First-pass MOSFET Model

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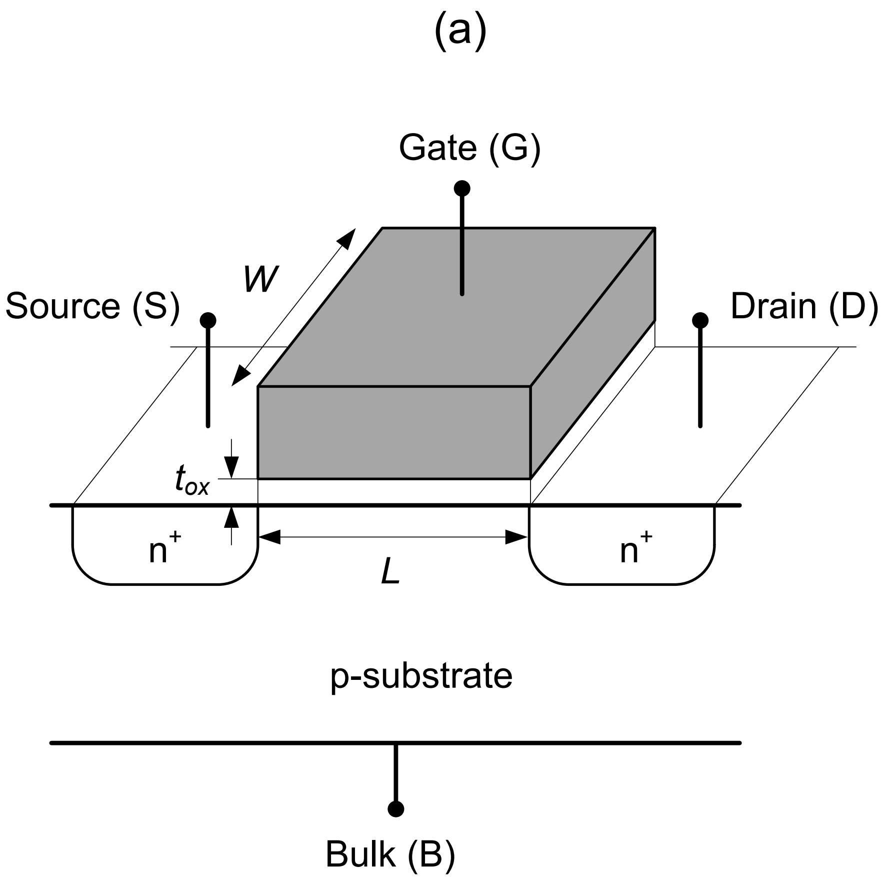
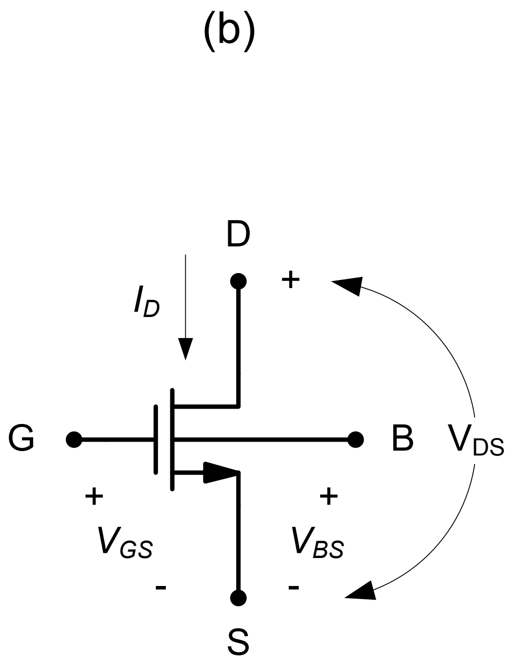
“First-pass” MOSFET Model

