MOSFET basics

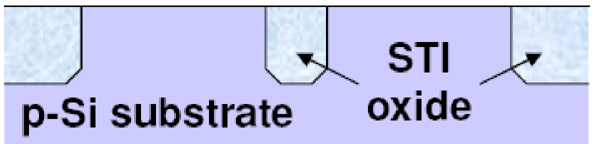
LECTURE 18

- MOSFET fabrication
- Depletion of the semiconductor surface
- Formation of inversion layer
- Band diagrams galore
- Surface potential model (towards I-V characteristic)

Sec. 13.1

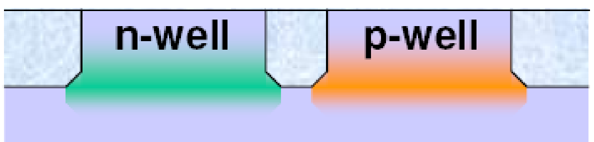
Deep Submicron FET Fabrication Sequence

1



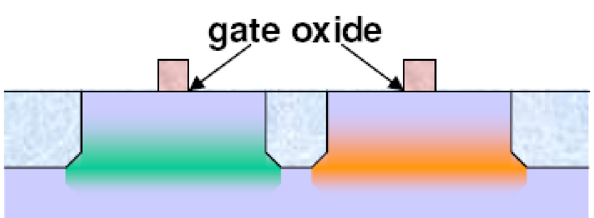
Shallow Trench Isolation

2



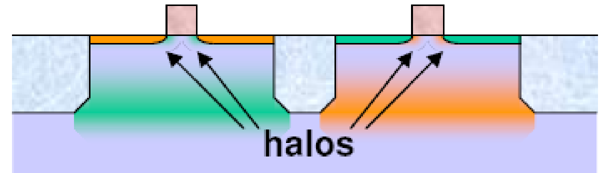
Well Implantation

3



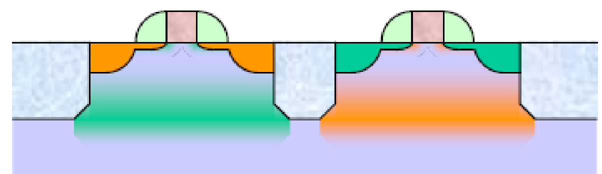
Gate Oxidation &
Poly Definition

4



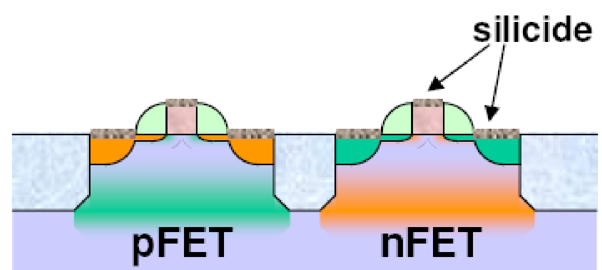
Source/Drain Extension
& Halo Implantation

