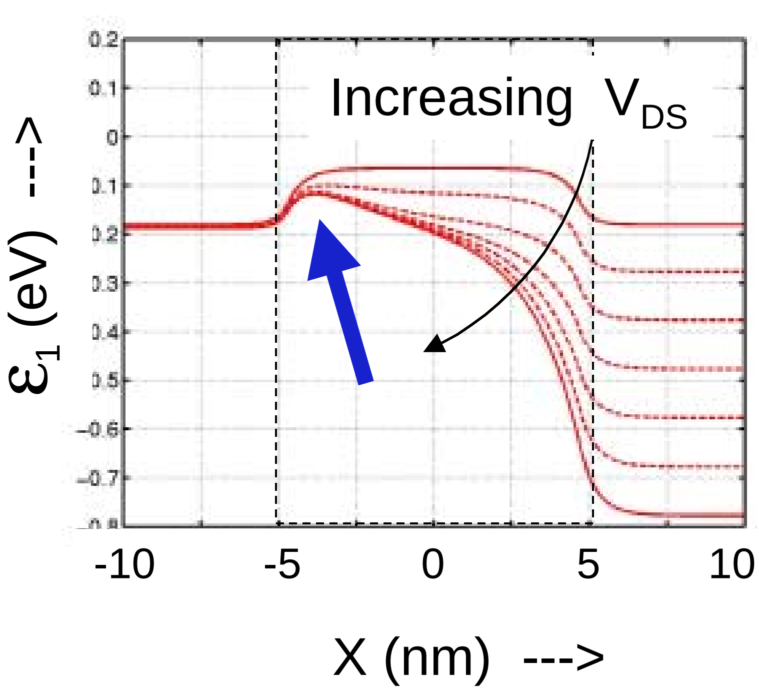
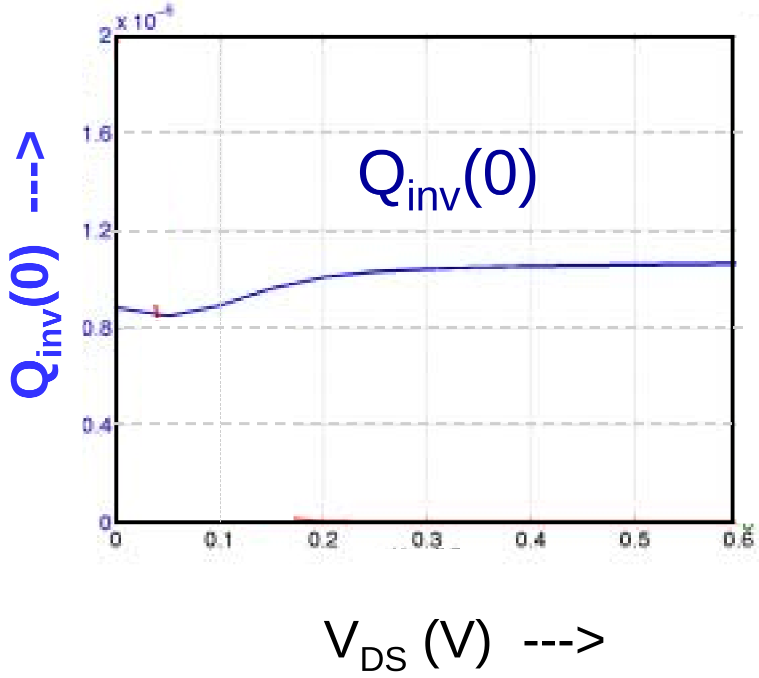
2. The Ballistic MOSFET..... ‘(2-T) effect’

