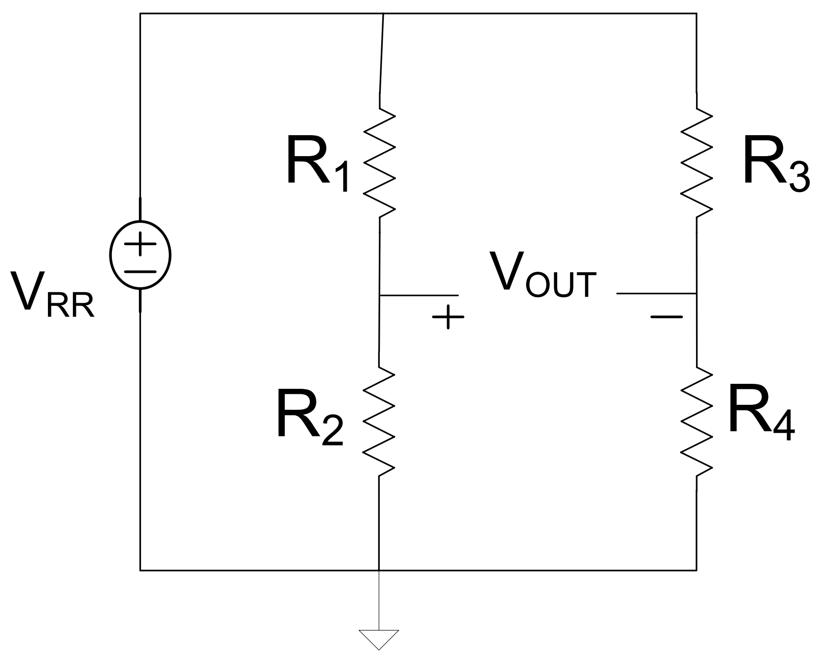
EE 434
Lecture 15

Devices in Semiconductor Processes

Quiz 10

The resistors in this strain-gauge bridge circuit have a temperature coefficient that is +200ppm/^{o}C and measured unstrained resistance value at T=300^{o}K of 100Ω. Assume that the temperature of R_4 was 30^{o}C higher than that of the remaining resistors which are all operating at 300^{o}K. If the signal information is carried in the change in R_2 which is 0.01Ω. What percent error in V_{OUT} is introduced by the temperature variation of R_4?



And the number is ….

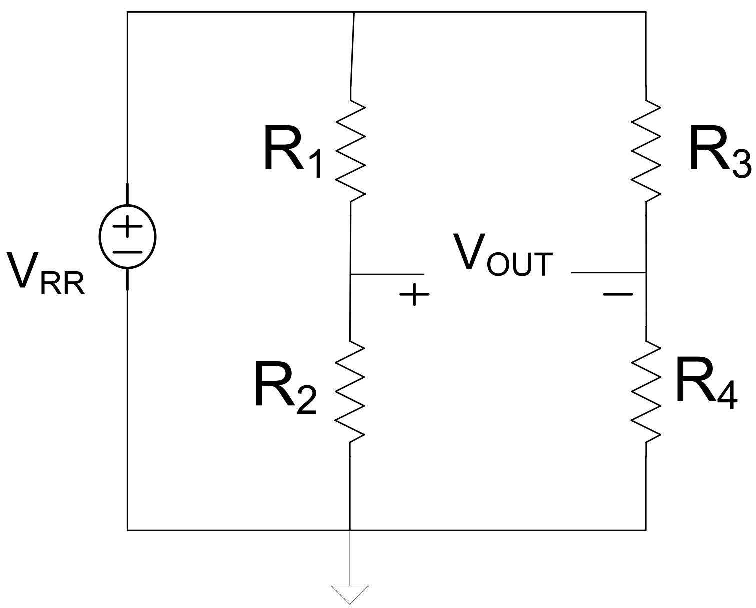
1 8 7 5 3

6 9 4 2

3

Quiz 10 Solution:

The resistors in this strain-gauge bridge circuit have a temperature coefficient that is +200ppm/^{o}C and measured unstrained resistance value at T=300^{o}K of 100Ω. Assume that the temperature of R_4 was 30^{o}C higher than that of the remaining resistors which are all operating at 300^{o}K. If the signal information is carried in the change in R_2 which is 0.01Ω. What percent error in V_{OUT} is introduced by the temperature variation of R_4?



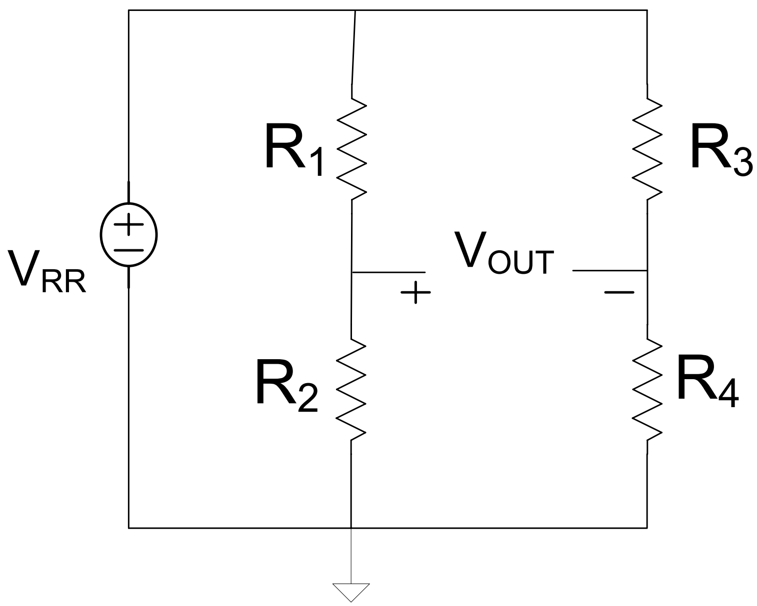
$$V_{OUTD} = V_{RR}\left(\frac{R_{2A}}{R_{1N}+R_{2A}} - \frac{R_{4N}}{R_{4N}+R_{3N}}\right)$$

$$V_{OUTD} = V_{RR}\left(\frac{100.01}{200.01} - \frac{100}{200}\right) = V_{RR}(2.49E-5)$$

$$R_4(T_2) \approx R_4(T_1)\left[1+(T_2-T_1)\frac{TCR}{10^6}\right]$$

$$R_4(T_2) \approx 100\left[1+(30)\frac{200}{10^6}\right] = 100.6\Omega$$

Quiz 10 Solution:



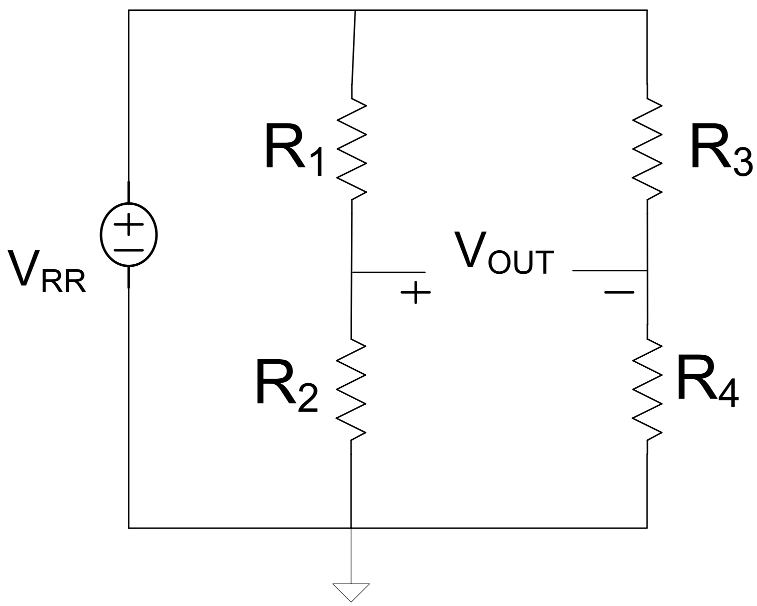
$$V_{OUTD} = V_{RR}\left(\frac{100.01}{200.01} - \frac{100}{200}\right) = V_{RR}(2.49E-5)$$

$$V_{OUTA} = V_{RR}\left(\frac{R_{2A}}{R_{1N}+R_{2A}} - \frac{R_{4NT}}{R_{4NT}+R_{3N}}\right)$$

$$V_{OUTA} = V_{RR}\left(\frac{100.01}{100+100.01} - \frac{100.6}{100.6+100}\right) = V_{RR}(1.47E-3)$$

$$\text{Error} = \frac{V_{OUTD} - V_{OUTA}}{V_{OUTD}}100\% = \frac{2.49E-5-1.47E-3}{2.49E-5}100\%$$

Quiz 10 Solution:



$$V_{OUTD} = V_{RR}\left(\frac{100.01}{200.01} - \frac{100}{200}\right) = V_{RR}(2.49E-5)$$

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$$V_{OUTA} = V_{RR}\left(\frac{100.01}{100+100.01} - \frac{100.6}{100.6+100}\right) = V_{RR}(1.47E-3)$$

$$\text{Error} = \frac{V_{OUTD}-V_{OUTA}}{V_{OUTD}}100\% = \frac{2.49E-5-1.47E-3}{2.49E-5}100\%$$

$$\text{Error} = 5800\%$$

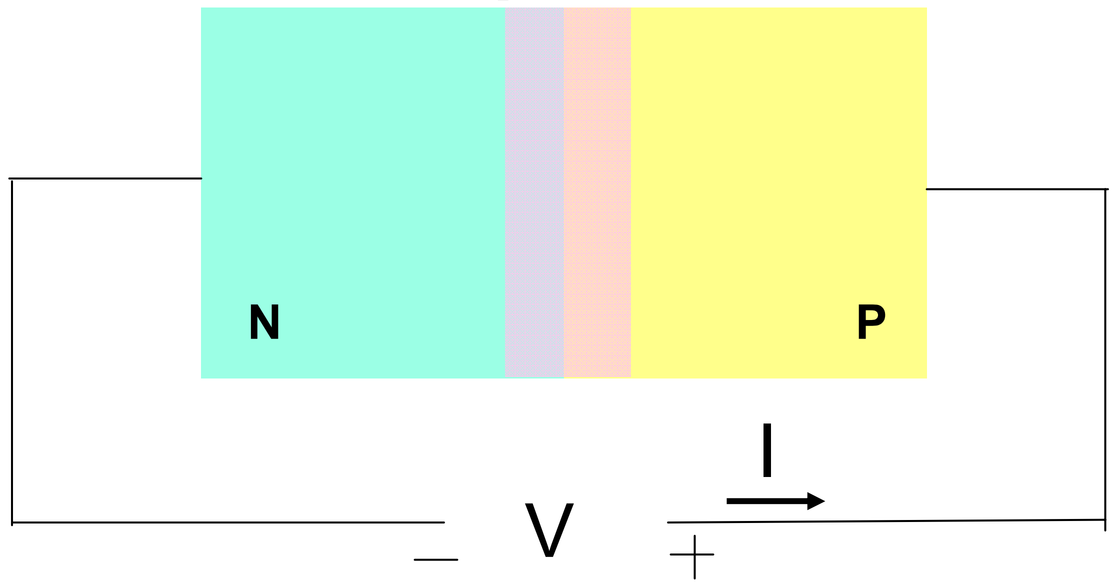
Review from Last Time

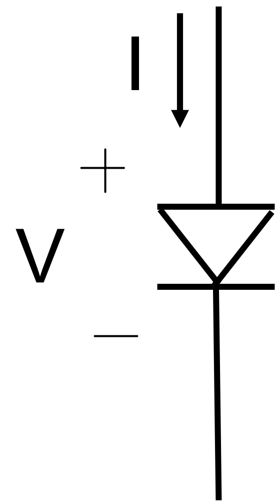
Basic Devices and Device Models

- Resistor
- Diode
- Capacitor
- MOSFET
- BJT

Review from Last Time

pn Junctions





Diode Equation:

$$I = \begin{cases} J_S A e^{\frac{V}{nV_T}} & V > 0 \\ 0 & V < 0 \end{cases}$$

J_S= Sat Current Density
A= Junction Cross Section Area
V_T=kT/q
n is approximately 1

