DIC L9: MOSFET (3)

Sung-Min Hong (smhong@gist.ac.kr)

Semiconductor Device Simulation Lab.
School of Electrical Engineering and Computer Science
Gwangju Institute of Science and Technology

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2.4. Nonideal IV (1)

- Review of ideal IV characteristics
  - After some manipulation, we have

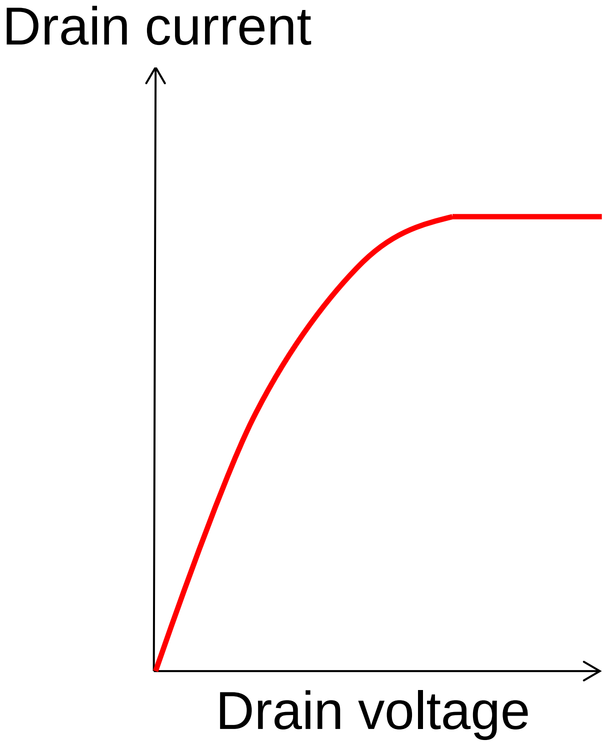
Subthreshold $$I_d = 0$$

Linear $$I_d = \beta\left(V_{gs} - V_t - \frac{V_{ds}}{2}\right)V_{ds}$$

