Lecture 8: Connection to Traditional Model

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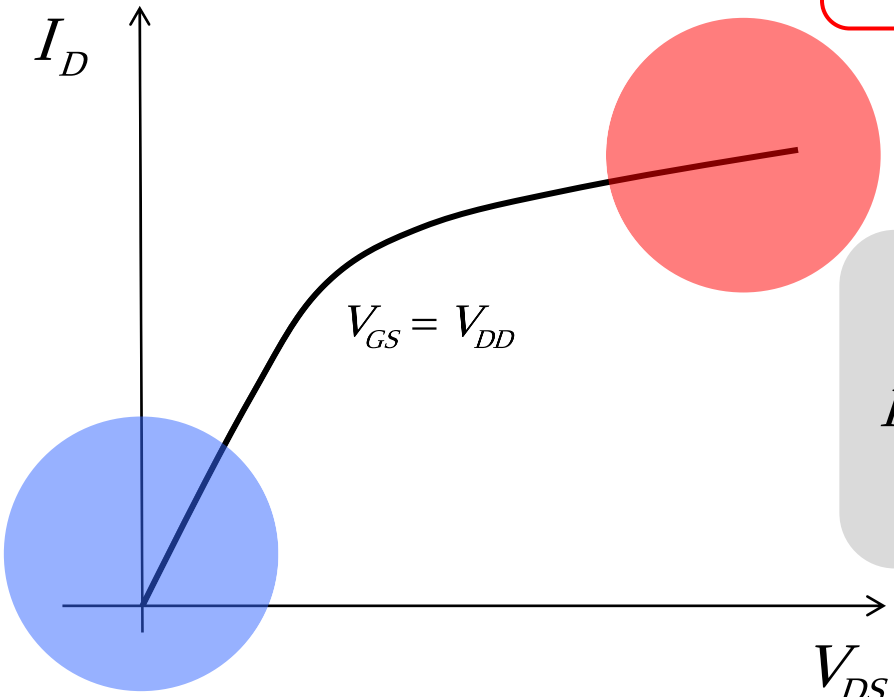
ballistic MOSFET (MB)

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

$$\left\langle \upsilon(0)\right\rangle = \left(\frac{1 - e^{-qV_{DS}/k_BT_L}}{1 + e^{-qV_{DS}/k_BT_L}}\right)\upsilon_T = F_{SAT}\left(V_{DS}\right)\upsilon_T$$

ballistic MOSFET (MB)

$$I_D = WQ_n\left(V_{GS}, V_{DS}\right)\upsilon_T$$



$$I_D = WQ_n\left(V_{GS}, V_{DS}\right)F_{SAT}\left(V_D\right)\upsilon_T$$

$$I_D = WQ_n\left(V_{GS}, V_{DS}\right)\frac{\upsilon_T}{2k_BT_L/q}V_{DS}$$

VS model for the MOSFET

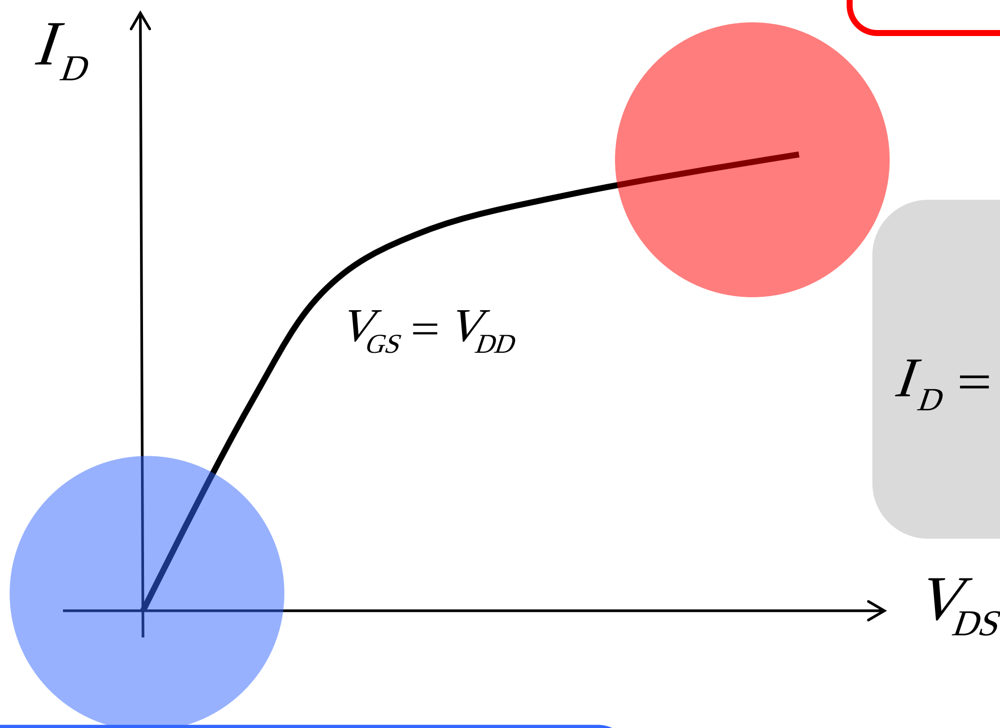
$$I_D = W Q_n\left(V_{GS}, V_{DS}\right)\left\langle \upsilon(0)\right\rangle$$

