SENSORS and TRANSDUCERS

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- Thermal microtransducers
  - Principles of detection for thermal sensors:
    - Bimetallic switch
    - Golay cell
    - Thermoresistive
    - Thermocoupler
    - Bolometer
  - Indirect thermal detection for flow, gas pressure

    Thermally driven actuators

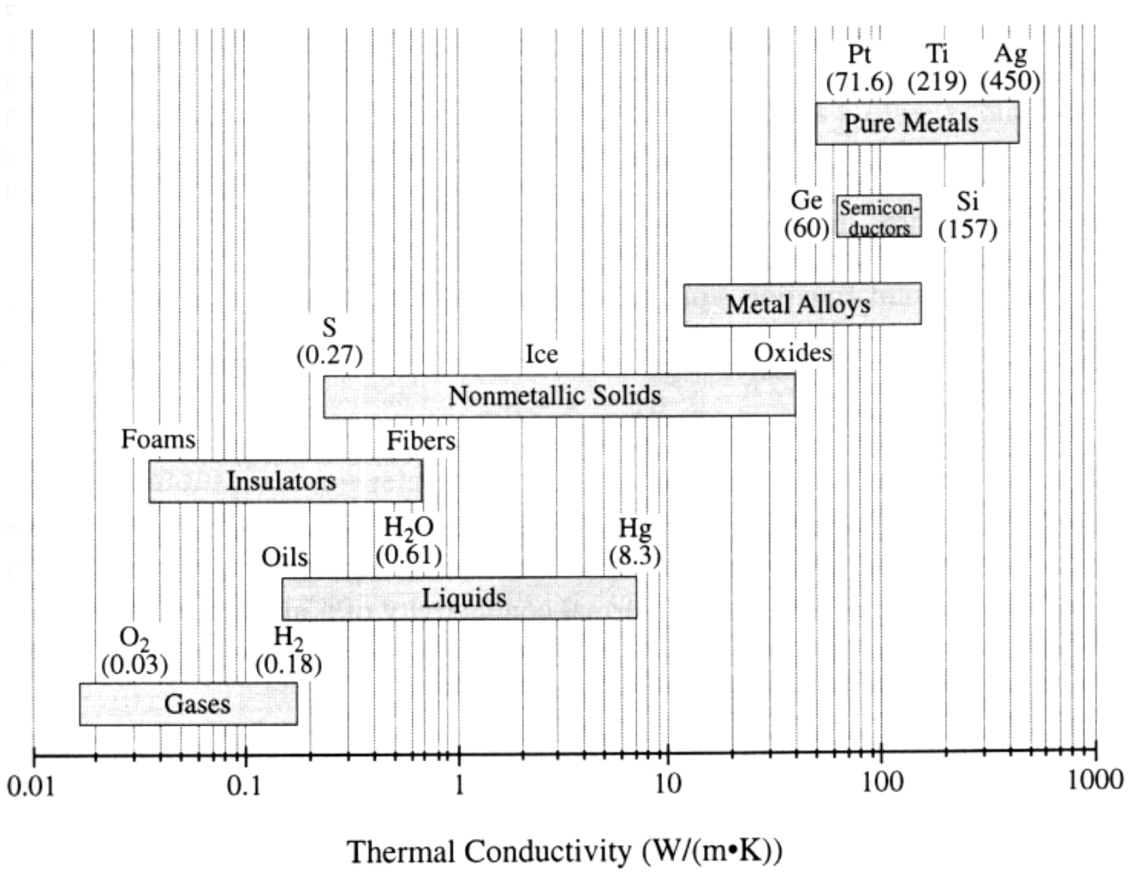
Thermal transducers

- Basic definitions
  - Temperature
  - Heat transport: conduction, convection, radiation

$$Heat\ \ flux\ \ q = \frac{dQ}{dt} = -\mathrm{K}A\frac{dT}{dx}\ \ \left(Fourier's\ law\right)$$