Saturation $$I_d = \frac{\beta}{2}\left(V_{gs} - V_t\right)^2$$

  - Here,

$$\beta = \mu_n C_{OX}\frac{W}{L}$$



2.4. Nonideal IV (2)

- 65nm IBM

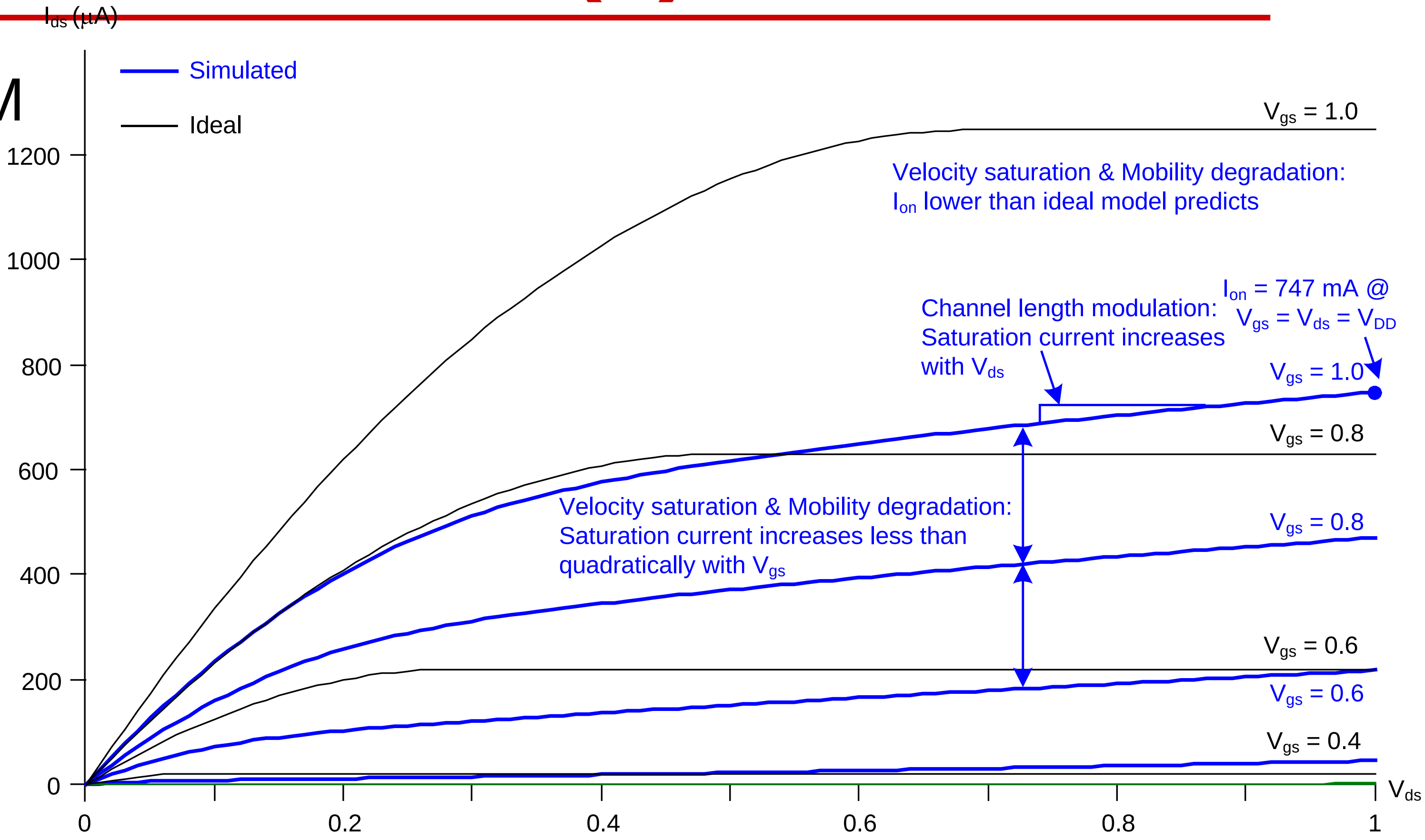
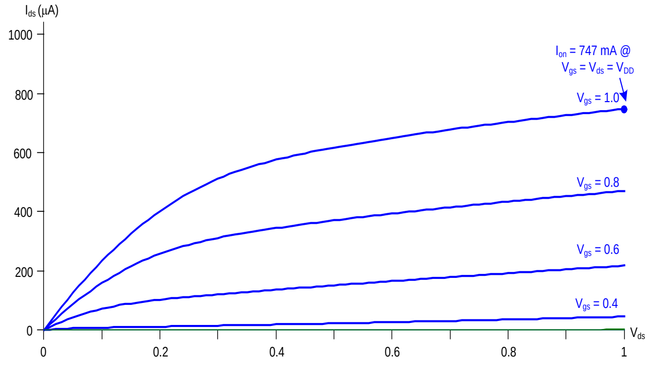
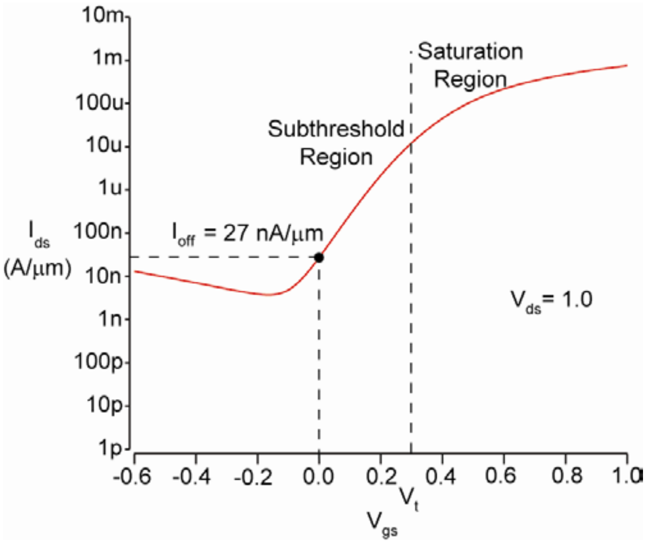


Fig. 2.14

2.4. Nonideal IV (3)

- ON and OFF currents (Drain currents)
  - ON current: $V_{gs} = V_{ds} = V_{DD}$
  - OFF current: $V_{gs} = 0, V_{ds} = V_{DD}$ (In the ideal model, it vanishes.)