nMOST

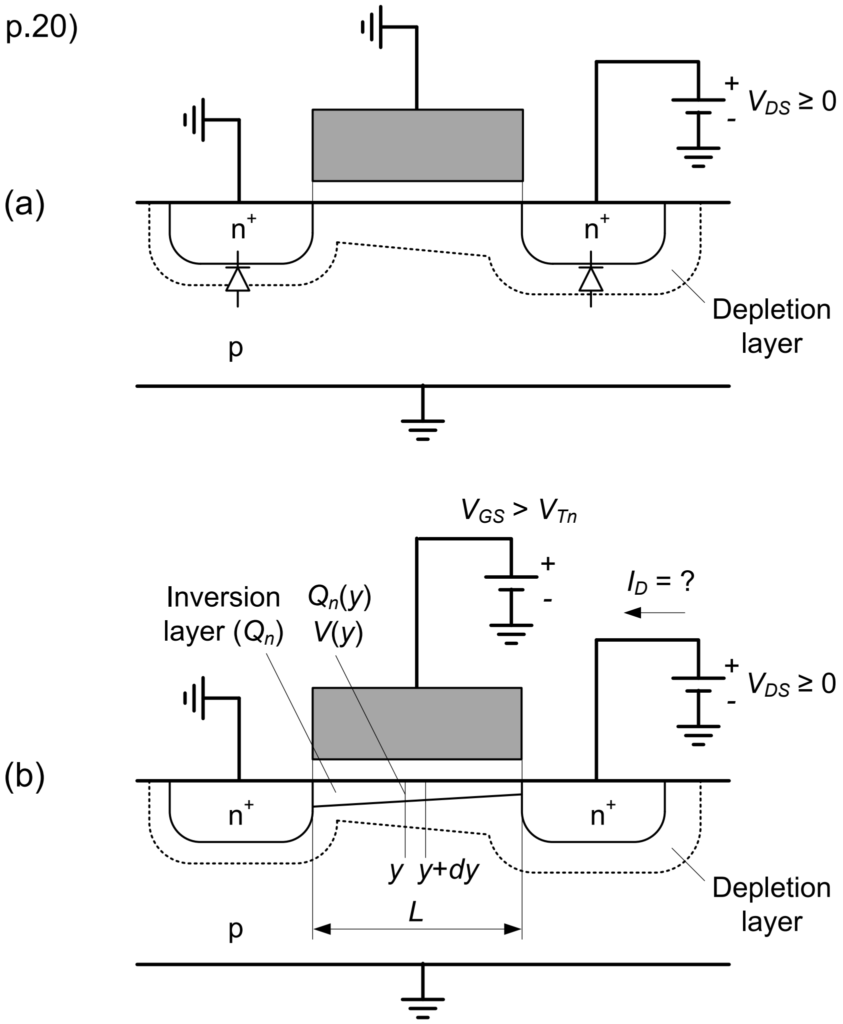




Source: B. Murmann (Textbook p.19)

nMOST with V_{GS}=0 and $V_{GS} > V_{Tn}$

Source: B. Murmann (Textbook p.20)



First-pass Model Assumptions

1. The current primarily depend on the number of mobile electrons in the channel times their velocity

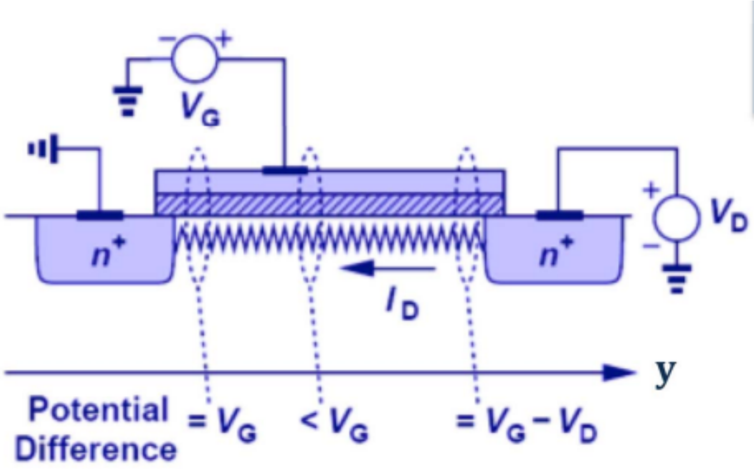
2. The number of mobile electrons in the channel is set by the vertical electric field from gate to the conductive channel (gradual channel approximation)

3. The threshold voltage is constant along the channel: this assumption neglects the so called body effect (more on body effect later …)

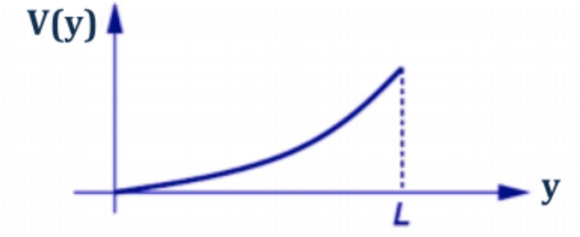
4. The velocity of the electrons traveling from source to drain is proportional to the later electric filed in the channel

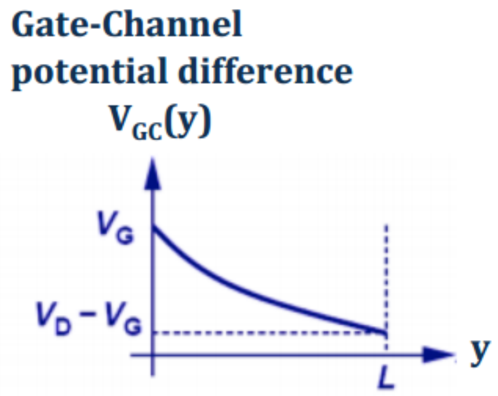
Model Assumptions

Source: B. Razavi



$$Q_N(y) = C_{OX} \cdot \left(V_{GC}(y) - V_{Tn}\right)$$
$$V_{GC}(y) = V_G - V(y)$$