ε_1 vs. x for V_{GS} = 0.5V



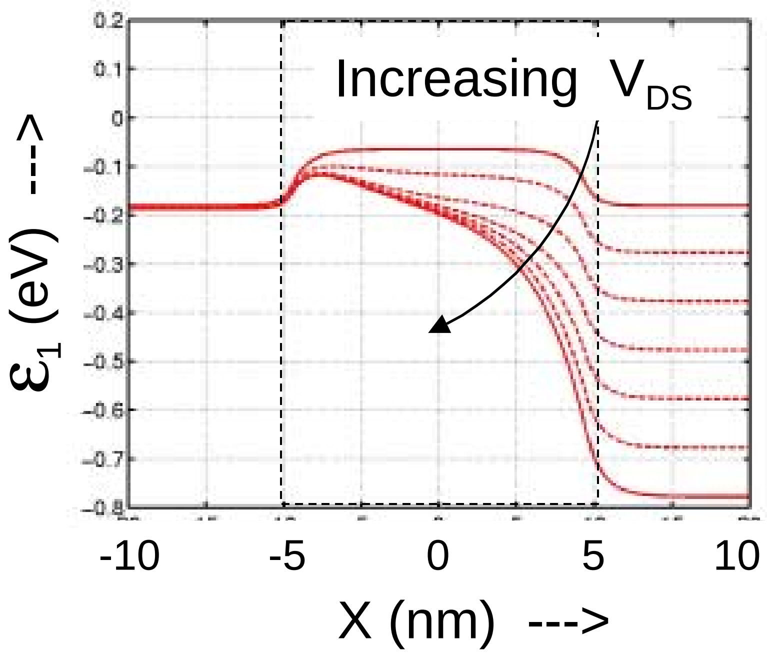


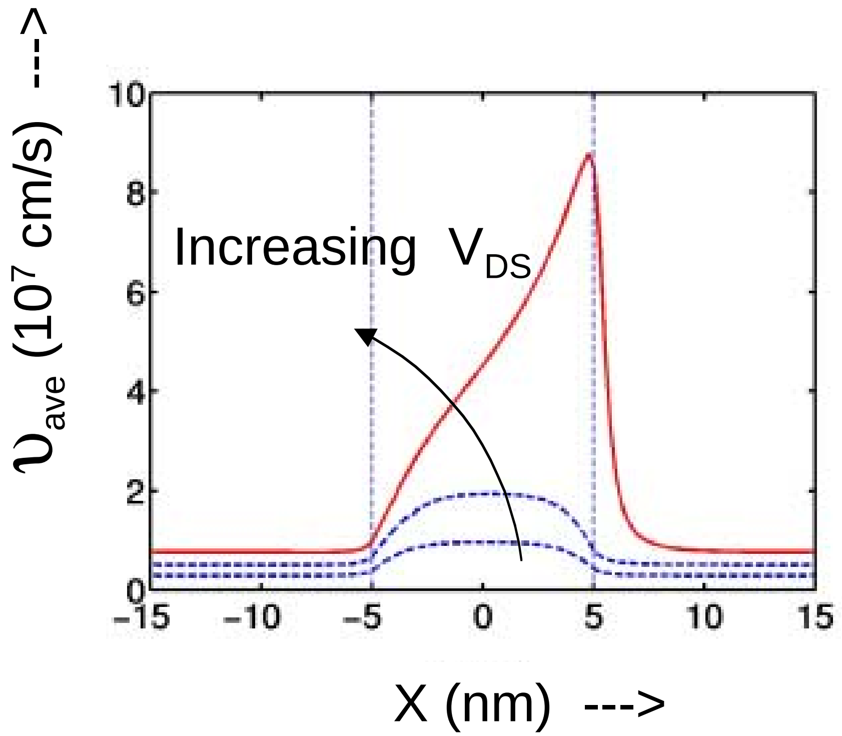
i) $Q_i(0) \approx$ constant

2. The Ballistic MOSFET.....

$\mathcal{E}_1$ vs. x for $V_{GS} = 0.5V$

