Sensors and Actuators

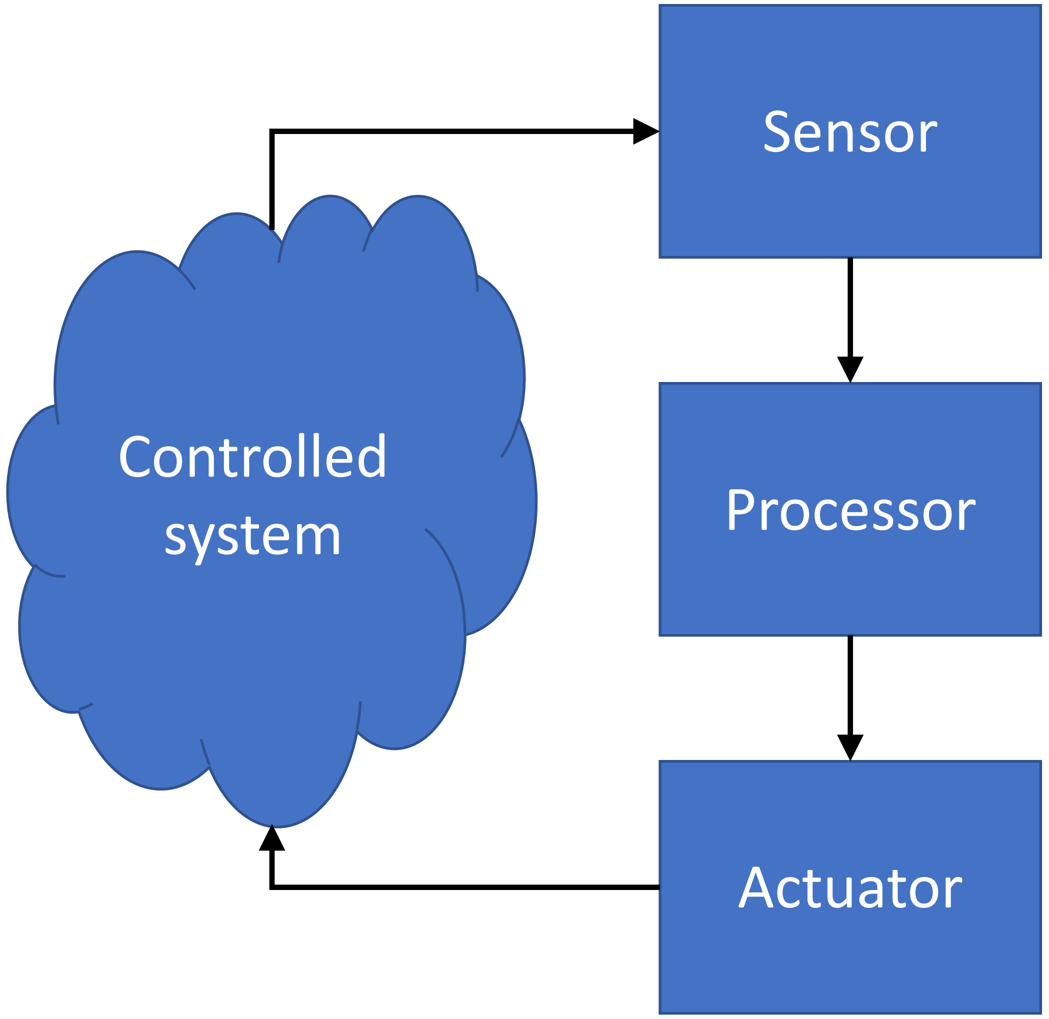
Dr. Aftab M Hussain

Transducers

- Transducers convert one form of energy into another
- Sensors and actuators are both transducers
  - Sensors convert a physical phenomenon into voltage
  - Actuators convert a voltage into a physical phenomenon
- Some things can do both
  - Thermocouple

Transducers

- Both sensors and actuators are key components of a controlled system
- A physical phenomenon is sensed by a sensor, processed using some algorithm and then an actuator is actuated to control the phenomenon
- Example: AC temperature control



Types of sensors

- There are many types of sensors:
  - Linear/displacement sensors
  - Acceleration sensors
  - Flow sensors
  - Temperature sensors
  - Light sensors
  - Gas sensors
  - Microbe sensors

Human sensors

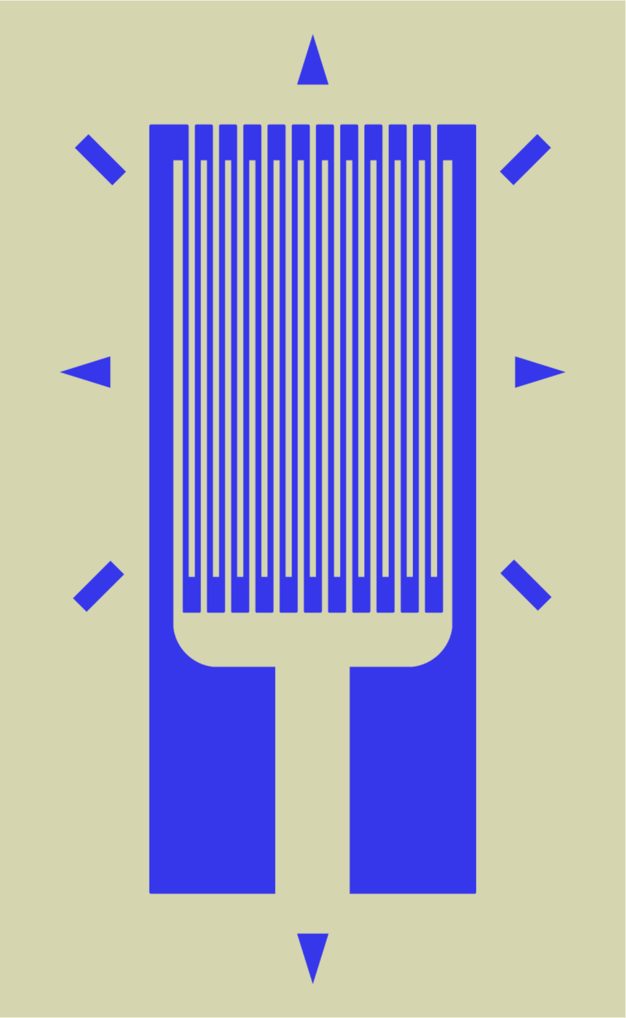
- Human beings are equipped with 5 different types of sensors

