Chapter 19.

MODERN FET STRUCTURES

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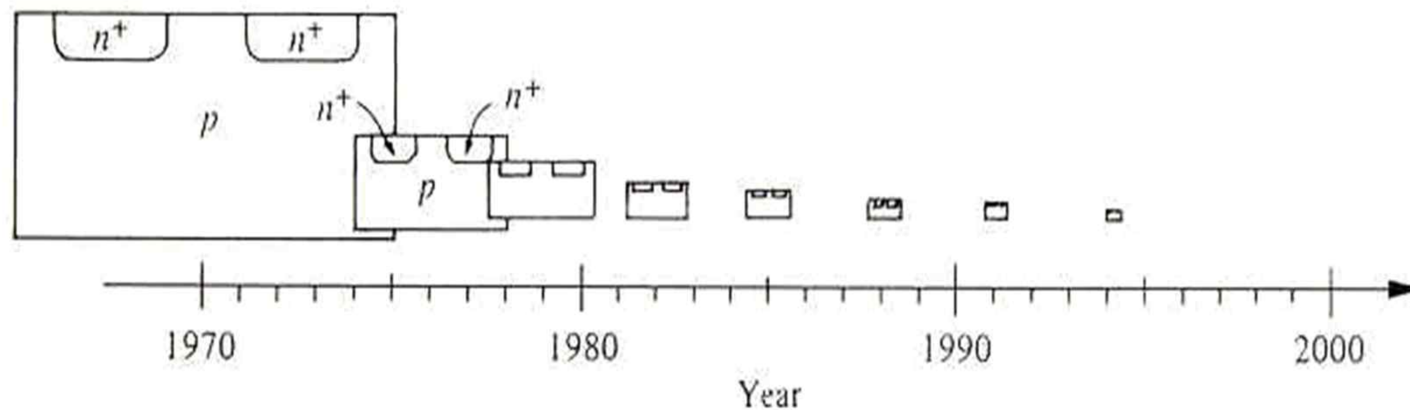
CONTENTS

