

Lecture 8: Connection to Traditional Model

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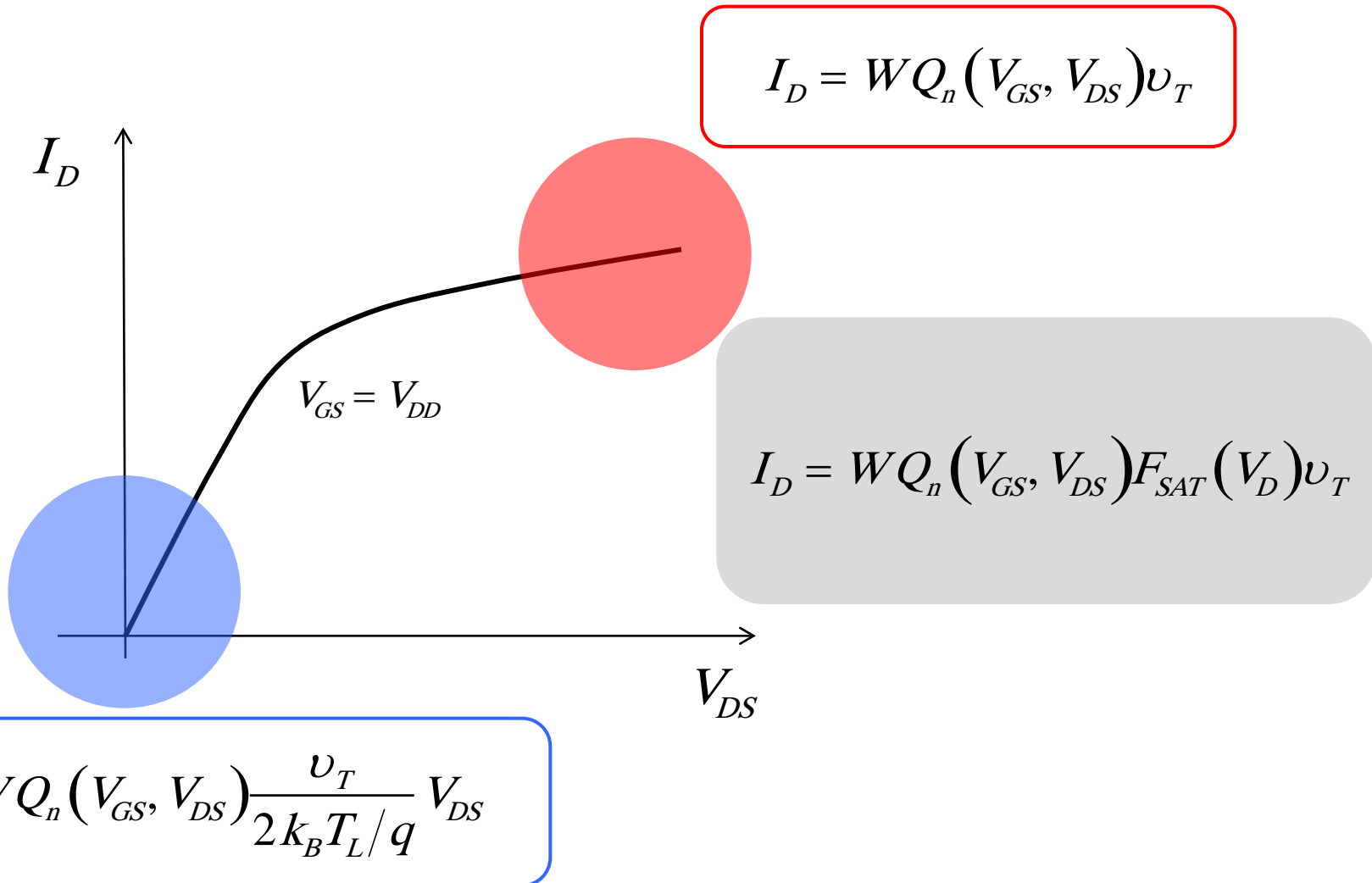
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ballistic MOSFET (MB)

$$I_D = W Q_n (V_{GS}, V_{DS}) \langle v(0) \rangle$$

$$\langle v(0) \rangle = \left(\frac{1 - e^{-qV_{DS}/k_B T_L}}{1 + e^{-qV_{DS}/k_B T_L}} \right) v_T = F_{SAT}(V_{DS}) v_T$$

ballistic MOSFET (MB)