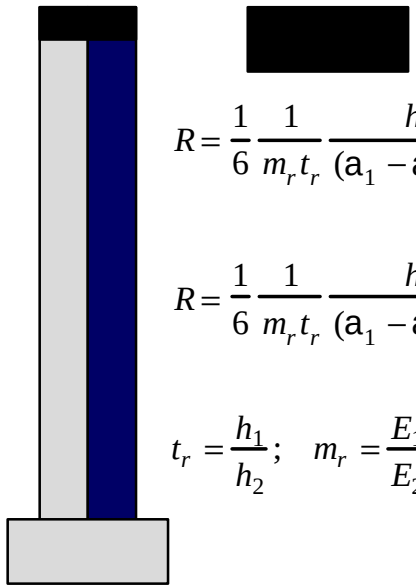
$$Thermal\ \ diffusivity\ \ \frac{\mathrm{K}}{\rho c};\ \frac{dT}{dt} = \frac{\mathrm{K}}{\rho c}\frac{d^2T}{dx^2}$$

Thermal conductivity



Thermomechanical sensors

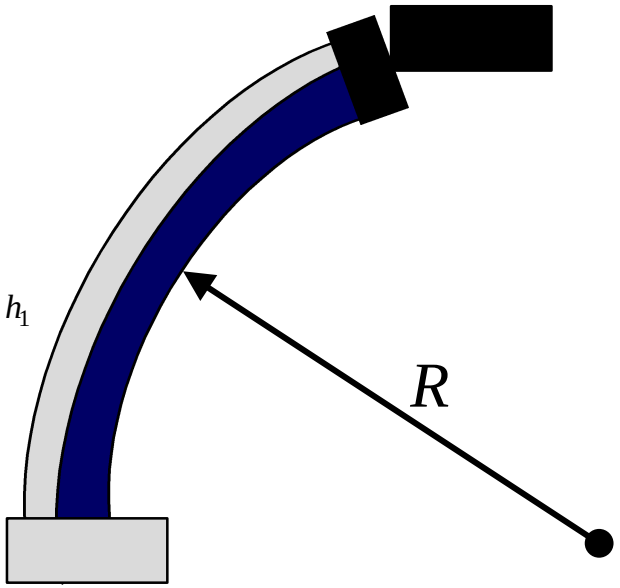
- Bimetallic switch



$$R = \frac{1}{6}\frac{1}{m_r t_r}\frac{h_2}{(a_1 - a_2)\Delta T};\ h_2 >> h_1$$

$$R = \frac{1}{6}\frac{1}{m_r t_r}\frac{h_2}{(a_1 - a_2)\Delta T}\frac{1 + m_r t_r(4 + 6t_r + 4t_r^2 + m_r t_r^3)}{1 + t_r};\ h_2 \approx h_1$$

