Temperature Dependence

Start with diode *I-V* relation:

$$I = I_s\left[e^{qV_d/nkT} - 1\right] \approx I_s e^{V_d/nV_T} \quad \Rightarrow \quad V_d \simeq nV_T \ln\frac{I}{I_s} \qquad V_T = \frac{kT}{q}$$

Note: $I_s \propto T^3 e^{-E_g/kT}$

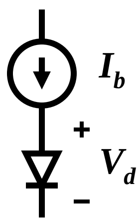
$$\frac{\partial I_s}{\partial T} \approx \frac{I_s}{T}\left(3 + \frac{E_g}{kT}\right)$$

$E_g = \text{bandgap enegy} = 1.13\text{eV (Si)}$

$k = \text{Boltzman constant} = 8.62\times 10^{-5}\ \text{eV/°K}$

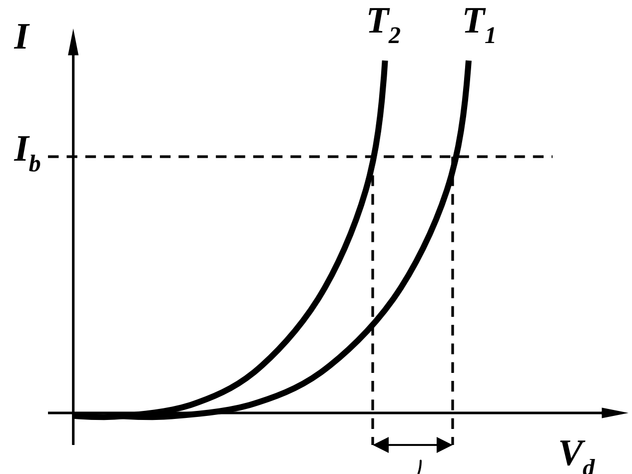
$q = 1.6\times 10^{-19}\ \text{C}$

For constant-*current* biasing:



$$\text{TCV} = \frac{\partial V_d}{\partial T} \approx \frac{V_d}{T} - n\frac{V_T}{T}\left(3 + \frac{E_g}{kT}\right)$$

$$\left.\begin{aligned} T &= 290\,\text{K} \\ I_d &= 10\,\text{mA} \\ I_s &= 1\,\text{pA} \\ n &= 1 \end{aligned}\right\} \quad \boxed{\text{TCV} \approx -2\,\text{mV/°C}}$$



$$\Delta V \approx -2\,\text{mV}\left(T_2 - T_1\right)$$

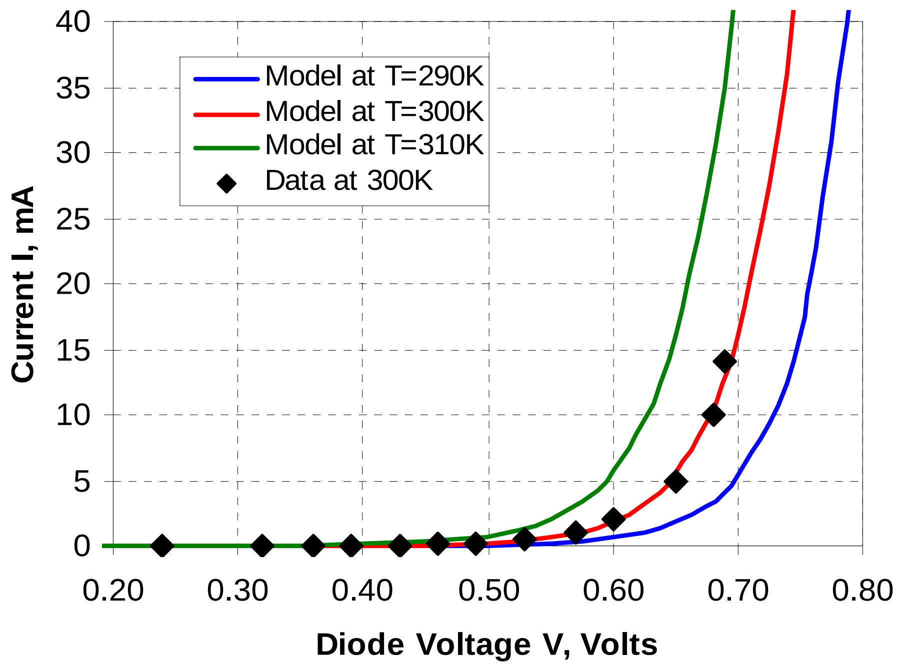
Temperature Dependence

Note: for discrete diodes the ideality factor is closer to n=2

Significantly increased temperature coefficient

Ex: 1N4005 measured data

$$\left.\begin{aligned} T &= 300\,\mathrm{K} \\ I_d &= 10\,\mathrm{mA} \\ I_s &= 5.5\,\mathrm{nA} \\ n &= 1.82 \end{aligned}\right\} \quad \mathrm{TCV} \approx -5\,\mathrm{mV/°C}$$



The change in voltage or current in diodes and transistors must be dealt with in the design of circuits

Can be exploited too: a temperature sensor!

