Typical signal response of the amplified wheatsone bridge when the sensor is placed in oil compared to when is out it air.



•Does the change in response correspond to a change in the properties of the fluid/membrane interaction or is it just a result of the membrane not being able to heat as fast and as much as when in air?

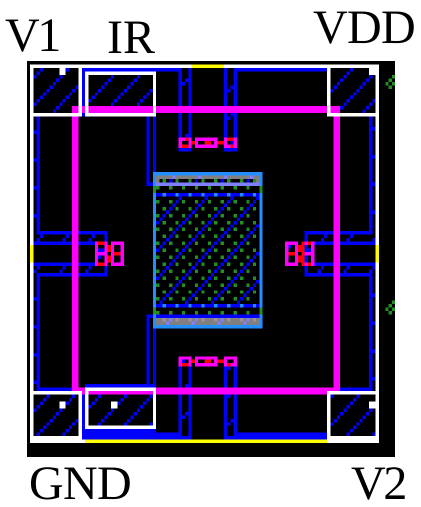
5W30 – 115.4 cSt
10W40 – 239.4 cSt
SAE60 – 758.4 cSt

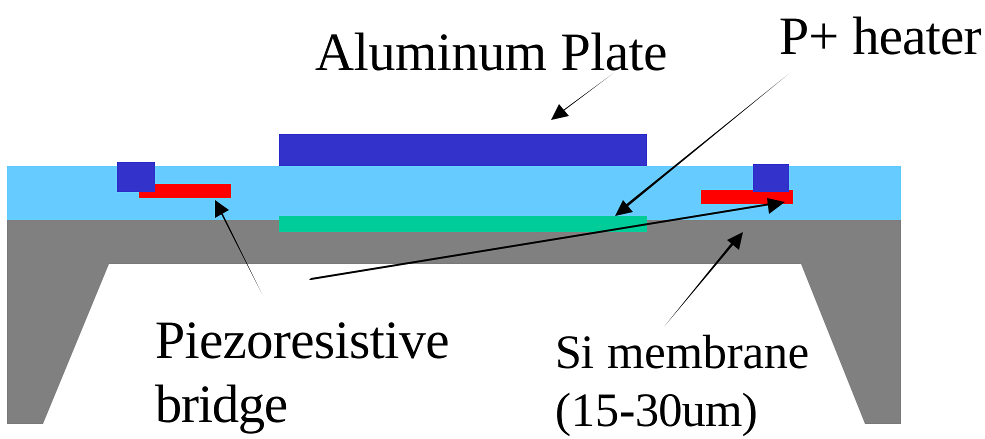
•Investigate temperature of membrane in and out of oil.

Temperature Measurement

Three ways to measure membrane temperature:

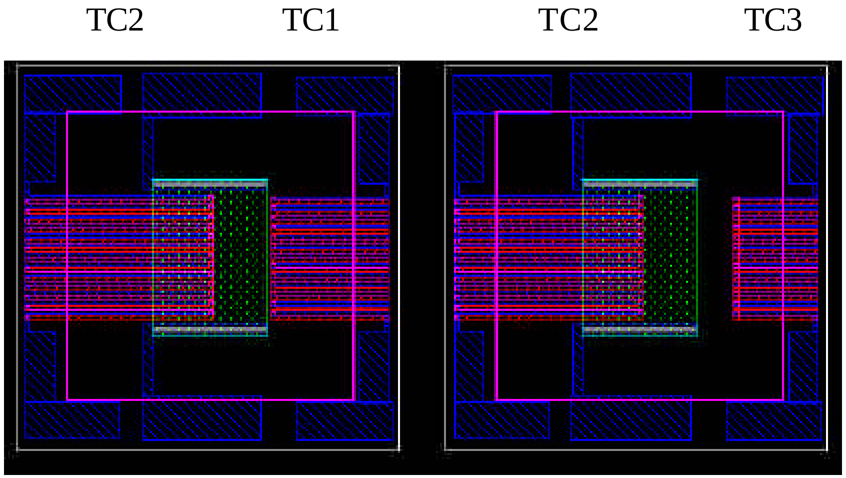
1. Thermocouples (seebeck effect)
2. Diode (diode temperature dependence)
3. Heating resistor (resistance change)