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

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

VS model for the MOSFET

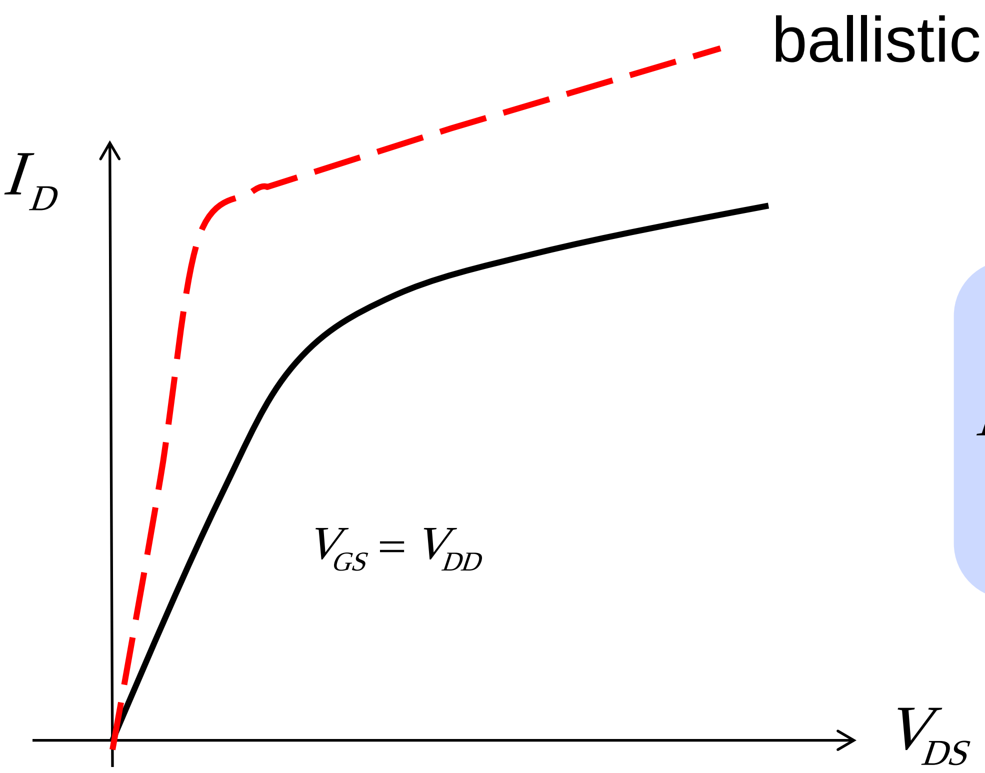
$$I_D = W C_{inv} \upsilon_{SAT} \left(V_{GS} - V_T \right)$$



$$I_D = W Q_n \left(V_{GS}, V_{DS} \right) F_{SAT} \left(V_D \right) \upsilon_{SAT}$$