i) $Q_i(0) \approx$ constant
ii) $\langle \upsilon(0) \rangle$ --> υ_T



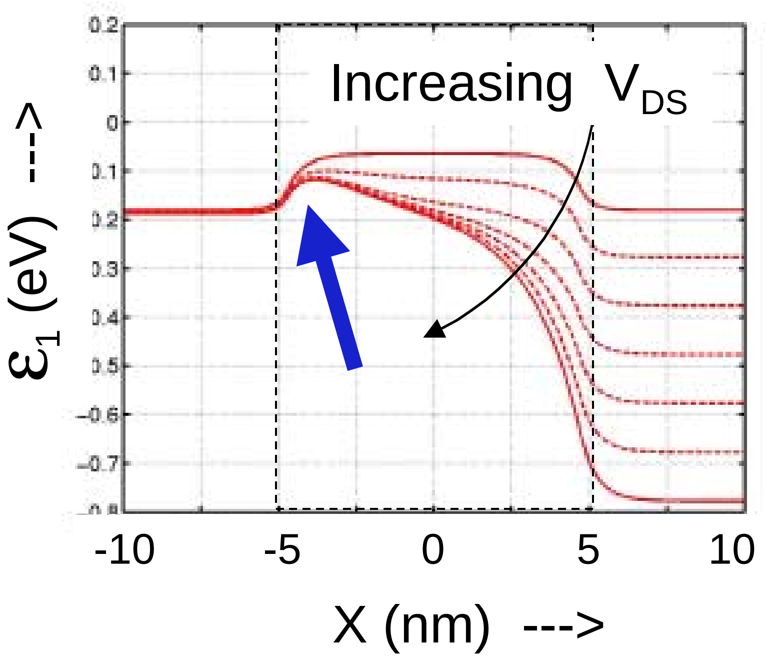


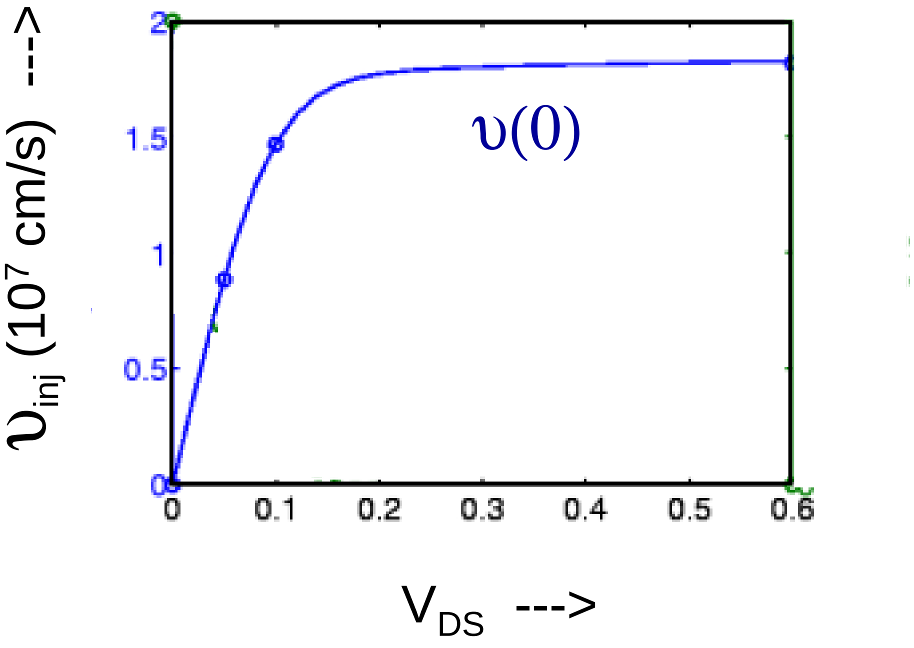
2. The Ballistic MOSFET..... velocity saturation in a ballistic FET