2.4. Nonideal IV (4)

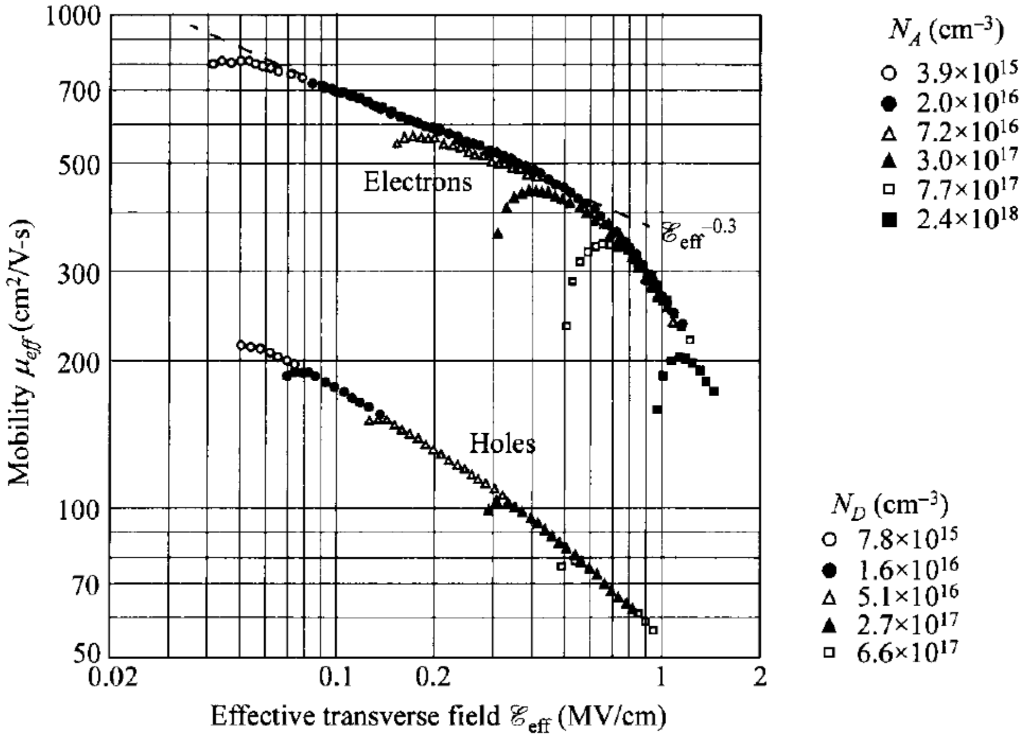
- Mobility degradation due to the vertical E-field
  - Collisions with oxide interface

$$\mu_{\mathrm{eff}-n} = \frac{540\,\dfrac{\mathrm{cm}^2}{\mathrm{V}\cdot\mathrm{s}}}{1+\left(\dfrac{V_{gs}+V_t}{0.54\,\dfrac{\mathrm{V}}{\mathrm{nm}}\,t_{\mathrm{ox}}}\right)^{1.85}} \qquad \mu_{\mathrm{eff}-p} = \frac{185\,\dfrac{\mathrm{cm}^2}{\mathrm{V}\cdot\mathrm{s}}}{1+\dfrac{\left|V_{gs}+1.5V_t\right|}{0.338\,\dfrac{\mathrm{V}}{\mathrm{nm}}\,t_{\mathrm{ox}}}} \quad \text{Eq. (2.23)}$$

  - Why do we have different behaviors for electrons and holes?

2.4. Nonideal IV (5)

- Experimental data (So-called "universal" mobility)



Inversion-layer mobility (Sze's book)

2.4. Nonideal IV (6)

- Example 2.3
  - Calculation of the mobilities at $|V_{gs}| = 1.0\ \mathrm{V}$. Assume that $t_{ox} = 1.05\ \mathrm{nm}$ and $|V_t| = 0.3\ \mathrm{V}$.

```
>> 540 / (1 + ((1.0+0.3)/(0.54*1.05))^1.85)

ans =

   95.7177

>> 185 / (1 + ((1.0+1.5*0.3)/(0.338*1.05))^1.0)

ans =

   36.3768
```