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

VS model vs. ballistic



$$I_D = WQ_n\left(V_{GS}, V_{DS}\right)F_{SAT}\left(V_D\right)\upsilon_{SAT}$$

connecting the two: linear region

ballistic theory

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

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

$$\mu_B \equiv \frac{\upsilon_T L}{2 k_B T_L / q}$$ "ballistic mobility"

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

traditional theory

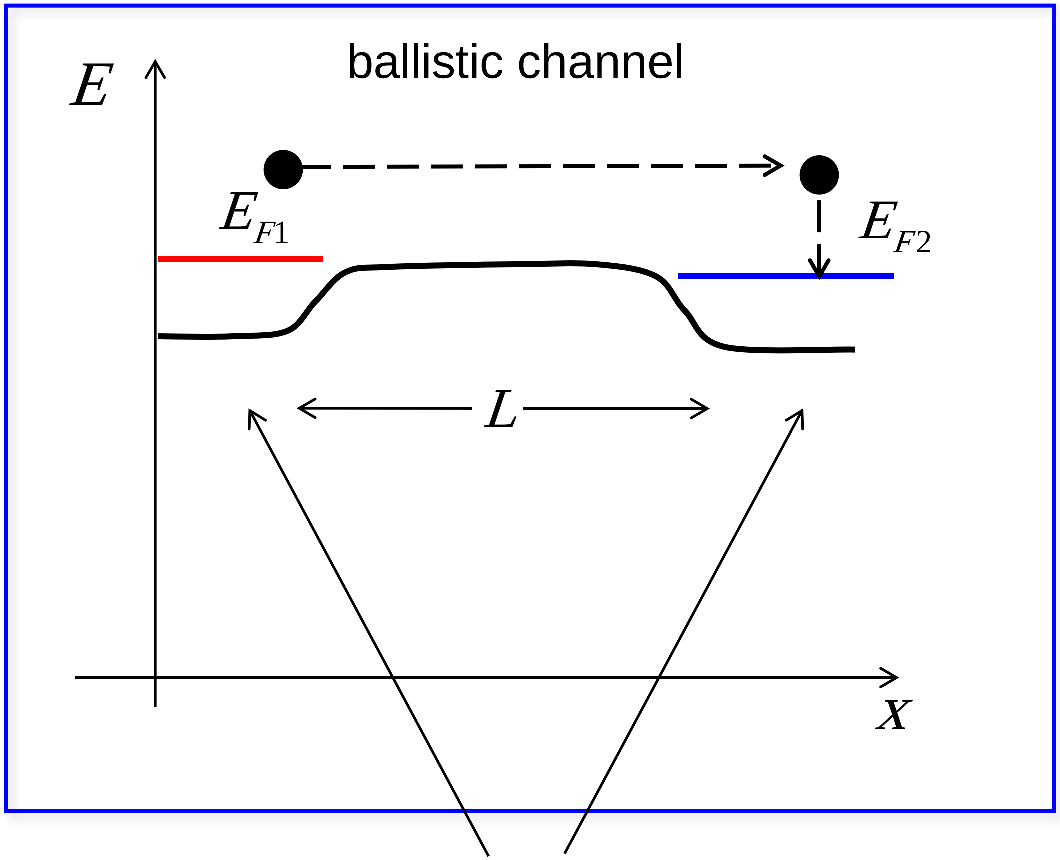
$$I_D = \frac{W}{L} C_{in} \mu_{eff} (V_{GS} - V_T) V_{DS}$$