$\mathcal{E}_1$ vs. x for V_{GS} = 0.5V

i) $Q_i(0) \approx$ constant

ii) $\langle \upsilon(0) \rangle$ --> υ_T



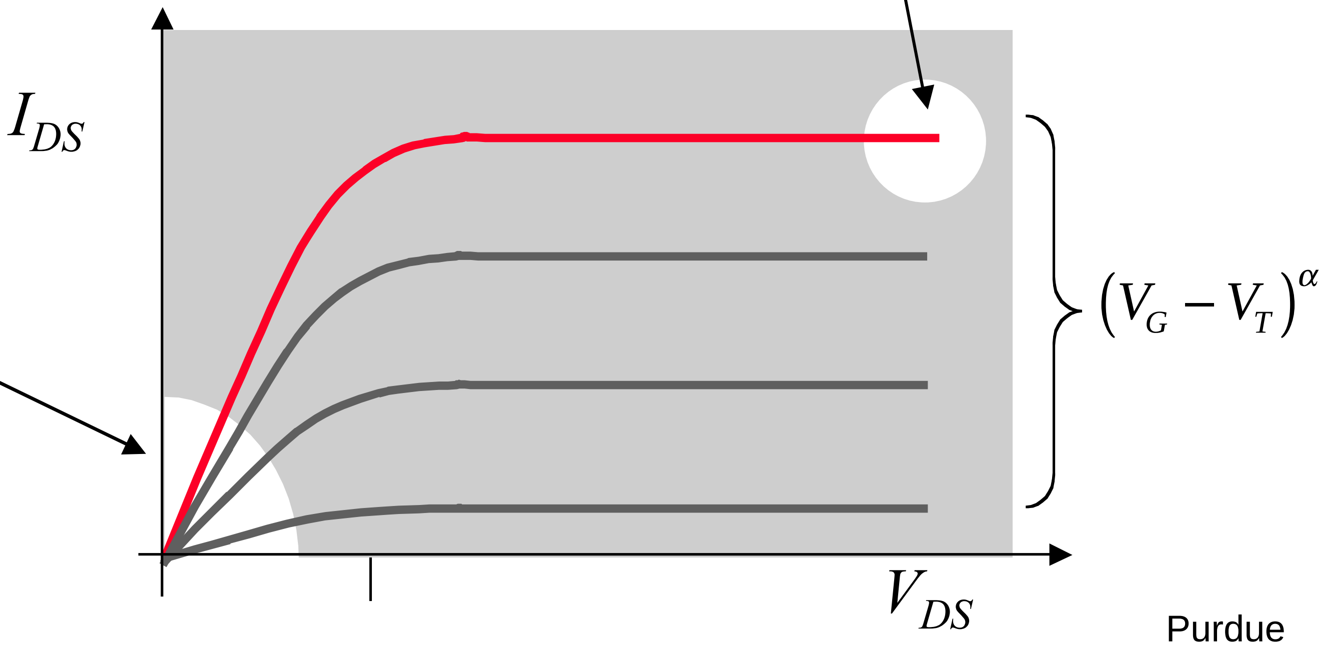


$$\upsilon(0) \rightarrow \tilde{\upsilon}_T$$

2. The Ballistic MOSFET.....

$$I_{DS} = W Q_i(V_{GS})\,\tilde{\upsilon}_T \times \left\{ \frac{\left[1 - \dfrac{F_{1/2}(\eta_F - U_{DS})}{F_{1/2}(\eta_F)} \right]}{\left[1 + \dfrac{F_0(\eta_F - U_{DS})}{F_0(\eta_F)} \right]} \right\}$$

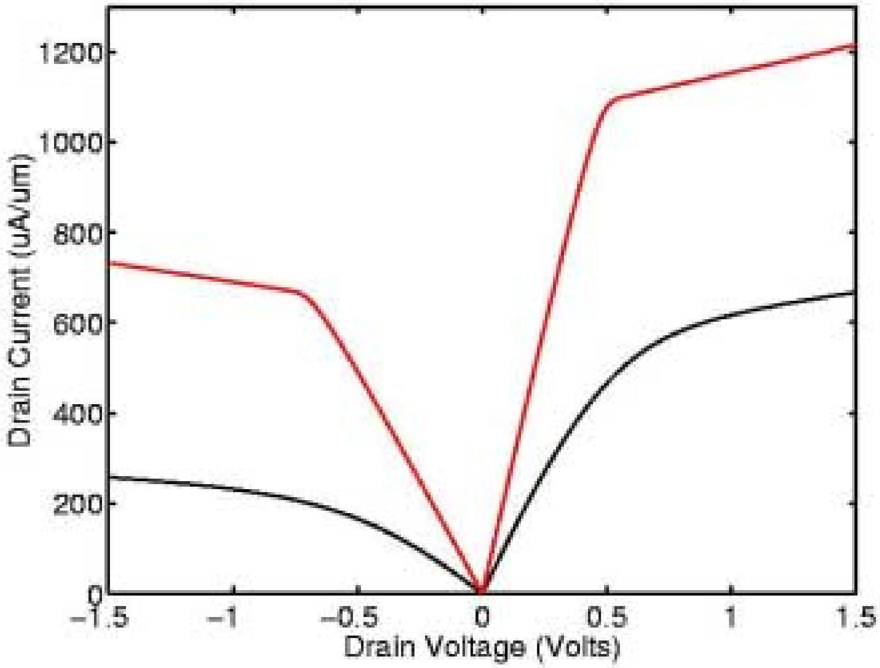
$$I_{DS}(on) = W\,C_{ox}\,\tilde{\upsilon}_T\,(V_{GS} - V_T)$$