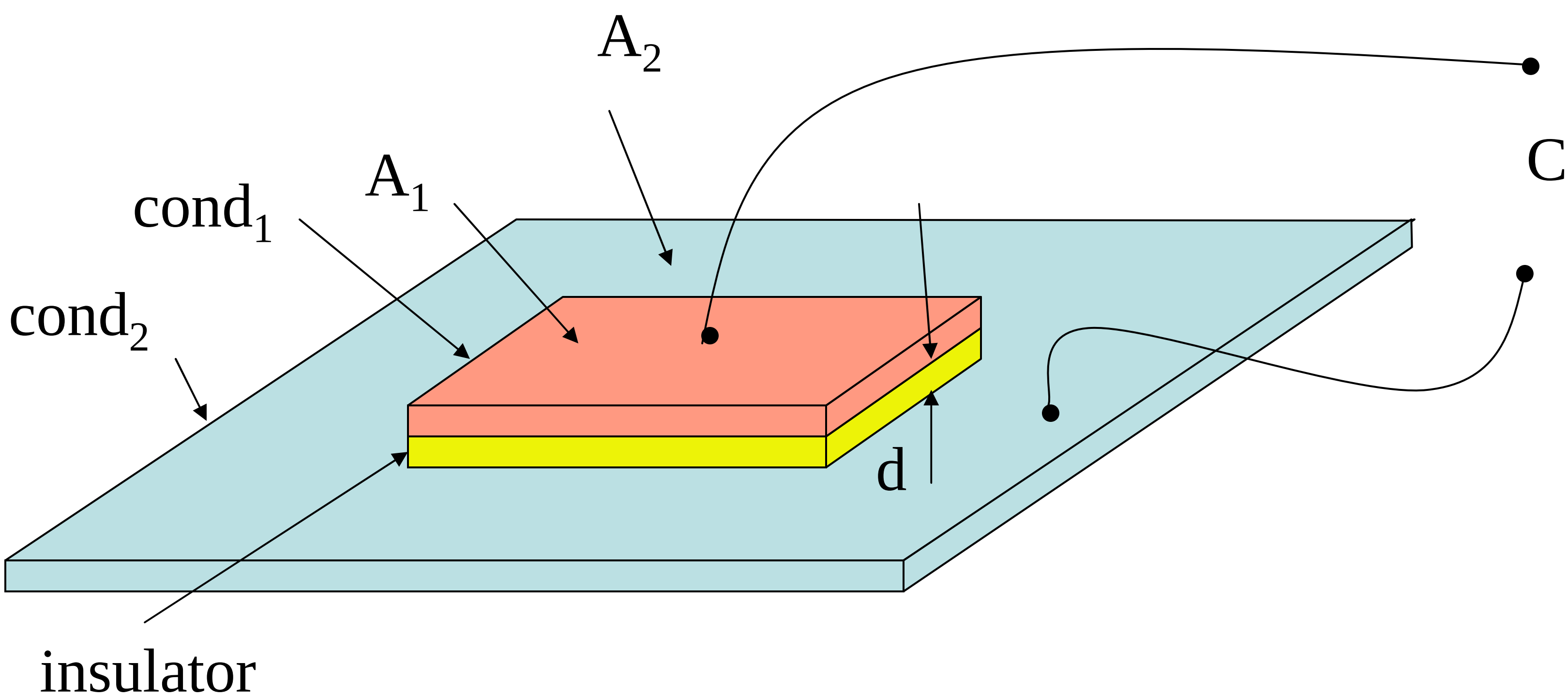
Review from Last Time

Capacitors

- Types
  - Parallel Plate
  - Fringe
  - Junction

Review from Last Time

Parallel Plate Capacitors



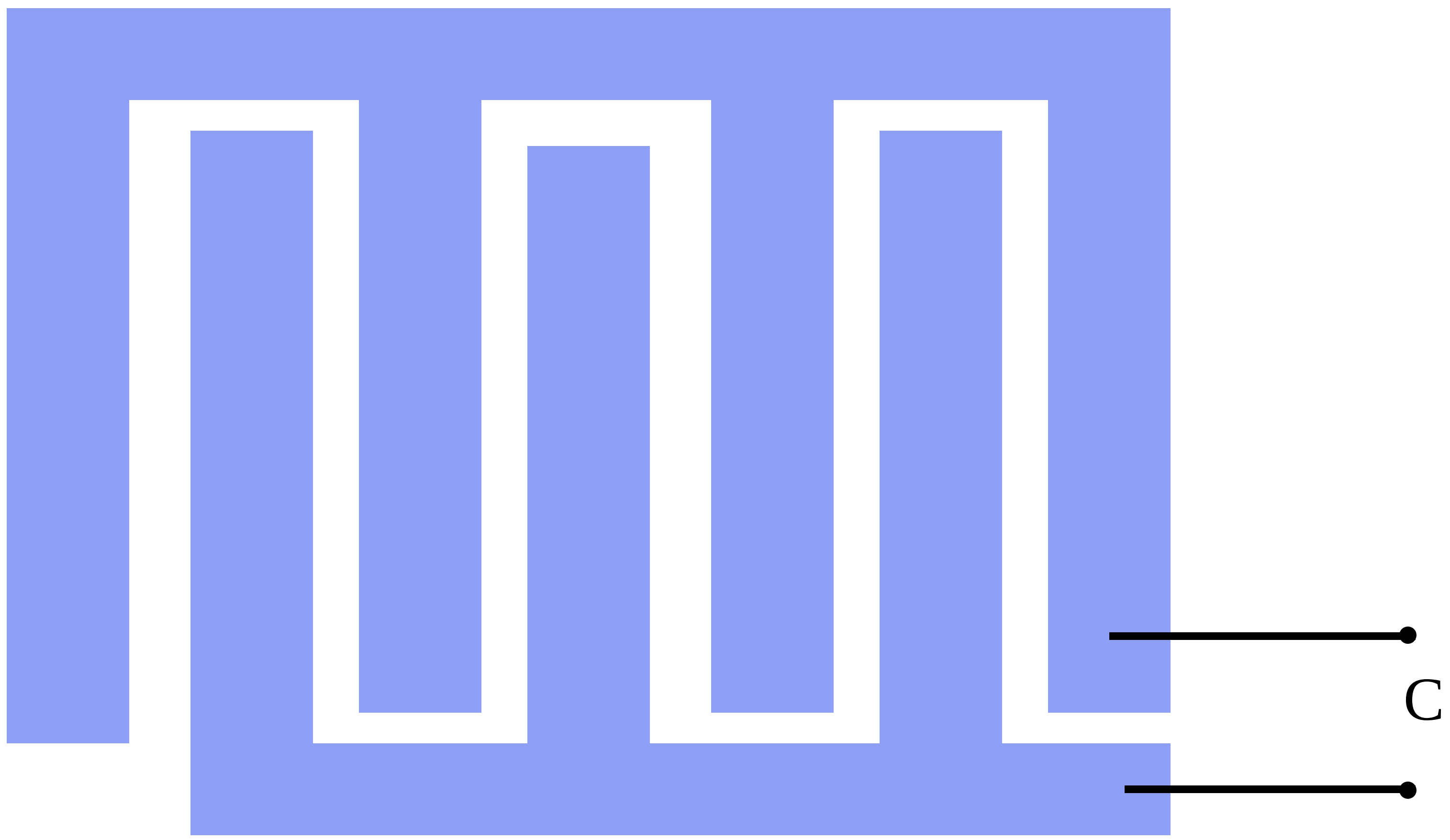
A = area of intersection of A_1 & A_2

One (top) plate intentionally sized smaller to determine C

$$\mathbf{C} = \mathbf{C_d A}$$

Review from Last Time

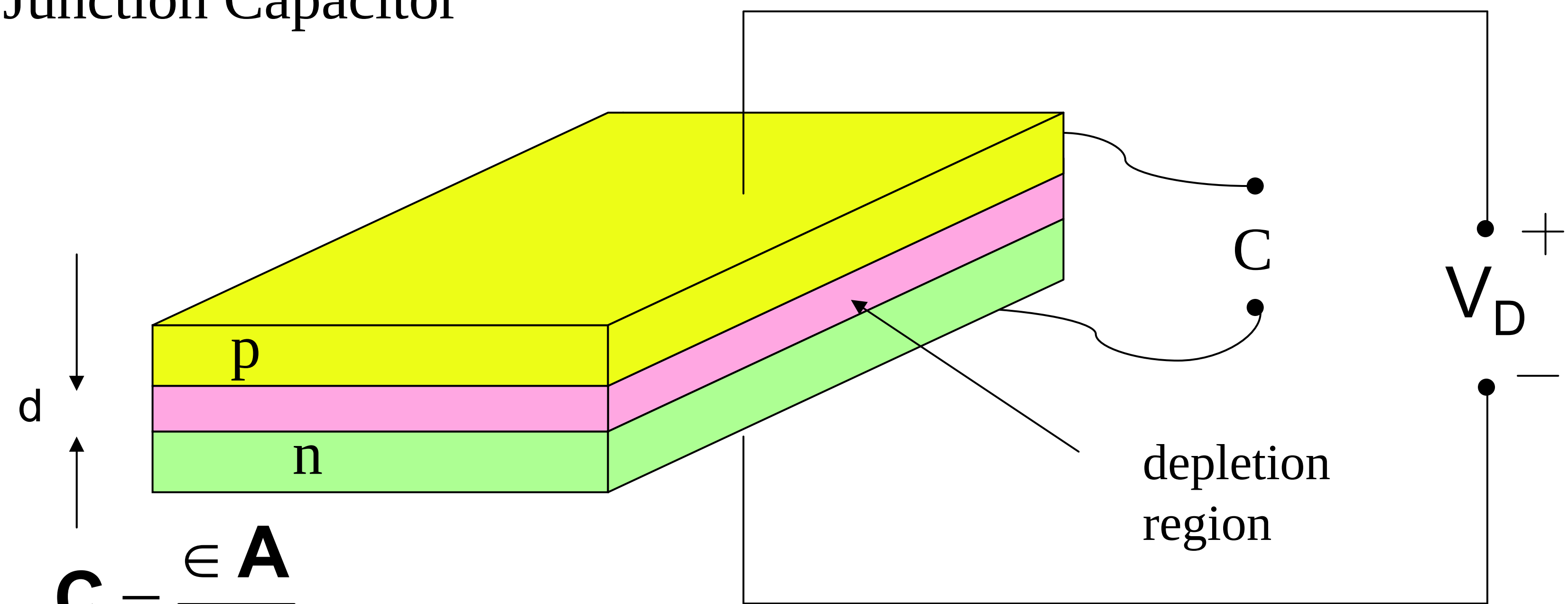
Fringe Capacitors



Review from Last Time

Capacitance

Junction Capacitor



$$C = \frac{\in A}{d}$$

Note: d is voltage dependent
-capacitance is voltage dependent
-usually parasitic caps
-varicaps or varactor diodes exploit voltage dep. of C

$$C = \frac{C_{jo}A}{\left(1 - \frac{V_D}{\varphi_B}\right)^n} \qquad \textit{for} \quad V_{FB} < \frac{\varphi_B}{2}$$

$$\varphi_B \cong 0.6V$$

C_{j0}: junction capacitance at V_D = 0V

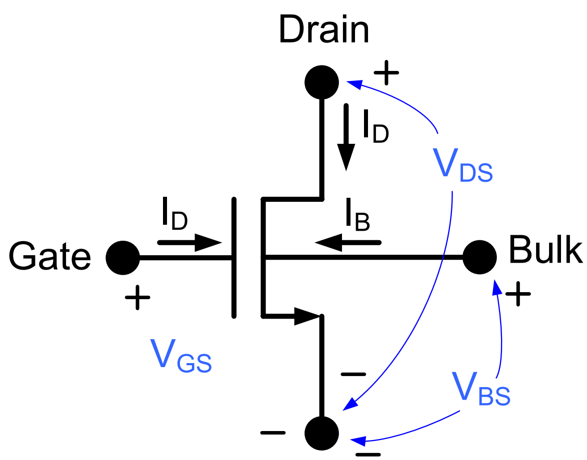
φ_B: barrier or built-in potential

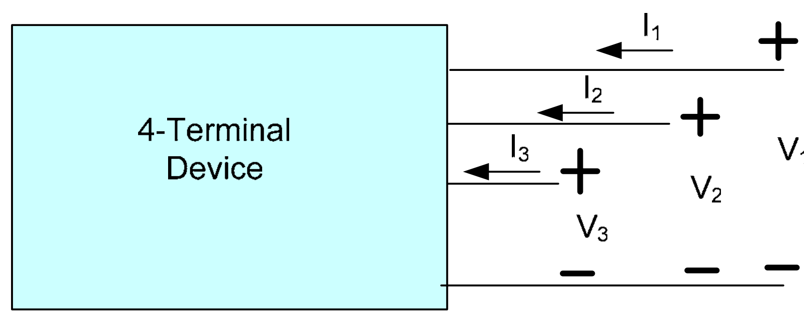
Basic Devices and Device Models

- Resistor
- Diode
- Capacitor
- MOSFET
- BJT

Operation and Modeling of MOSFET

Goal: Obtain a mathematical relationship between the port variables of a device.