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

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

$$\mu_n \rightarrow \mu_B$$

ballistic mobility

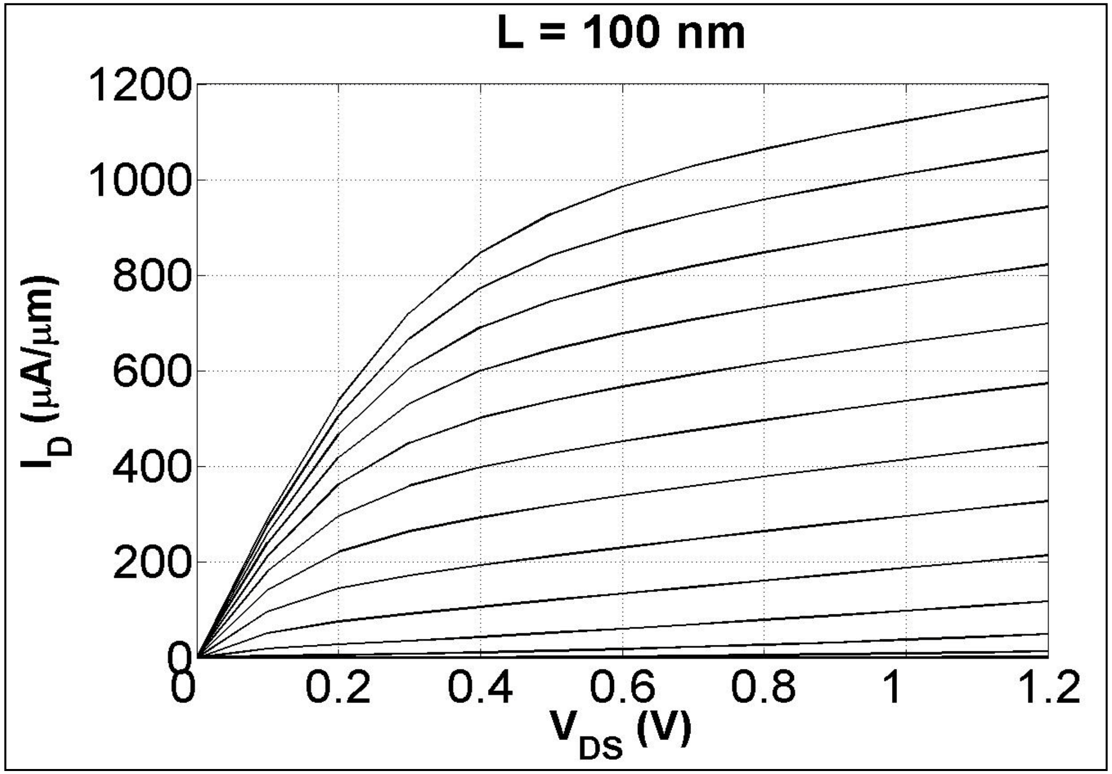


strong scattering in the S/D contacts

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

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

ballistic mobility



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

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

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

$$\mu_B >> \mu_B$$

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

connecting the two: saturation region

ballistic theory

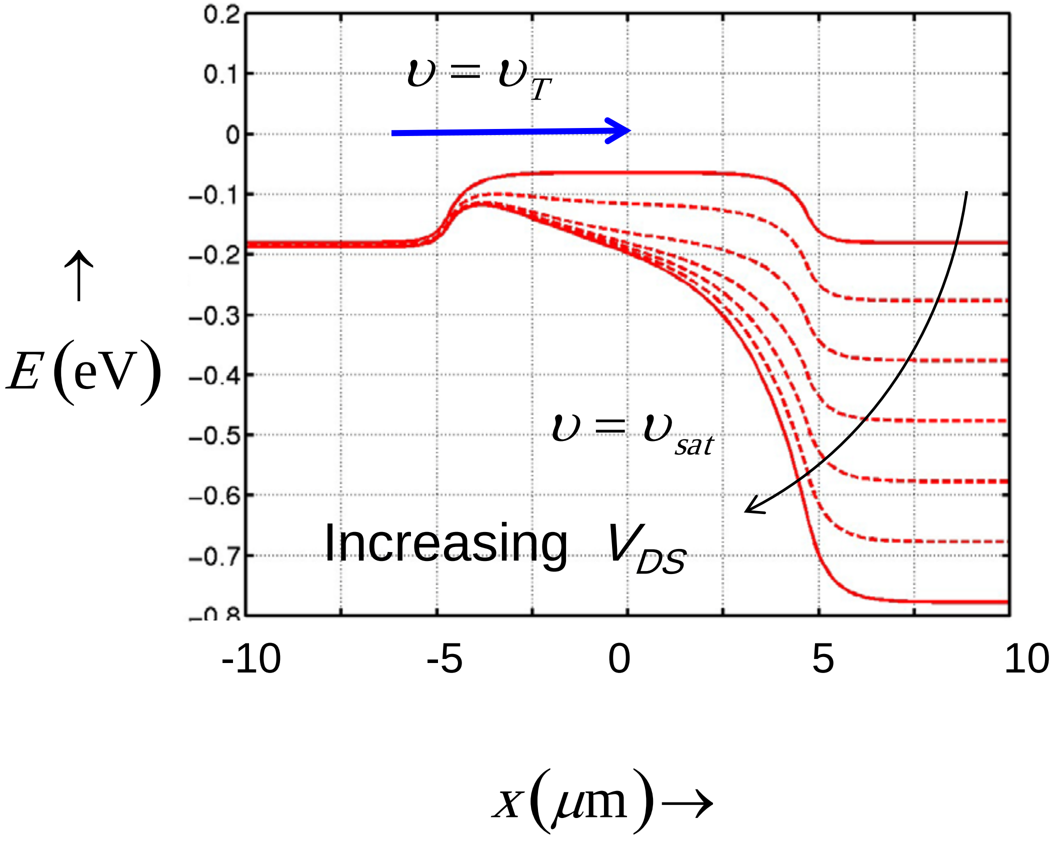
$$I_D = WC_{inv}\upsilon_T\left(V_{GS} - V_T\right)$$