quantum
conductance
G = M $2e^2/h$

2. The Ballistic MOSFET..... *comparison with measurements.....*

L_{eff} = 115/125 nm technology



— measured

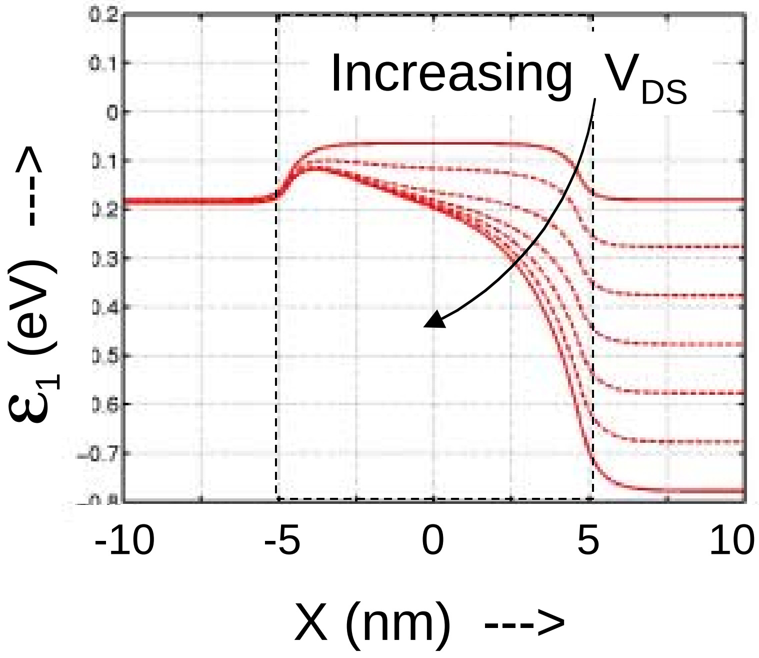
— ballistic
(with measured Rs)