$$\left.\begin{aligned} I_D &= f_1(V_{GS}, V_{DS}, V_{BS}) \\ I_G &= f_2(V_{GS}, V_{DS}, V_{BS}) \\ I_B &= f_3(V_{GS}, V_{DS}, V_{BS}) \end{aligned}\right\}$$

$$\left.\begin{aligned} I_1 &= f_1(V_1, V_2, V_3) \\ I_2 &= f_2(V_1, V_2, V_3) \\ I_3 &= f_3(V_1, V_2, V_3) \end{aligned}\right\}$$

Modeling of the MOSFET

Strategy

Develop multiple models that are useful for specific classes of applications

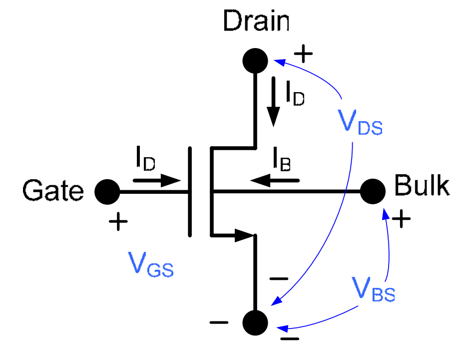
Use as simple of a model as we can justify

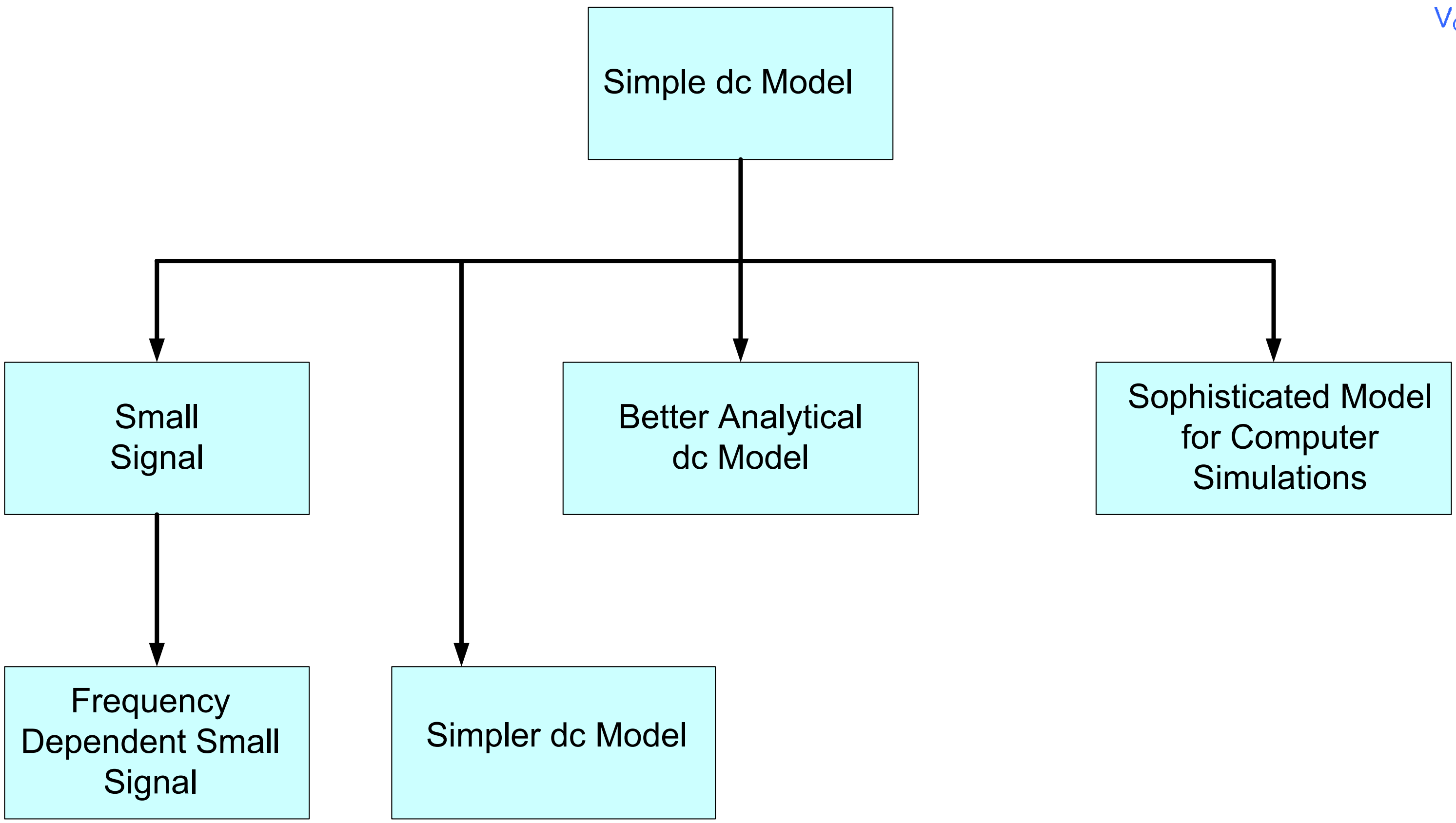
Often must consider a modestly more complicated model to justify a simpler model

Modeling of the MOSFET

Goal: Obtain a mathematical relationship between the port variables of a device.