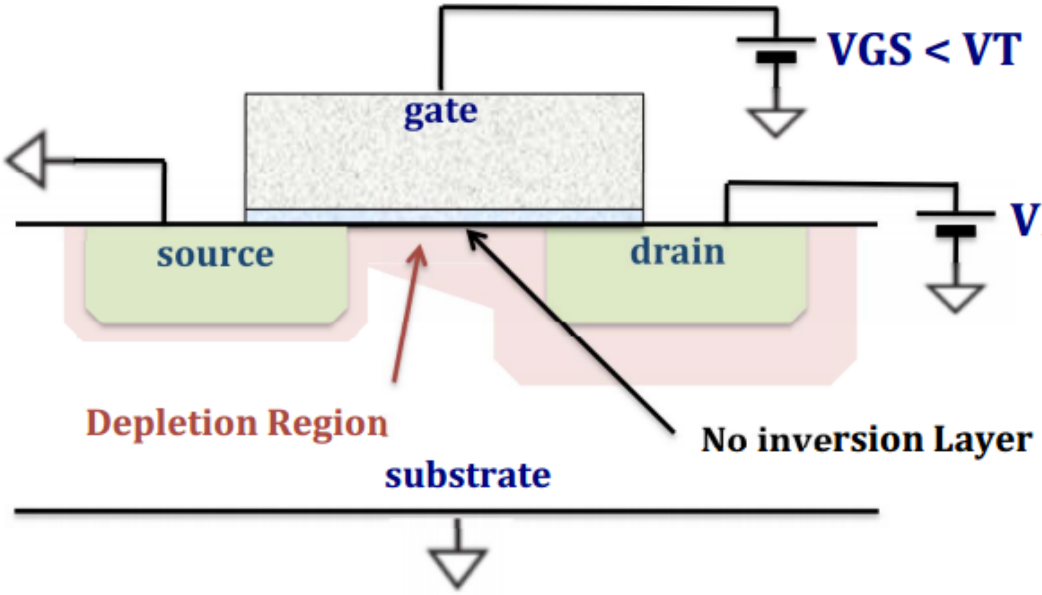




nMOST in cut-off

- $V_{GS} < V_{Tn}$
- Q_N = inversion charge = 0

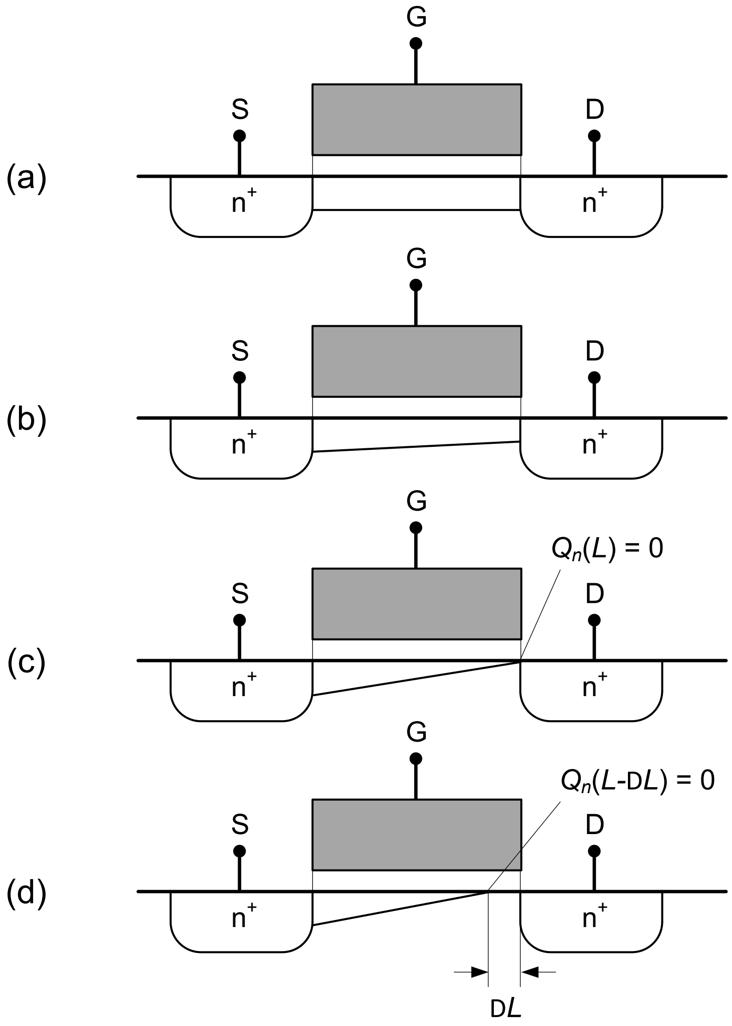
$$\boxed{I_D = 0}$$



Physically S and D are identical.
By convention, we call D the diffusion at higher potential

Channel profile for varying V_{DS} (and $V_{GS} > V_{Tn}$)

Source: B. Murmann (Textbook p.21)



(a) $V_{DS} = 0$

(b) $0 < V_{DS} < V_{GS} - V_{Tn}$

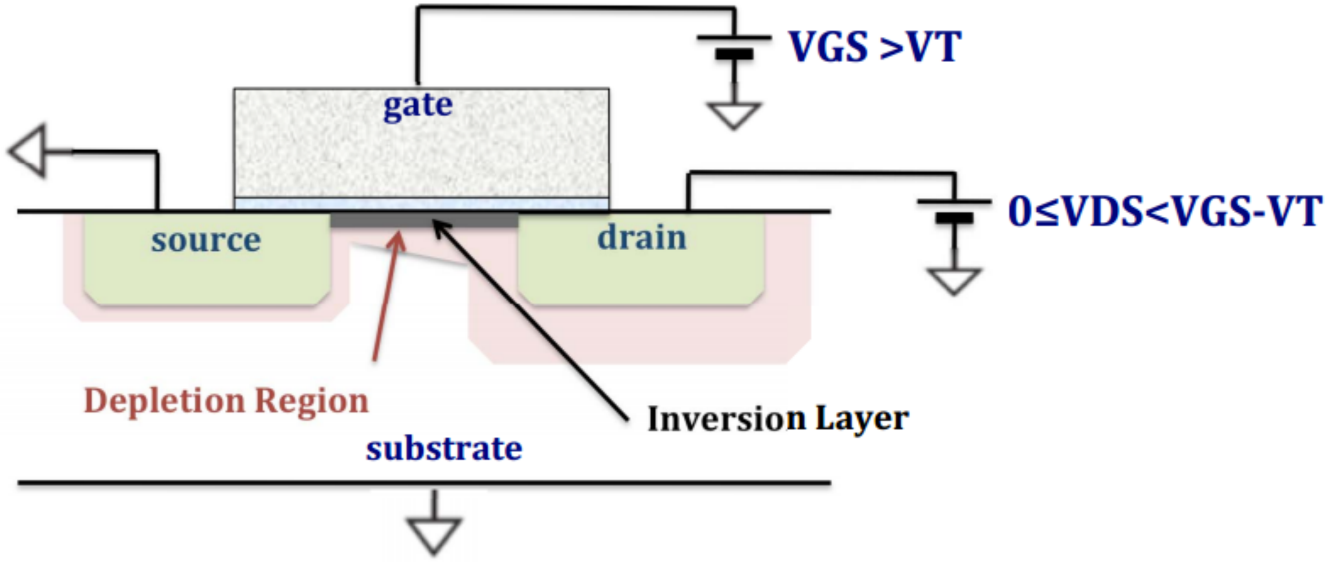
(c) $V_{DS} = V_{GS} - V_{Tn}$

(d) $V_{DS} > V_{GS} - V_{Tn}$

nMOST in triode (a.k.a. linear)