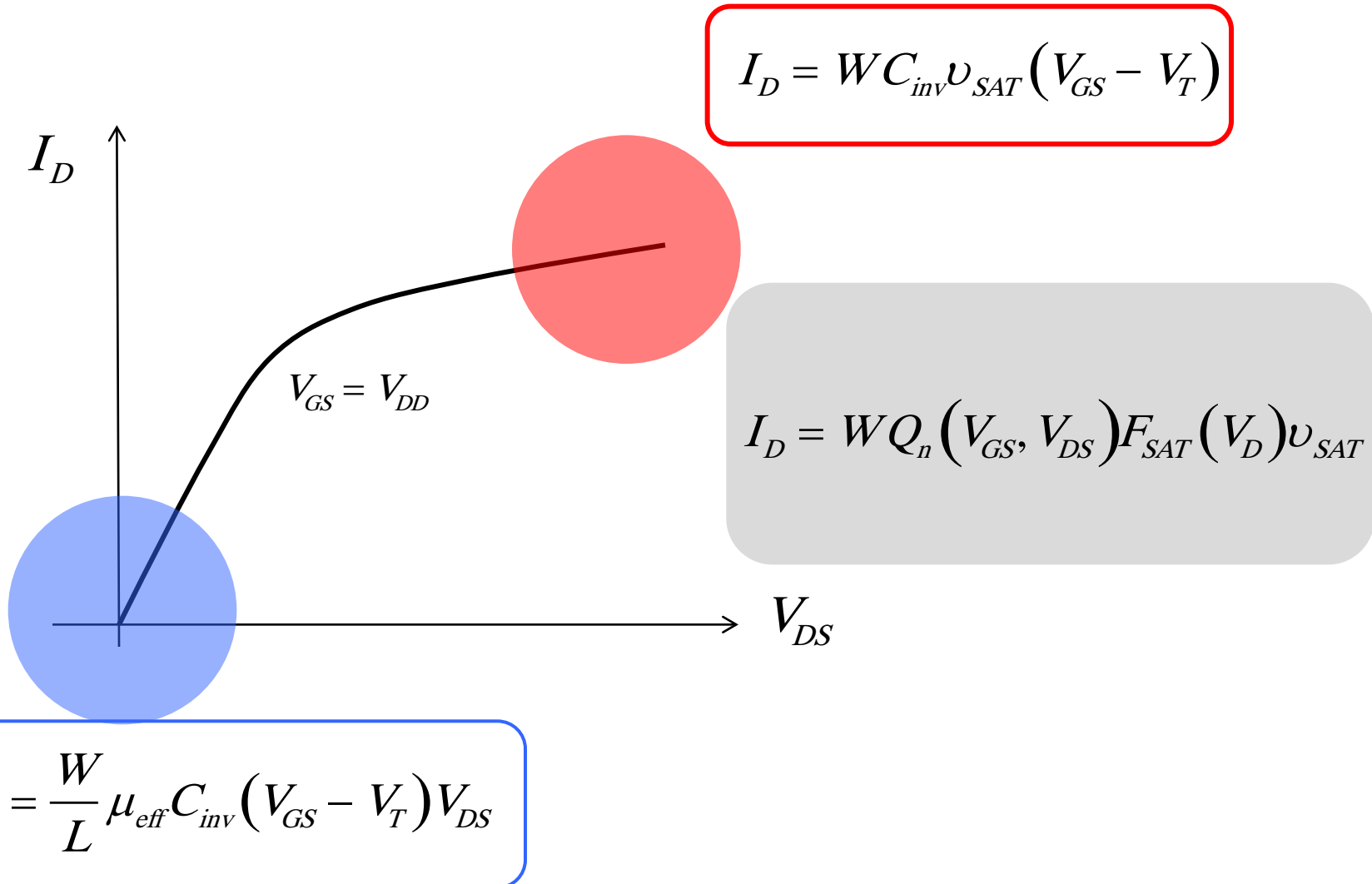
VS model for the MOSFET

$$I_D = WQ_n(V_{GS}, V_{DS})\langle v(0) \rangle$$

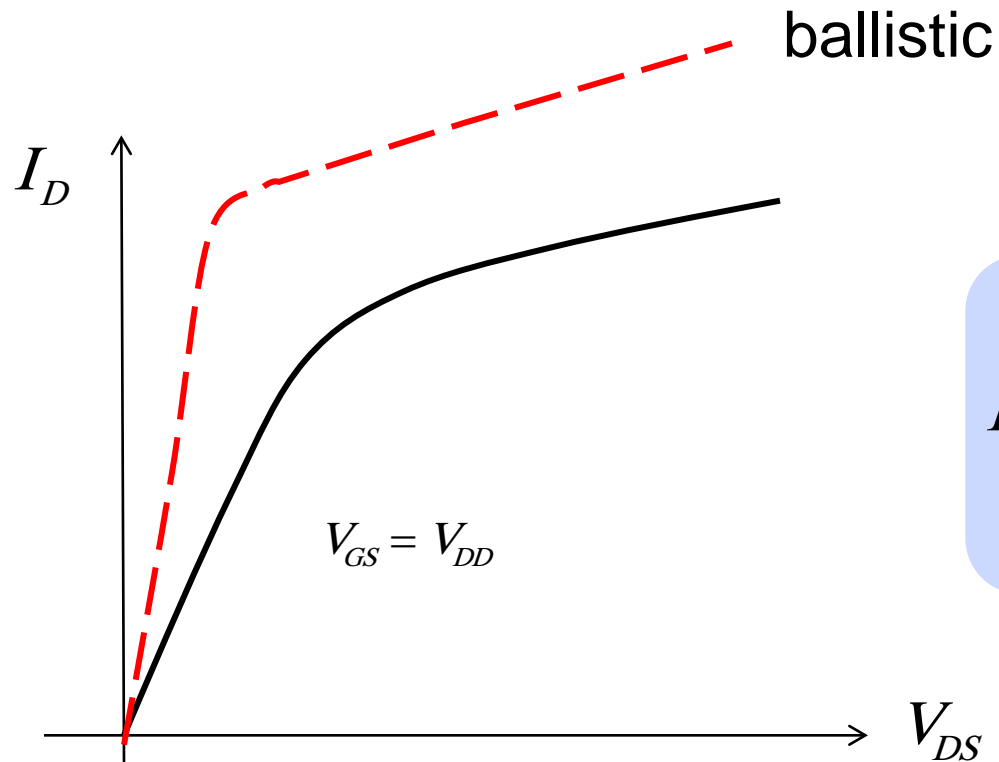
$$\langle v(0) \rangle = \left\{ \frac{V_D / V_{DSAT}}{\left[1 + (V_D / V_{DSAT})^\beta \right]^{1/\beta}} \right\} v_{SAT} = F_{SAT}(V_{DS}) v_{SAT}$$

$$V_{DSAT} = \frac{v_{SAT} L}{\mu_{eff}}$$

VS model for the MOSFET



VS model vs. ballistic



$$I_D = WQ_n(V_{GS}, V_{DS})F_{SAT}(V_D)v_{SAT}$$

connecting the two: linear region

ballistic theory

$$I_D = WC_{inv} \frac{v_T}{2k_B T_L / q} (V_{GS} - V_T) V_{DS}$$

$$I_D = \frac{W}{L} C_{inv} \frac{v_T L}{2k_B T_L / q} (V_{GS} - V_T) V_{DS}$$

$$\mu_B \equiv \frac{v_T L}{2k_B T_L / q} \quad \text{“ballistic mobility”}$$

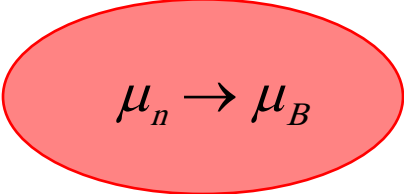
$$I_D = \frac{W}{L} C_{inv} \mu_B (V_{GS} - V_T) V_{DS}$$