- **Small-Dimension Effects**
- **Select Structure Survey**

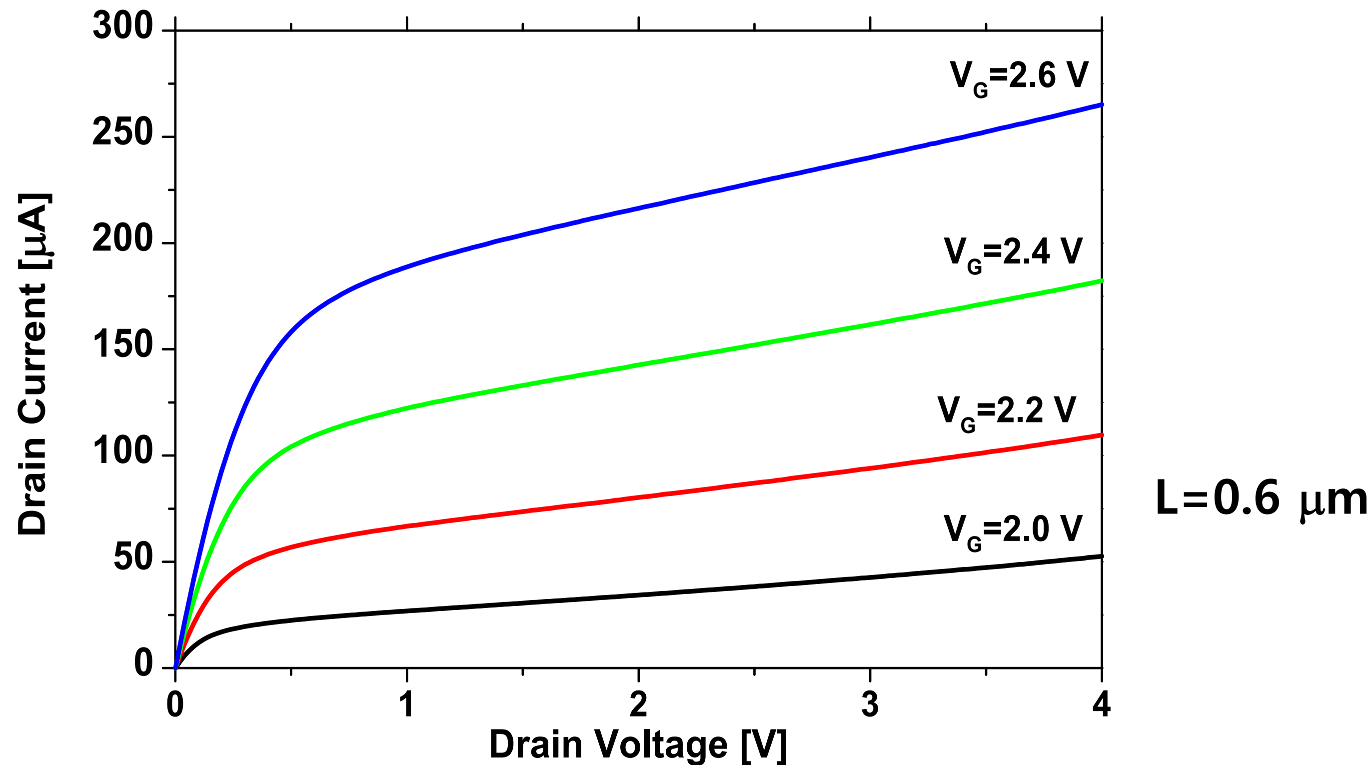
Small-Dimension Effects

- **To achieve higher speeds and increased packing densities, FET device structures have become smaller and smaller.**

