

Fundamentals of Nanoelectronics

ECE495 - Session 41, Dec 9, 2009

Thermoelectricity I

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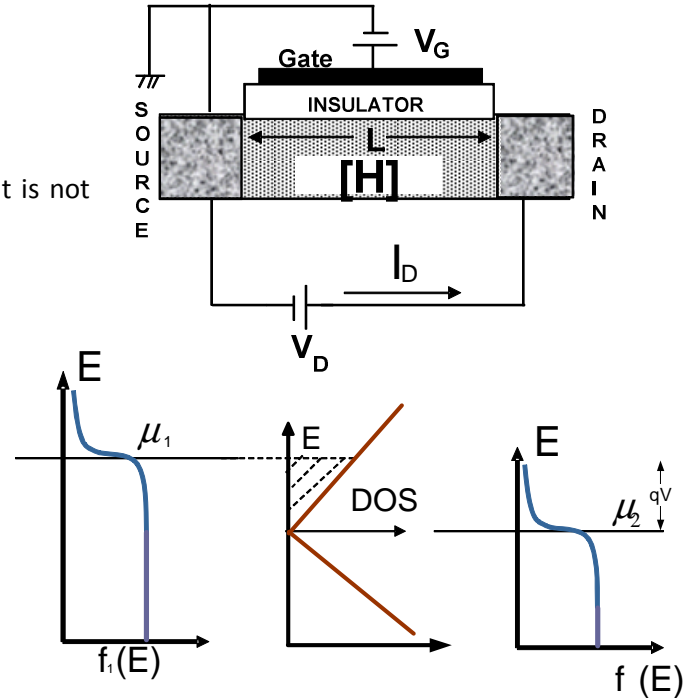
Class notes taken by: Mehdi Salmani

$$I = GV$$

G is conductance

With a cold and hot contact we can make current. It is not very efficient.

$$\begin{cases} I = G_{11}V + G_{12}\Delta T \\ I_Q = G_{21}V + G_{22}\Delta T \end{cases} \leftarrow \text{Heat current}$$



$$G_{11} = \begin{cases} qn\mu \frac{A}{L} \\ \frac{q^2}{h} M \frac{\lambda}{L + \lambda} \end{cases} \leftarrow \text{for small device far more general}$$

$$\mu = \frac{q\tau}{m} \quad \text{where } m \text{ is effective mass}$$

$$\begin{aligned} I &= 2 \frac{q}{h} \int dE \frac{M(E)}{\bar{T}(E)} \frac{\lambda}{L + \lambda} \frac{(f_1 - f_2)}{\left(\frac{\partial f}{\partial E}\right)_{\mu_1 - \mu_2}} = \frac{2q}{h} \int dE \bar{T}(E) \left(-\frac{\partial f}{\partial E}\right) (\mu_1 - \mu_2) \\ &= \frac{2q}{h} \int dE \bar{T}(E) \left(-\frac{\partial f}{\partial E}\right) q \cdot V \\ &\quad \underbrace{\hspace{10em}}_{G_{11}} \end{aligned}$$

$$f(E) = \frac{1}{e^{(E-\mu)/kT} + 1} \quad \text{where } z \equiv (E - \mu)/kT$$

$$\frac{\partial f}{\partial \mu} = \frac{df}{dz} \frac{dz}{d\mu} = -\frac{df}{dE} \frac{dz}{dE}$$

$$G_{11} = \frac{2q^2}{h} \int dE \left(-\frac{\partial f}{\partial E} \right) \overbrace{\bar{T}(E)}^{M \frac{\lambda}{L+\lambda}}$$

For heat current:

$$I = 2 \frac{q}{h} \int dE \underbrace{M(E) \frac{\lambda}{L+\lambda}}_{\bar{T}(E)} \underbrace{(f_1 - f_2)}_{\left(\frac{\partial f}{\partial T}\right) \Delta T}$$

$$I = 2 \frac{q}{h} \int dE \bar{T}(E) \frac{(E - \mu)}{T} \left(-\frac{\partial f}{\partial E} \right) \Delta T$$

$$\frac{\partial f}{\partial T} = \frac{df}{dz} \frac{dz}{dT} \Rightarrow \frac{dz}{dE} \cdot \frac{(E - \mu)}{T}$$

$$G_{12} = \frac{2q}{h} \int dE \bar{T}(E) \frac{(E - \mu)}{T} \left(-\frac{\partial f}{\partial E} \right)$$