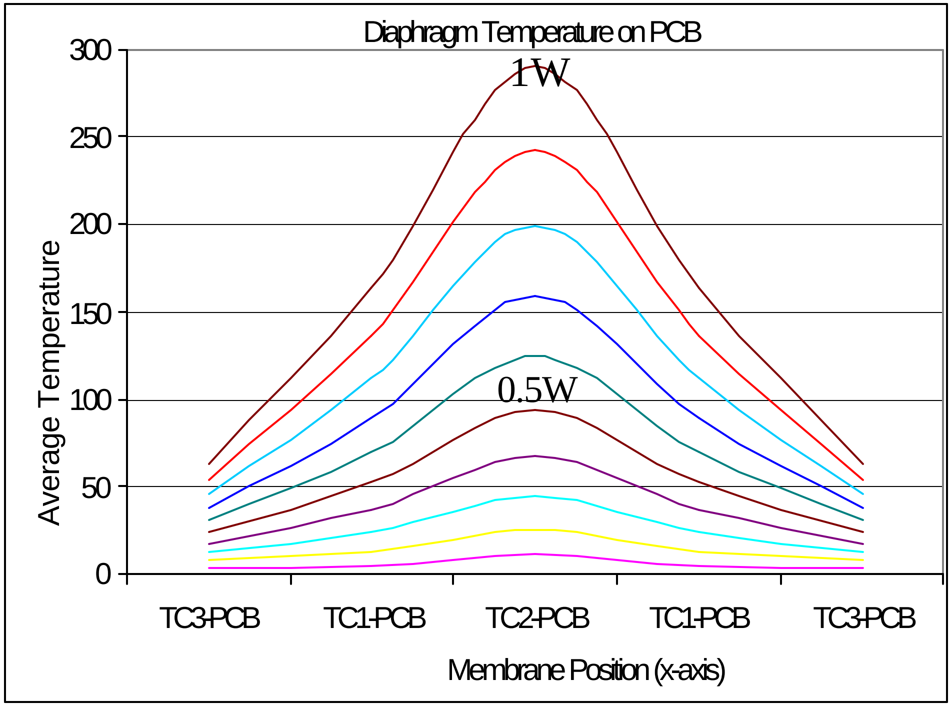
Thermocouple delta temperature

Thermocouples on Diaphragm



Thermopile = 13 thermal contacts
Diaphragm thickness is ~15µm

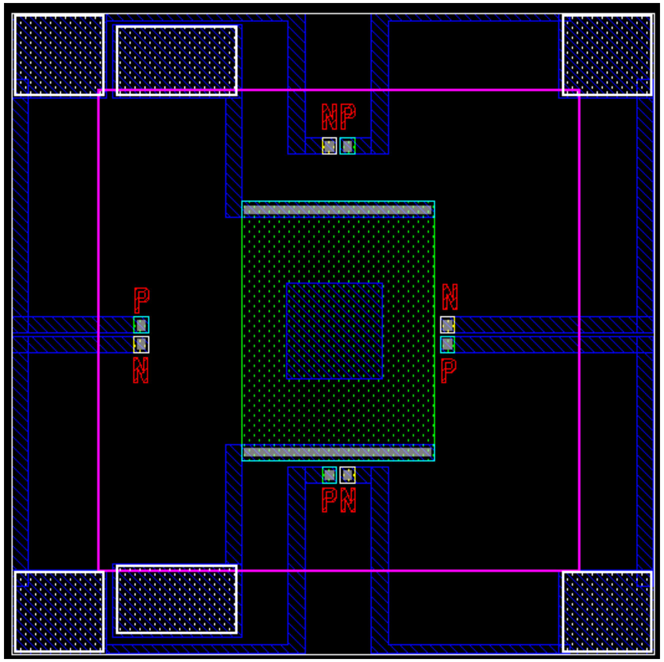
Theory 104 µV/K/contact
Or 1.352mV/K for thermopile