$$I_D = f_1(V_{GS}, V_{DS}, V_{BS})$$
$$I_G = f_2(V_{GS}, V_{DS}, V_{BS})$$
$$I_B = f_3(V_{GS}, V_{DS}, V_{BS})$$

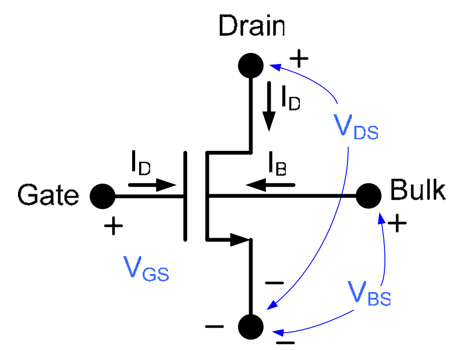


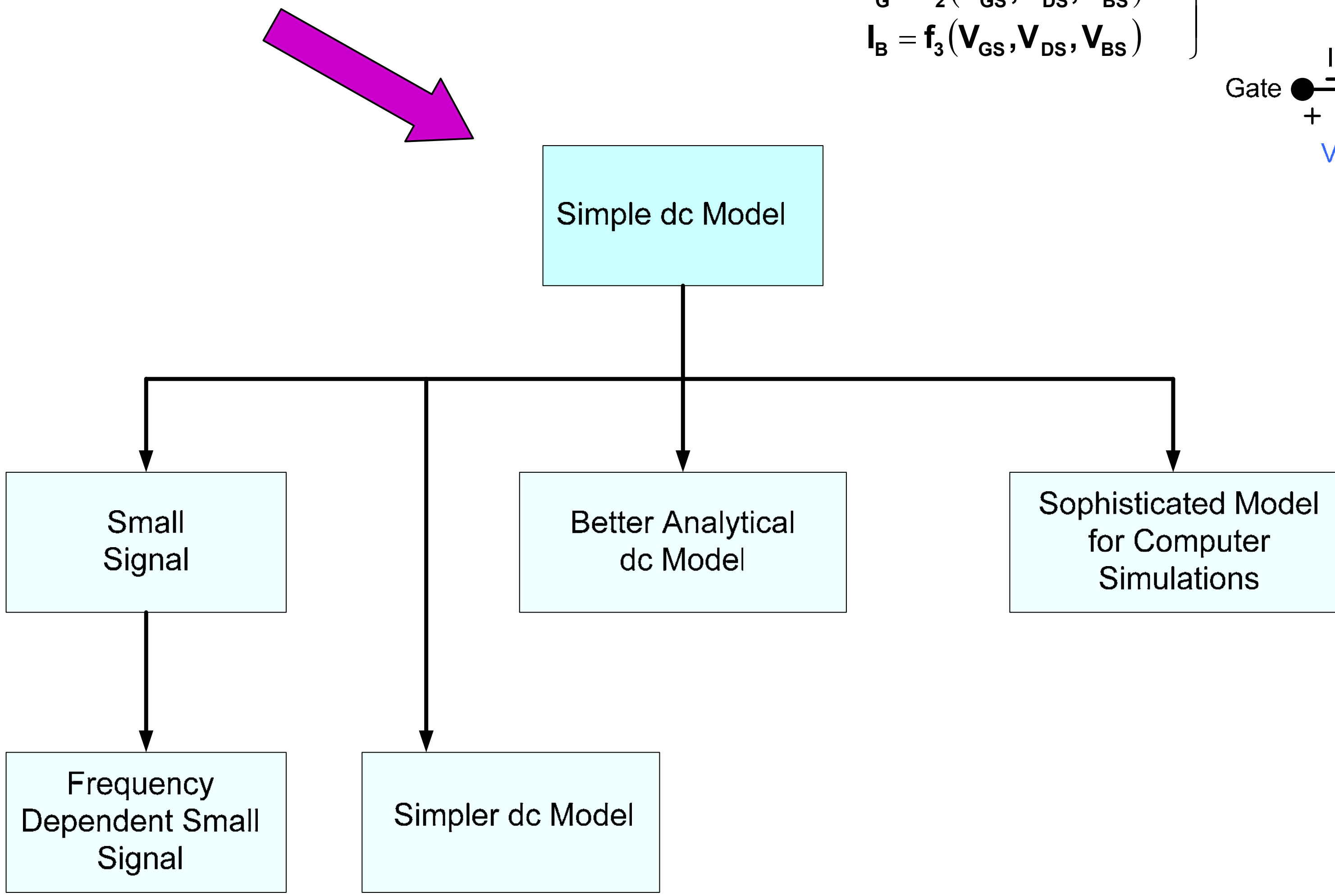


Modeling of the MOSFET

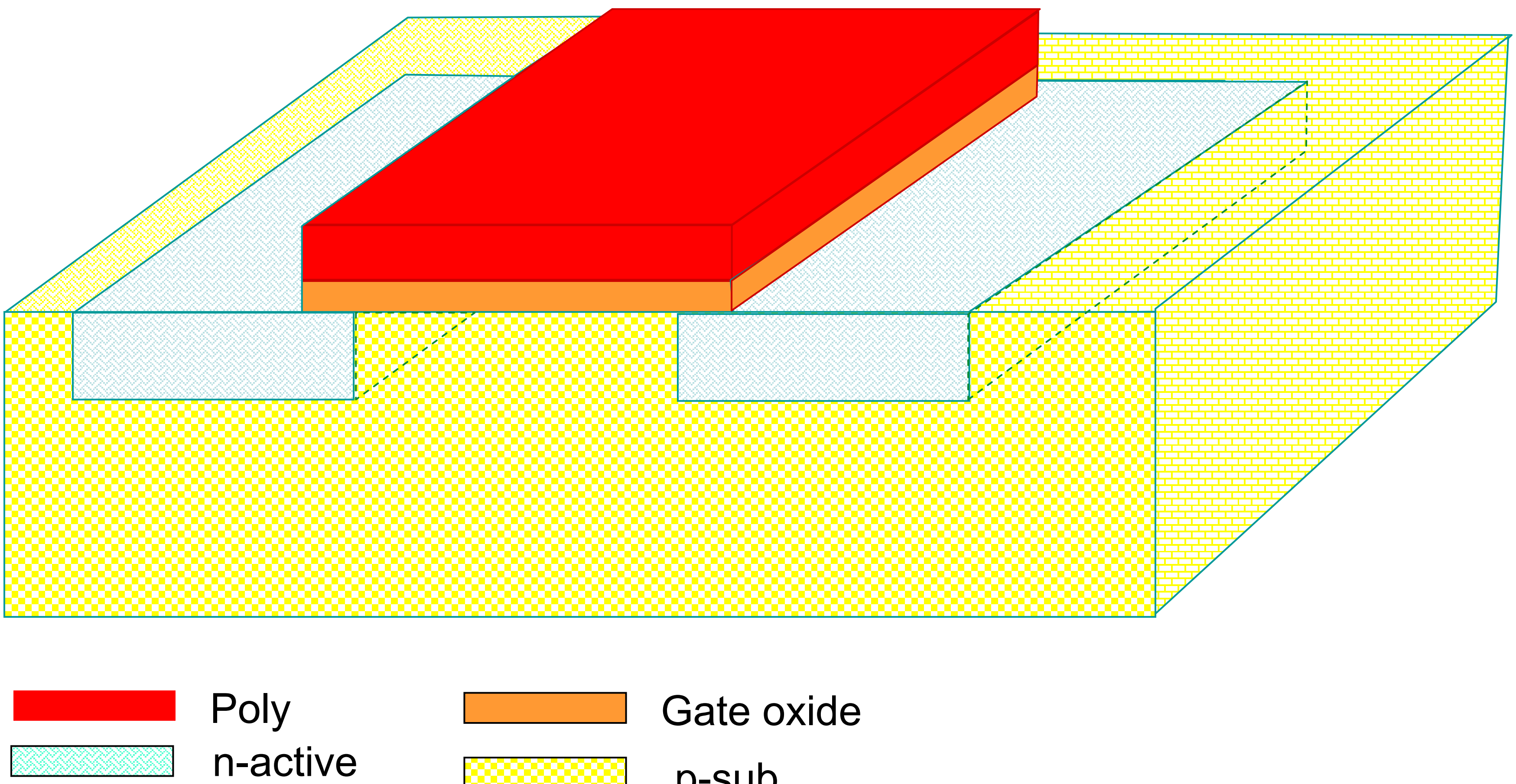
Goal: Obtain a mathematical relationship between the port variables of a device.

$$\begin{aligned} I_D &= f_1(V_{GS}, V_{DS}, V_{BS}) \\ I_G &= f_2(V_{GS}, V_{DS}, V_{BS}) \\ I_B &= f_3(V_{GS}, V_{DS}, V_{BS}) \end{aligned}$$