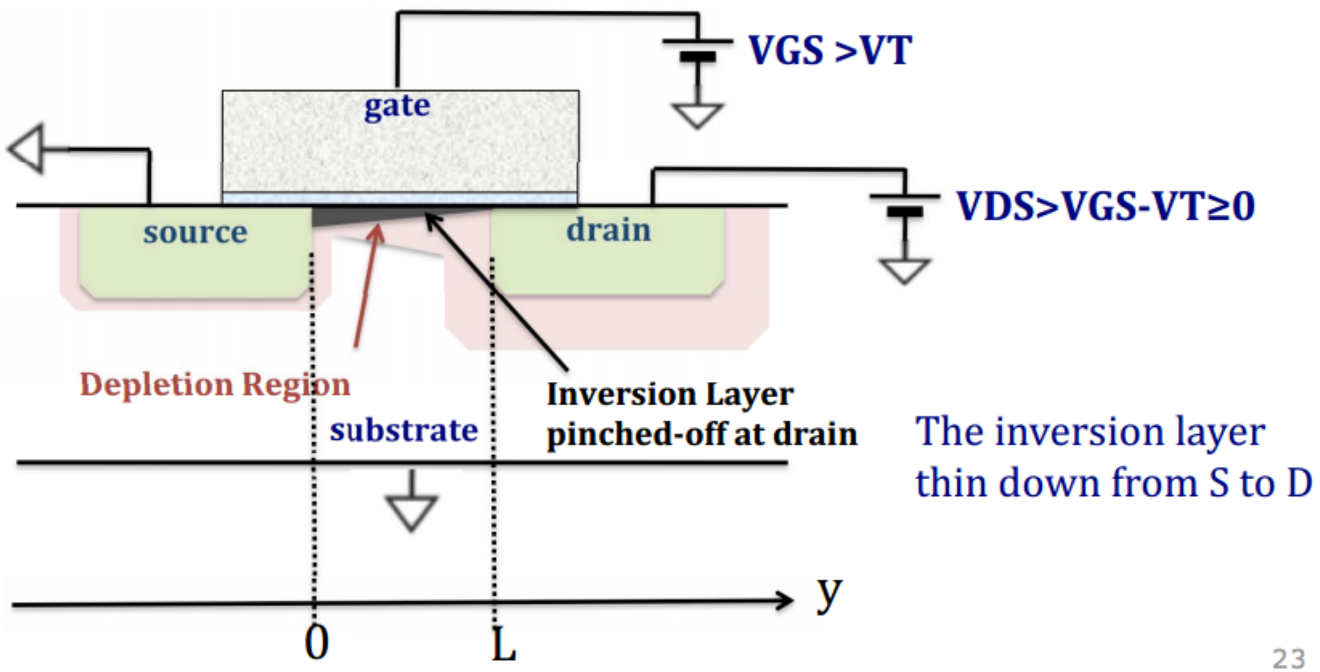
$$\boxed{I_D = \mu_n C_{OX} \frac{W}{L} (V_{GS} - V_{Tn} - V_{DS}/2) V_{DS}}$$

$$C_{OX} \triangleq \frac{\varepsilon_{OX}}{t_{OX}}; \quad KP_n \triangleq \mu_n C_{OX}; \quad \beta \triangleq \mu_n C_{OX} \frac{W}{L}$$



nMOST in Saturation (1)

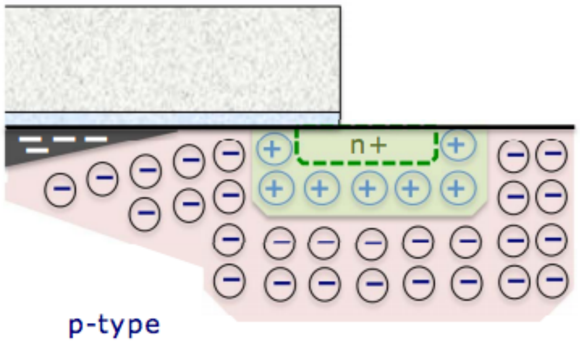
$$\boxed{I_D = \frac{\mu_n C_{OX}}{2}\frac{W}{L}(V_{GS} - V_{Tn})^2}$$

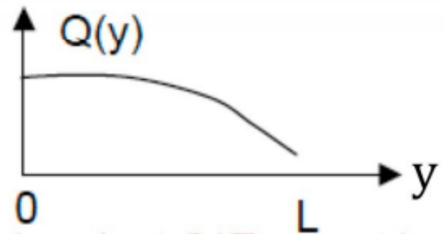


The inversion layer thin down from S to D

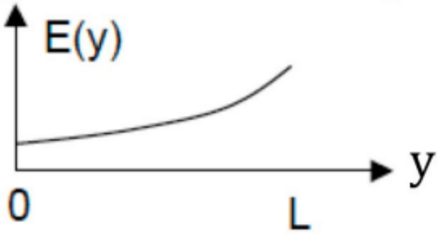
nMOST in saturation (2)

- Increase in lateral field E(y) (that is V_{DS}) is compensated by decrease in $Q_N(y)$
- When Q_N=0 at the drain then I_D saturates





