DIC L10: MOSFET (4)

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2.4. Nonideal IV (6)

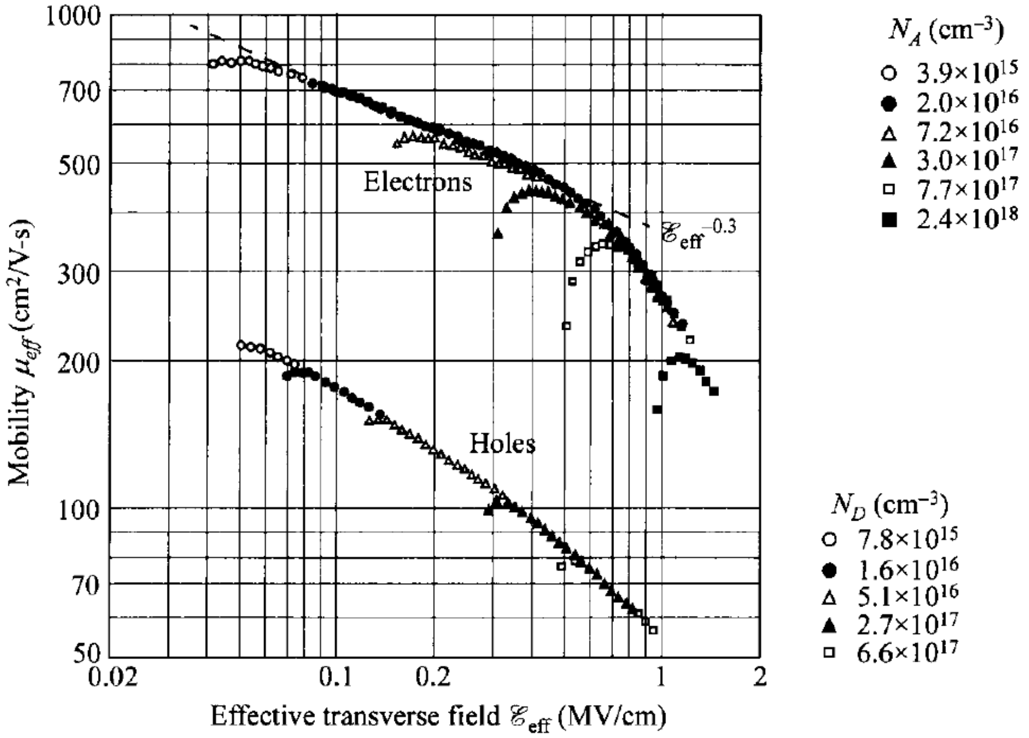
- Mobility degradation due to the vertical E-field
  - Collisions with oxide interface

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

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

2.4. Nonideal IV (7)

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



Inversion-layer mobility (Sze's book)

2.4. Nonideal IV (8)

- 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 (9)

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

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

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

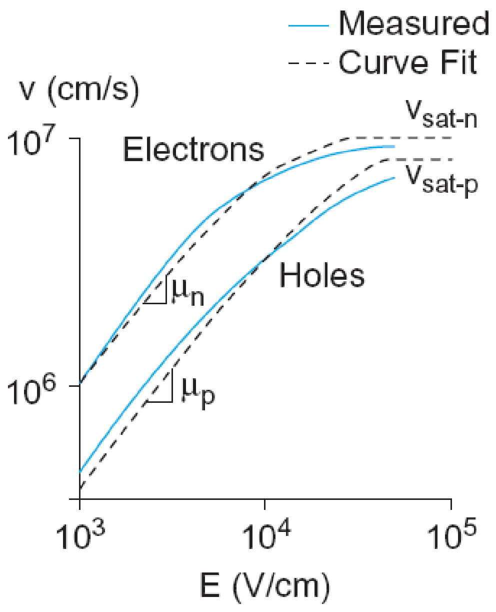


Fig. 2.15

2.4. Nonideal IV (10)

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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 (11)