traditional theory

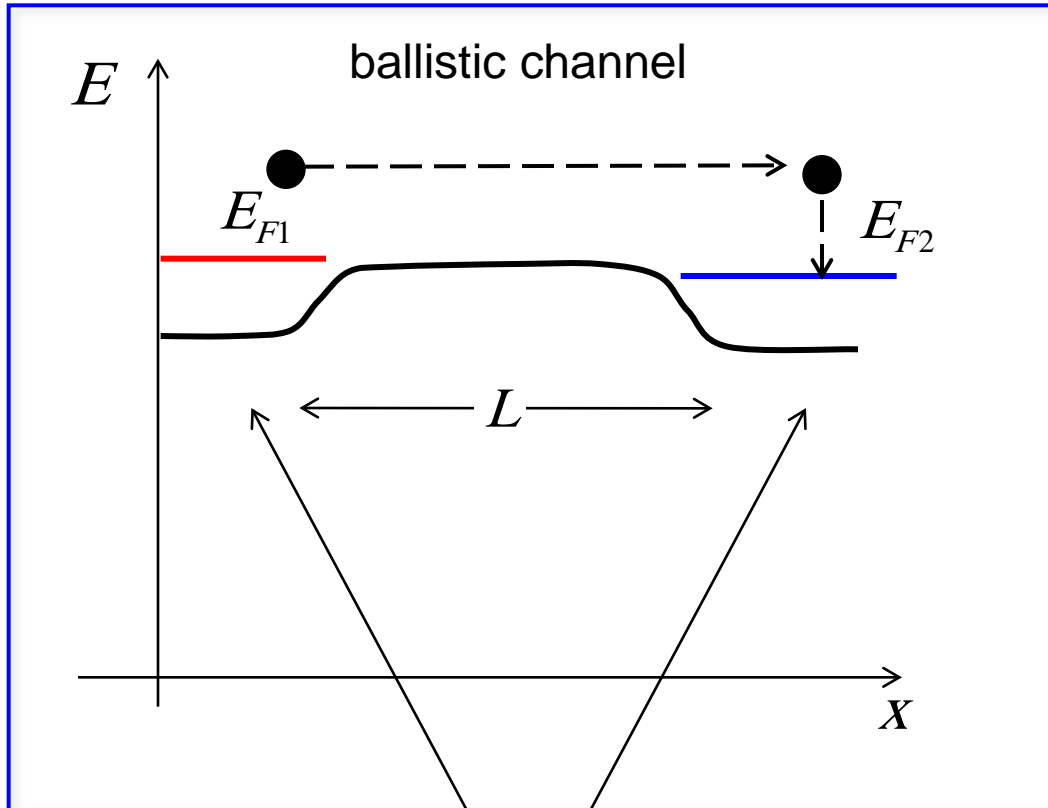
$$I_D = \frac{W}{L} C_{in} \mu_{eff} (V_{GS} - V_T) V_{DS}$$

$$D_n = \frac{v_T \lambda_0}{2}$$

$$\mu_{eff} = \frac{D_n}{(k_B T_L / q)} \quad \mu_{eff} = \frac{v_T \lambda_0}{2k_B T_L / q}$$