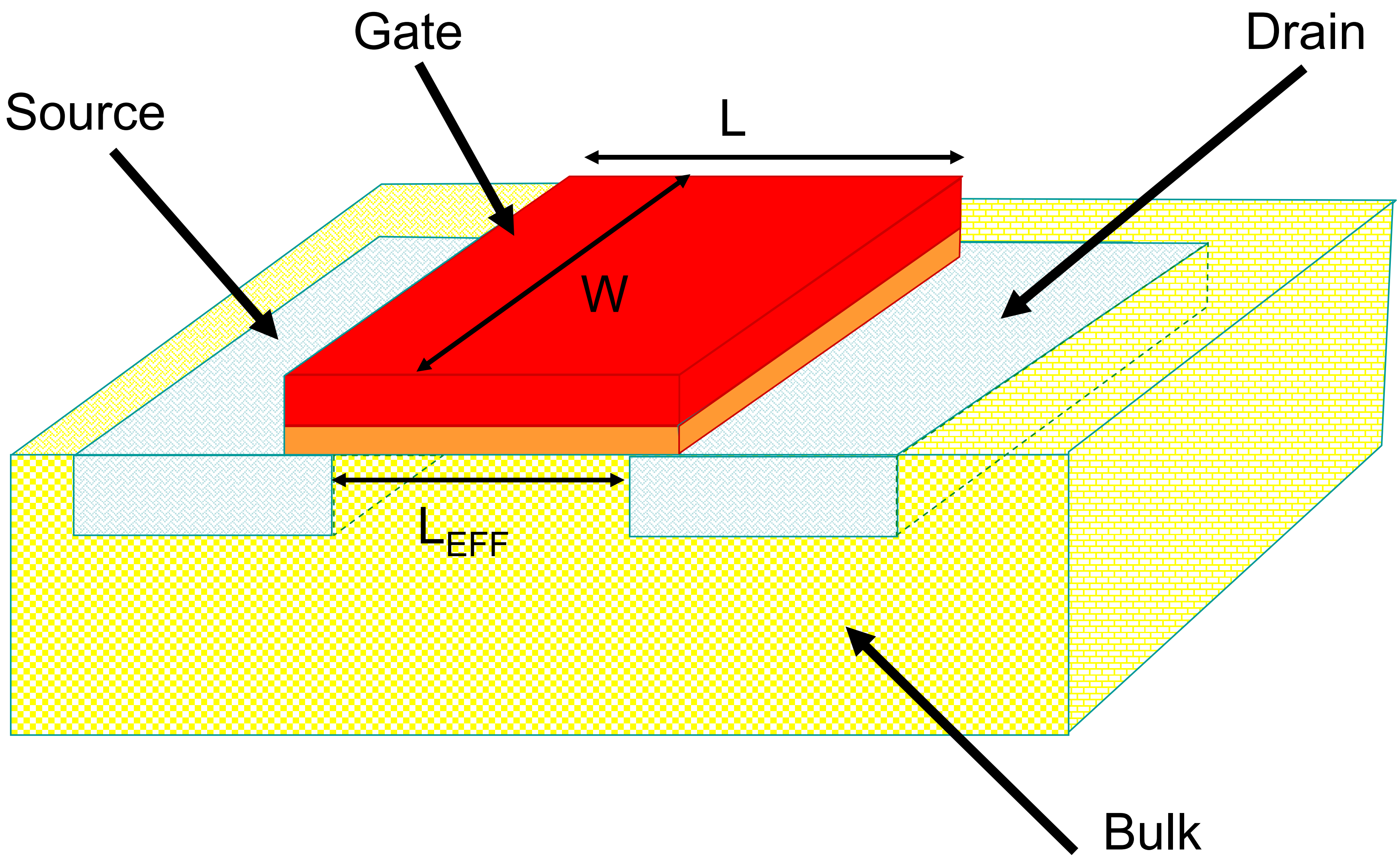




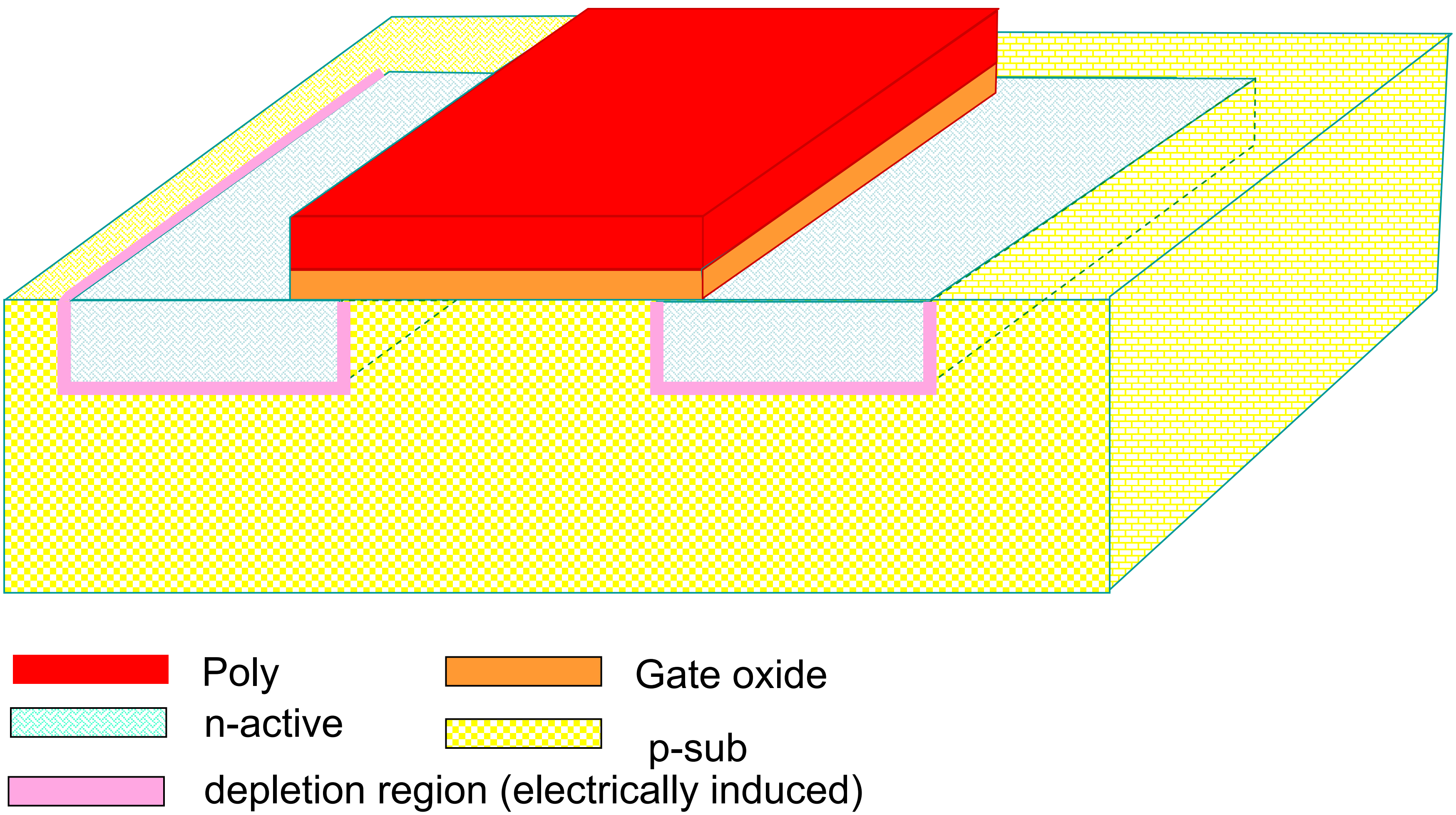
n-Channel MOSFET



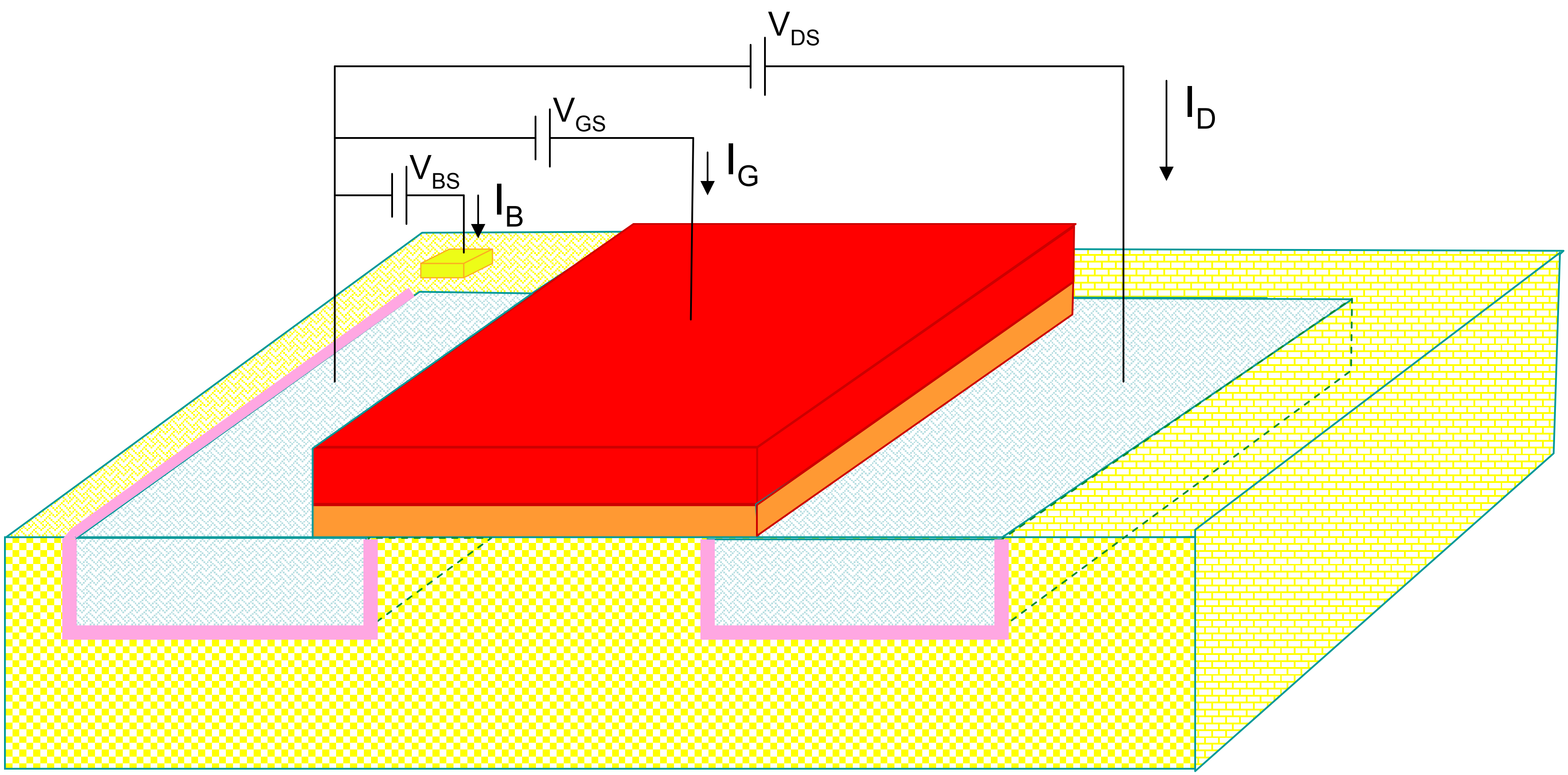
n-Channel MOSFET



n-Channel MOSFET



n-Channel MOSFET Operation and Model



Apply small V_{GS}

(V_{DS} and V_{BS} assumed to be small)

Depletion region at drain and source block current

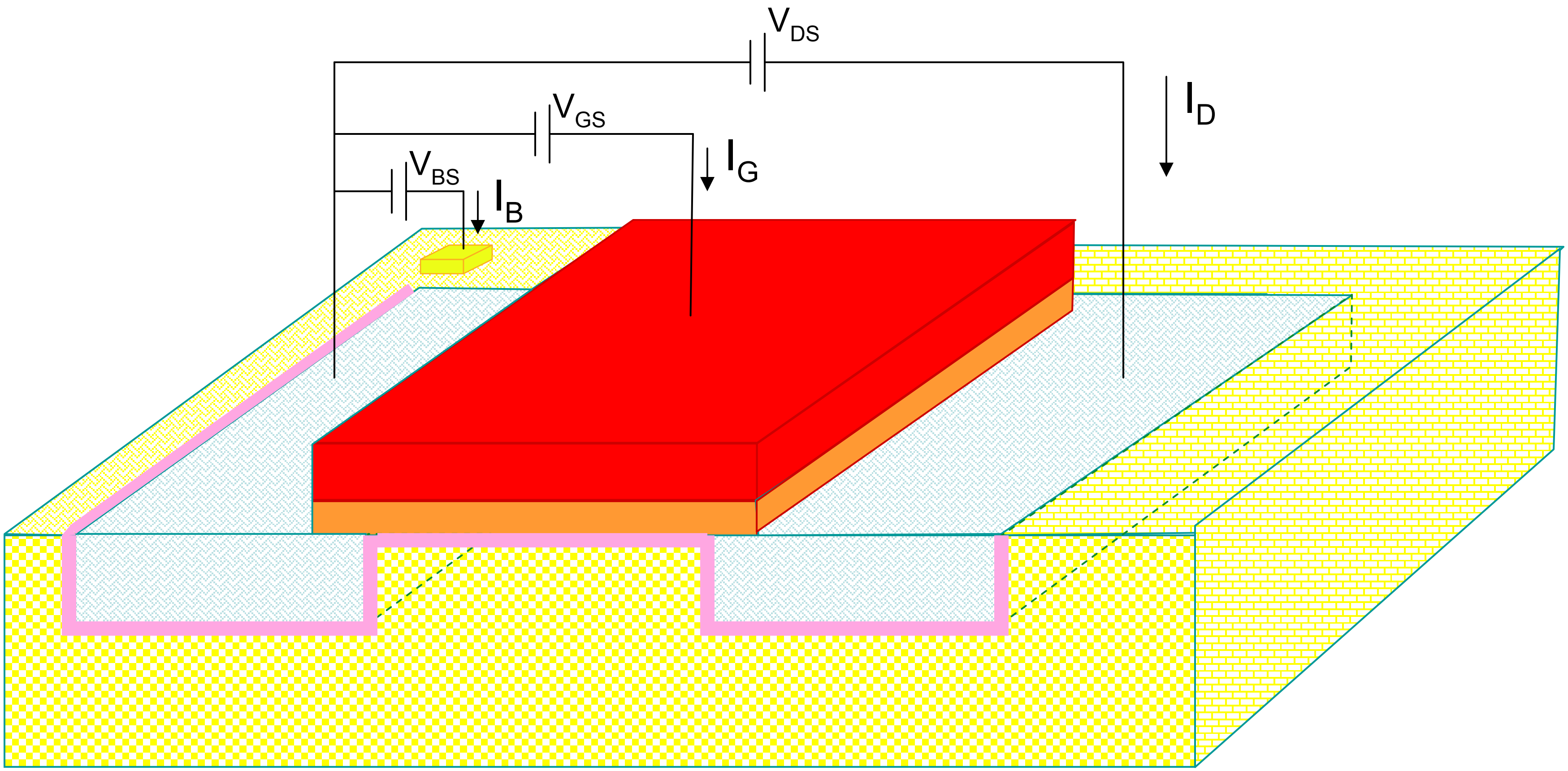
Termed “cutoff” region of operation

$I_D=0$

$I_G=0$

$I_B=0$

n-Channel MOSFET Operation and Model



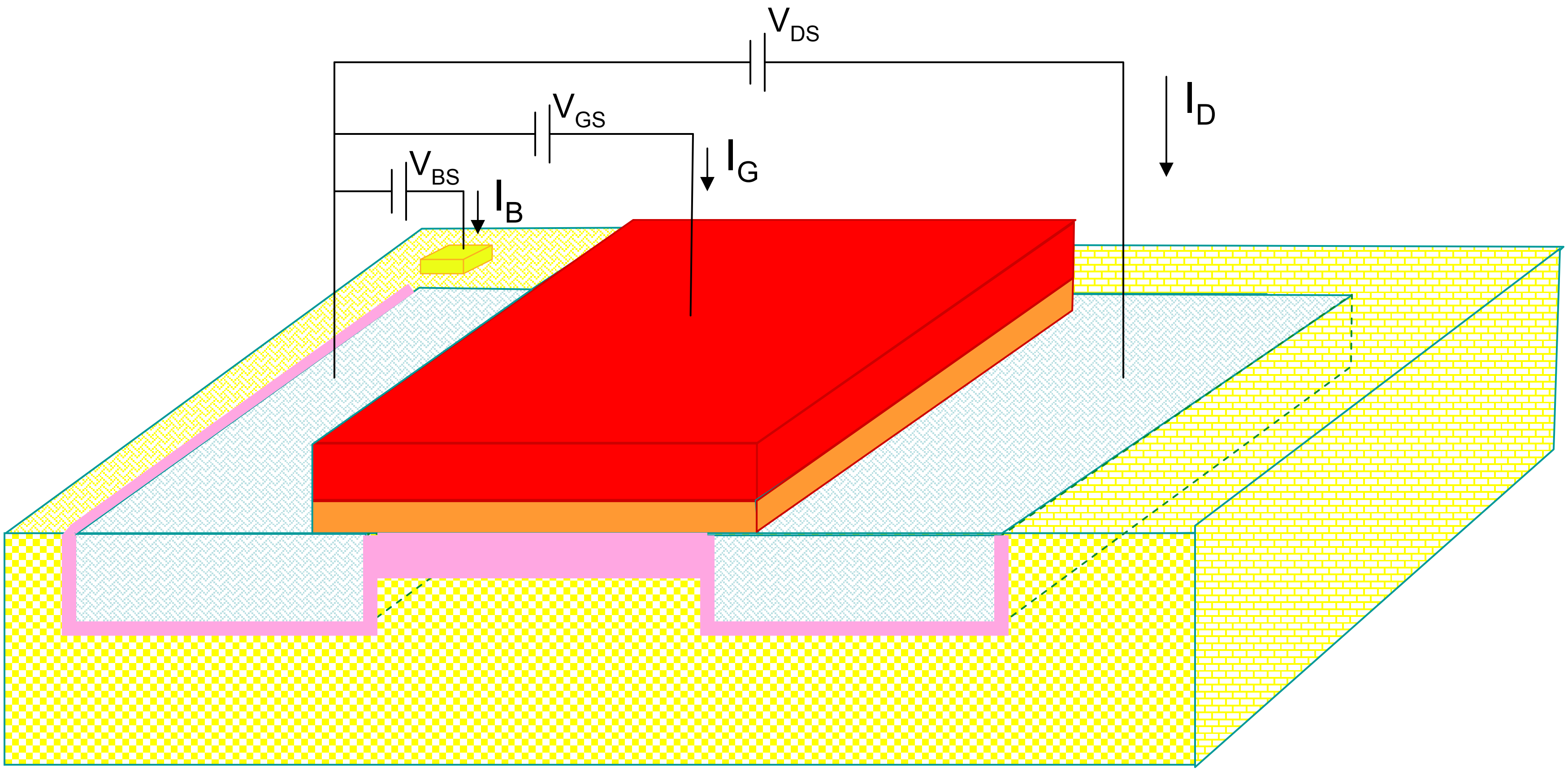
Apply small V_{GS} but a little larger than before
(V_{DS} and V_{BS} assumed to be small)