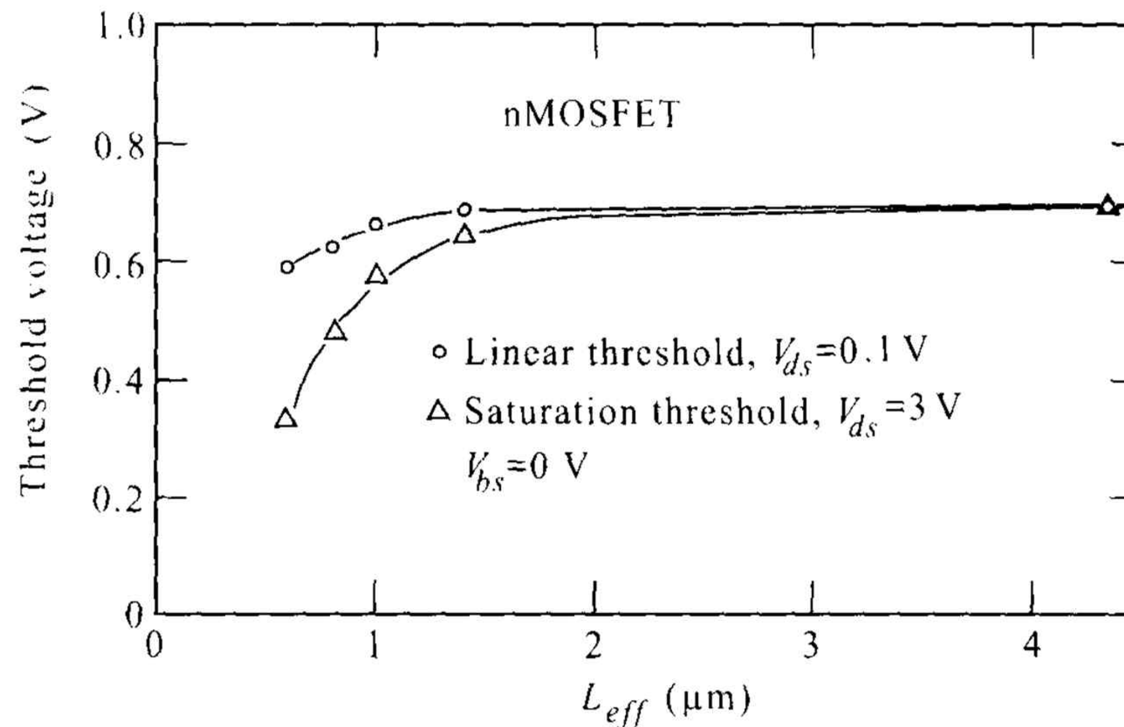


• Departure from long-channel behavior

– Significant upward slant in the post pinch-off portions of the I_D - V_D

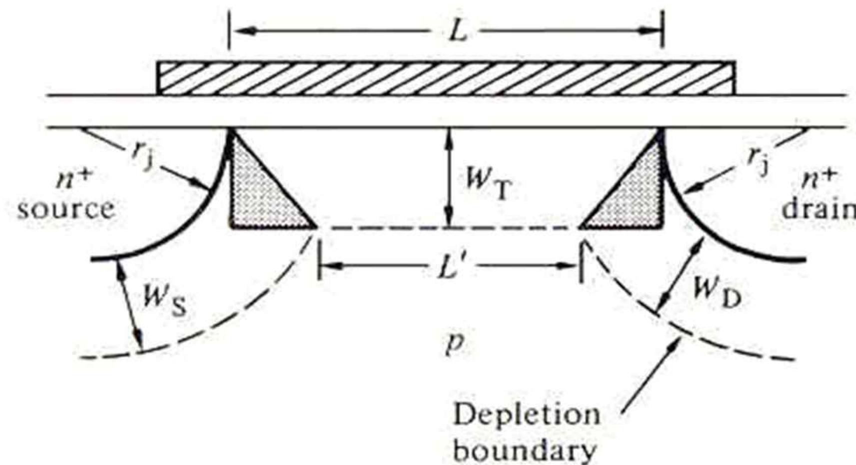


- **In short-channel devices, V_T becomes a function of the gate dimension and the applied biases.**



Threshold Voltage Modification

- **Short-channel**
  - **$|V_T|$ monotonically decreases with decreasing L.**
  - **The source and drain assist in depleting the region under the gate. ⌫ less gate charge for inversion ⌫ V_T↓**



– **First order quantitative expression**

$$\Delta V_T = V_T(\,short - channel\,) - V_T(\,long - channel\,)$$

$$= -\frac{1}{C_o}(Q_{BS} - Q_{BL}),$$ Q_{BS} : Q_B **for short-channel**

Q_{BL} : Q_B **for long-channel**

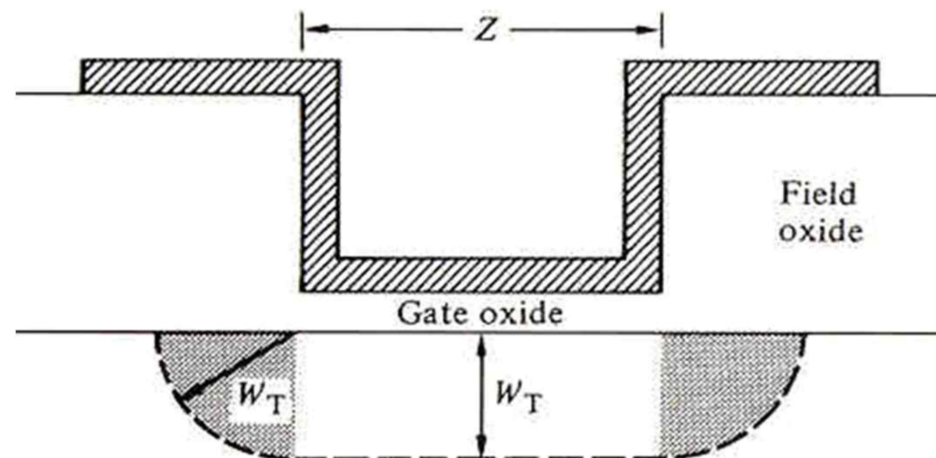
$$= -\frac{qN_A W_T}{C_o}\frac{r_j}{L}\left(\sqrt{1+\frac{2W_T}{r_j}}-1\right)$$