$$\mu_n \rightarrow \mu_B$$

ballistic mobility

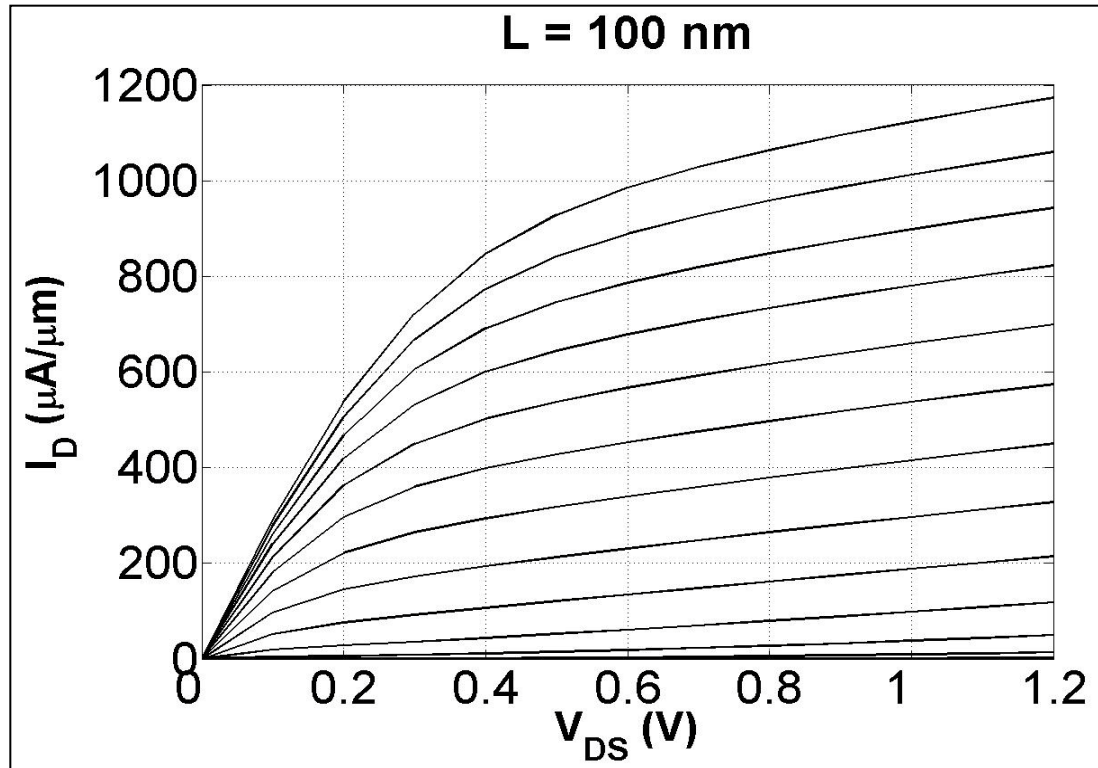


strong scattering in the S/D contacts

$$\mu_n = \frac{v_T \lambda_0}{2 k_B T_L / q}$$

$$\mu_B = \frac{v_T L}{2 k_B T_L / q}$$

ballistic mobility



(Thanks to Shuji Ikeda of ATDF for supplying these devices in Dec. 2007)

$$\mu_{eff} \approx 250 \text{ cm}^2/\text{V-s}$$

$$\mu_B \approx 3200 \text{ cm}^2/\text{V-s}$$

$$\mu_B \gg \mu_{eff}$$

$$\mu_B = \frac{v_T L}{2 k_B T_L / q}$$

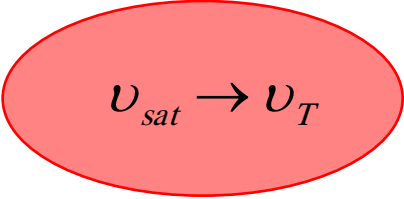
connecting the two: saturation region

ballistic theory

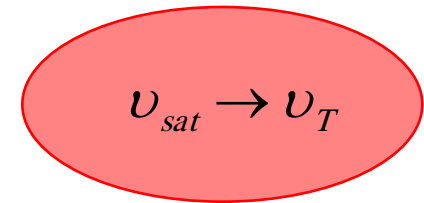
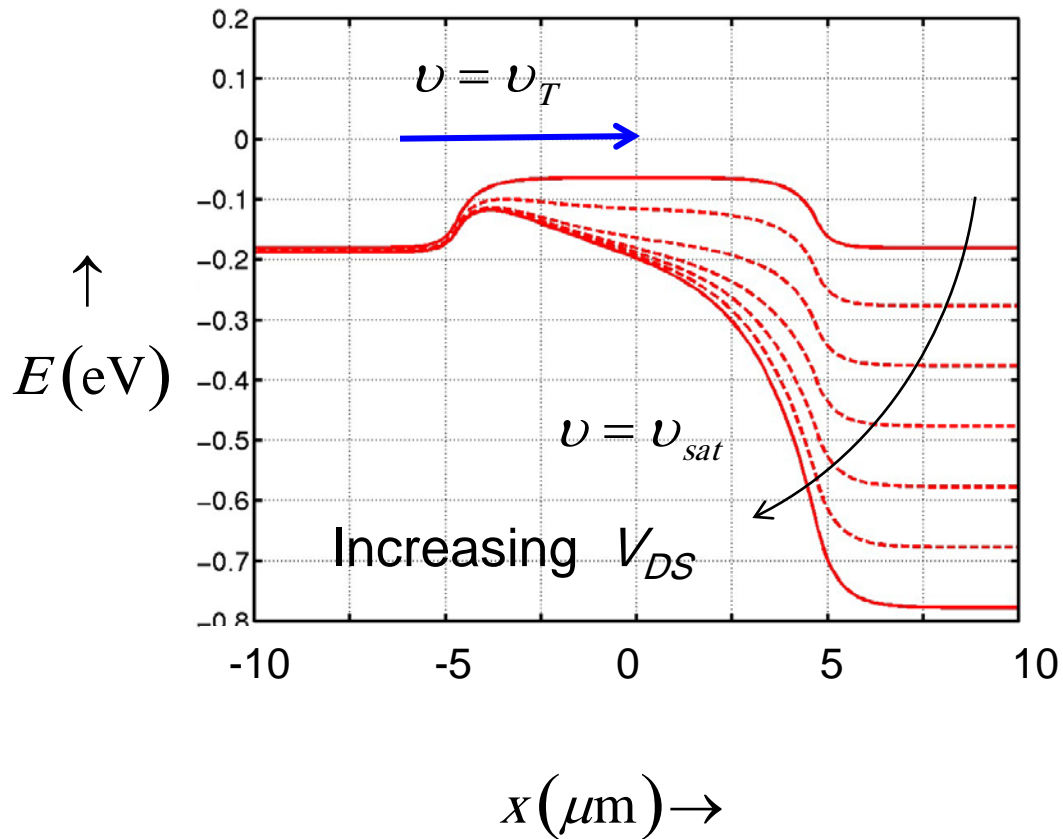
$$I_D = WC_{inv} \nu_T (V_{GS} - V_T)$$