Sensor operation – displacement sensor

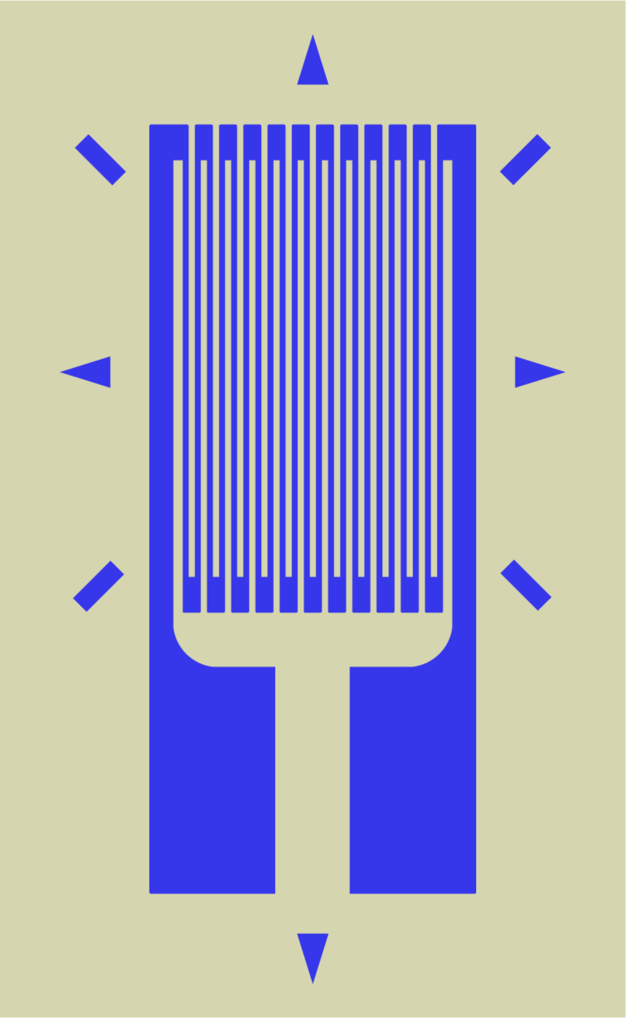
- Most common displacement sensor is the strain gauge
- When an electrical conductor is stretched, it will become narrower and longer, which increases its electrical resistance end-to-end
- Gauge factor is defined as:

$$GF = \frac{\left(\frac{\delta R}{R_g}\right)}{\epsilon}$$



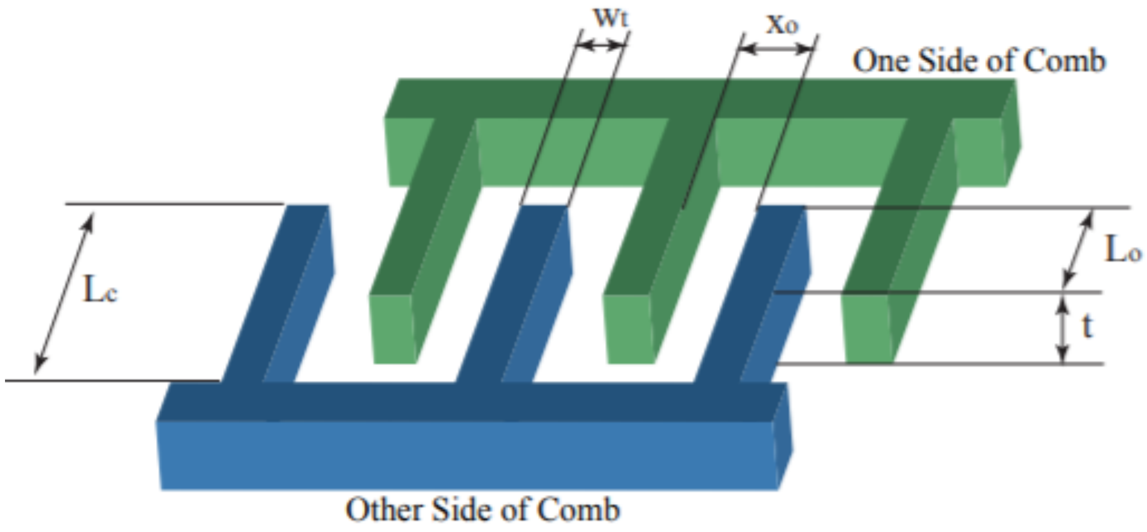
Sensor operation – displacement sensor

- Advantages:
  - Simple
  - Low-cost
  - Proportional
- Problems:
  - Low signal strength
  - Resistance of the gauge can change due to temperature
  - If the wires connecting the strain gauge to the signal conditioner are not protected against humidity, corrosion can occur, leading to parasitic resistance
- Typically deployed in a Wheatstone bridge arrangement