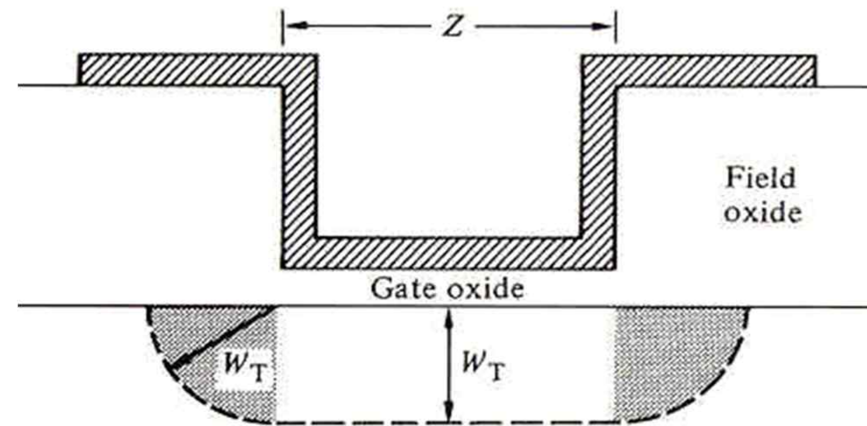
[homework]

– **Examing** $\Delta V_T / V_T(long\ channel)$**, short-channel effects are decreased by reducing** x_o**, reducing** r_j**, and increasing** N_A**.**

• Narrow channel (skip)

- $|V_T|$ monotonically increases with decreasing *Z*. (Opposite to the L-dependence)
- The gate-controlled depletion region extends to the side, lying in part outside the *Z*-width of the gate; that is, the effective charge /cm^2 being balanced by the gate charge↑ ⌫ V_T↓





- **If the lateral regions are assumed to be quarter-cylinders of radius W_T**

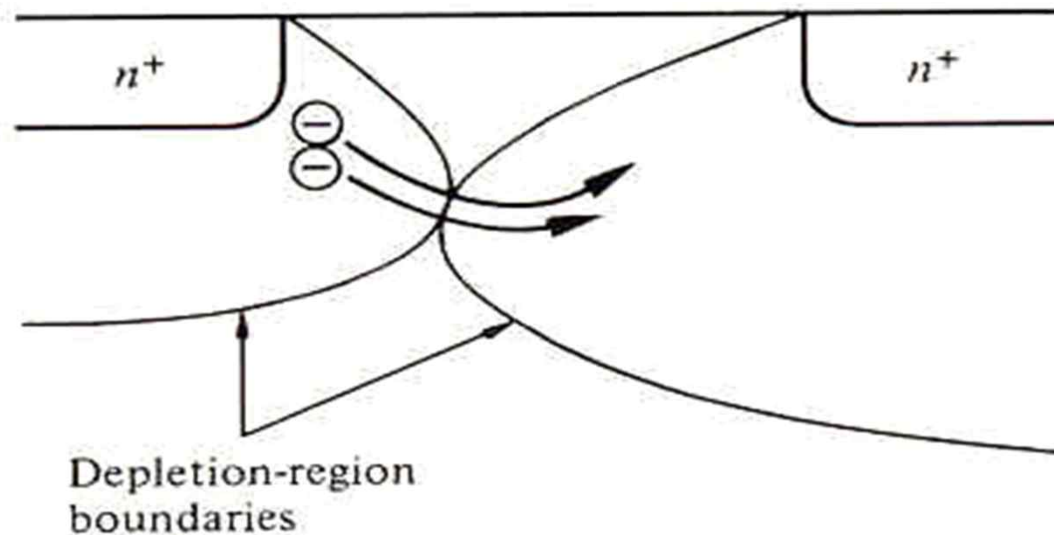
$$Q_B(\,narrow\ width\,) = -\frac{qN_A\left(ZLW_T + \frac{\pi}{2}W_T^2 L\right)}{ZL}$$

$$= -qN_A W_T\left(1 + \frac{\pi}{2}\frac{W_T}{Z}\right)$$

$$\therefore\ \Delta V_T(narrow\ width) = \frac{qN_A W_T}{C_o}\frac{\pi W_T}{2Z}$$

Parasitic BJT Action

- **MOSFET bears a physical resemblance to a lateral BJT**
- **Punch-through**
  - **The depletion regions around the source and drain to touch.**
  - **The gate loses control of the subgate region and the I_D flows beneath the surface through the touching depletion regions.**