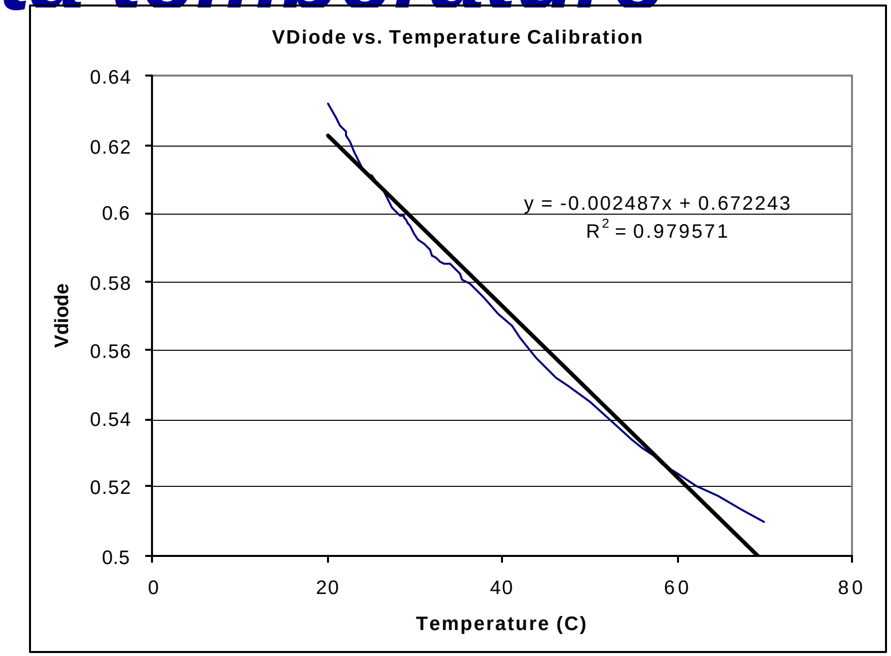


Temperature values are theoretical predictions of temperature change.
Calibration is not possible as both cold and hot junctions would be heated equally.
Deflection cannot be monitored.