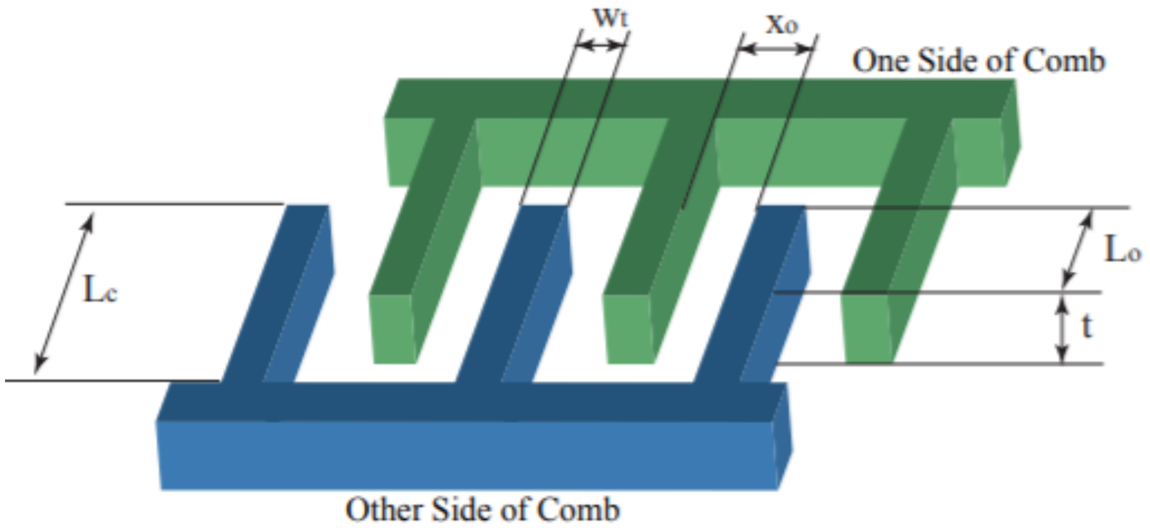
Sensor operation – accelerometers

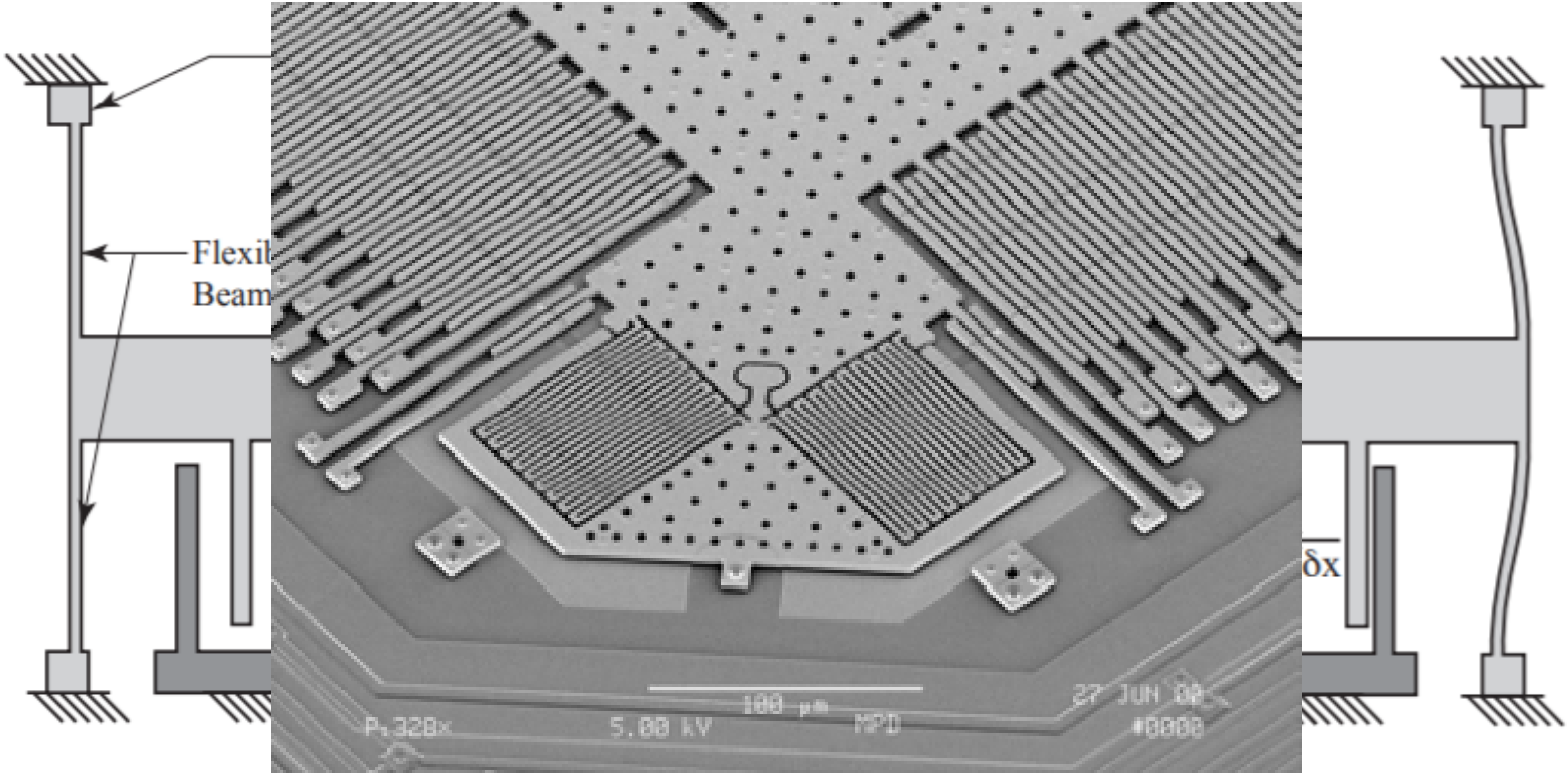
- If you have a linear displacement sensor, you can differentiate the output time series to get acceleration
- But some systems give output only for an accelerating system
- Classic example is the microcomb structure present in all of our smart phones!