$$t_r = \frac{h_1}{h_2};\quad m_r = \frac{E_1(1 - n_2)}{E_2(1 - n_1)}$$

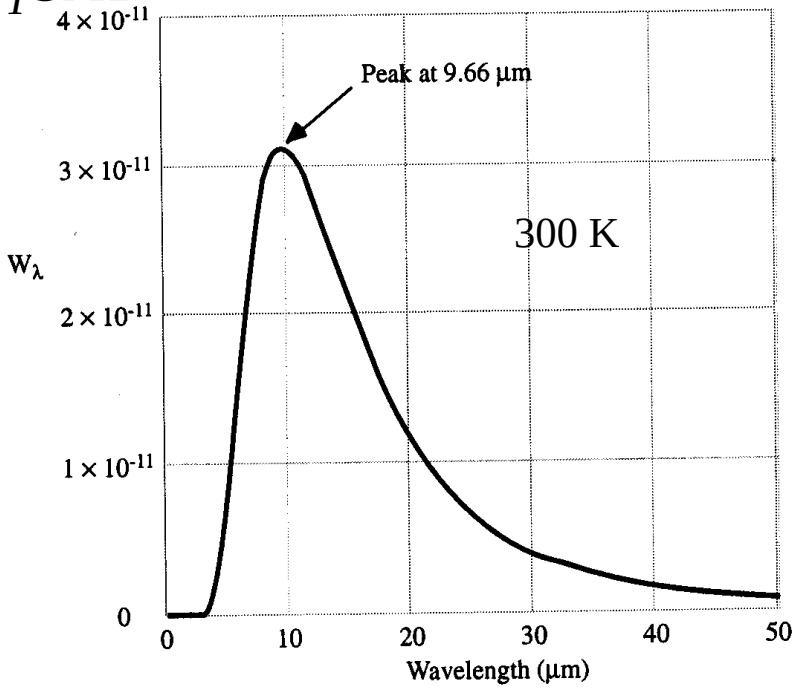


Blackbody radiation

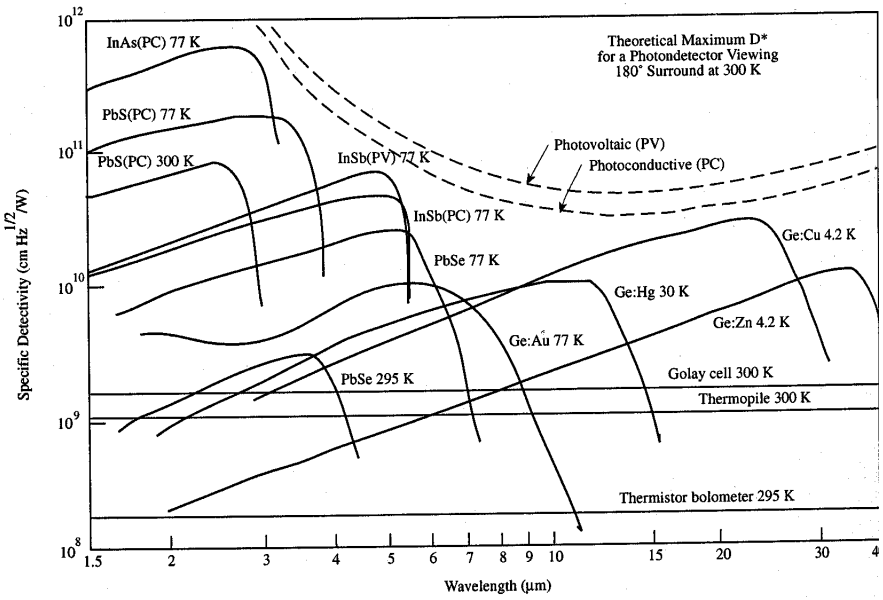
$$\text{Reflective radiation } \frac{dQ}{dt} = CT^m; 4 \le m \le 5.5$$

$$\text{Blackbody radiation } \frac{dQ}{dt} = \varepsilon_T \sigma A T^4$$

$$\text{Wien's displacements law: } \lambda_{max} = \frac{2898}{T[K]}[\mu m]$$



Optical Energy Domain - Physics



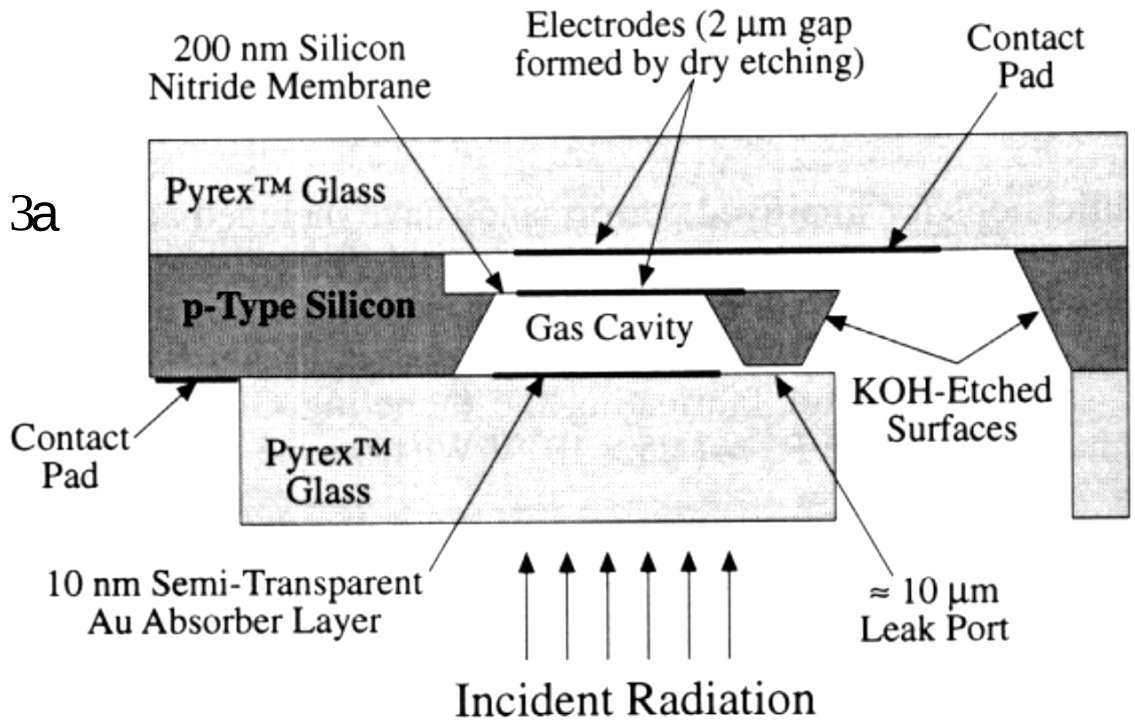
Plots of detectivities of various detectors, including Golay cells, thermopiles, an bolometers for comparison. After Cobbold (1974). Photovoltaic and photoconduc tive devices are identified as "PC" and "PV," respectively.