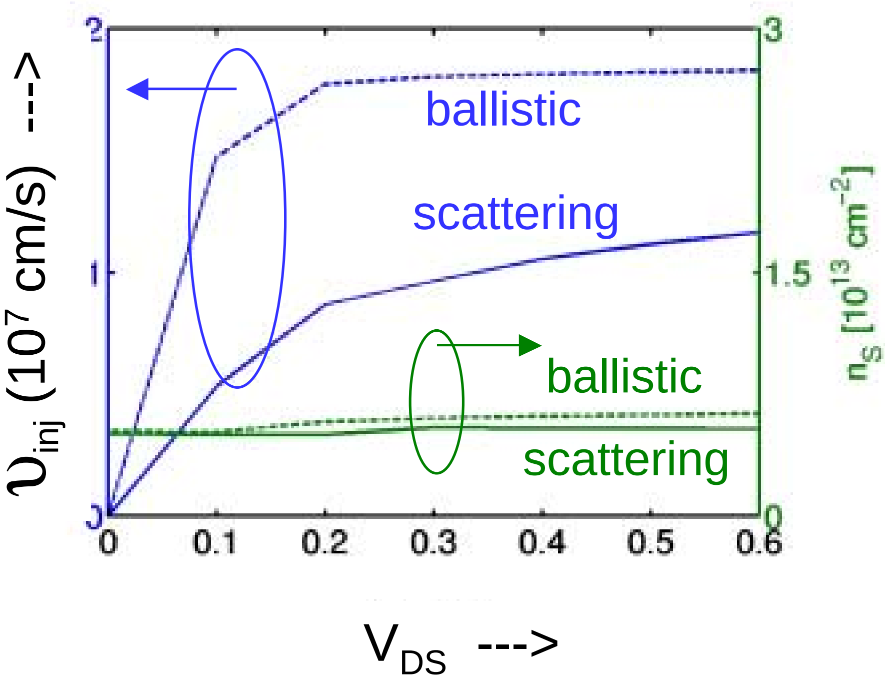
NMOS: ~ 50% of limit

PMOS: ~ 33% of limit

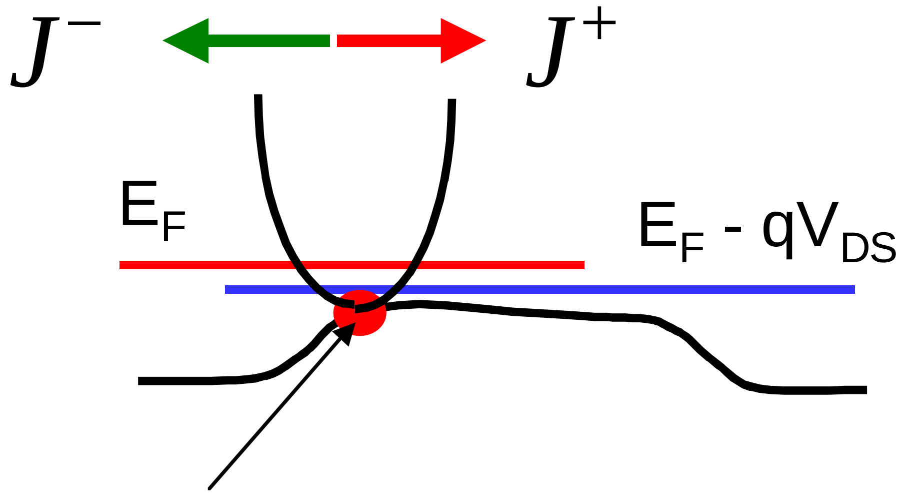
- F. Assad, et al. (1999 IEDM)
- G. Timp, J. Bude, et al., (1999 IEDM)
- D. Rumsey (TECHON 2000)
- A. Lochtefeld, D. Antoniadis (EDL, Feb 2001)

3. Scattering Theory of the MOSFET.....





3. Scattering Theory of the MOSFET.....



$Q_i \approx$ constant $\approx C_{ox}(V_{GS} - V_T)$

$$J^+ = n^+ \tilde{\upsilon}_T^+$$

$$J^- = (1-T)J^+ + TJ^-_{ball}$$

$$I_D = Wq\left(J^+ - J^-\right)$$

$$Q_i(V_{GS}) = \frac{q\left(J^+ + J^-\right)}{\tilde{\upsilon}_T^+}$$

$$I_{DS} = WQ_i(V_{GS})\,\tilde{\upsilon}_T\left(\frac{T}{2-T}\right)\times\left\{\frac{1-\dfrac{F_{1/2}(\eta_F - U_{DS})}{F_{1/2}(\eta_F)}}{1+\left(\dfrac{T}{2-T}\right)\dfrac{F_0(\eta_F - U_{DS})}{F_0(\eta_F)}}\right\}$$

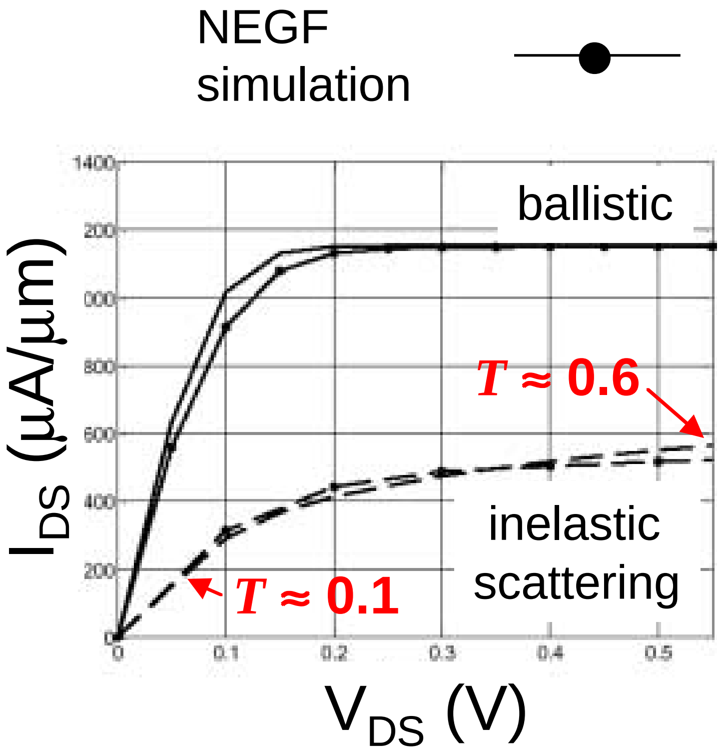
3. Scattering Theory of the MOSFET.....