Sensor operation – accelerometers

- Most commonly made using interdigitated fingers (or comb drive) with one side free to move and the other side static
- For a given acceleration, the capacitance difference between the adjacent fingers changes due to motion of the free end
- The stiffness of the structure known, the acceleration can be calculated

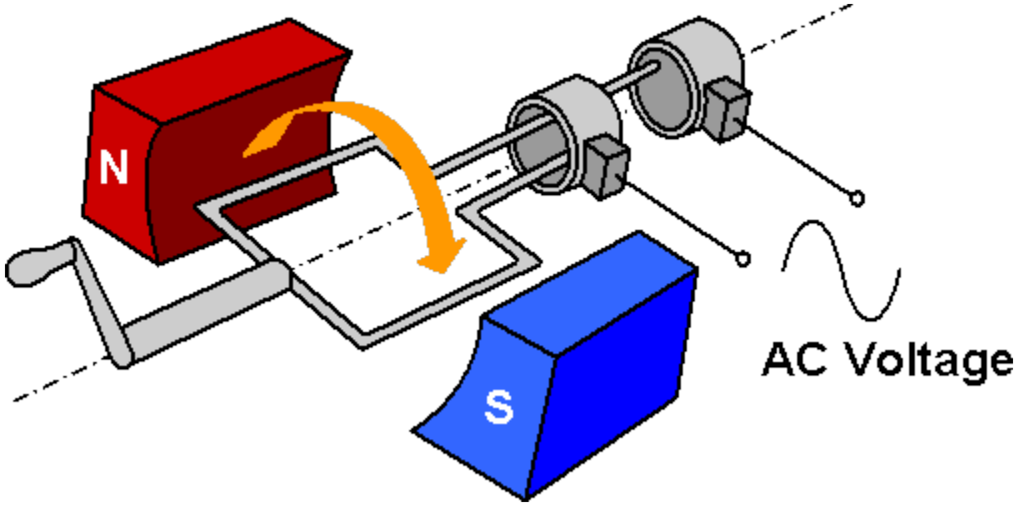




δx
100 µm
27 JUN 00
P:320x
5.00 kV
MPD
#0000

Sensor operation – rotation

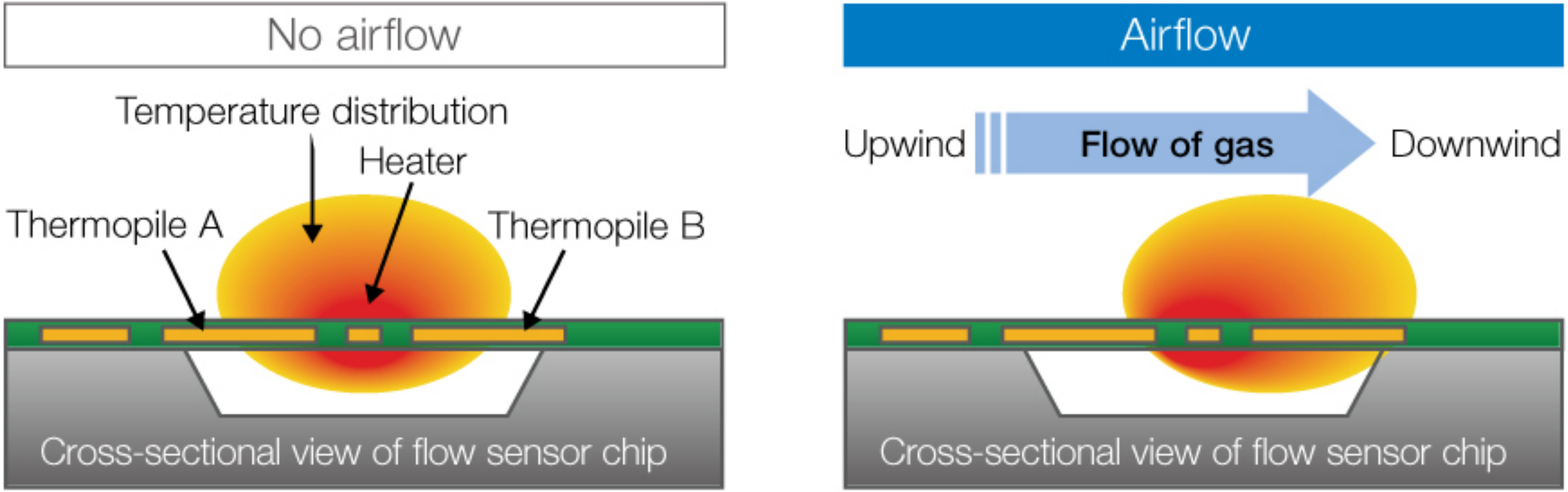
- Electrical drives are generally used as both sensor and actuator systems
- A simple AC drive or an alternator with a permanent magnet stator can be used to generate alternating current with frequency proportional to speed of rotation