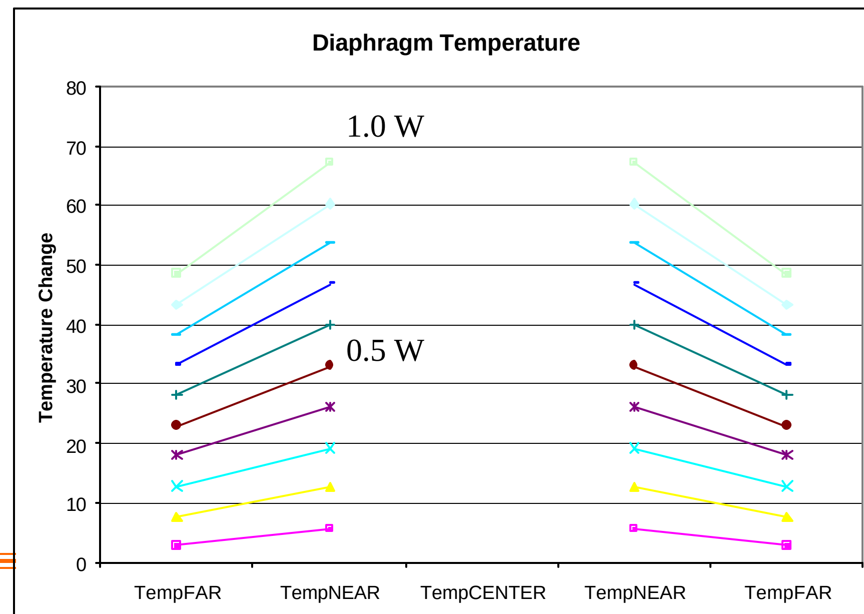
Diode delta temperature

Diode dependence on temperature
Constant current, S=-2.2mV/C





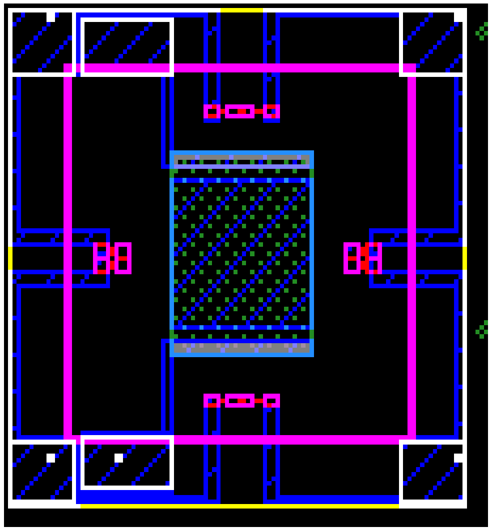
No information from center of diaphragm.
Deflection cannot be monitored.



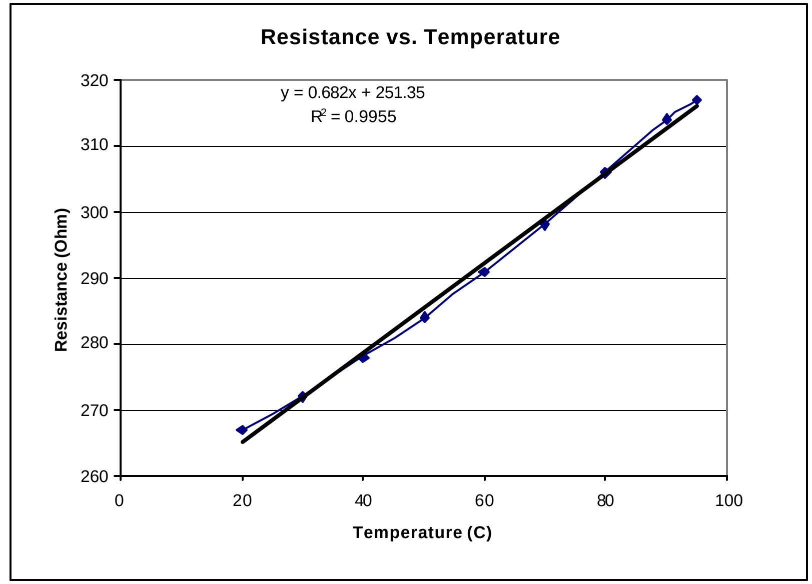
Semiconductor resistor temperature dependence

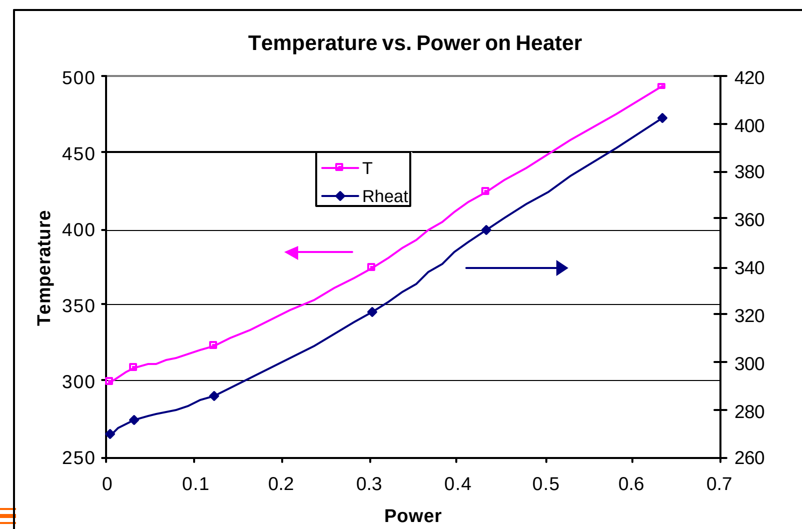
$$R(T,N) = \frac{1}{q\mu_n(T,N)\,n + q\,\mu_p(T,N)\,p}\,\frac{L}{Wt}$$