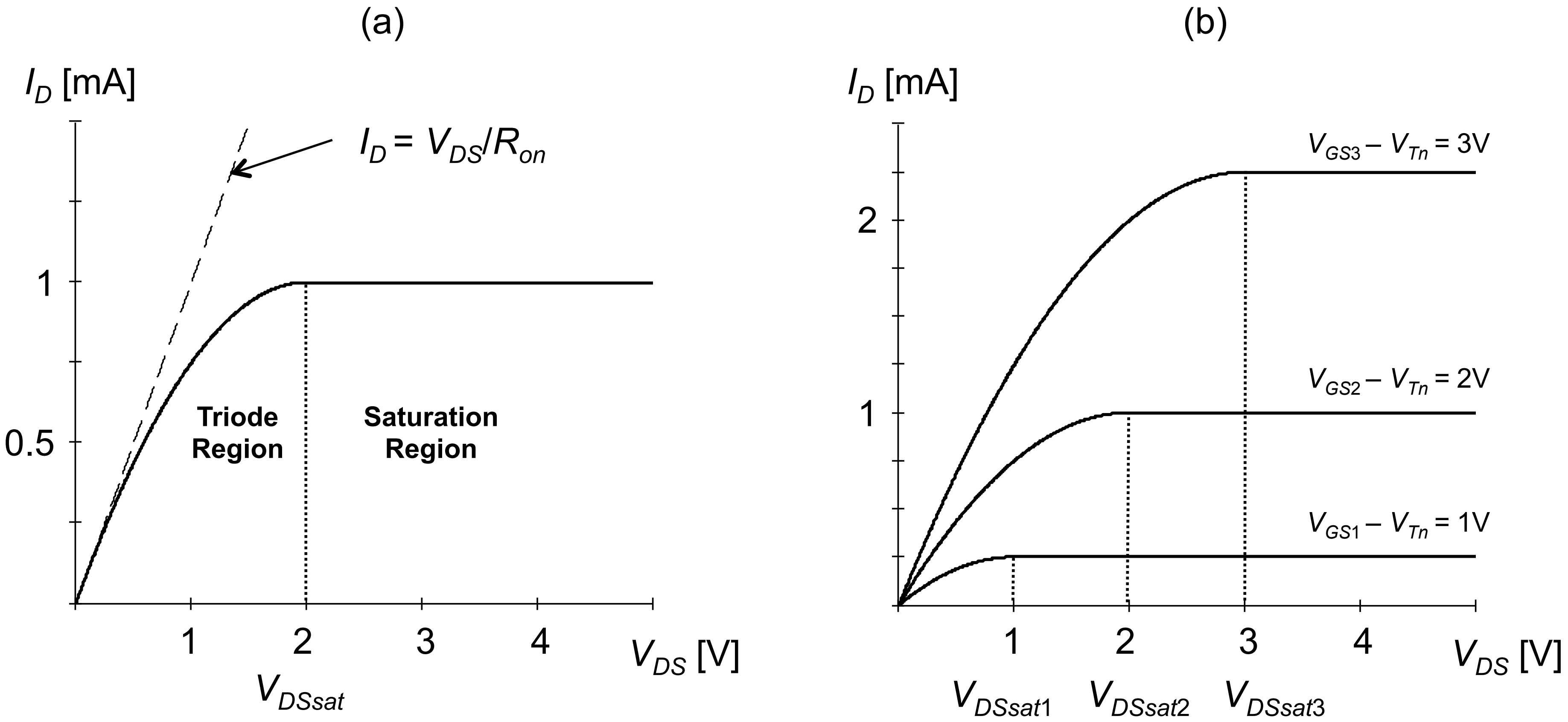
(product Q*E=const.)



After channel charge goes to 0, there is a high lateral field that ‘sweeps’ the carriers to the drain*, and drops the extra voltage (this is a depletion region of the drain junction)

* It is important to remember what a reverse biased PN junction does to minority carriers.
Electrons (in the p-type material) get swept back into the n-region

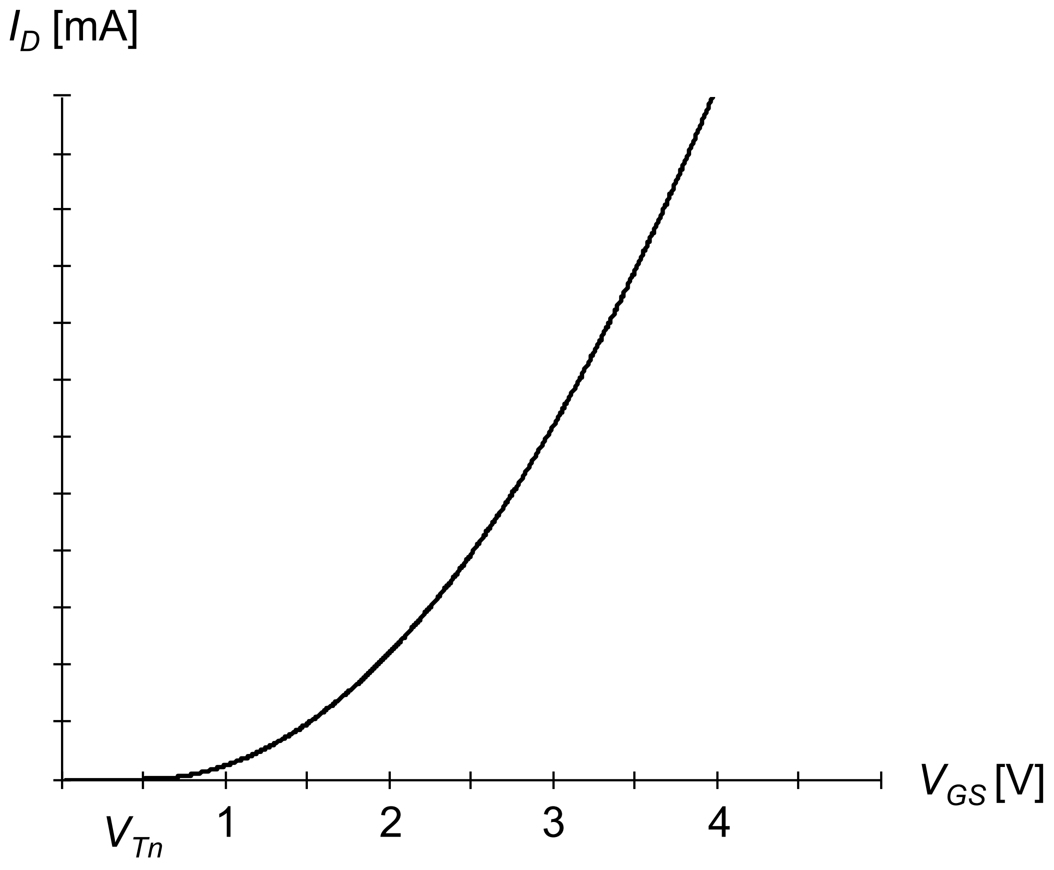
I-V Characteristics (1)