5



Spacer Formation &
Source/Drain Implantation

6



Salicidation

Loke *et al.*
Avago Technologies

Photolithography

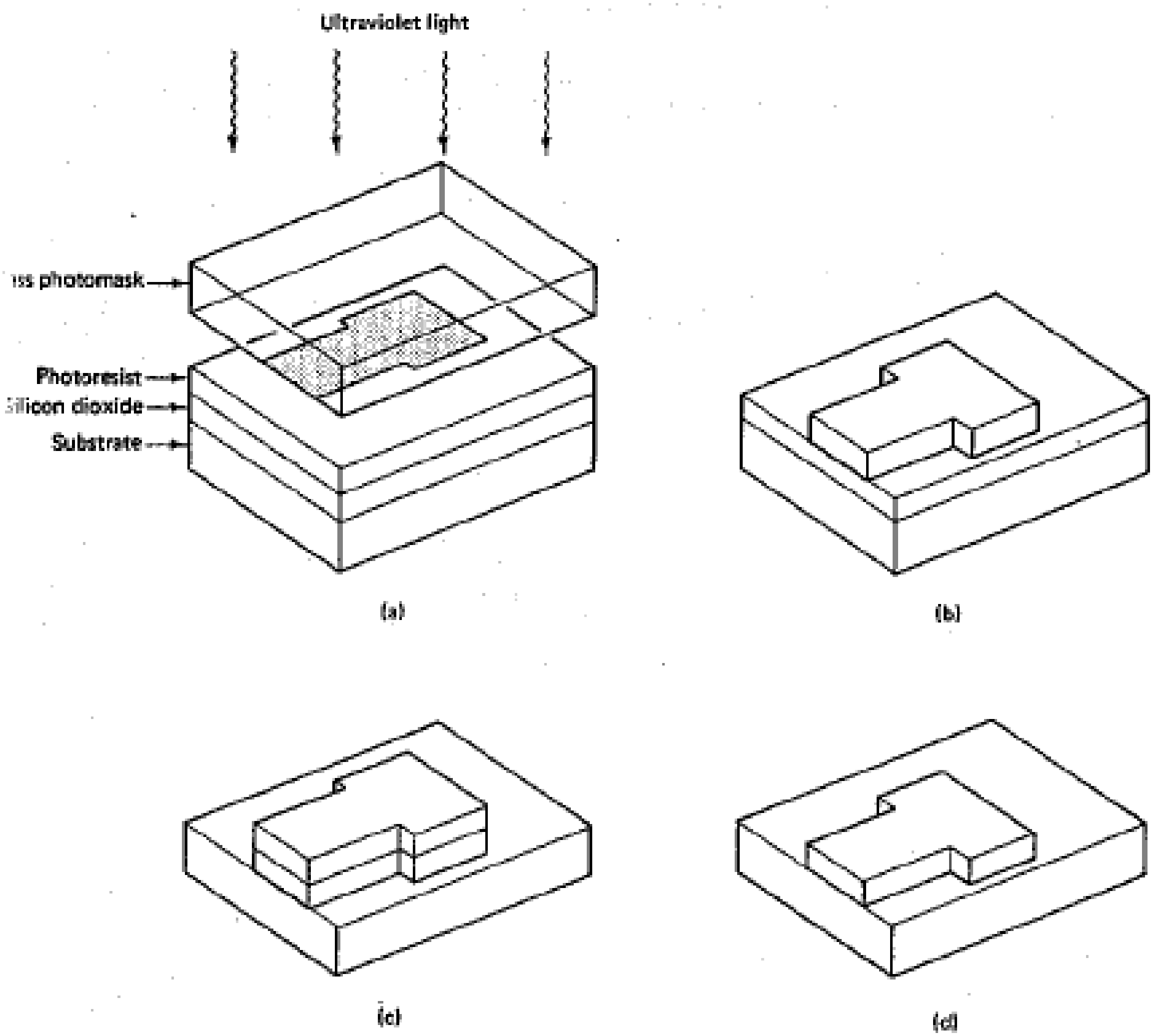
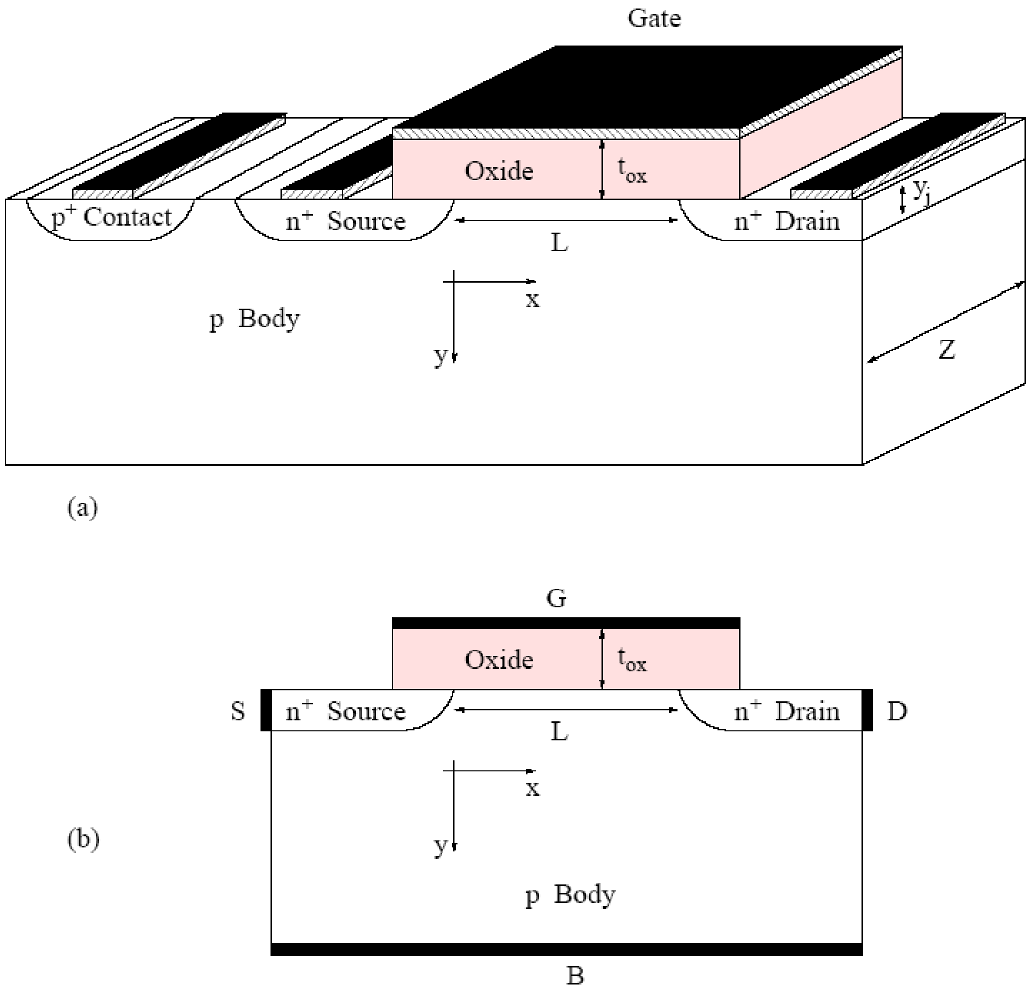


Figure 12.16 Patterning a silicon dioxide layer using positive photoresist photolithography. (a) Photoresist-coated wafer is pressed into contact with photomask and exposed to ultraviolet light. (b) Pattern on photomask is transferred to the photoresist during development. (c) Silicon dioxide is removed from those areas not protected by photoresist by etching in buffered hydrofluoric acid. (d) Photoresist is removed, leaving patterned silicon dioxide.