V1 IR VDD



GND V2

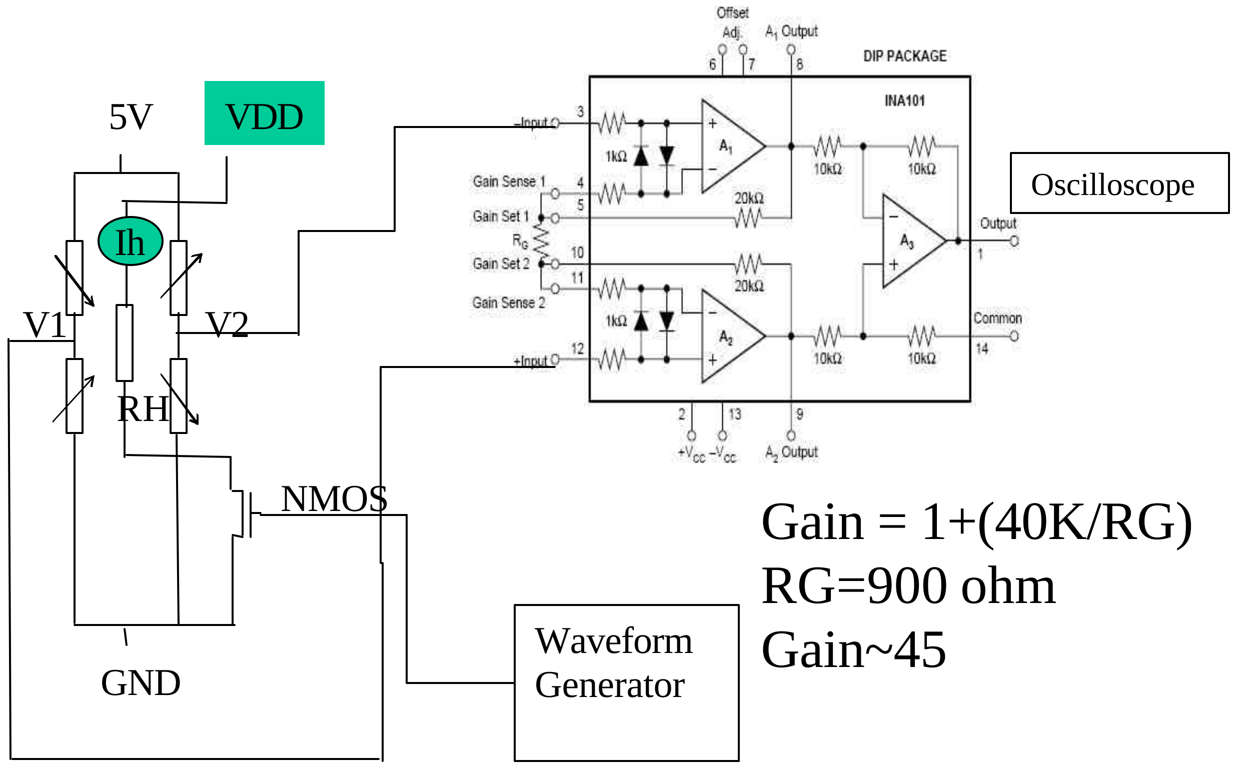




Direct monitor of heater temperature.

Z deflection can also be measured.

Determine cooling effect of oil on sensor



Gain = 1+(40K/RG)
RG=900 ohm
Gain~45

Observe deflection at 5Hz
Measure RH (VDD/Ih) and vertical displacement in air.
Measure RH and vertical displacement in oil.
Compare results and determine whether the displacement differences are due to temperature effects or viscosity dampening.