Source: B. Murmann (Textbook p.22)

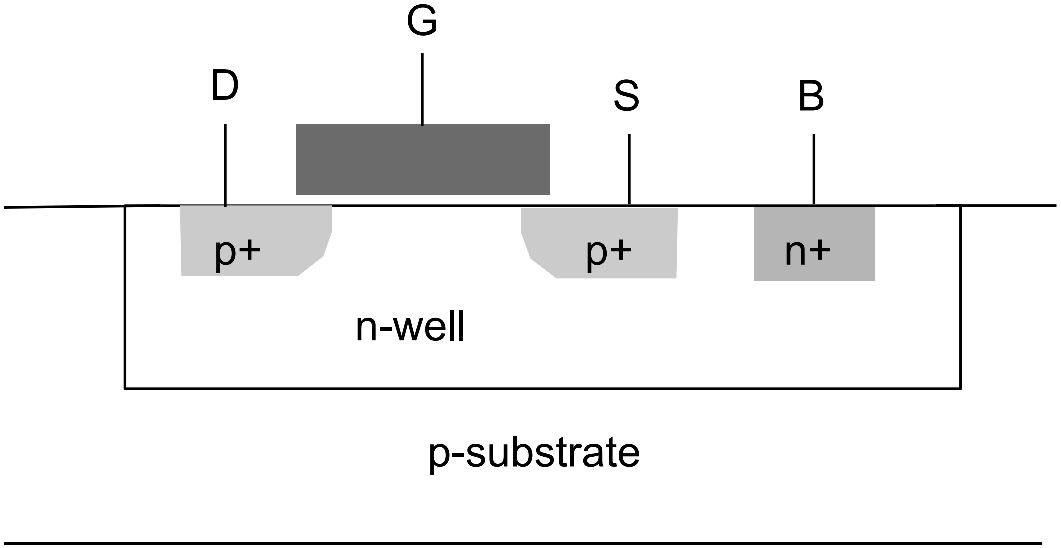
I-V Characteristics (2)

Source: B. Murmann (Textbook p.23)

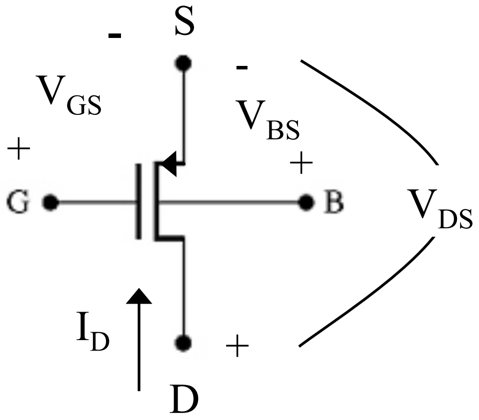


pMOST

(a)



(b)



Source: B. Murmann (Textbook p.24)