traditional theory

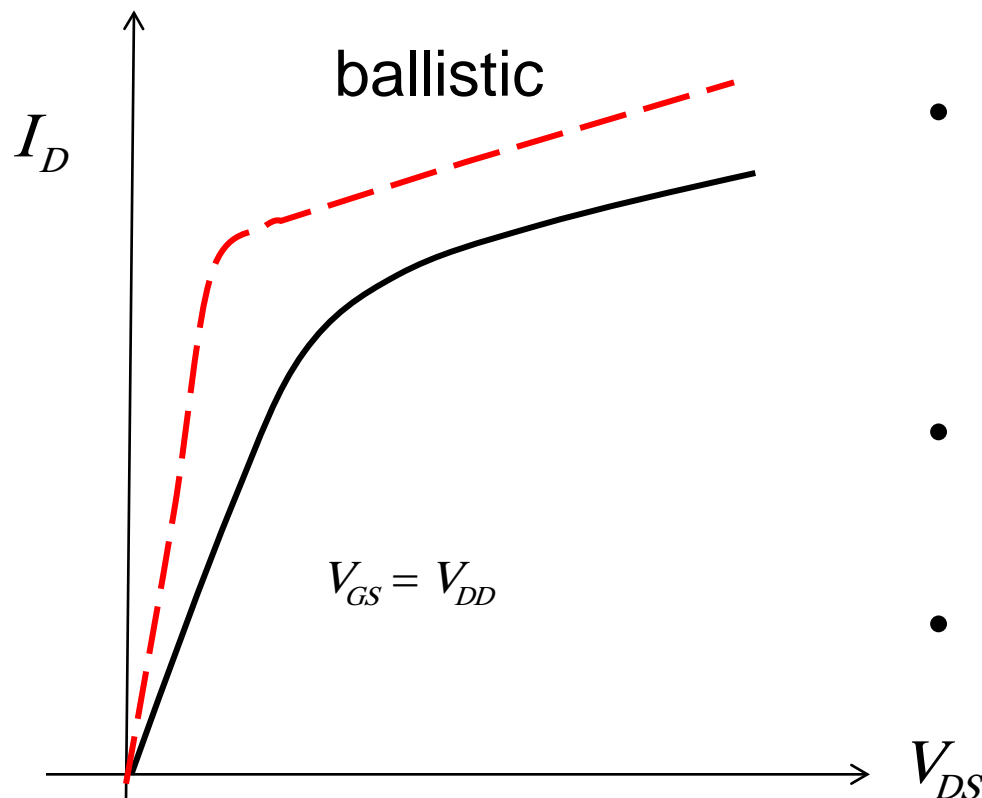
$$I_{DS} = WC_{inv} \nu_{sat} (V_{GS} - V_T)$$


$$\nu_{sat} \rightarrow \nu_T$$

injection vs. saturation velocity



wrap-up



- Ballistic and DD MOSFET models give similar IV's because the current is controlled by modulating barriers.
- Ballistic currents are higher and...
- transition from linear to saturation is sharper.

references

The concept of ballistic mobility was introduced by Shur:

M.S. Shur, "Low ballistic mobility in submicron HEMTs," *IEEE Electron Dev. Letters*, **9**, 511-513, 2002.