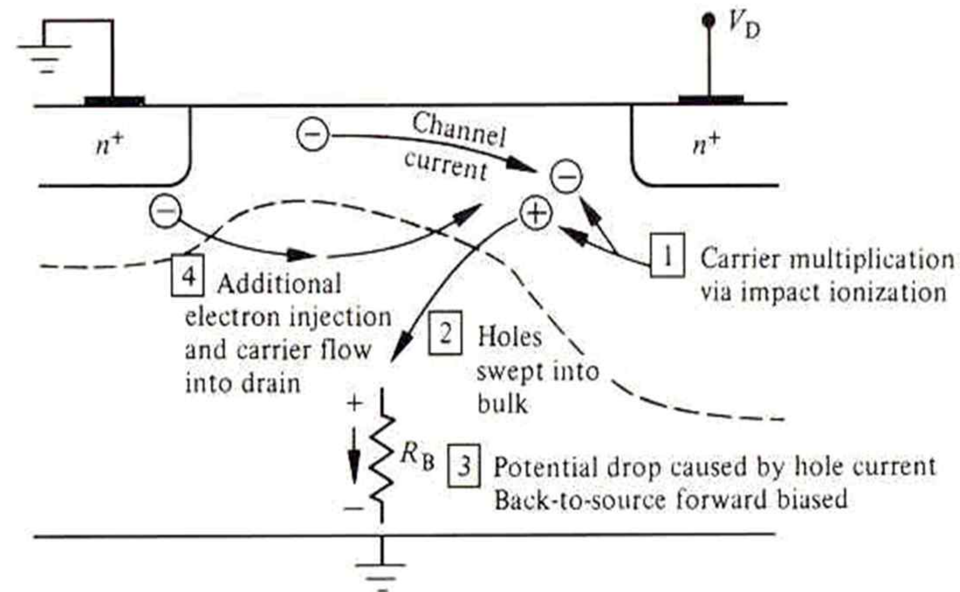


– **Punch-through can be suppressed by increasing N_A and decreasing the depletion widths.**

⇒ increasing parasitic capacitances.

⇒ perform a deep-ion implantation to selectively increase the doping of the subgate region.

- **Carrier multiplication and regenerative feedback**
  - **In short-channel devices, the carrier multiplication coupled with regenerative feedback can dramatically increase I_D and places a reduced limit on the maximum V_D.**



  - **The added electrons drift into the drain. The source PN junction is forward biased.**

Hot-Carrier Effects

- **Oxide charging (charge injection and trapping in the oxide)**
  - **In the vicinity of the drain, some of carriers gain a sufficient amount of energy to surmount the Si-SiO_2 barrier.→ A charge build-up within the oxide**
  - **A larger percentage of the gated region is affected in the smaller devices.**
  - **Significant changes in V_T and g_m.**
  - **Oxide charging limits the useful "life" of a device.**
  - **To minimize hot-carrier effects, the LDD (Lightly Doped Drain) structure is used.**

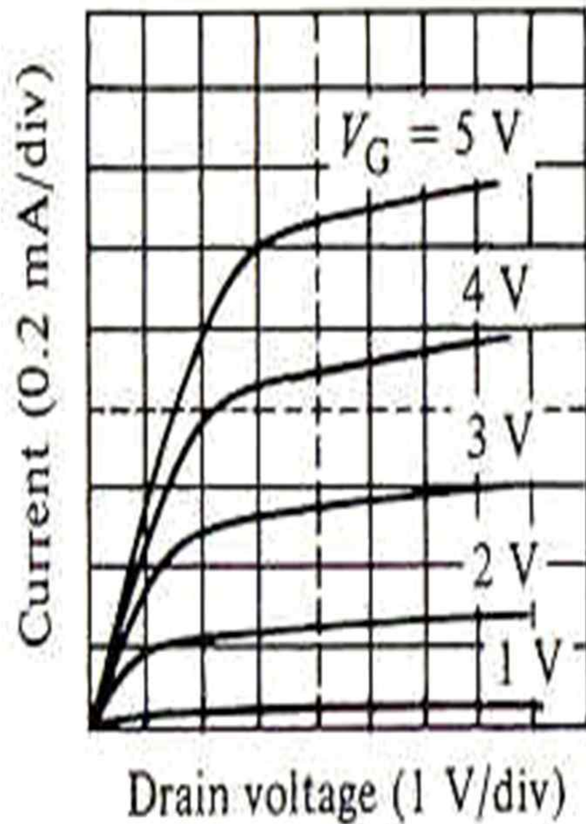
- **Velocity saturation**
  - **The carrier drift velocities inside Si at $T=300K$ approach a maximum value of $v_{dsat} \cong 10^7\ cm/sec$ when the electric fields are large.**
  - **I_{Dsat} is significantly reduced. Approximately,**