Depletion region electrically induced in channel

Termed “cutoff” region of operation

I_D=0
I_G=0
I_B=0

n-Channel MOSFET Operation and Model

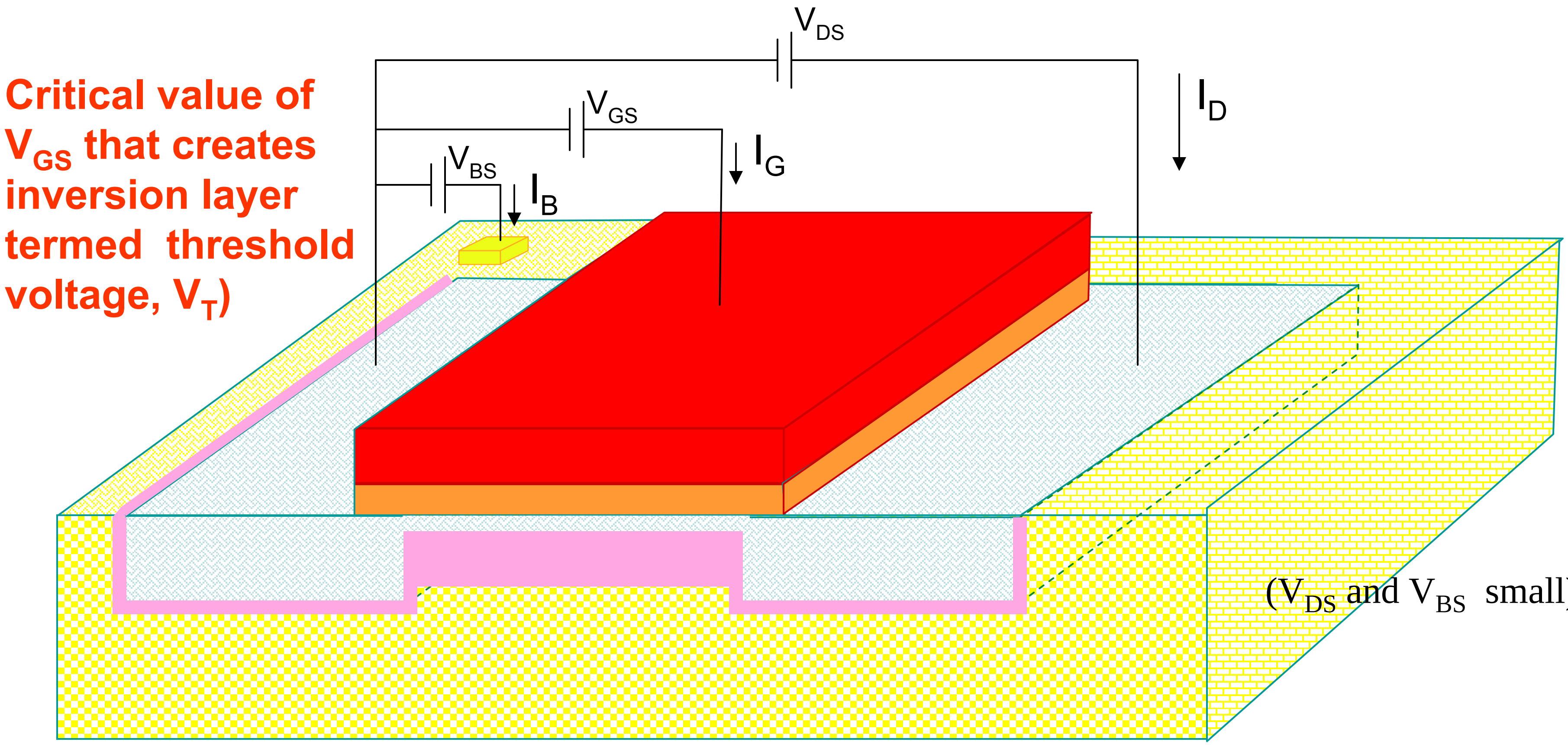


Increase V_{GS}
(V_{DS} and V_{BS} assumed to be small)

Depletion region in channel becomes larger

$I_D=0$
$I_G=0$
$I_B=0$

n-Channel MOSFET Operation and Model



Increase V_{GS} more

Inversion layer forms in channel

Inversion layer will support current flow from D to S

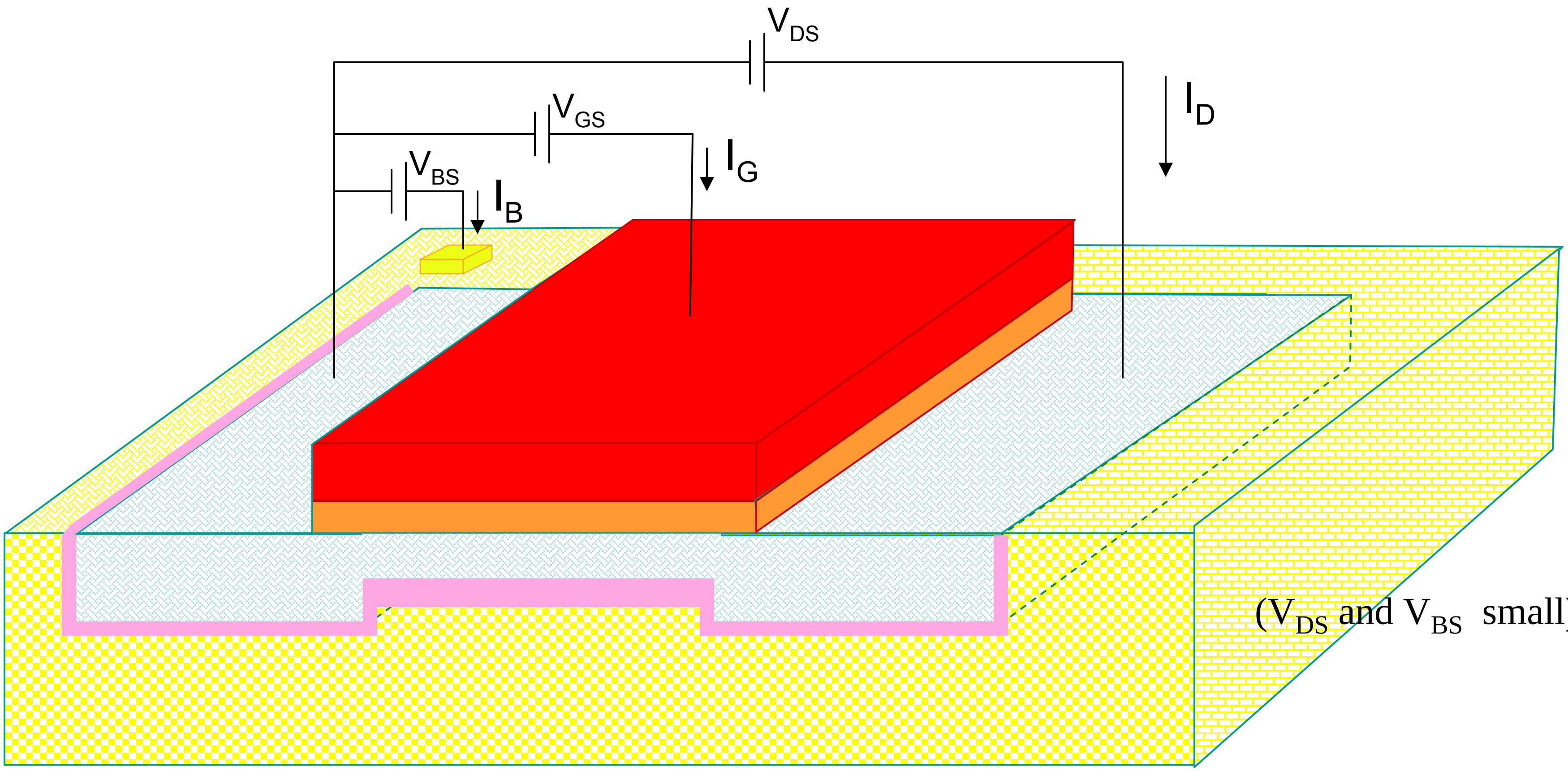
Channel behaves as thin-film resistor

$I_D R_{CH} = V_{DS}$

$I_G = 0$

$I_B = 0$

n-Channel MOSFET Operation and Model



Increase V_{GS} more

Inversion layer in channel thickens

R_{CH} will decrease

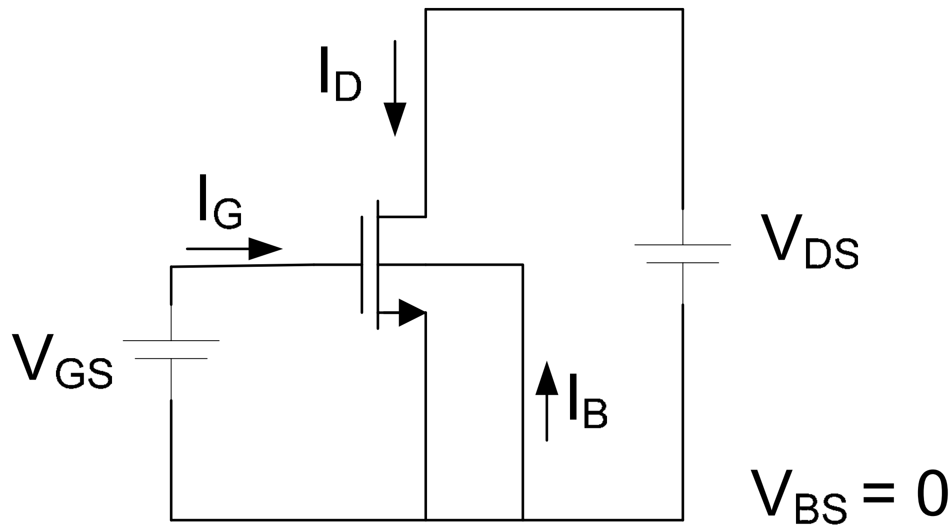
Termed “ohmic” or “triode” region of operation