Sensor operation – flow sensors

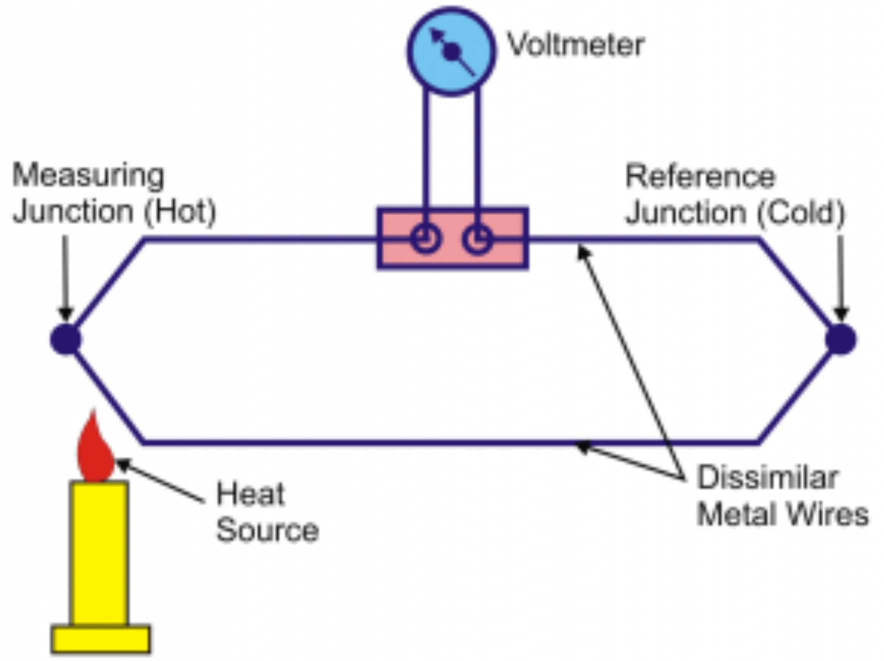
- Flow sensing is relatively a difficult task
- The fluid medium can be liquid, gas, or a mixture of the two
- Anemometer converts flow to rotation and then to voltage
- Hot wire anemometers use the fact that flow if air cools a metal wire
  - Cooling causes change in resistance that can be measured

Sensor operation – flow sensors



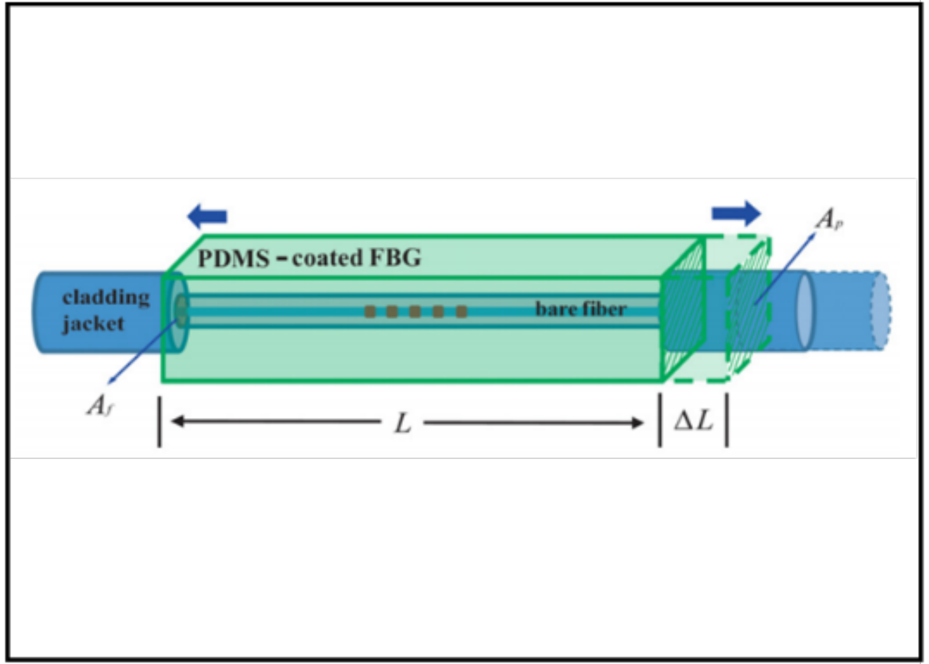
Sensor operation – temperature

- Thermocouples
  - Low output voltage
  - Hard to manufacture
- Temperature dependant resistance
  - Strain is an issue
- Semiconductor temperature sensors (Thermodiode and Thermotransistor)
  - Upper limit is the breakdown of pn junction



Sensor operation – temperature

a)