traditional theory

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

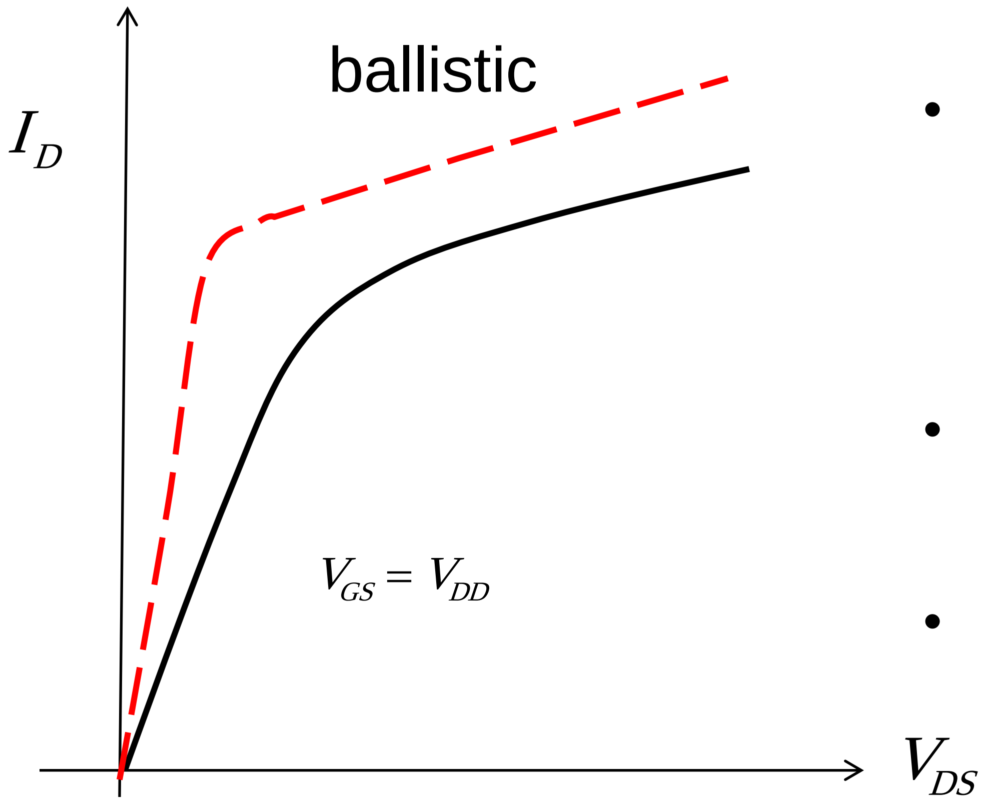
$$\upsilon_{sat} \rightarrow \upsilon_T$$

injection vs. saturation velocity



$\upsilon_{sat} \rightarrow \upsilon_T$

wrap-up



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

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.