$$I_{Dsat} \cong ZC_o(V_G - V_T)v_{dsat}$$

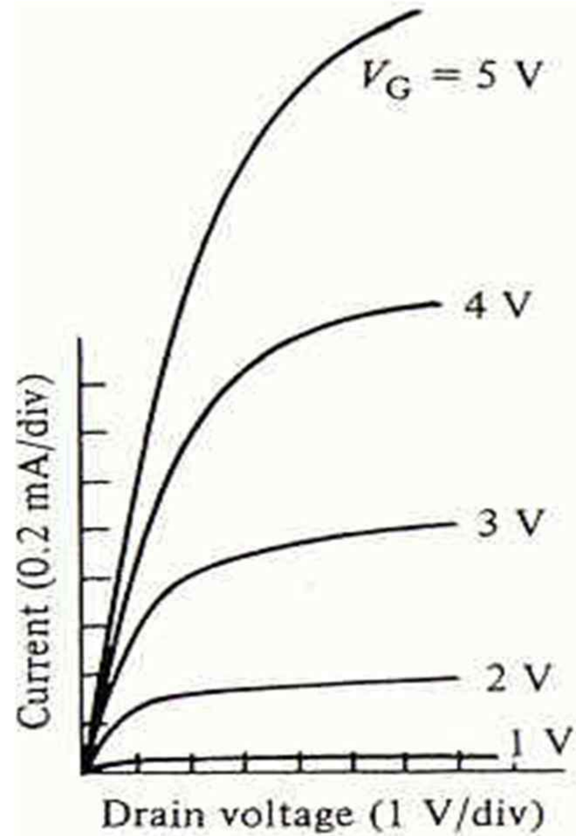
$$I_{Dsat} \propto (V_G - V_T); \text{short-channel}$$

$$I_{Dsat} \propto (V_G - V_T)^2; \text{long-channel}$$

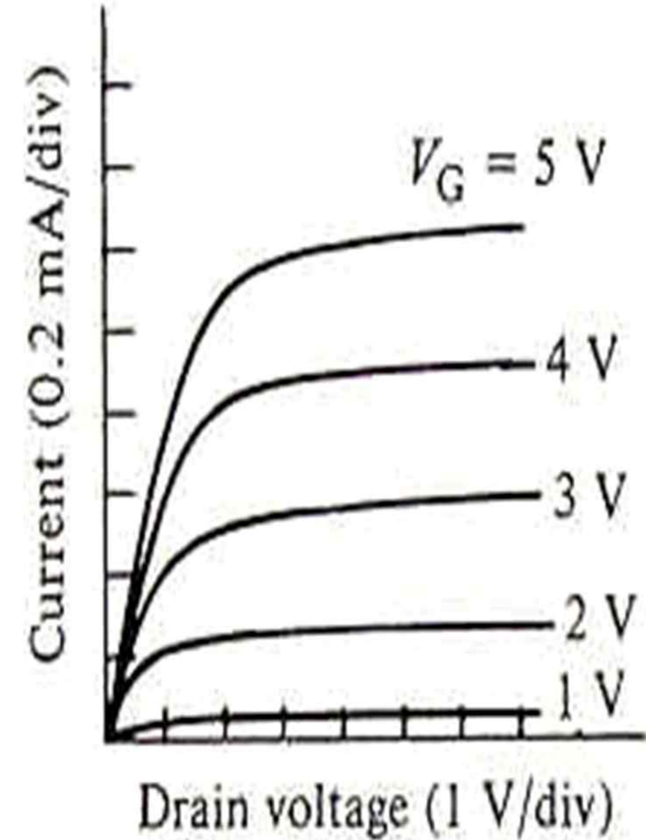
(a) Experimental characteristics



(b) Theoretical characteristics including velocity saturation



(c) Theoretical characteristics ignoring velocity saturation



- **Ballistic Transport**
  - **If very small dimension structures have $L< l$ (the average distance between scattering events), a large percentage of the carriers travel from the source to the drain without experiencing a single scattering event.**
  - **It can lead to super-fast devices.**