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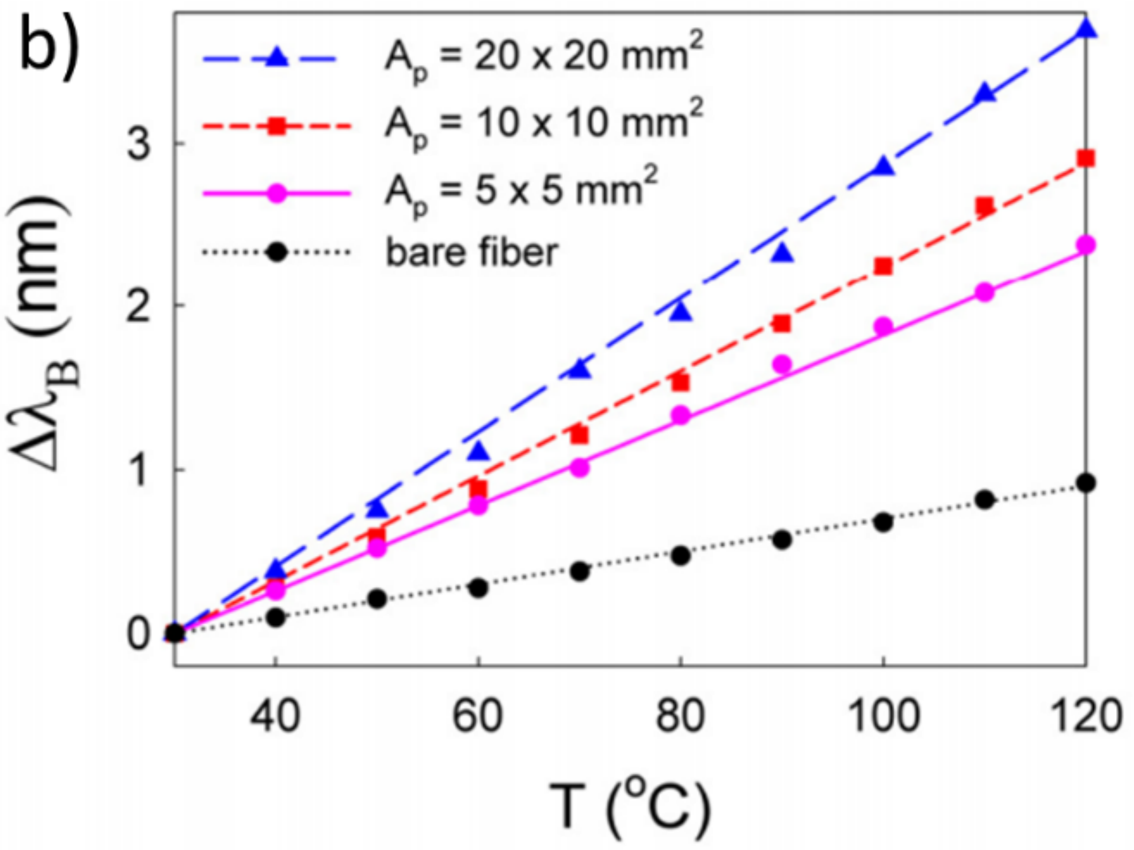
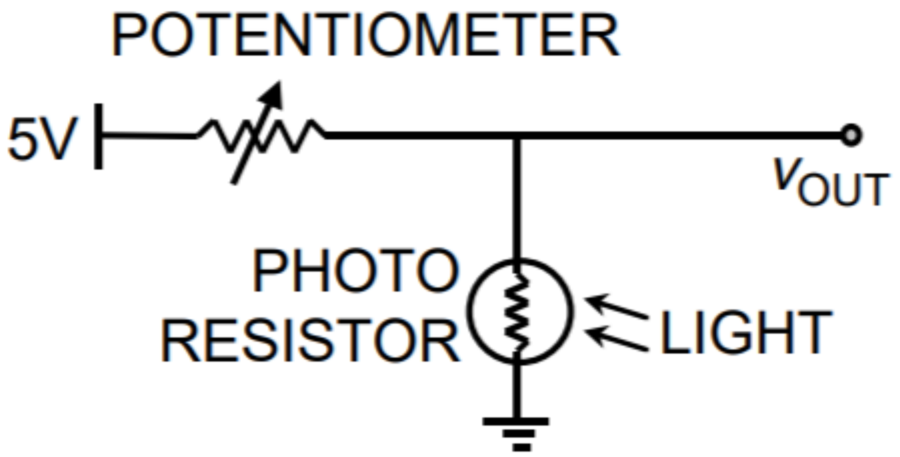