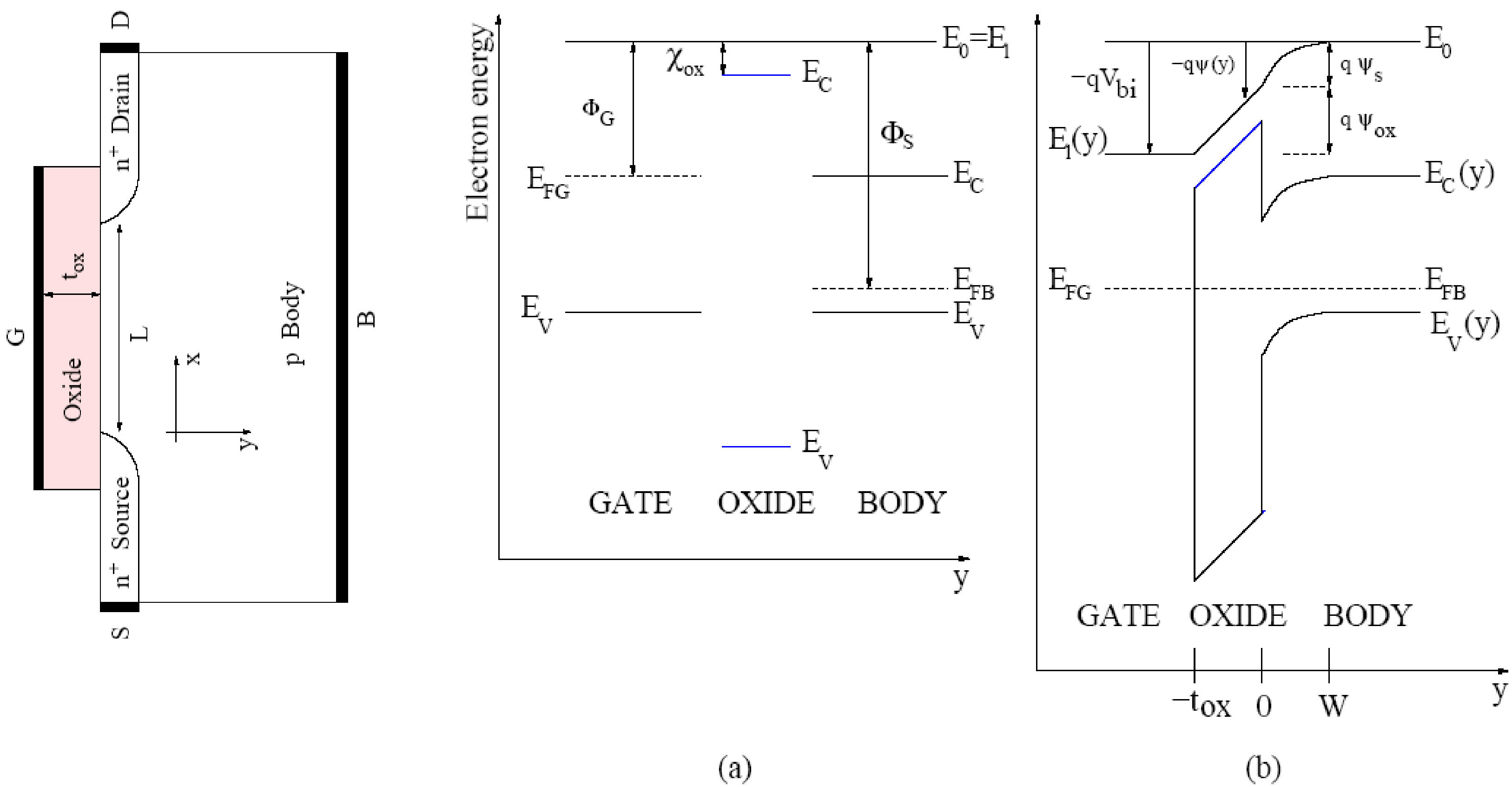
Si MOSFET features



- 4 terminals
- 2D-device
- "The most abundant object made by mankind"

Sec. 10.2.1

Energy band diagram in y-direction

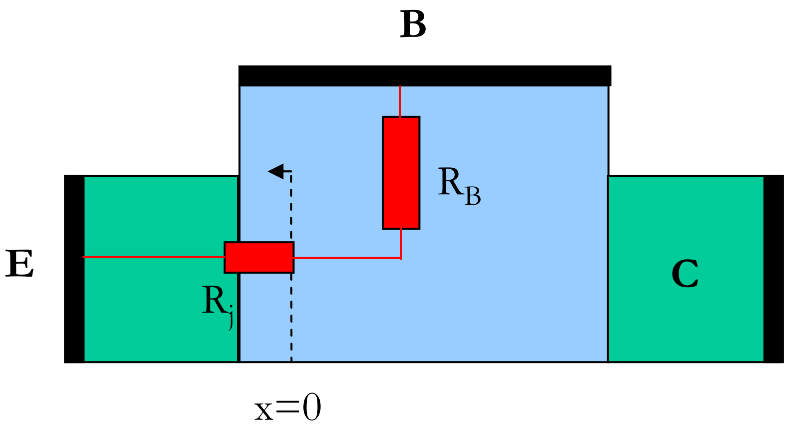


Note depletion of semiconductor surface in equilibrium (in this case)