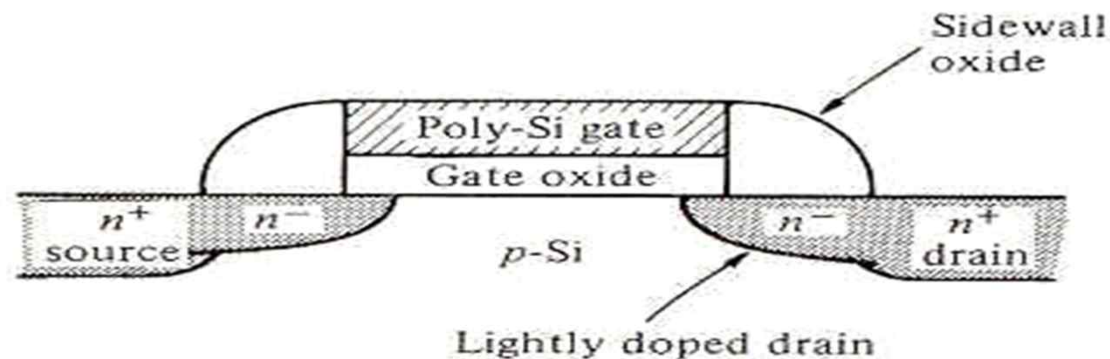
$$\because \text{the average velocity of carriers} > v_{dsat}$$

Select Structure Survey

- **LDD (Lightly Doped Drain) Transistors**
  - **The reduced dimension devices are more susceptible to hot-carrier effects.**
  - **Lightly doped drain region (n^- region) between the end of the channel and the drain**
  - **Electric field ←The voltage drop in the n^- region lowers the maximum**

→Carrier injection into the oxide

→Oxide charging



Ch19

Modern FET

scales down.

P692 Table 19.1

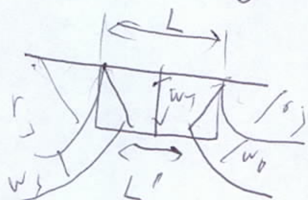
Short channel Effect.

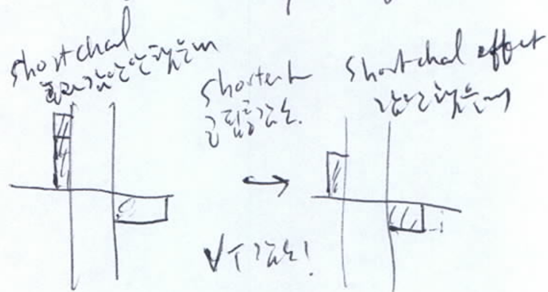
$$I_D \propto \frac{W}{L}$$

V_T function of L

L ↓ → $|V_T|$ ↓ (S-D circuit in depletion gate region so less charge is required for inversion)

Quantitatively,





$$\Delta V_T = V_T(\text{short-ch}) - V_T(\text{long-ch})$$

$$= -\frac{1}{C_o}(Q_{BS} - Q_{BL}) = -q\frac{N_A W_T}{C_o}\frac{r_j}{L}\left(\sqrt{1+\frac{2W_T}{r_j}} - 1\right)$$

W_T: width of depletion region at threshold

Q_{BS}: depletion region charge for short channel

Q_{BL}: depletion region charge for long-channel

$$\frac{\Delta V_T}{V_T} = -\frac{r_j}{L}\left(\sqrt{1+\frac{2W_T}{r_j}} - 1\right)$$

V_T → $-\frac{qN_A W_T}{C_o}$

To reduce, r_j, $\frac{W_T}{}$ needs to be reduced

r_j ↓ smaller S-D; W_T ↓ larger N_A (smaller x_o)

Also by empirical relation

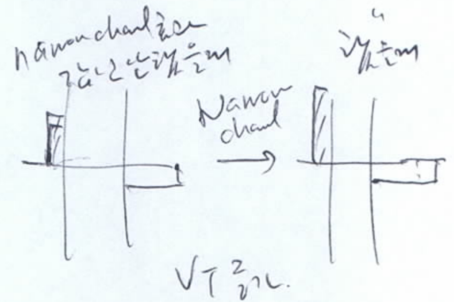
$L_{min} = 0.4[r_j x_o (W_S + W_D)^2]^{1/3}$

min. chanl below which sh-ch. effects occur.