$I_D R_{CH} = V_{DS}$

$I_G = 0$

$I_B = 0$

Triode Region of Operation



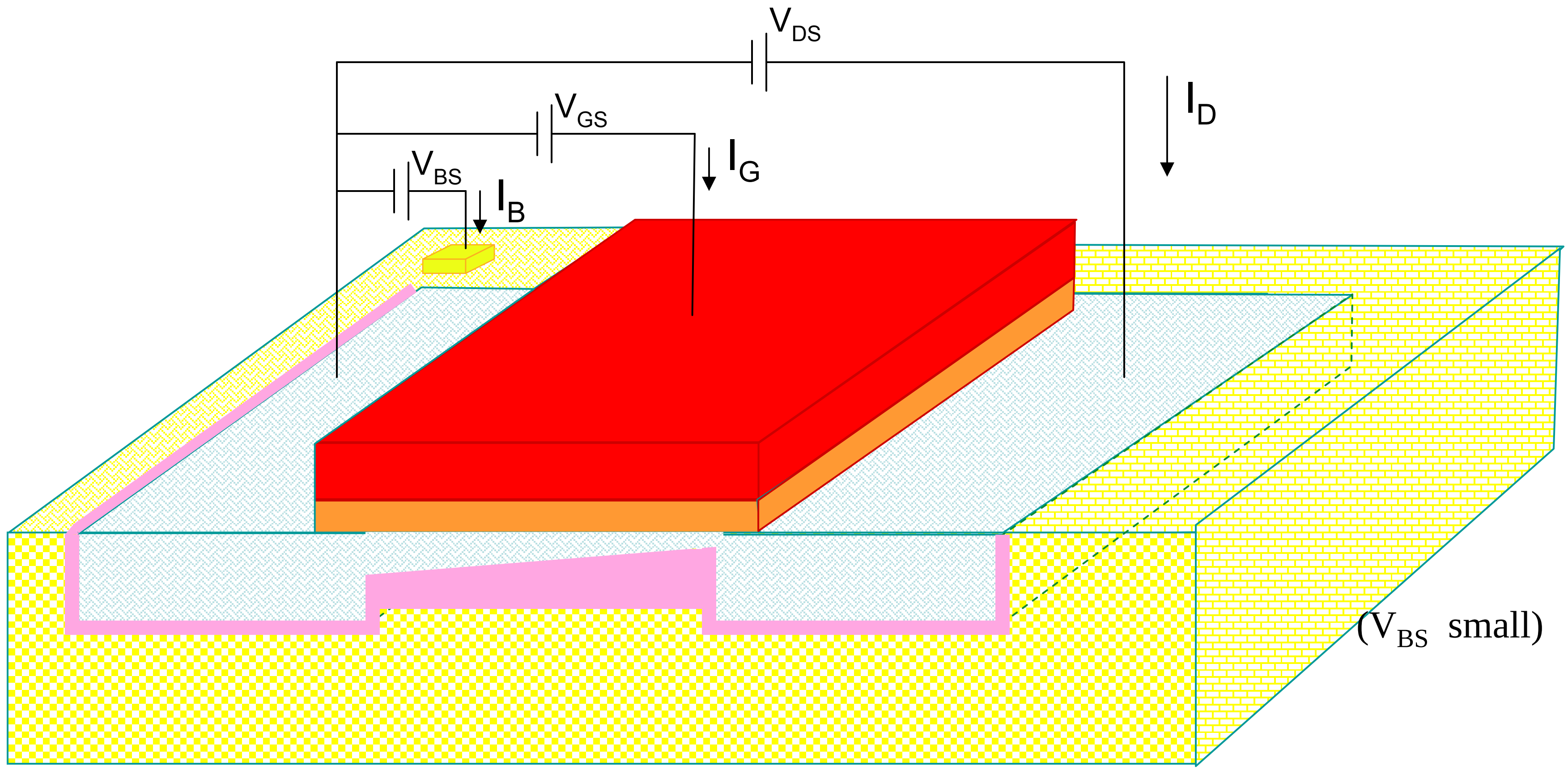
For V_{DS} small

$$R_{CH} = \frac{L}{W}\left(V_{GS} - V_T\right)^{-1}\frac{1}{\mu C_{OX}}$$

$$\mathbf{I_D = \mu C_{OX}\frac{W}{L}(V_{GS} - V_T)V_{DS}}$$

$$\mathbf{I_G = I_B = 0}$$

n-Channel MOSFET Operation and Model



Increase V_{DS}

Inversion layer thins near drain

I_D no longer linearly dependent upon V_{DS}

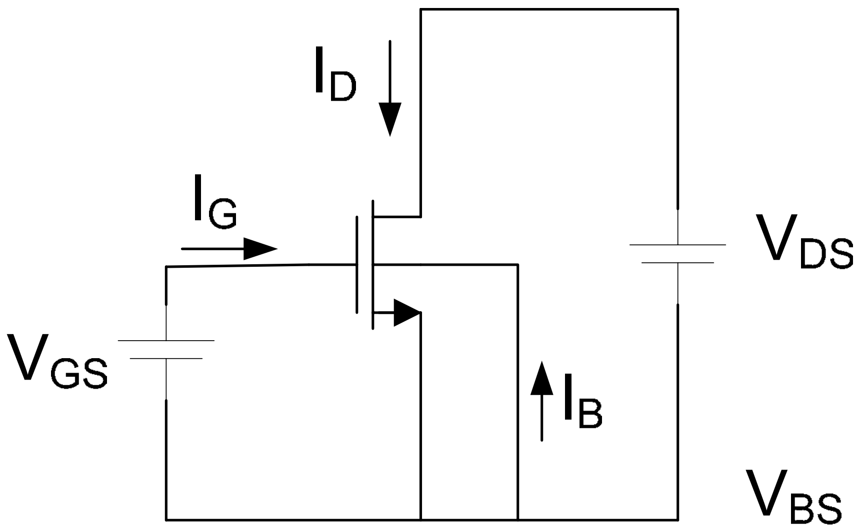
Still termed "ohmic" or "triode" region of operation

I_D=?

I_G=0

I_B=0

Triode Region of Operation



$V_{BS} = 0$

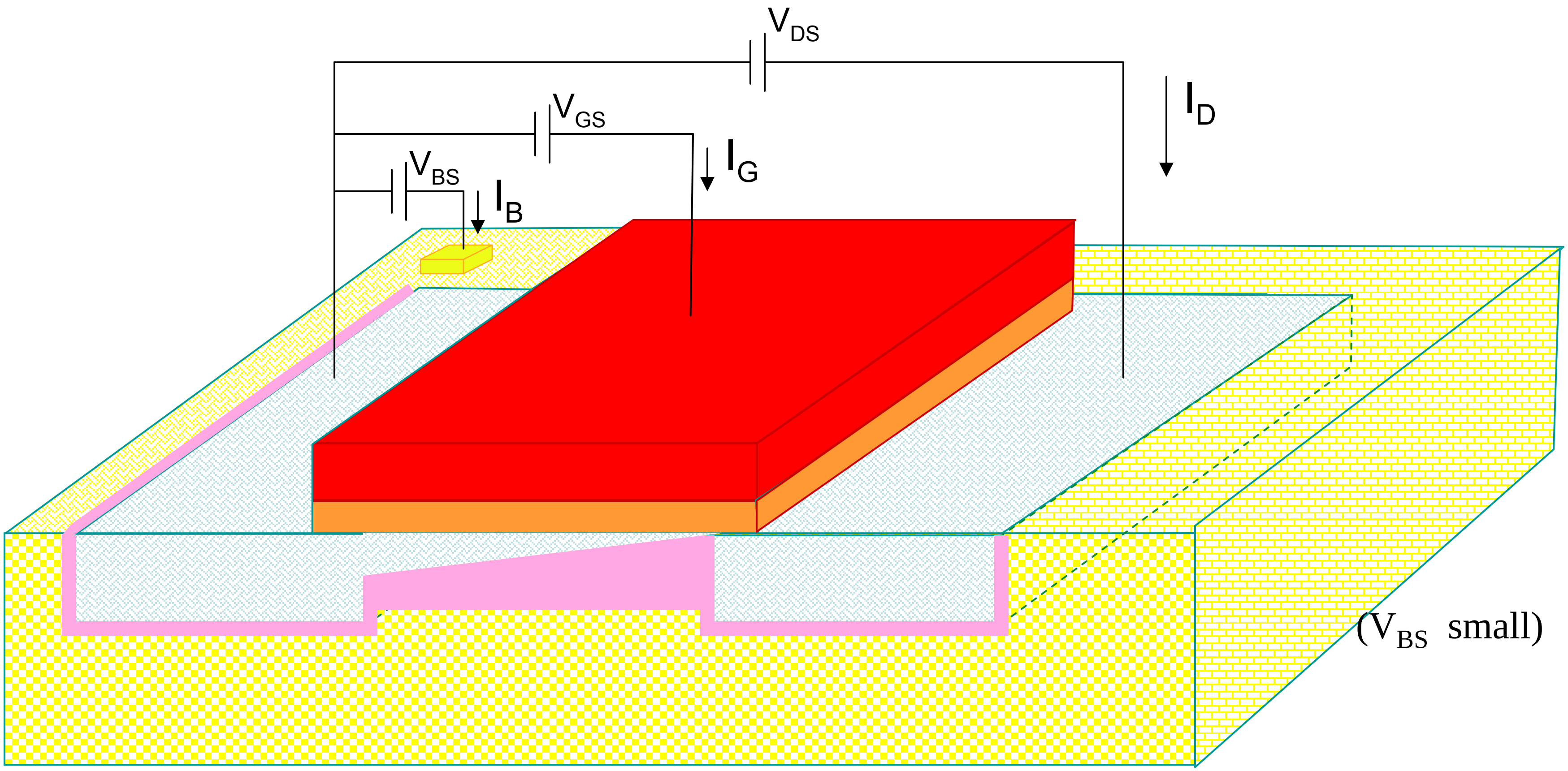
For V_{DS} larger

$$\cancel{R_{CH} = \frac{L}{W}(V_{GS} - V_T)^{-1}\frac{1}{\mu C_{OX}}}$$

$$\mathbf{I_D = \mu C_{OX} \frac{W}{L}\left(V_{GS} - V_T - \frac{V_{DS}}{2}\right)V_{DS}}$$

$$\mathbf{I_G = I_B = 0}$$

n-Channel MOSFET Operation and Model



Increase V_{DS} even more

Inversion layer disappears near drain

Termed “saturation”region of operation

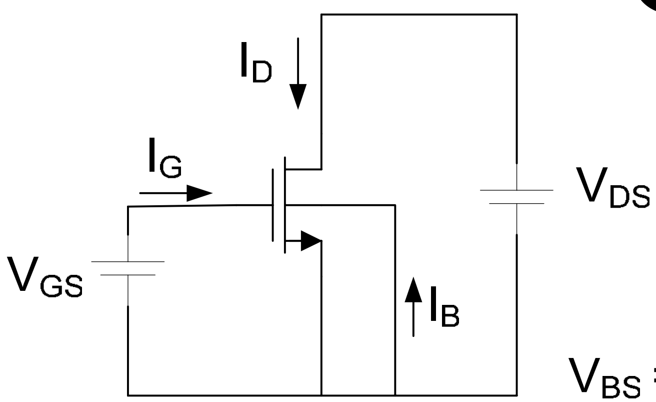
Saturation first occurs when $V_{DS}=V_{GS}-V_T$

$I_D=?$

$I_G=0$

$I_B=0$

Saturation Region of Operation



$V_{BS} = 0$

$$I_D = \mu C_{OX} \frac{W}{L}\left(V_{GS} - V_T - \frac{V_{DS}}{2}\right)V_{DS}$$

or equivalently

For V_{DS} at saturation

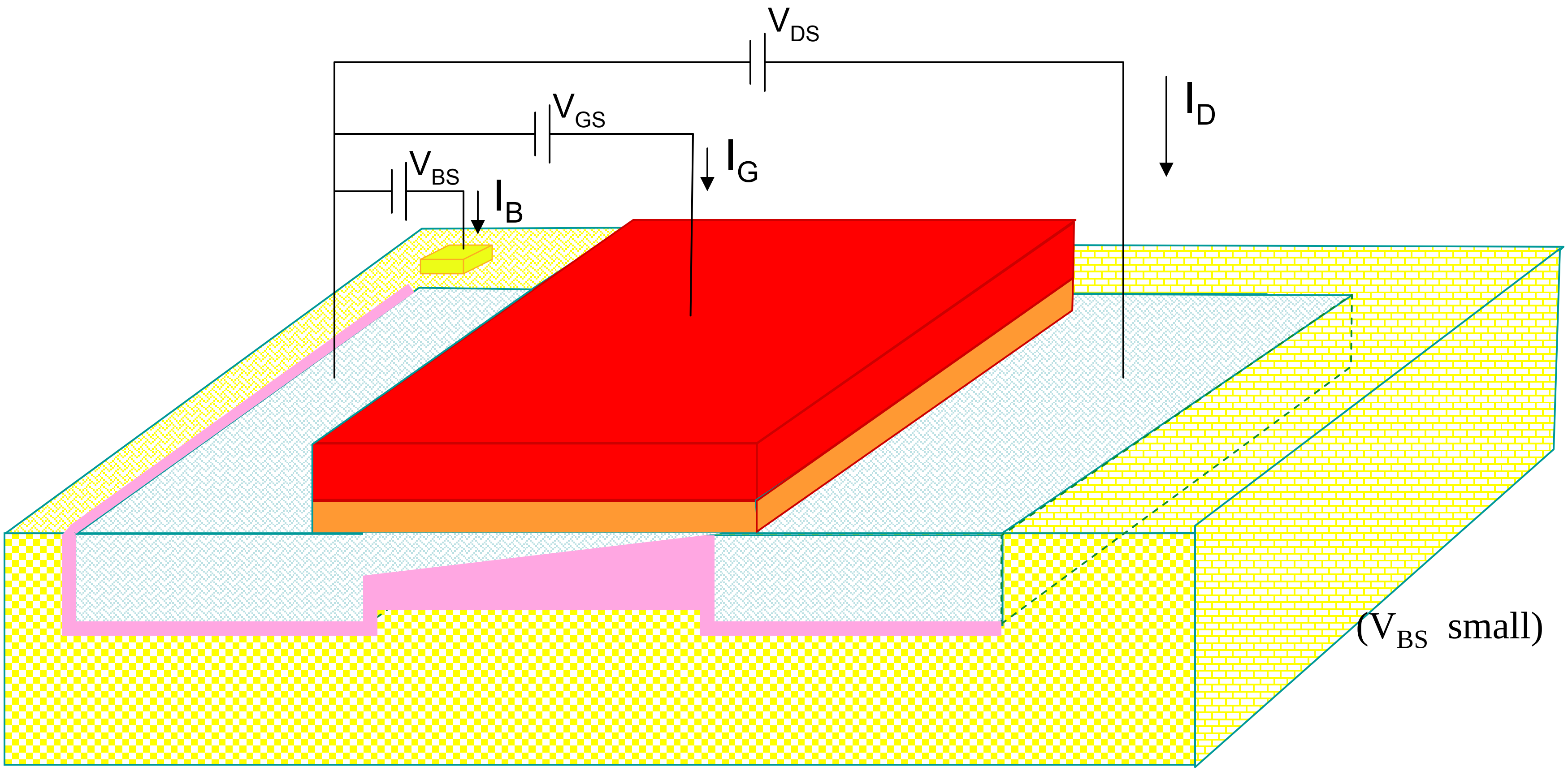
$$I_D = \mu C_{OX} \frac{W}{L}\left(V_{GS} - V_T - \frac{V_{GS} - V_T}{2}\right)(V_{GS} - V_T)$$

or equivalently

$$I_D = \frac{\mu C_{OX} W}{2L}(V_{GS} - V_T)^2$$

$$I_G = I_B = 0$$

n-Channel MOSFET Operation and Model



Increase V_{DS} even more (beyond V_{GS}-V_T)

Nothing much changes !!