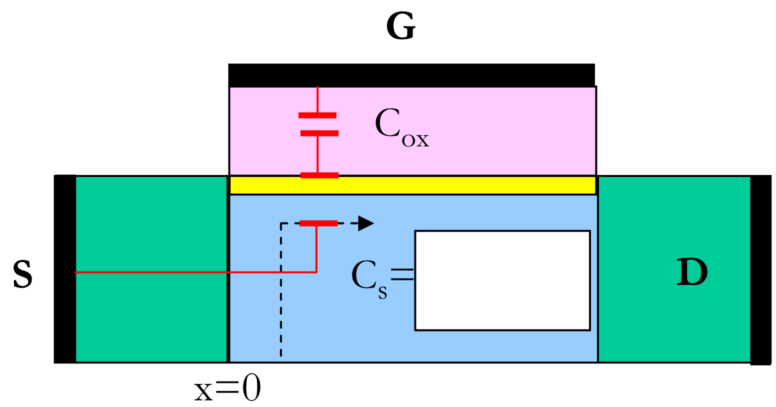
$V_{bi} =$

NP-junctions and transistor action

HBT, BJT



MOSFET



$$V_{aj} = V_{BE} \frac{R_j}{R_B + R_j}$$

$$\approx V_{BE}$$

$$\therefore Q(0) \propto \exp(qV_{BE}/kT)$$

and

$$I_C \propto \exp(qV_{BE}/kT)$$

$$\partial V_{aj} = \partial V_{GS} \frac{1}{1 + C_s(V_{GS})/C_{ox}}$$

if $C_s(V_{GS}) << C_{ox}$

$$V_{aj} \approx V_{GS}$$

$$\therefore Q(0) \propto \exp(qV_{GS}/kT)$$

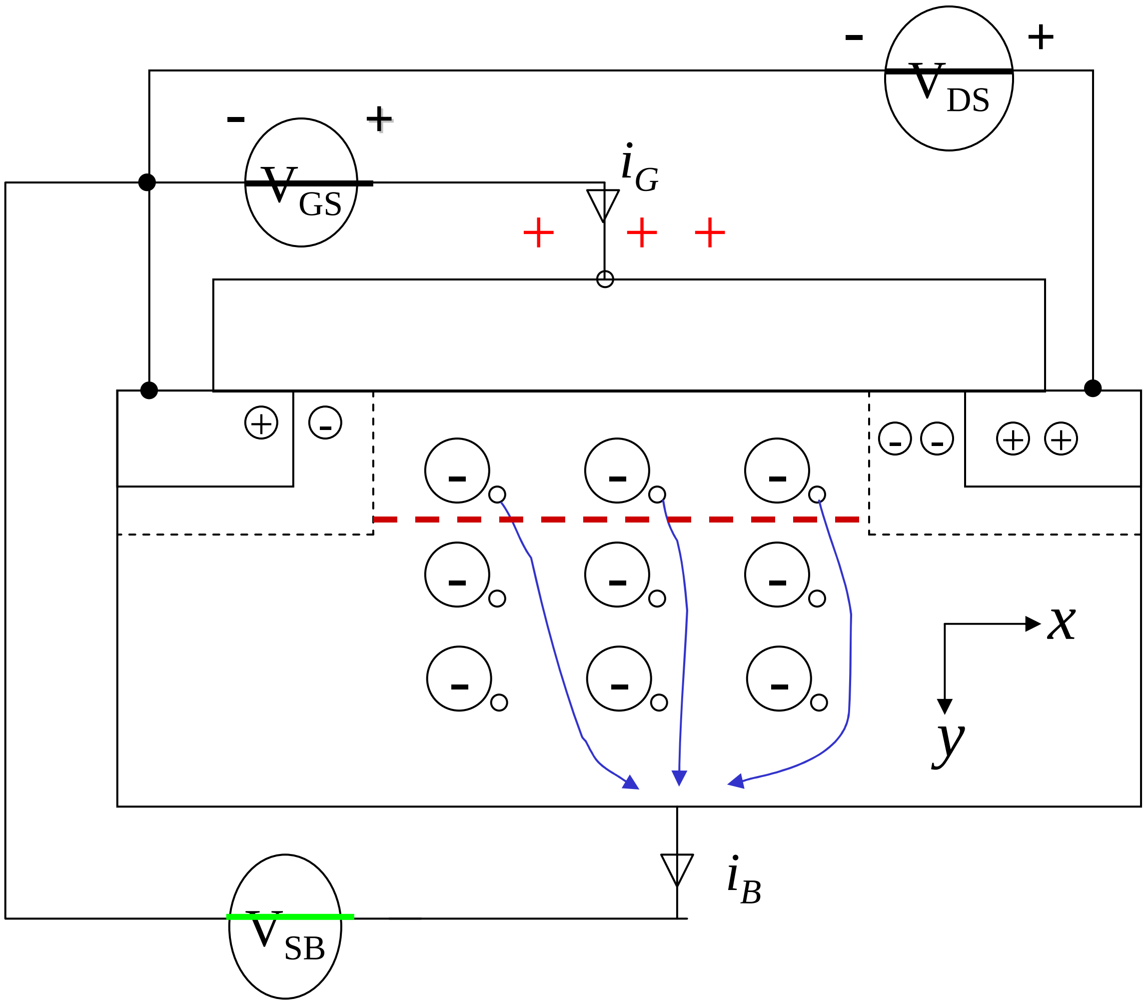
and

$$I_D \propto \exp(qV_{GS}/kT)$$

What happens if $C_s(V_{GS}) > C_{ox}$?

Sec. 10.1

Depletion of Si surface



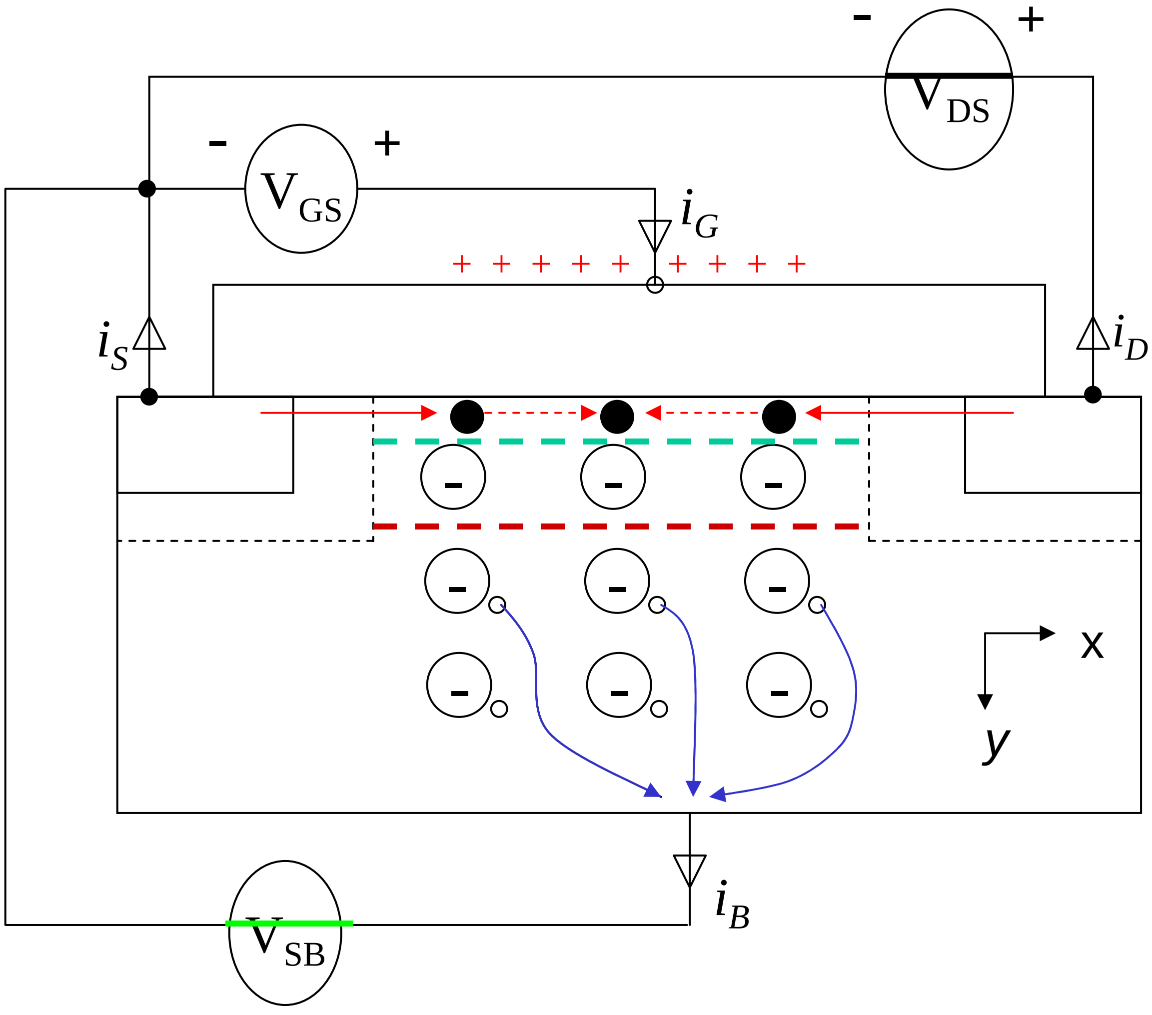
Note: presently we have $V_{DS}=V_{GS}=0$