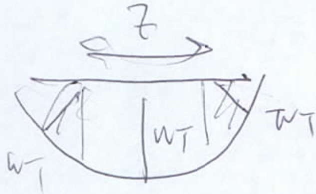
smaller x_o is required

Narrow chanl

$|V_T| \uparrow$ as $Z \downarrow$



~~depletion~~ V_G is wasted(?)
in side regions ~~out~~ of gate.



$Z \downarrow$ More charge required to achieve balance
$|V_T| \uparrow$

$$\Delta V_T = q\frac{N_A W_T}{C_o} \cdot \frac{\pi}{2}\frac{W_T}{Z}$$

If $Z \sim W_T$, problematic

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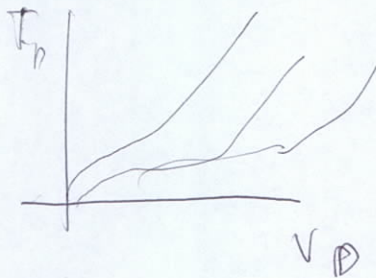
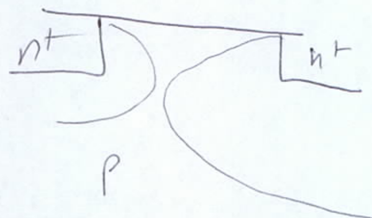
punch-thru (pinch off 현상 리게 되)





as $V_D \uparrow$ → punch-thru current (gate loses control)
S, D depletion regions meet!
like in BJT

$$I_D \propto V_{DS}^2$$

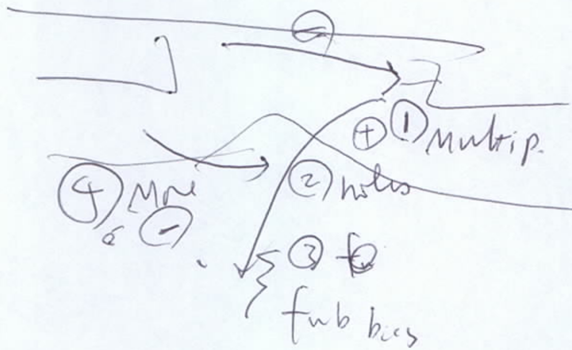
Solution : $N_A \uparrow$ → W_S, $W_D \downarrow$
↓ also increases $C \uparrow$

channel ~~S, D~~ gate 아래만 implanting으로 doping을 증가시킴
(주로 only Undergate)

Carrier Multiplication & Regenerative Effect (positive feedback)

See picture in Fig 19.7

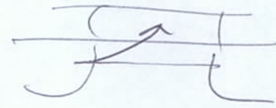
$V_D \rightarrow$ e's accelerated



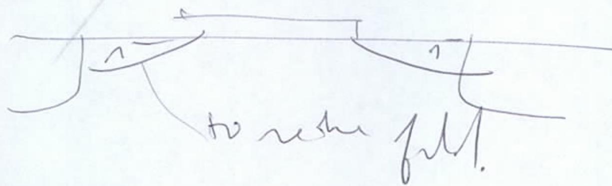
Hot carrier Effect

$V_D \rightarrow$ energy of $e^- \uparrow$, Oxide charging $\rightarrow$ changes V_T & g_m

Also reliability.



Solution LDD for short ch. devices



Vel. saturation (drift velocity)

$V_{sat,Si} \sim 10^7$ cm/sec

$I = Z \cdot C \cdot V \cdot$ ($Q \cdot v$)

Then I_D is limited to

$I_{Dsat} \doteq Z C_o (V_G - V_T) V_{d,sat}$

$\therefore I_D \propto (V_G - V_T)$

not $(V_G - V_T)^2 \rightarrow$ long channel.

This saturation can be avoided if $L < l$ (avg dist between scattering events)

$\rightarrow$ Super fast, Ballistic Transport