Thermomechanical sensors

- Golay cell

$$PV = nRT$$

$$\frac{\Delta V}{V} = \beta \Delta T; \quad \beta = 3\alpha$$



Thermoresistive sensors

- Thermoresistors (PTC)
  - Metalbased, easy to integrate on silicon

    Pt thermometers may resolve

$$R_T = R_0(1+\alpha)([1+0.01\delta]T - 0.0001\delta T^2 + 10^{-6}\beta T^3 - 10^{-8}\beta T^4)$$

$$R_0 = R(0°C);\ \alpha = 0.00392;\ \beta = 0\ (T > 0°C) = 0.11\ (T < 0°C);\ \delta = 1.49$$

- Thermistors (NTC)
  - Conductive metal-oxides

Thermocoupler

- The Seebeck effect

Carriers do not only transport charge, but also energy.

A thermal diffusion also leads to

$$V_s = \alpha_s (T_1 - T_2)$$

$$\alpha_{met} \approx 10^{-8} V/K$$

$$\alpha_{SC} \approx 10^{-4} - 10^{-3} V/K$$

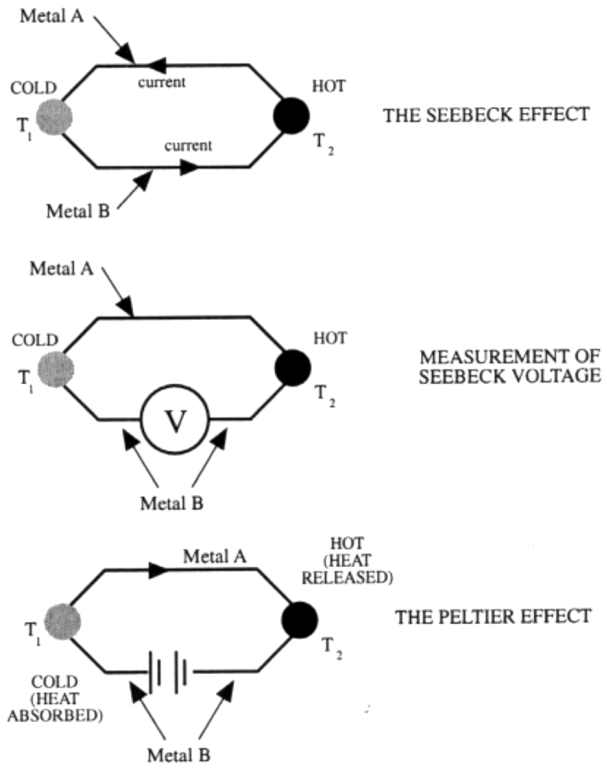
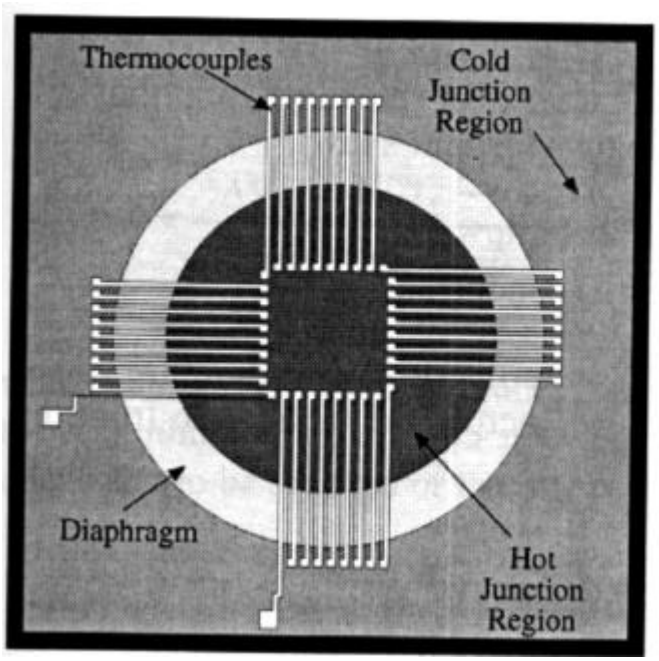