Landauer/McKelvey model

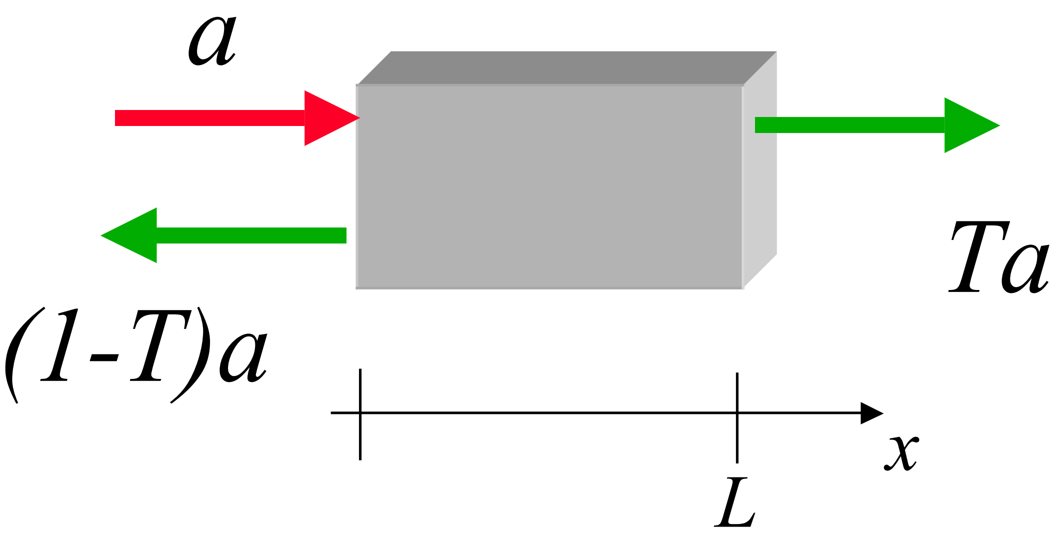
$$I_{DS} = WC_{ox}\left(V_{GS}-V_T\right)\tilde{\upsilon}_T\left(\frac{T}{2-T}\right)\times$$

$$\frac{F_{1/2}(\eta_F)}{\ln(1+e^{\eta_F})}\times\left\{\frac{1-\dfrac{F_{1/2}(\eta_F-U_{DS})}{F_{1/2}(\eta_F)}}{1+\left(\dfrac{T}{2-T}\right)\dfrac{\ln(1+e^{\eta_F-U_{DS}})}{\ln(1+e^{\eta_F})}}\right\}$$