But there is $V_{bi} \neq 0$

- Depletion layer forms

Sec. 10.1

Inversion of Si surface



Note: we have kept V_{DS}=0,

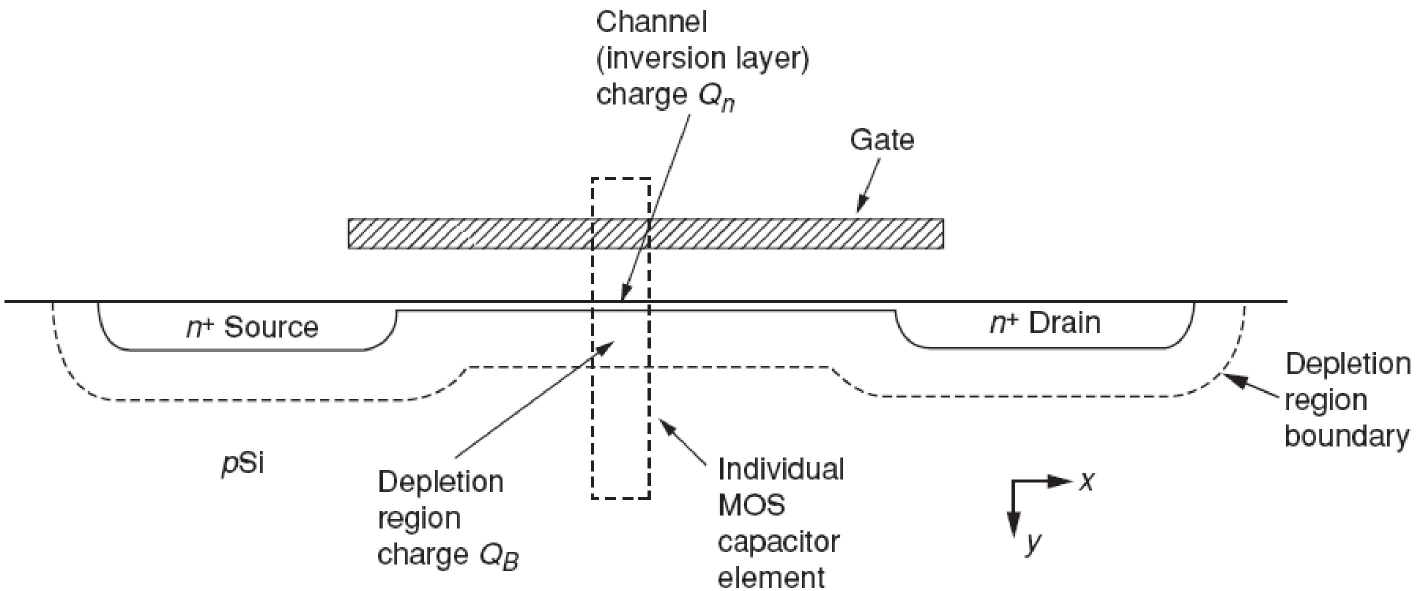
but now V_{GS}>0

- Depletion layer widens
- Inversion layer forms

Where do the electrons come from?

Count the charges.