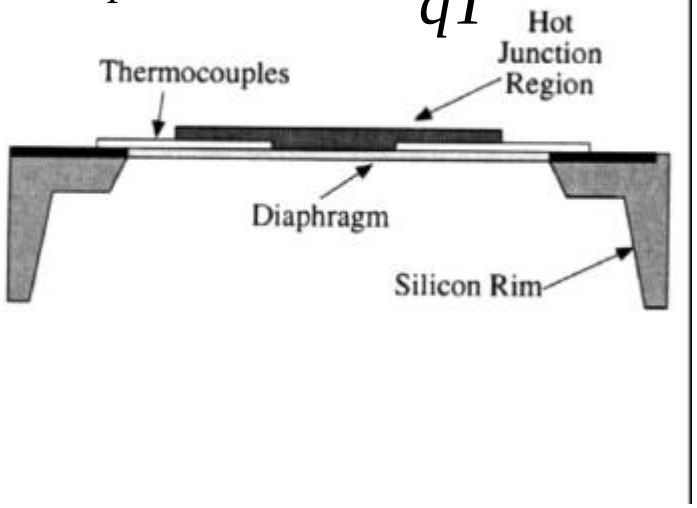
Illustration showing the basic thermoelectric effects.

Thermocoupler

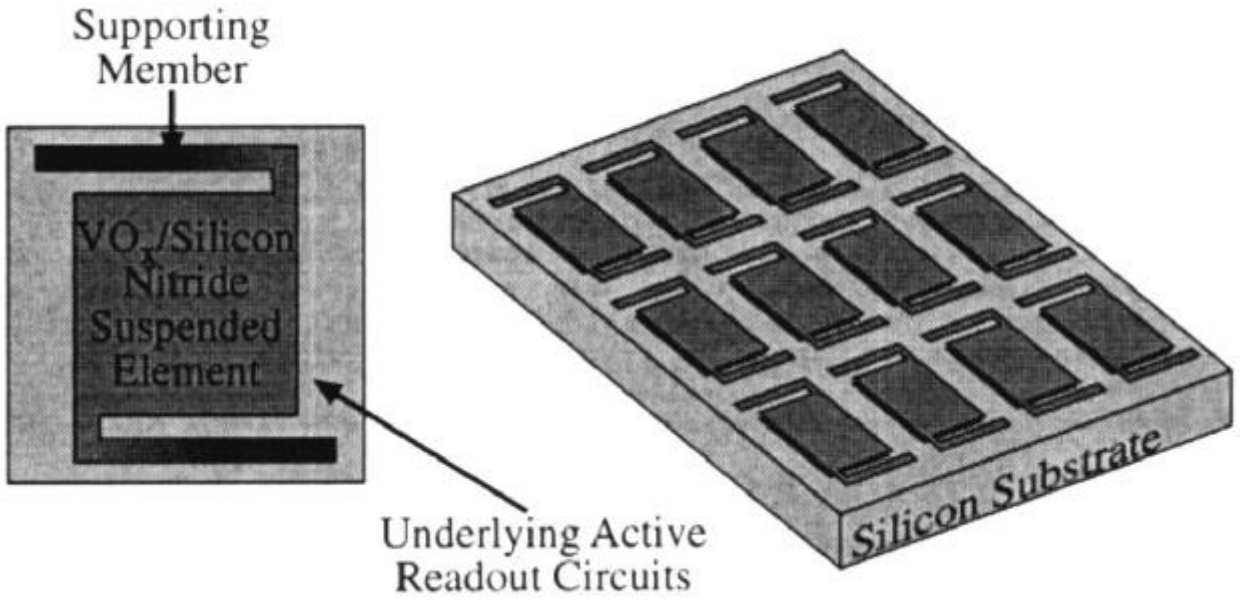
$$\alpha_n = -\frac{E_C - E_F + 2kT}{qT}$$