$$T(V_{GS},V_{DS})$$



computing T: low V_{DS}

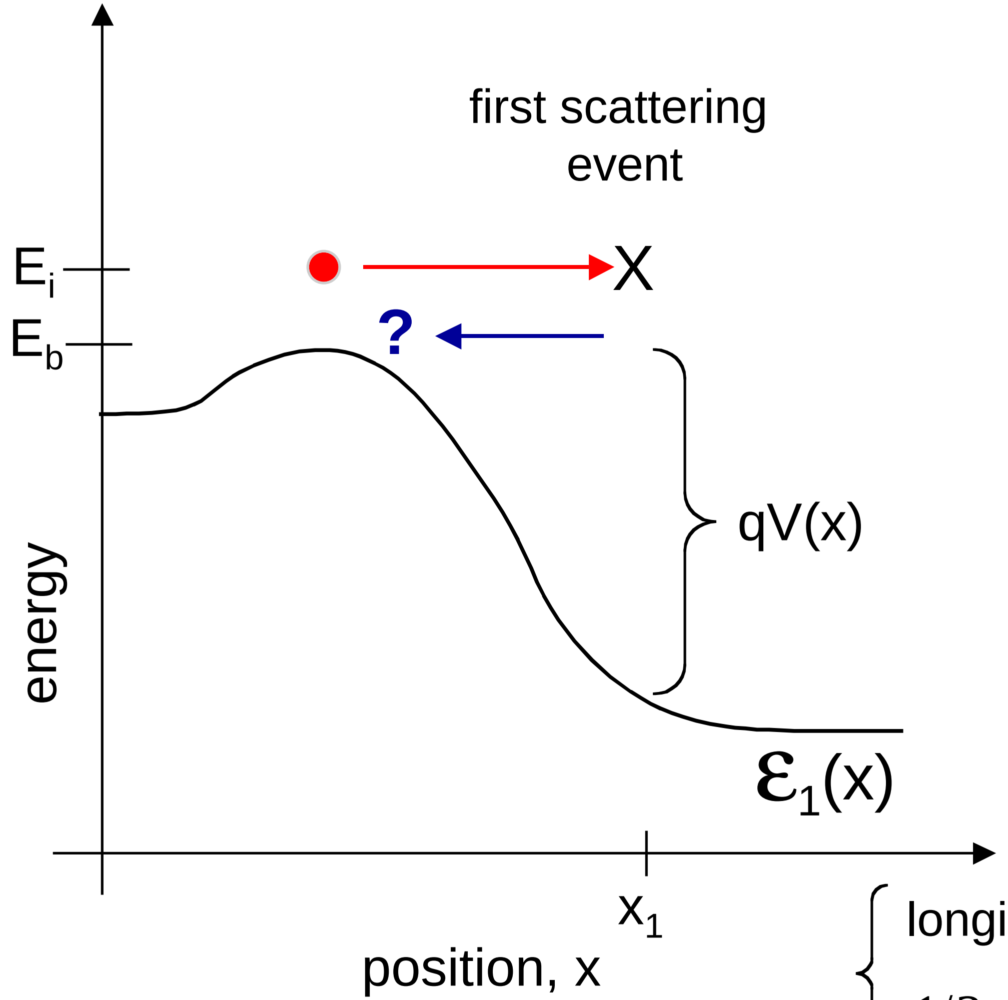


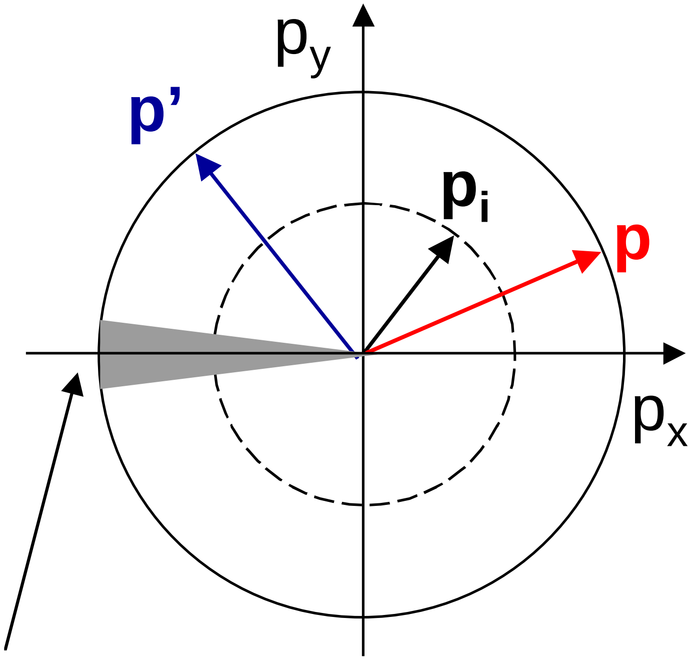
$$T = \frac{\lambda_0}{L + \lambda_0}$$

$$I_{DS} = W C_{ox}\left(\frac{\upsilon_T}{k_B T / q}\right) T\left(V_{GS} - V_T\right) V_{DS}$$

$$I_{DS} = \mu_{eff} C_{ox}\left(\frac{W}{L + \lambda_0}\right)\left(V_{GS} - V_T\right) V_{DS}$$

computing T: high V_{DS}





longitudinal energy

$$\frac{1}{2} m \upsilon_x^2 > qV(x_1)$$