nMOST vs. pMOST

source: N. Weste and D. Harris

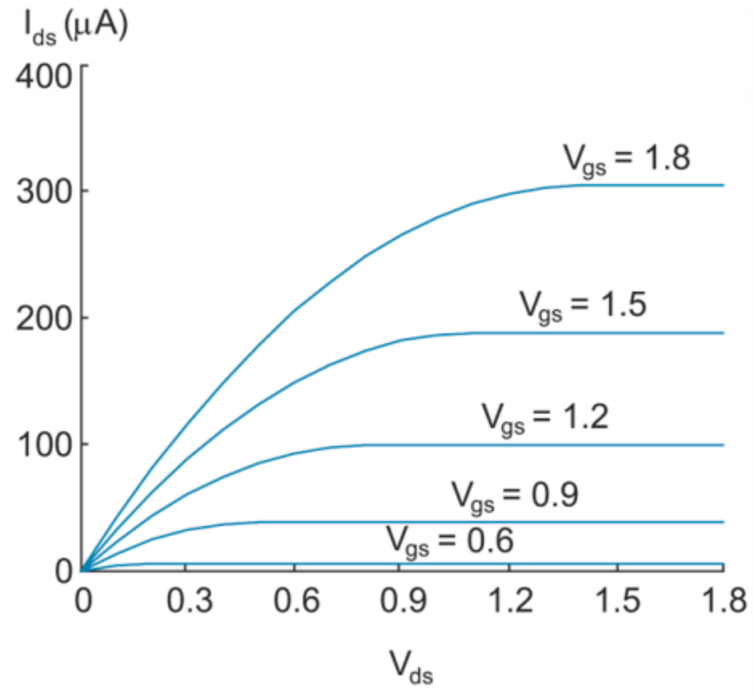


FIG 2.7 I-V characteristics of ideal nMOS transistor

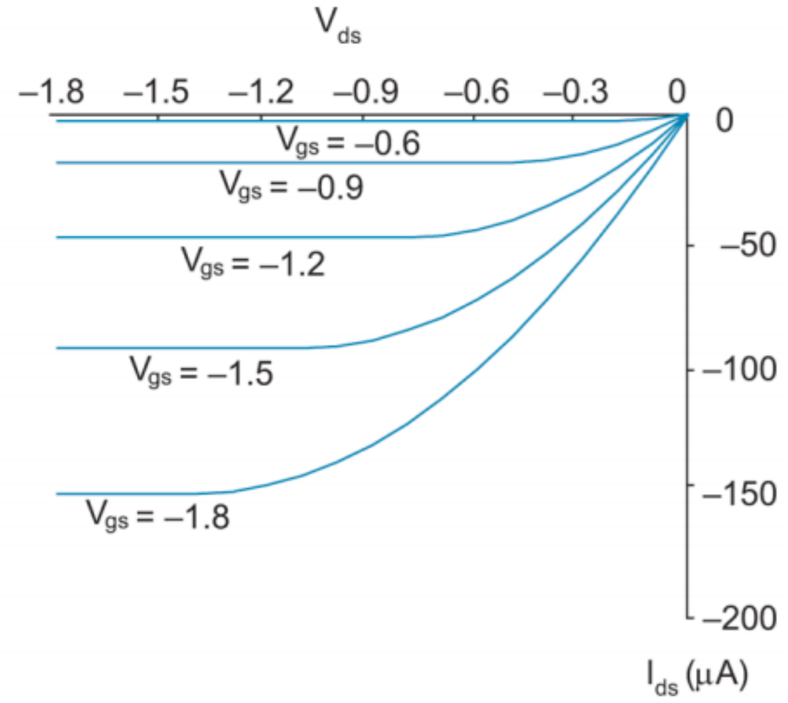
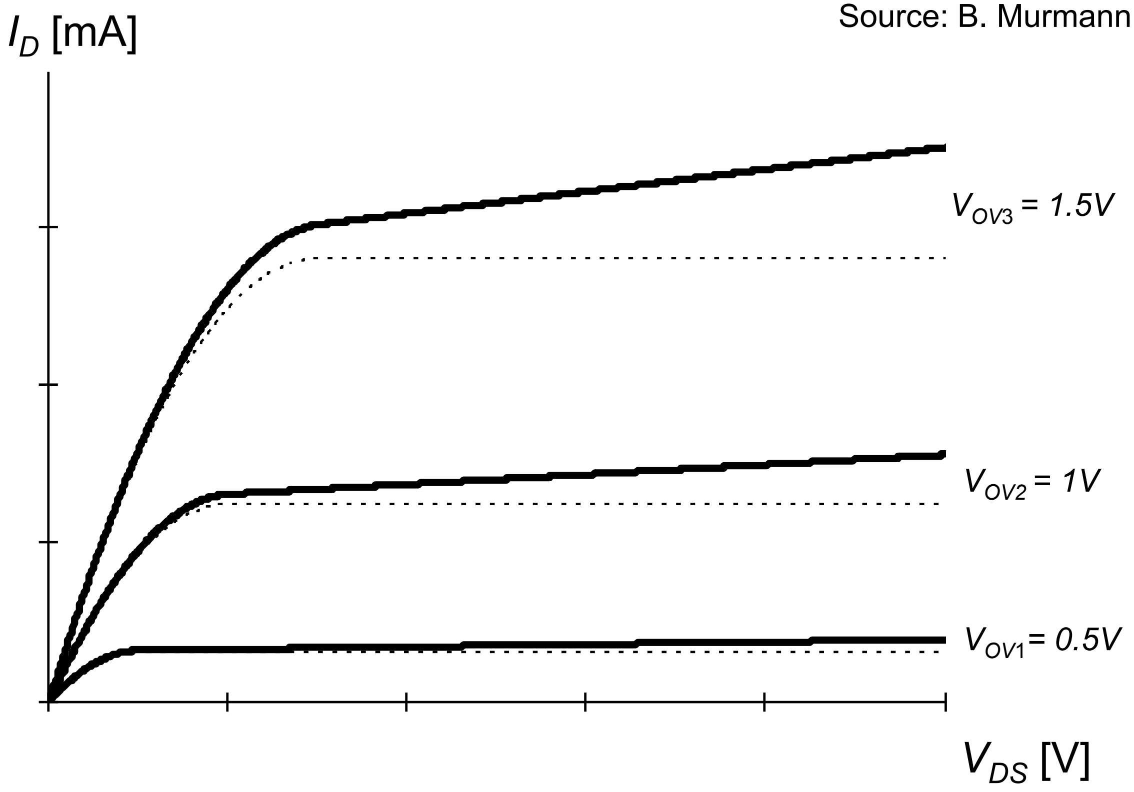


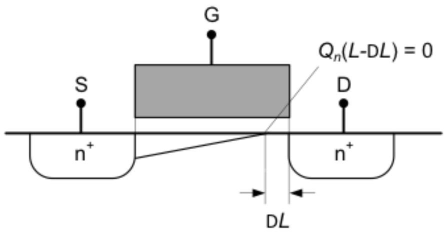
FIG 2.8 I-V characteristics of ideal pMOS transistor