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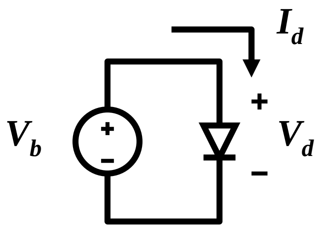
Temperature Dependence

For constant-*voltage* biasing: $I_d \approx I_s e^{V_b/nV_T}$

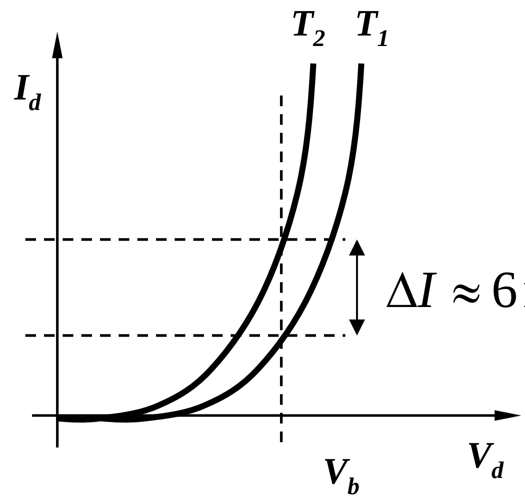


$$\text{TCI} = \frac{\partial I_d}{\partial T} \approx \frac{I}{T}\left(3 + \frac{E_g}{kT} - \frac{qV_b}{nkT}\right)$$

$$\left.\begin{aligned} T &= 300\,\text{K} \\ V_b &= 0.65\,\text{V} \\ I_s &= 1\,\text{pA} \\ n &= 1 \end{aligned}\right\}$$

$$I_d \approx 80\,\text{mA}$$

$$\text{TCI} \approx +6\,\text{mA/°C}$$



$$\Delta I \approx 6\,\text{mA}\left(T_2 - T_1\right)$$

Note: TCI depends exponentially on voltage and also a strong nonlinear function of temperature

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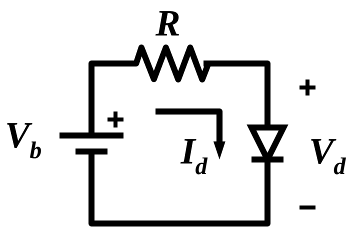
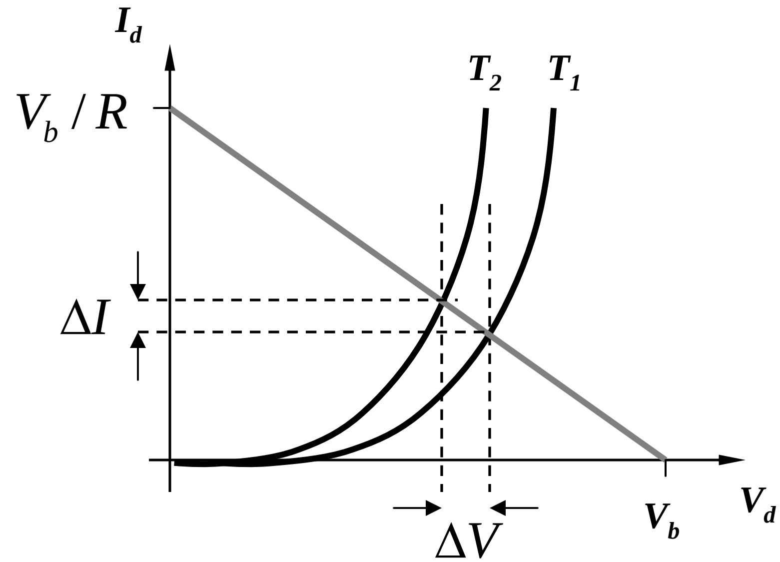
Temperature Stabilization

Biasing with a resistor and voltage source improves the stability with respect to temperature:



$$V_d = V_b - R\,I_d$$

$$\frac{\partial V_d}{\partial T} = -R\frac{\partial I_d}{\partial T}$$



$$\frac{\partial I_d}{\partial T} = \frac{\text{TCI}}{\left(1+\frac{R\,I_d}{nV_T}\right)}$$

$$\frac{\partial V_d}{\partial T} = \frac{\text{TCV}}{\left(1+\frac{nV_T}{R\,I_d}\right)}$$

Usually: $RI_d \gg nV_T$

So resistor biasing stabilizes current but voltage drift remains unchanged

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