2.4. Nonideal IV (7)

- Velocity saturation
  - Saturation velocity (Canali model)
    - Electrons: 1.07×10^7 cm/sec
    - Holes: 8.37×10^6 cm/sec
  - Simple model

$$v = \begin{cases} \dfrac{\mu_{\text{eff}} E}{1 + \dfrac{E}{E_c}} & E < E_c \\ v_{\text{sat}} & E \geq E_c \end{cases}$$

$$E_c = \frac{2 v_{\text{sat}}}{\mu_{\text{eff}}}$$

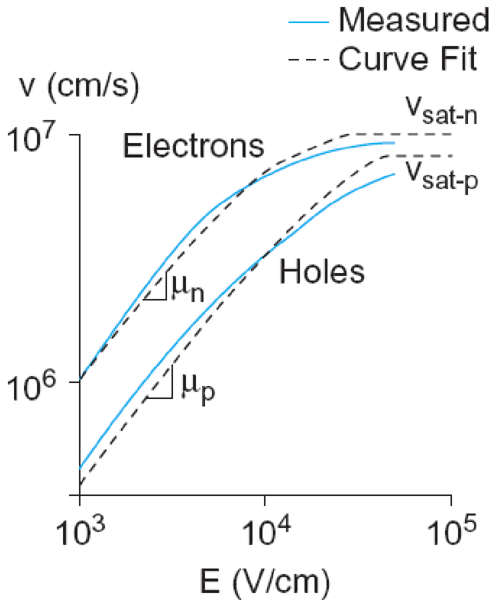


Fig. 2.15

2.4. Nonideal IV (8)

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>> 2 * 1e7 / 96

ans =

   2.0833e+05

>> 2 * 8e6 / 36

ans =

   4.4444e+05
```

- Example 2.4
  - Then, the critical fields are given by

  208 kV/cm (electrons) and 444 kV/cm (holes), respectively.
  - Assume that the channel length is 50 nm.
  - Then, at 1.04 V (NMOS) and 2.22 V (PMOS), the carrier velocities are saturated.
  - The NMOS transistor is velocity saturated in normal operation.

2.4. Nonideal IV (9)

- Leakage
  - Subthreshold slope
  - DIBL
  - GIDL

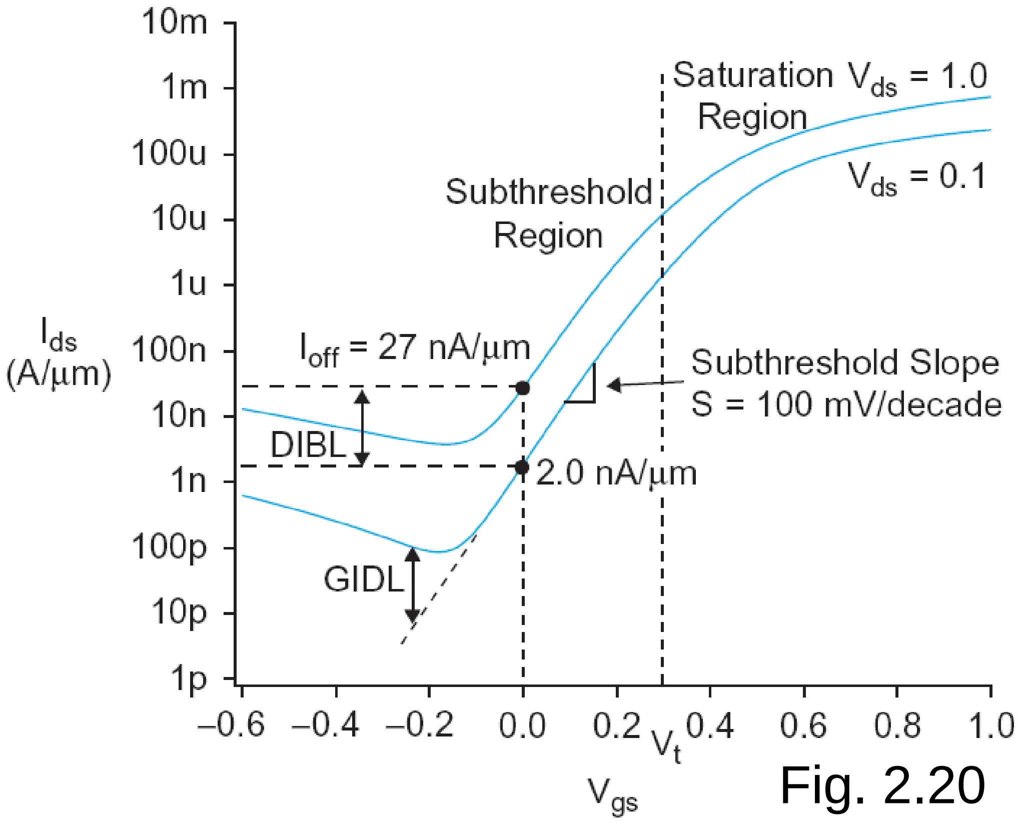

Fig. 2.20