Channel Length Modulation (saturation) (1)

nMOST

Source: B. Murmann (Textbook p.41)





$V_{DS} > V_{GS} - V_{Tn}$

$V_{GS} > V_{Tn}$

$$I_D = \frac{\mu_n C_{OX}}{2} \frac{W}{L - \Delta L} (V_{GS} - V_{Tn})^2$$

Channel Length Modulation (2)

$$I_D = \frac{\mu_n C_{OX}}{2} \frac{W}{L - \Delta L} (V_{GS} - V_{Tn})^2$$

$$\frac{1}{L - \Delta L} \simeq \frac{1}{L}\left(1 + \frac{\Delta L}{L}\right)$$

$$\Delta L = f(V_{DS})$$

$$\frac{\Delta L}{L} \simeq \lambda_n V_{DS}$$

The simplest thing we can do to approximate a function is to use a linear approximation

- The channel length modulation parameter λ is a “crude” fudge factor
- It is commonly acceptable to neglect λV_{DS} in bias point calculations

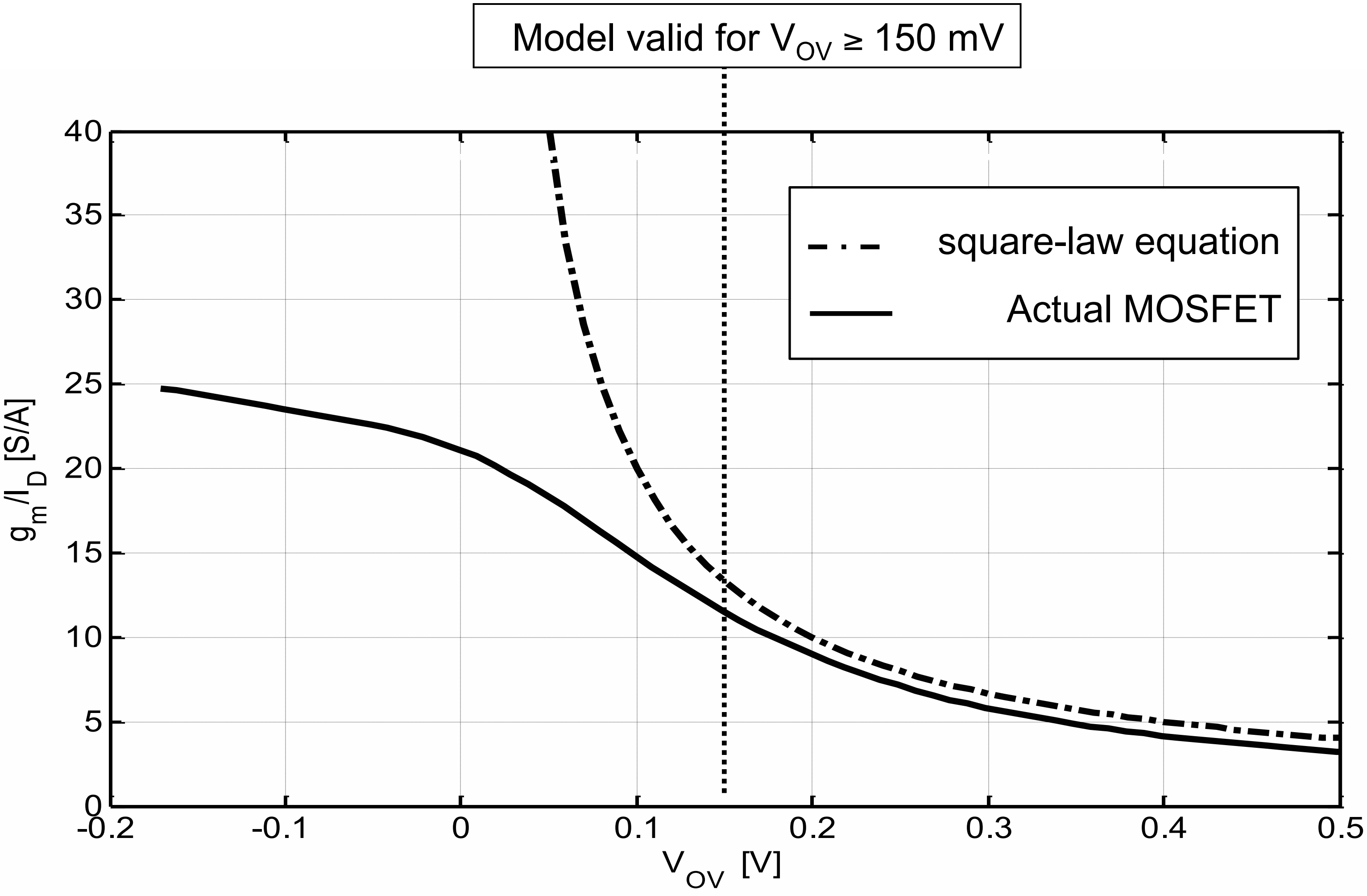
$$\boxed{I_D \simeq \frac{\mu_n C_{OX}}{2} \frac{W}{L} (V_{GS} - V_{Tn})^2 (1 + \lambda_n V_{DS})}$$

MOS Transistor in the subthreshold region

- Around $V_{GS} = V_t$ the device physics become very complex and our simple derivations loses accuracy
  - Rule of thumb for long channel MOSTs:
    use $V_{GS} > V_t + 150$ mV (see plot on next page)

- For $V_{GS} \leq V_t$ the I_D is exponentially related to V_{GS} (subthreshold region of operation)
  - There is a growing number of applications that make use of the subthreshold operation

* NOTE: 150 mV ≈ 6 x $V_{THERMAL}$= 6 x KT/q



Model valid for $V_{OV} \geq 150$ mV