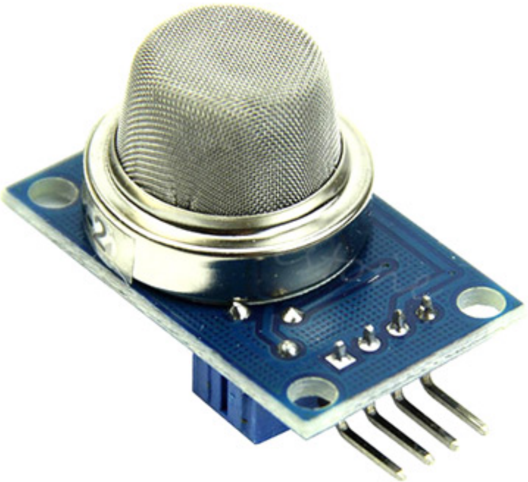
Sensor operation – light

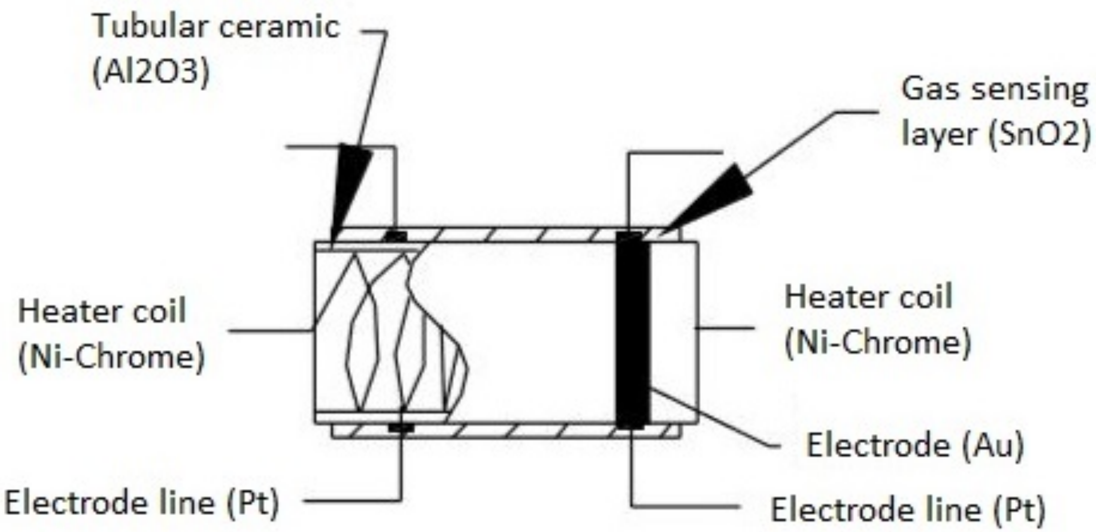
- Phototransistors, photoresistors, and photodiodes are some of the more common type of light intensity sensors
- A common photodiode is made of a semiconductor pn junction
- When the junction is exposed to light, its resistance drops in proportion to the intensity of light
- When interfaced with a circuit, the change in light intensity will show up as change in voltage



Sensor operation – gas sensors

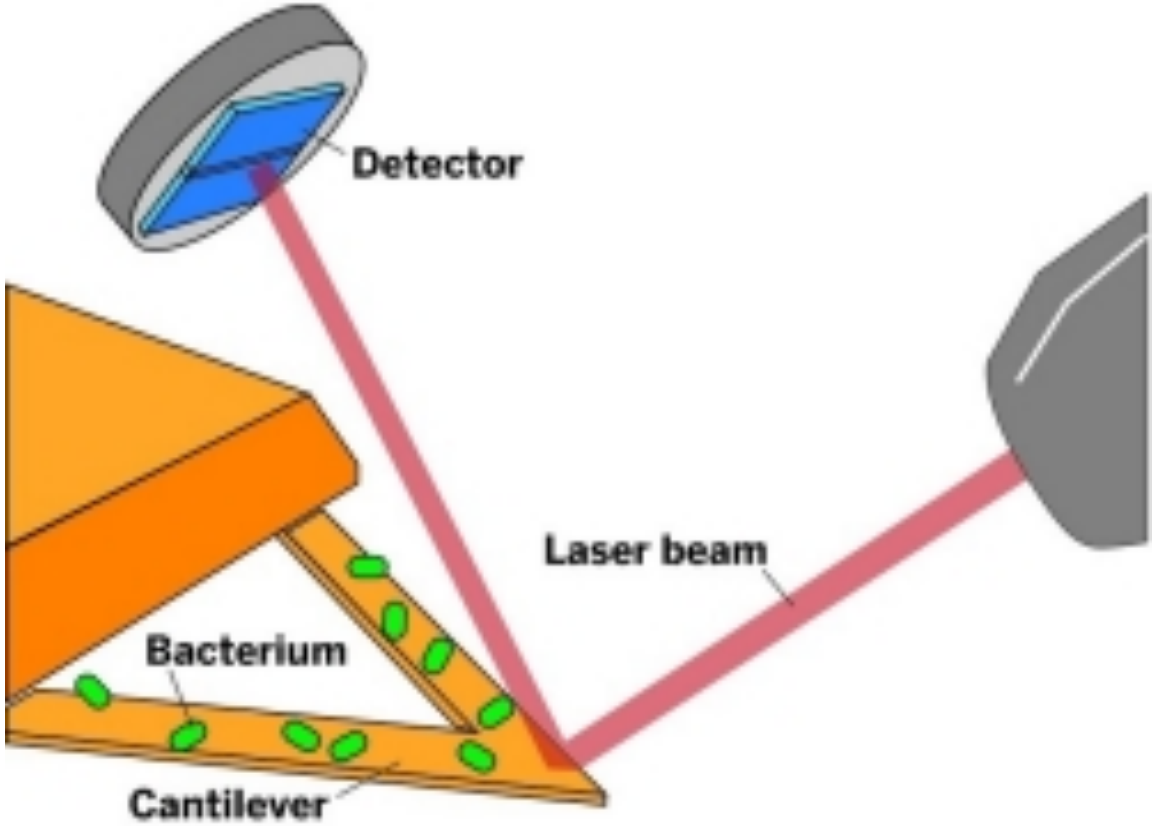
- There many ways to sense gases
- Most popular is the metal oxide gas sensor with SnO_2 as the sensing layer
- Tin Dioxide (SnO_2) in general has excess free electrons (donor element)
- So whenever toxic gases are detected, the resistance of the element changes and the current through it varies which represents the change in concentration of the gases





Sensor operation – microbe sensors

- A cantilever is planted with the antigen of the microbe to be sensed
- When the microbe attaches to the antigen, the frequency of the cantilever changes
- The antigen is specific only to a particular microbe and the magnitude of change gives the microbe concentration