Depletion and inversion of Si surface

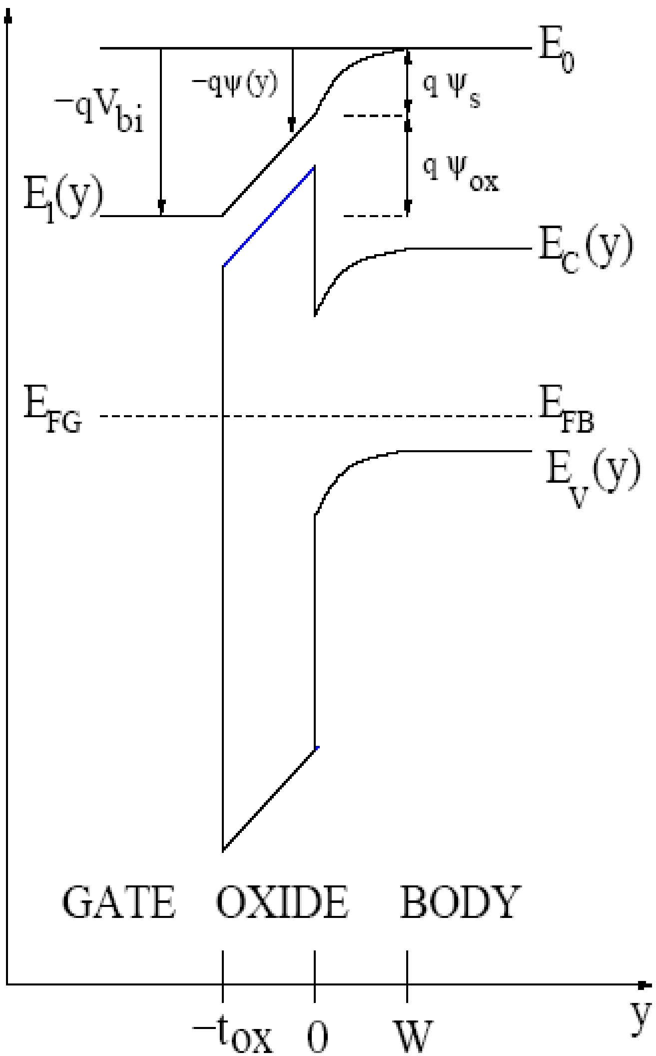


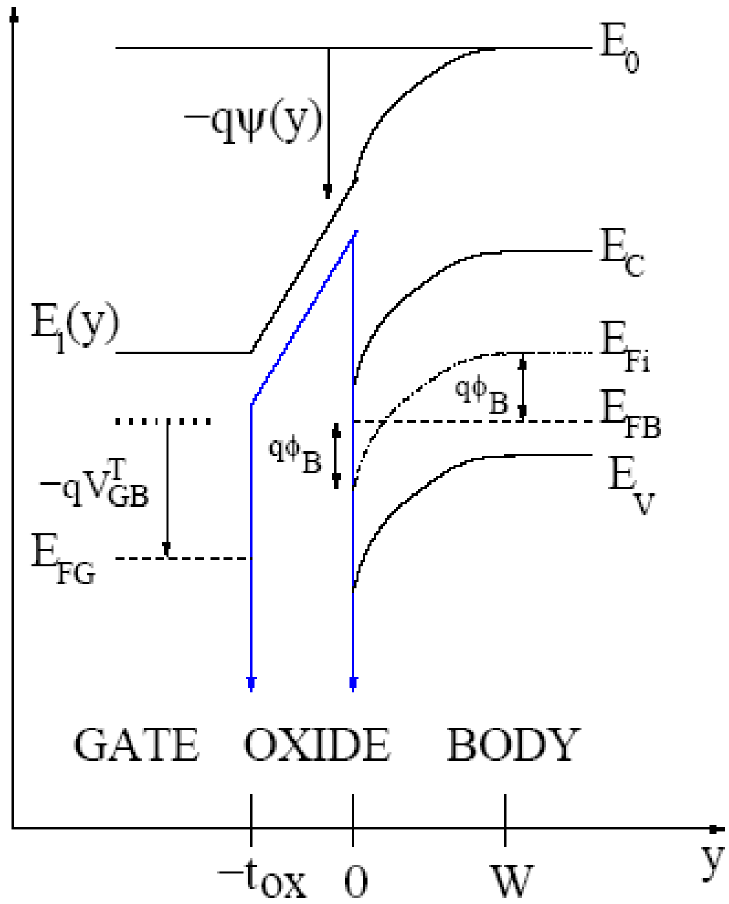
Note:

- notation for the channel and bulk charges
- uniformity of the channel and bulk charges when $V_{DS} = 0$.

Sec. 10.2.1

Band diagrams for depletion and strong inversion of Si surface



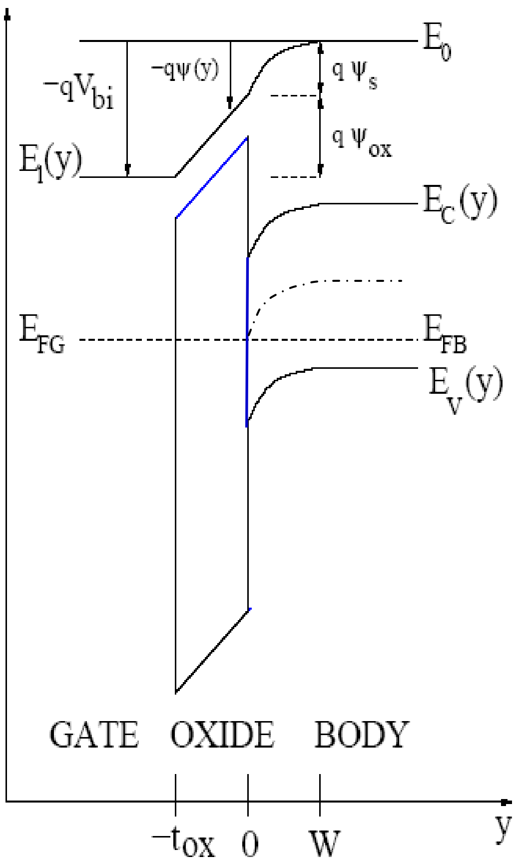


Onset of strong inversion:

n(y=0) =

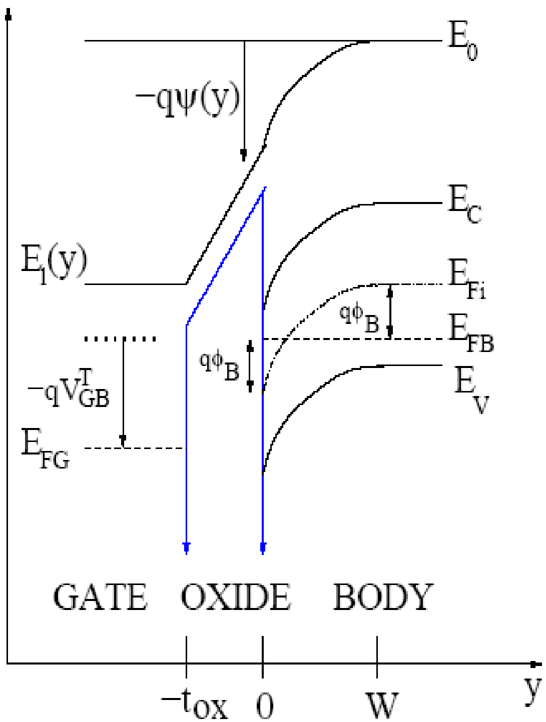
Sec. 10.2.1

Band diagrams for moderate- and strong- inversion of Si surface



Onset of moderate inversion:

n(y=0) =



Onset of strong inversion:

n(y=0) =

$$n(y) = n_i e^{(E_{FB} - E_{Fi}(y))/kT}$$

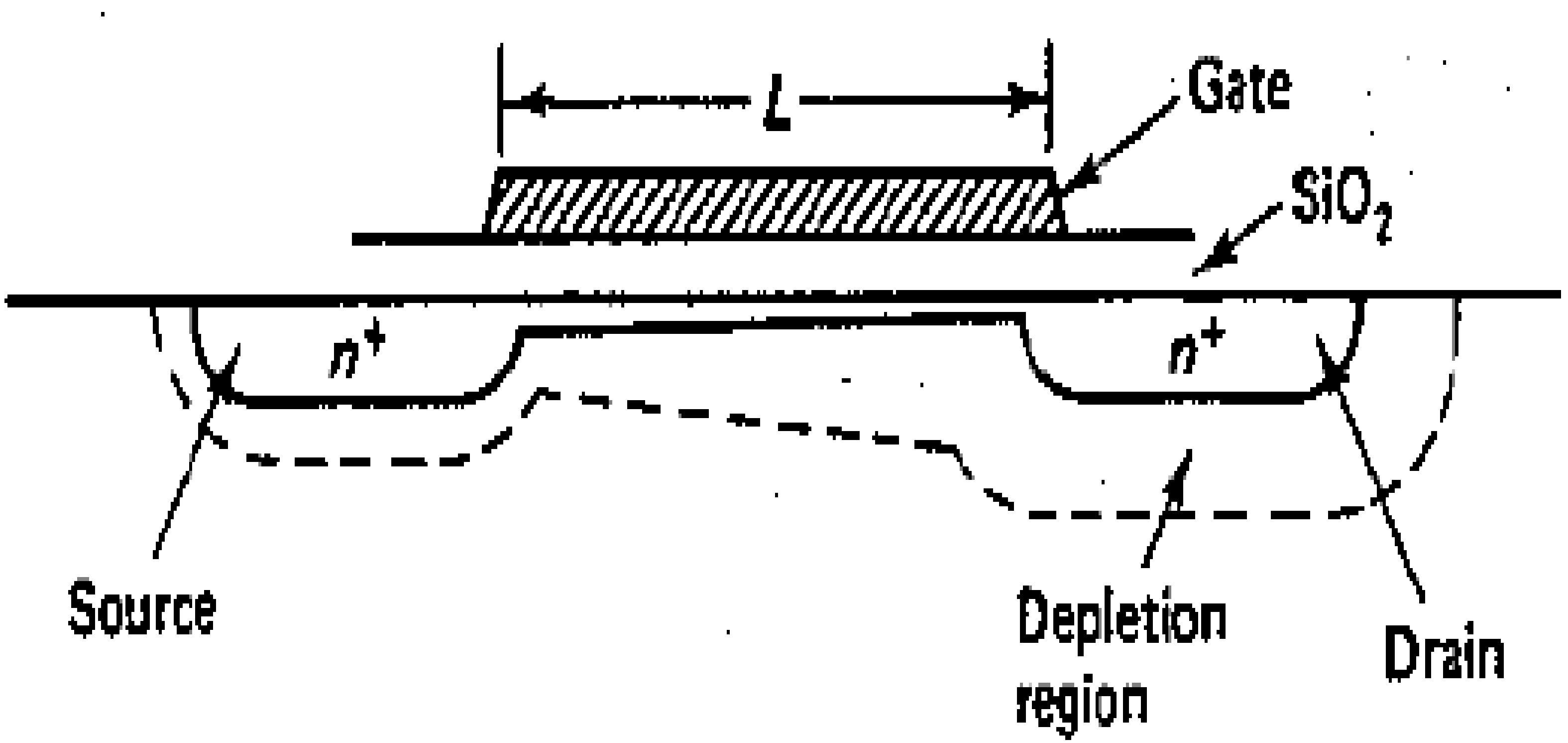
$$n(B) = n_i e^{-q\phi_B/kT} = \frac{n_i^2}{N_A}$$