- Saturation current
  - Simplified expression

$$I_{dsat} = W C_{ox} v_{sat} \frac{V_{GT}^2}{V_{GT} + V_c}$$

  - One extreme ($V_{GT} \ll V_c$)

$$I_{dsat} = W C_{ox} v_{sat} \frac{V_{GT}^2}{V_c}$$

  - Another one ($V_{GT} \gg \ V_c$)

$$I_{dsat} = W C_{ox} v_{sat} V_{GT}$$

2.4. Nonideal IV (12)

- Threshold voltage (Body effect)
  - It is given by

$$V_t = \frac{\sqrt{2\epsilon_{si} q N_A}}{C_{ox}} \sqrt{\phi_s + V_{sb}} + V_{FB} + \phi_s$$

Positive for negative V_b

γ, Eq. (2.37)

$\phi_s = 2v_T \log \frac{N_A}{n_i}$, Eq. (2.36)

  - Written as

$$V_t = V_{t0} + \gamma\left(\sqrt{\phi_s + V_{sb}} - \sqrt{\phi_s}\right)$$

2.4. Nonideal IV (13)

- Leakage
  - Subthreshold slope
  - DIBL
  - GIDL

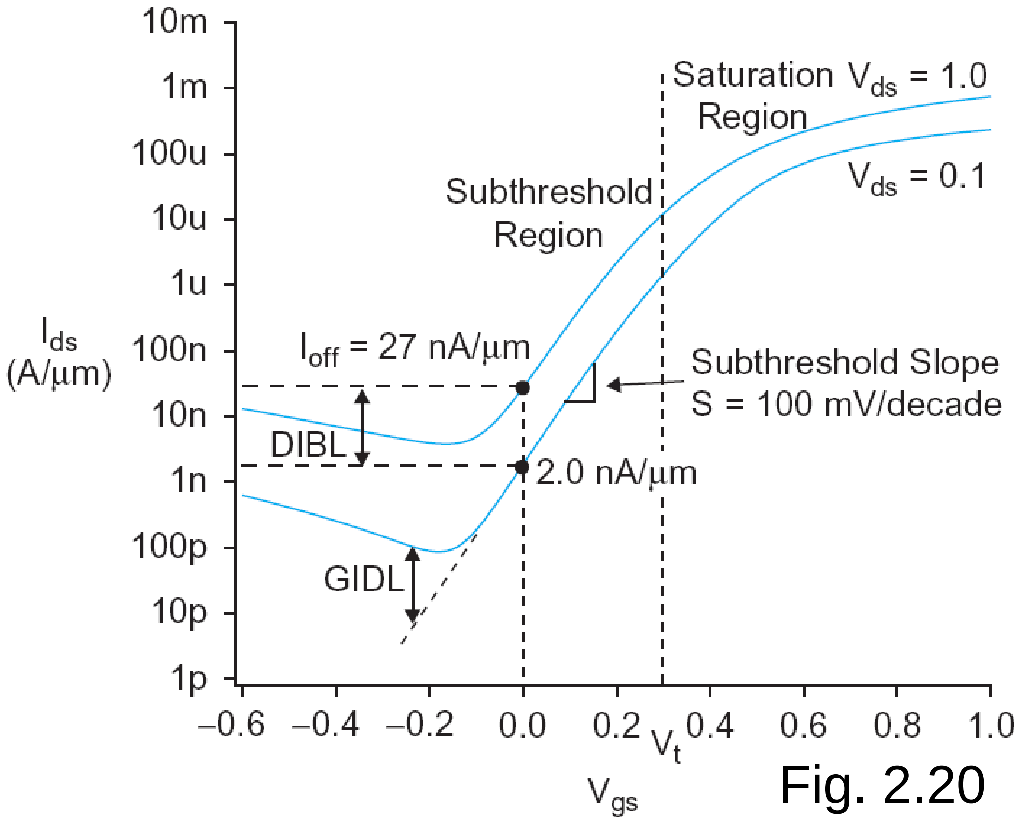

Fig. 2.20

Homework#4

- Write a report.
  - Select a CMOS technology. (It’s up to you.)
  - Describe its electrical characteristics. (Free style!)
  - Explicitly show your reference.

- Due: October 22, 2019 (Before the lecture starts)
  - Upload your Homework to our GitHub repository.