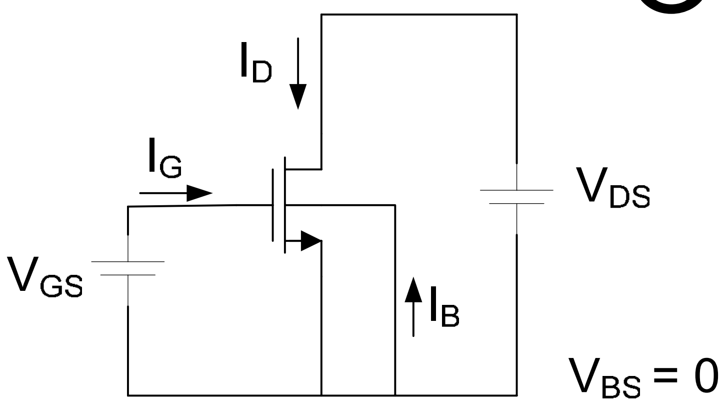
Termed “saturation”region of operation

I_D=?

I_G=0

I_B=0

Saturation Region of Operation

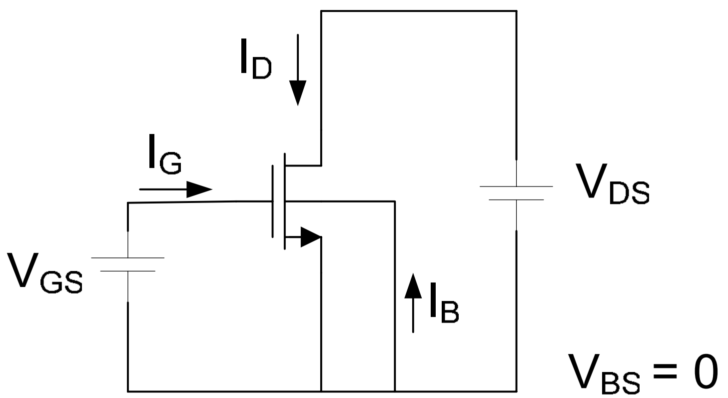


For V_{DS} in Saturation

$$I_D = \frac{\mu C_{OX} W}{2L}\left(V_{GS} - V_T\right)^2$$

$$I_G = I_B = 0$$

Model Summary



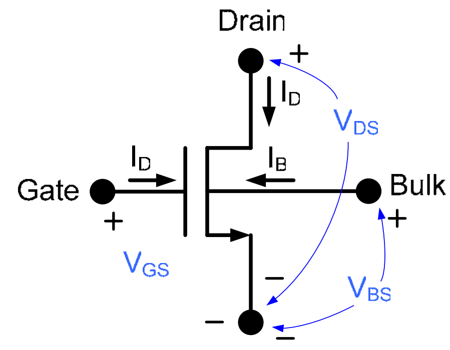
$$I_D = \begin{cases} 0 & V_{GS} \le V_T \\ \mu C_{OX} \dfrac{W}{L}\left(V_{GS} - V_T - \dfrac{V_{DS}}{2}\right)V_{DS} & V_{GS} \ge V_T \quad V_{DS} < V_{GS} - V_T \\ \mu C_{OX} \dfrac{W}{2L}\left(V_{GS} - V_T\right)^2 & V_{GS} \ge V_T \quad V_{DS} \ge V_{GS} - V_T \end{cases}$$

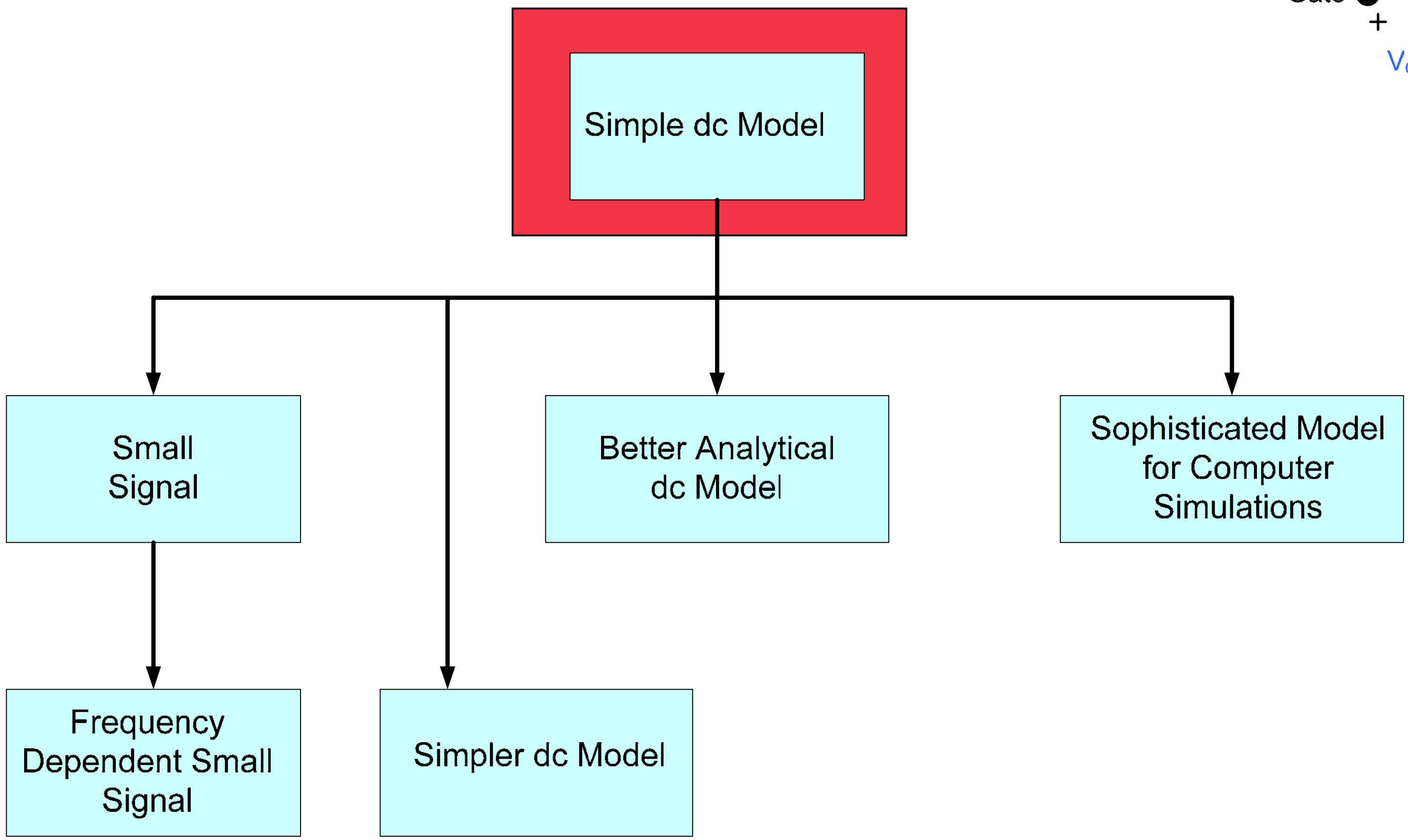
Note: This is the third model we have introduced for the MOSFET

Modeling of the MOSFET

Goal: Obtain a mathematical relationship between the port variables of a device.

$$
\left.\begin{aligned}
I_D &= f_1(V_{GS}, V_{DS}, V_{BS}) \\
I_G &= f_2(V_{GS}, V_{DS}, V_{BS}) \\
I_B &= f_3(V_{GS}, V_{DS}, V_{BS})
\end{aligned}\right\}
$$





Modeling of the MOSFET

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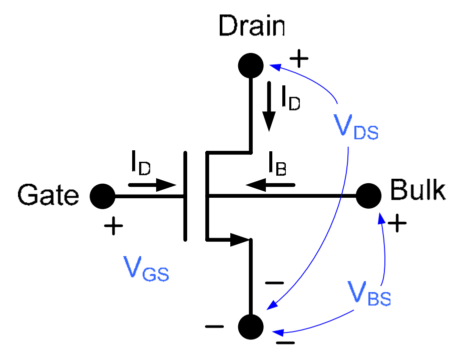

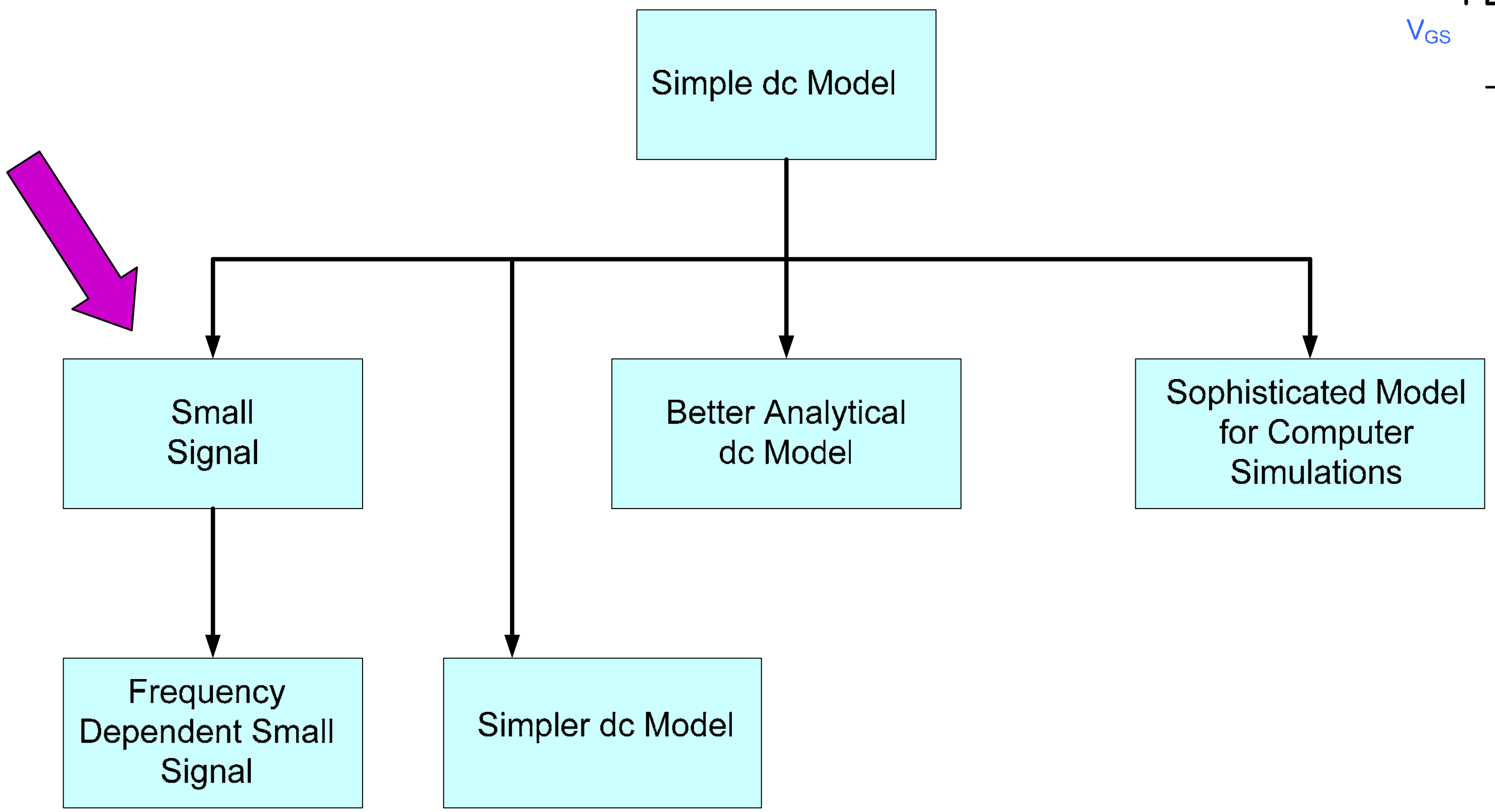

End of Lecture 15