$$\alpha_p = -\frac{E_F - E_V + 2kT}{qT}$$

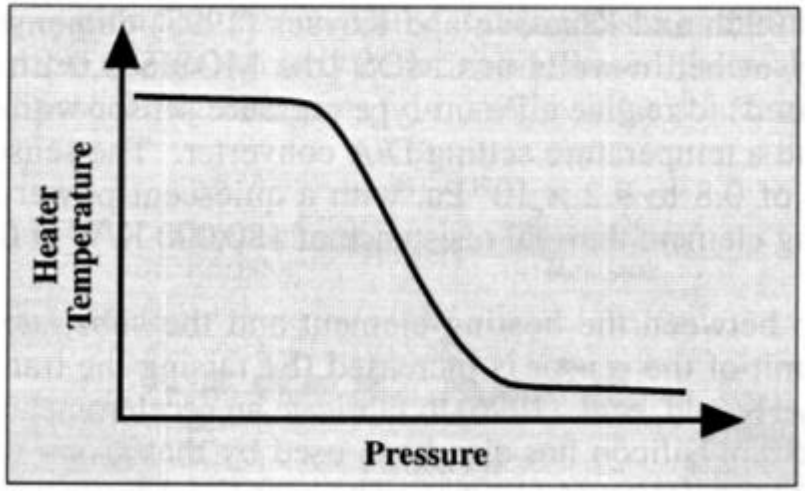


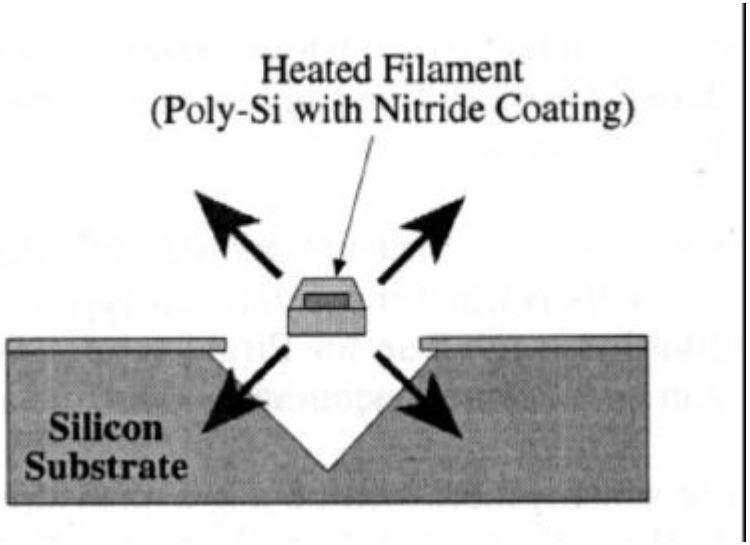


Bolometer


Supporting
Member
VO_x/Silicon
Nitride
Suspended
Element
Underlying Active
Readout Circuits
Silicon Substrate

Pirani - pressure sensor





Anemometer - flow sensor