$$E_{Fi}(y) - E_{FB} = q(\phi_B - \psi_s)$$

$$n(y) = N_A e^{q[\psi(y) - 2\phi_B]/kT}$$

Sec. 10.2.2

Now allow V_{DS}>0

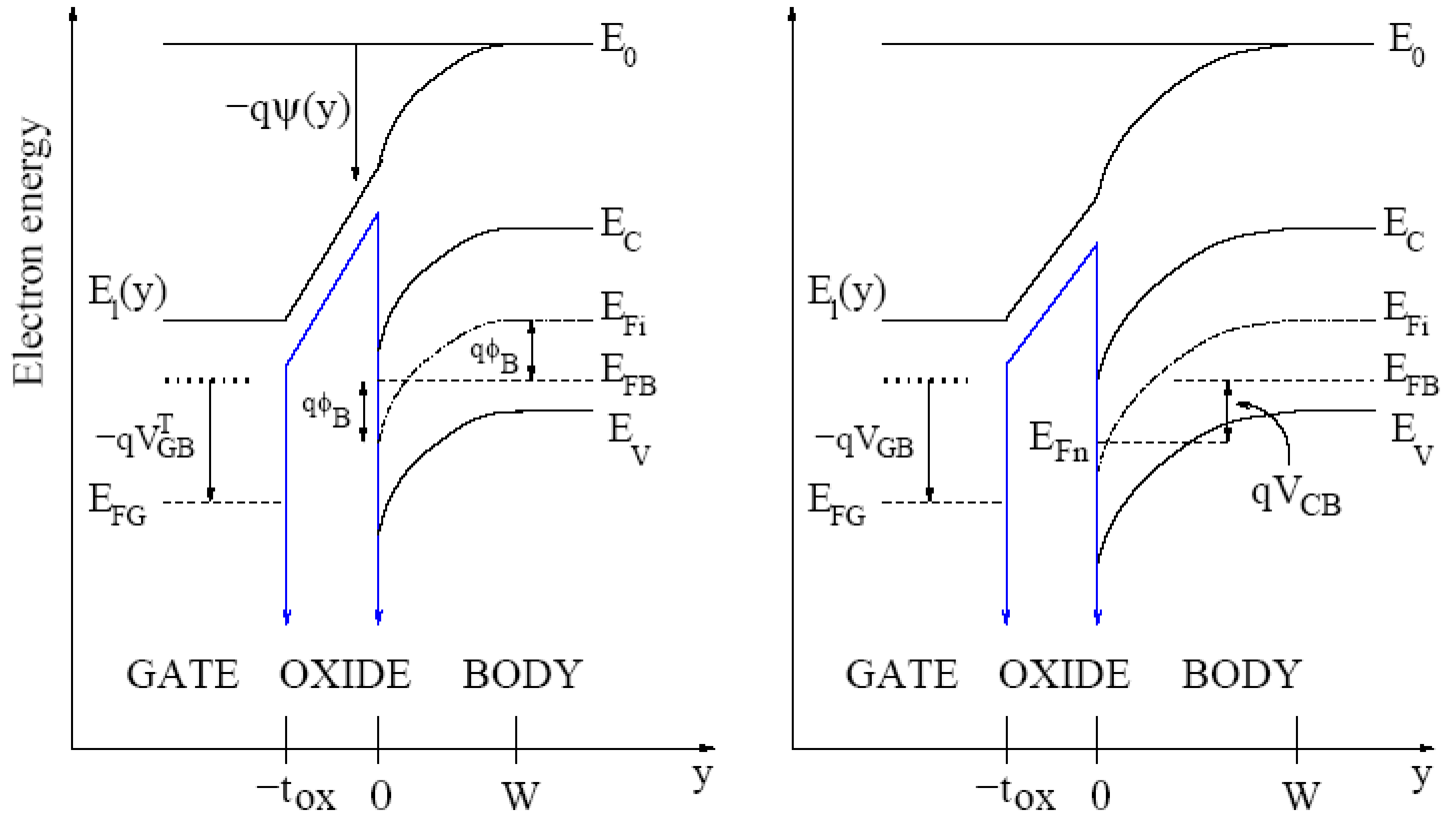


Note:

- presence of $V_{CB}(x)$
- non-uniformity of the channel and bulk charges when $V_{DS} > 0$ (IN STRONG INVERSION).

Sec. 10.2.2

Now allow $V_{DS}>0$ (STRONG INVERSION)



(a) (b)

Strong inversion when $V_{DS}=0$

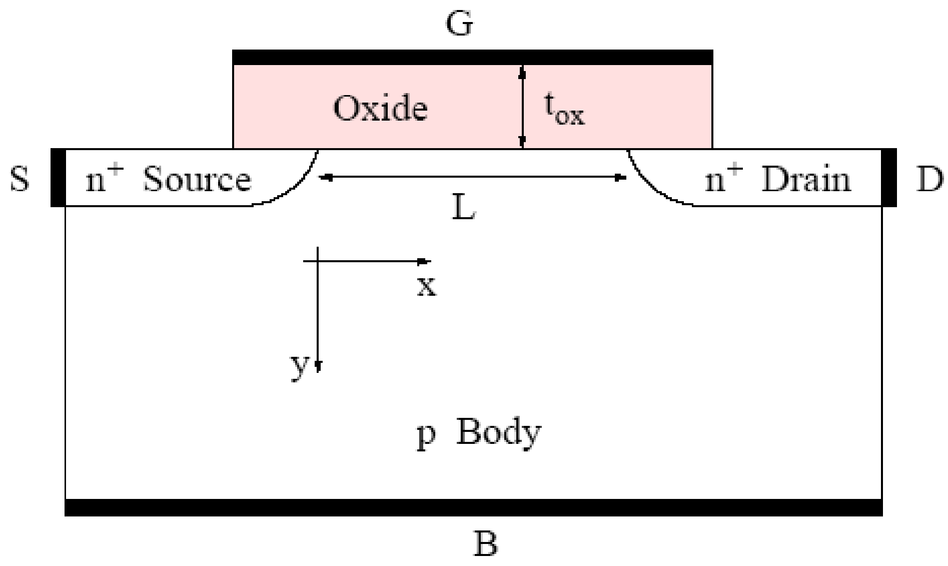
$$n(y) = N_A e^{q[\psi(y)-2\phi_B]/kT}$$

- More voltage drop across body (IN STRONG INVERSION)
- Oxide field reduced
- Less charge in channel

$$n(x,y) = N_A e^{[\psi(x,y)-2\phi_B - V_{CB}(x)]/V_{th}}$$

Secs. 10.1, 10.2

Si MOSFET summary



- E_y due to V_{GB} causes depletion and inversion
- E_x due to V_{DS} causes reduction in inversion (effect is greatest near the drain)
- V_{DS} gives rise to a channel voltage $V_{CB}(x)$