Sensor selection

- Range—Difference between the maximum and minimum value of the sensed parameter
- Resolution—The smallest change the sensor can differentiate
- Accuracy—Difference between the measured value and the true value
- Precision—Ability to reproduce repeatedly with a given accuracy
- Sensitivity—Ratio of change in output to a unit change of the input
- Zero offset—A nonzero value output for no input

Sensor selection

- Non Linearity—Percentage of deviation from the best-fit linear calibration curve
- Zero Drift—The departure of output from zero value over a period of time for no input
- Response time—The time lag between the input and output
- Operating temperature—The range in which the sensor performs as specified
- Deadband—The range of input for which there is no output
- Signal-to-noise ratio—Ratio between the magnitudes of the signal and the noise at the output

Sensor system

- Sensor system consists of a sensor and the readout circuitry
- Normally, the output from a sensor requires post processing of the signals before they can be fed to the controller
- The sensor output may have to be amplified, filtered, linearized, digitized, range quantized, and isolated so that the signal can be accepted by a typical controller
- All the electronics are integrated into one microcircuit and can be directly interfaced with the controllers

Sensor calibration!

- The sensor manufacturer usually provides the calibration curves. If the sensors are stable with no drift, there is no need to recalibrate
- However, often the sensor may have to be recalibrated after integrating it with a signal conditioning system
- This essentially requires that a known input signal is provided to the sensor and its output recorded to establish a correct output scale
- If the sensor is used to measure a time-varying input, dynamic calibration becomes necessary
    - Use of sinusoidal inputs is the most simple and reliable way of dynamic calibration
    - However, if generating sinusoidal input becomes impractical (for example, temperature signals) then a step input can substitute for the sinusoidal signal
    - The transient behavior of step response should yield sufficient information about the dynamic response of the sensor

Actuator operation – electromechanical

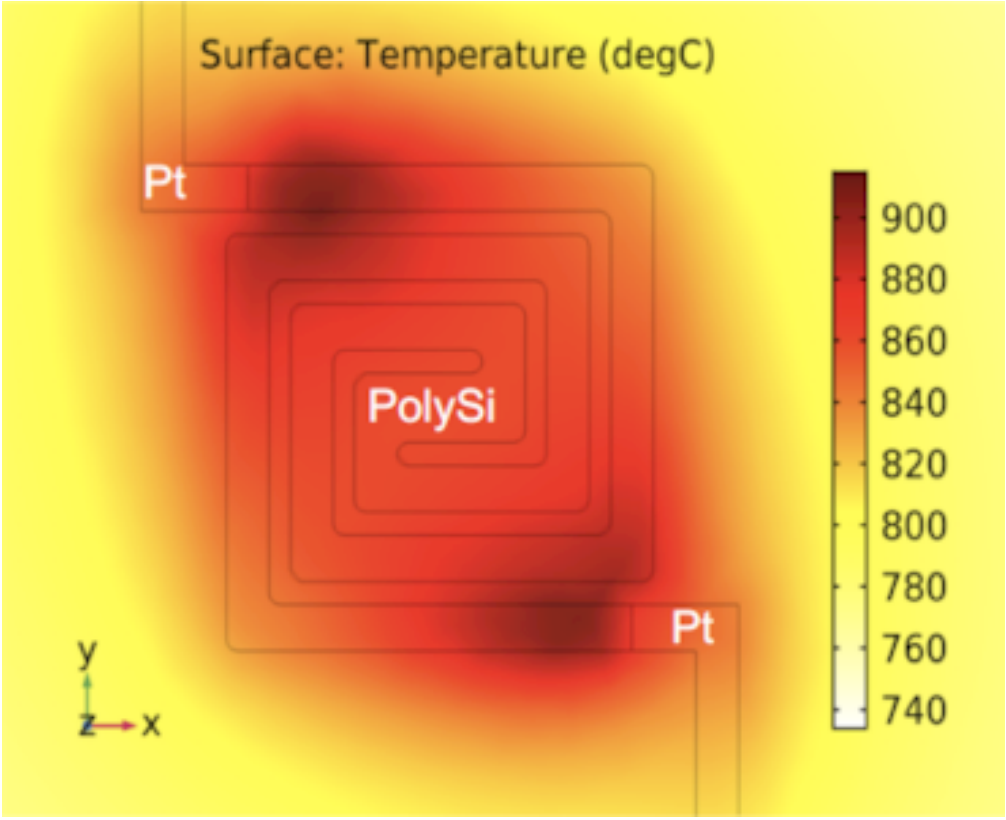
- AC and DC motors
  - Large drives
  - Servo motors
  - Stepper motors
- They use the interconversions of electrical and magnetic fields to create motion
- Stepper motor moves one step at a time, servos have an inbuilt motion sensor to control

Actuator operation – light

- Incandescent bulb uses thermal energy to go from electrical energy to light
- LED lights directly result in the recombination of electron-hole pairs in a direct bandgap semiconductor to cause irradiation. It is the opposite of photodiodes

Actuator operation – heat

- Joule heating is the most common method to convert from electrical to thermal energy
- When a current is passed through a resistor, the electrons hitting the lattice atoms cause phonons, which increases the temperature of the resistor
- Very effective, efficient and low-cost



Actuator selection

- Continuous power output—The maximum force/torque attainable continuously
- Range—The range of linear/rotary motion/temperature/light intensity achievable
- Resolution—The minimum increment of output attainable
- Accuracy—Linearity of the relationship between the input and output
- Speed characteristics—output versus speed relationship
- No load speed—Typical operating speed/velocity with no external load
- Power requirement—Type of power (AC or DC), number of phases, voltage level, and current capacity