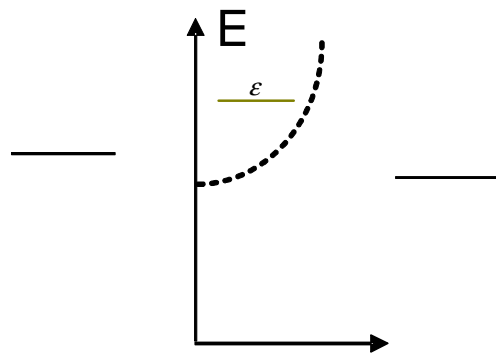
$I = 0$ then Seebeck coefficient: $\frac{V}{\Delta T} = \frac{G_{12}}{G_{11}} < \frac{1 \mu V}{k}$ for metal and about $\frac{10 \mu V}{k}$ for semiconductor

$$f_1 = f_2: \frac{\varepsilon - \mu_1}{k_B T_1} = \frac{\varepsilon - \mu_2}{k_B T_2} = \frac{\mu_2 - \mu_1}{k_B (T_1 - T_2)}$$

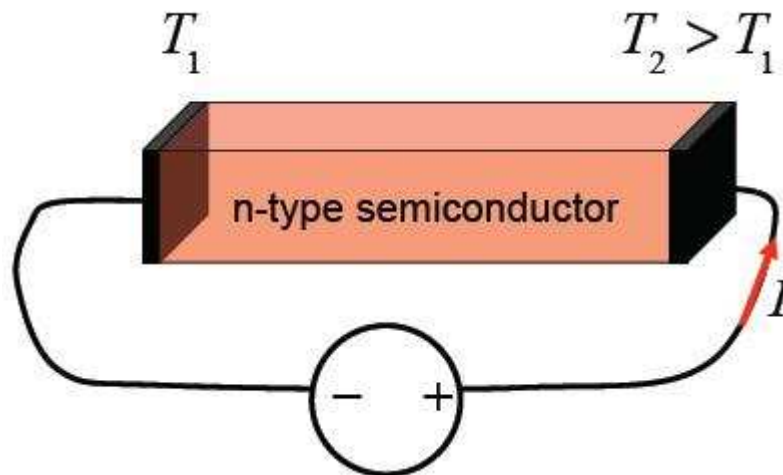
$$\frac{\Delta \mu}{T_1 - T_2} = qS \Rightarrow S \Rightarrow \frac{1}{q} \frac{(\varepsilon - \mu)}{T}$$

Best devices: $\varepsilon - \mu = k_B T \Rightarrow S = \frac{k_B T}{q} = \frac{k_B}{q}$

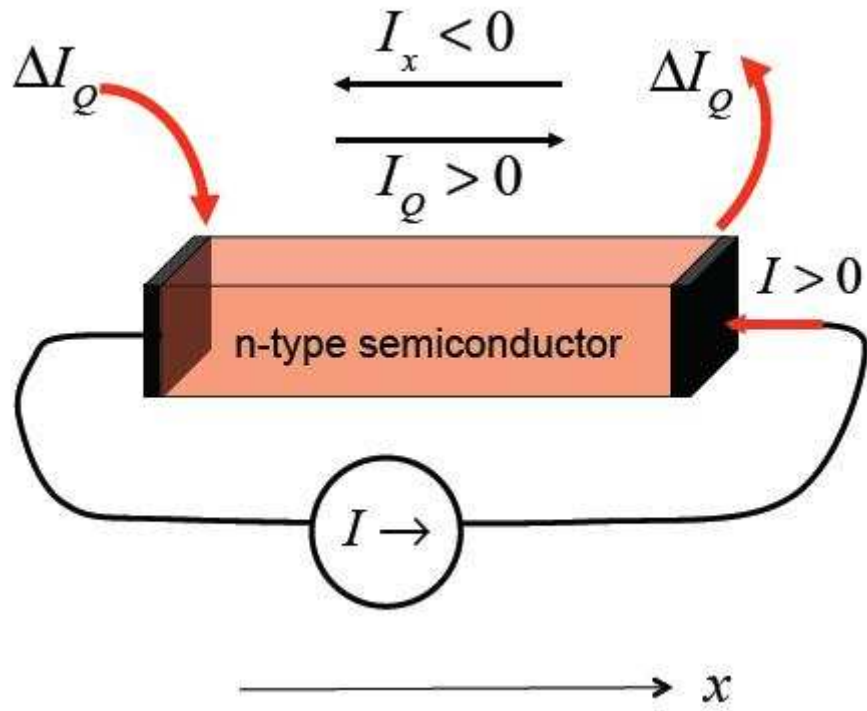
$$\frac{k_B}{q} = \frac{k_B T}{qT} = \frac{25 \text{ meV}}{300} = \frac{1 \text{ mV}}{12} \approx 86 \frac{\mu V}{k}$$



Seebeck effect is for generating electricity:



Peltier effect is for cooling by electricity:



Thermoelectric Device:

