PURDUE UNIVERSITY

NCN

www.nanohub.org

ECE606: Solid State Devices
Lecture 34: MOSCAP Frequency Response

Muhammad Ashraful Alam
alam@purdue.edu

Outline

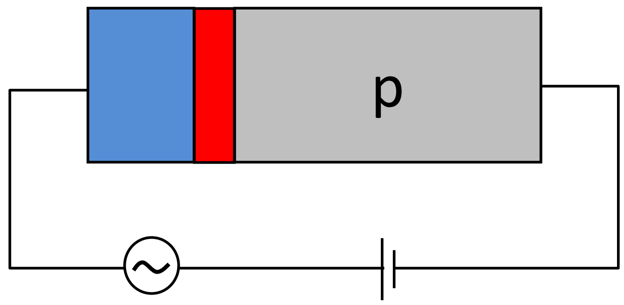
1. **Background**
2. Small signal capacitances
3. Large signal capacitance
4. Conclusion

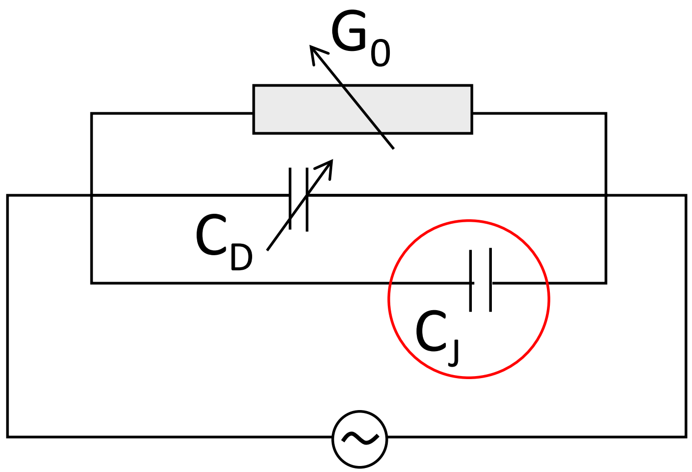
Ref: Sec. 16.4 of SDF

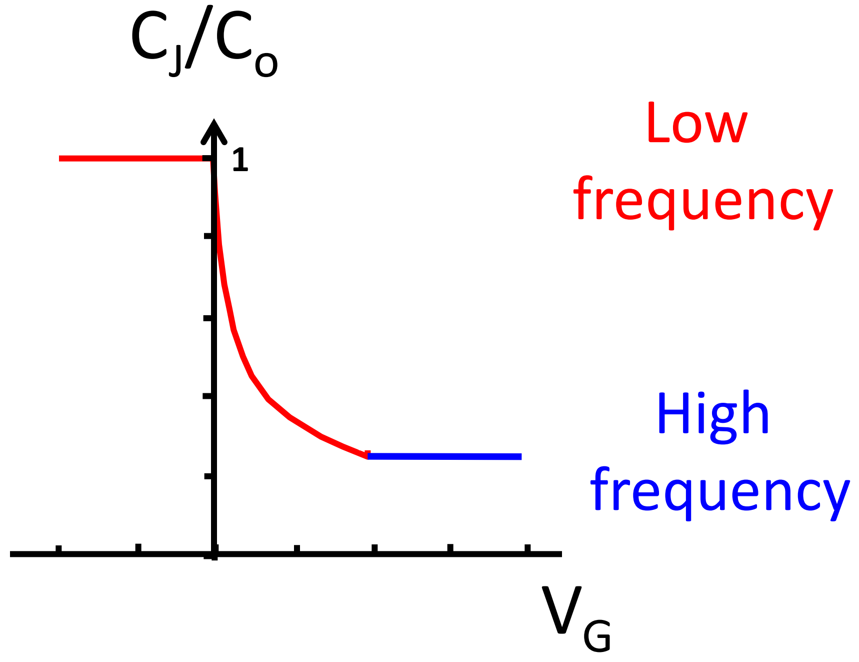
Topic Map

	Equilibrium	DC	**Small signal**	Large Signal	Circuits
Diode					
Schottky					
BJT/HBT					
MOSCAP			◆		

Small Signal Equivalent Circuit

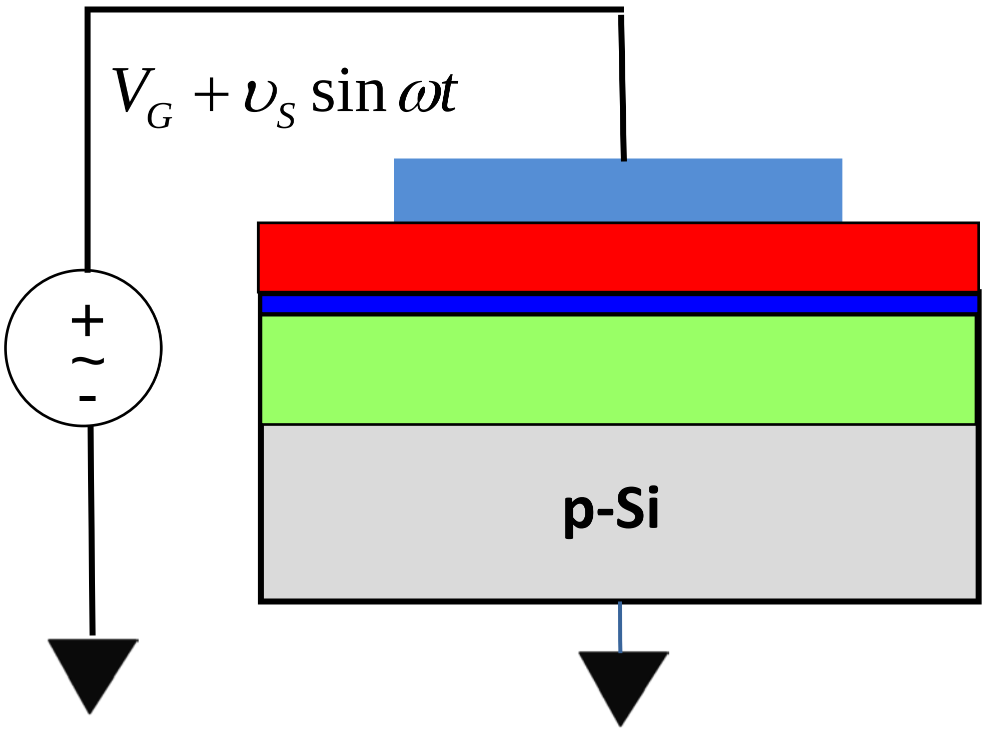






For insulated devices, consider only majority carrier junction capacitance C_J

Junction Capacitance



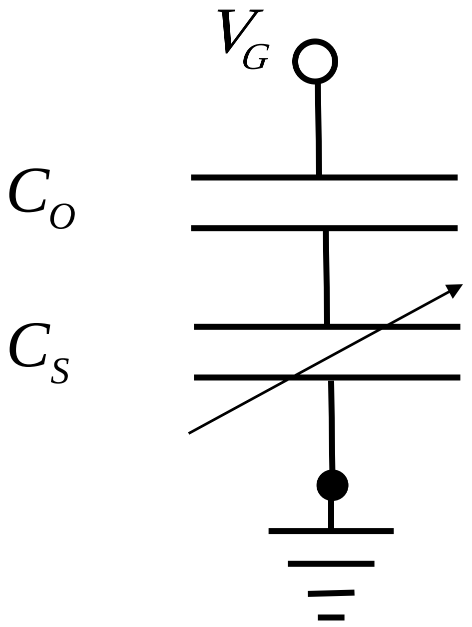
$$C_G \equiv \frac{dQ_G}{dV_G} = \frac{d(-Q_S)}{dV_G}$$

$$V_G = \psi_S - \frac{Q_S}{C_O}$$

$$\frac{dV_G}{d(-Q_S)} = \frac{d\psi_S}{d(-Q_S)} + \frac{1}{C_O}$$

$$\frac{1}{C_G} = \frac{1}{C_S} + \frac{1}{C_O}$$

Junction Capacitance



$$\frac{1}{C_G} = \frac{1}{C_S} + \frac{1}{C_O}$$

$$C_S \equiv \frac{d\left(-Q_S\right)}{d\psi_S}$$

$$Q_S\left(\psi_S\right)$$

which we already understand!

Definition of *m* for later use

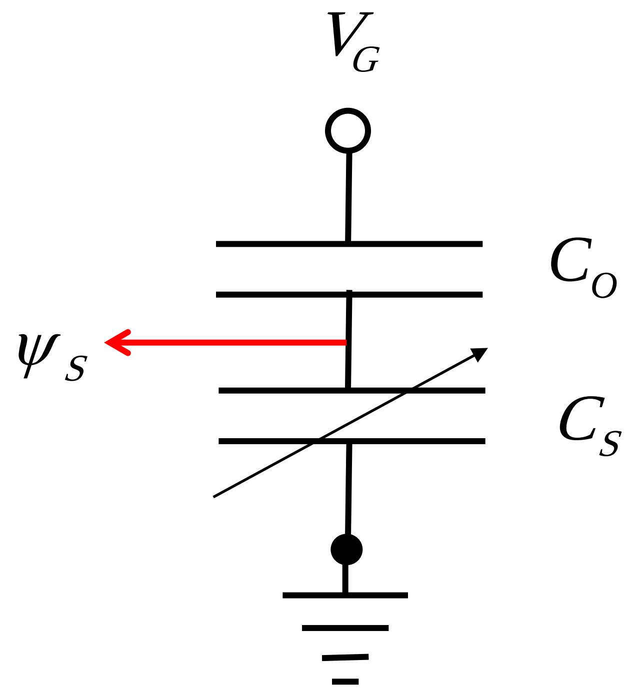
$$m = \left(1 + C_S / C_O\right)$$

'body effect coefficient'

$$m = \left(1 + \kappa_S x_O / \kappa_0 W_T\right)$$

in practice:

$$1.1 \leq m \leq 1.4$$



$$\psi_S = \frac{C_O}{C_O + C_S} V_G \equiv \frac{V_G}{m}$$

Outline

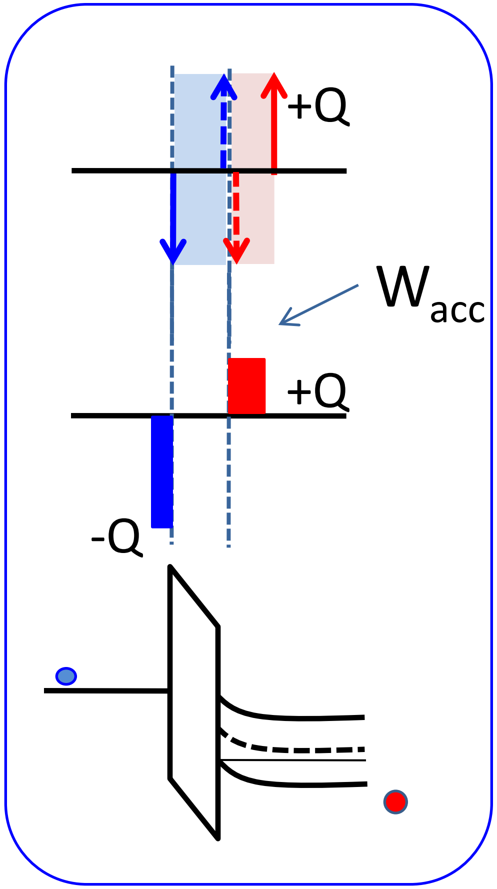
1. Background
2. **Small signal capacitances**
3. Large signal capacitance
4. Conclusion

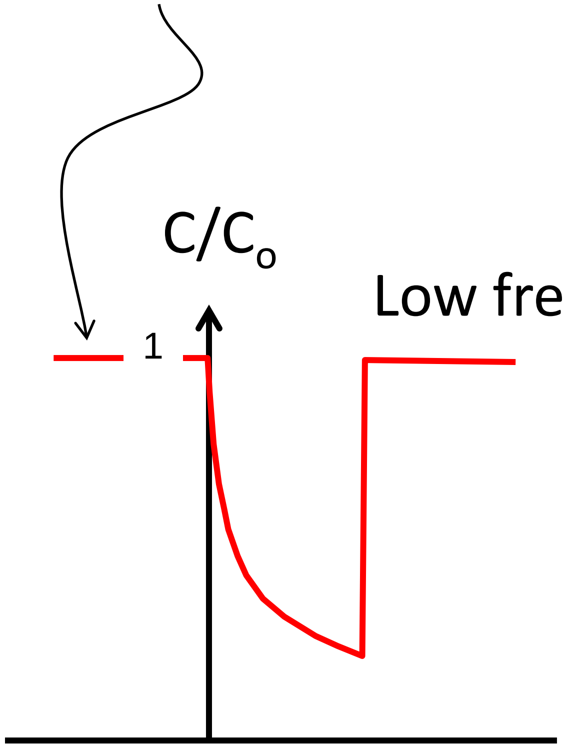
Junction Capacitance *in accumulation*

$$C_{j,acc} \approx \frac{\kappa_{ox}\varepsilon_0}{x_0} \equiv C_0$$

$$C_{j,acc} = \frac{C_o C_{s,acc}}{C_o + C_{s,acc}}$$

$$C_{s,acc} \equiv \frac{\kappa_s \varepsilon_0}{W_{acc}}$$

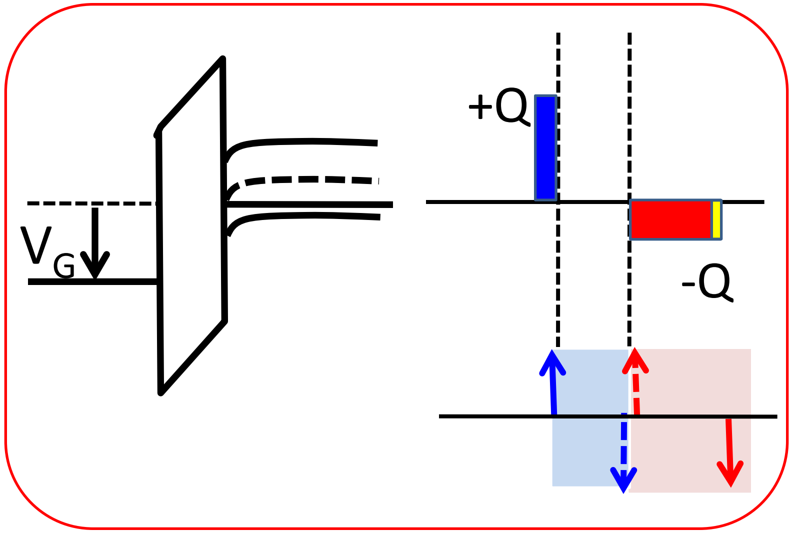




Junction Capacitance *in depletion*

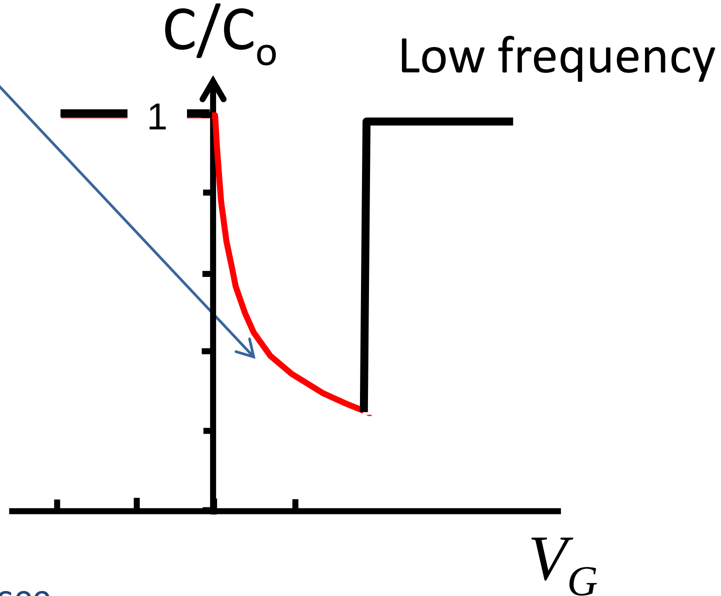
$$C_{j,dep} = \frac{C_0 C_s}{C_0 + C_s} = \frac{C_0}{1 + C_0 / C_s}$$

$$= \frac{C_0}{1 + \frac{\kappa_o \varepsilon_0}{x_0} \Big/ \frac{\kappa_s \varepsilon_0}{W}} = \frac{C_o}{\sqrt{1 + \frac{V_G}{V_\delta}}}$$

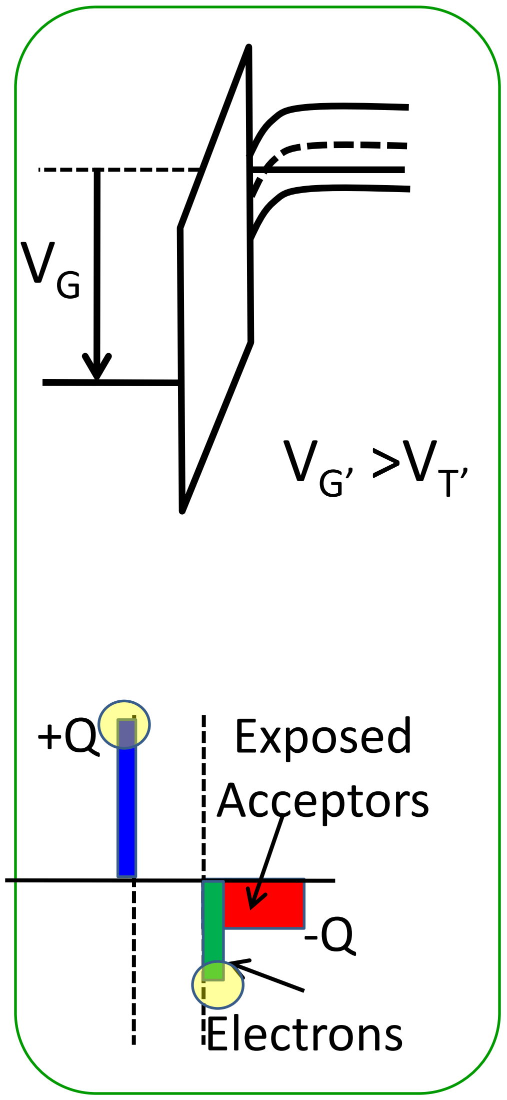


$$V_G = \frac{qN_A W}{\kappa_o \varepsilon_0} x_0 + \left(\frac{qN_A W^2}{2\kappa_s \varepsilon_0} \right)$$

$$\frac{\kappa_o}{\kappa_s} \frac{W}{x_0} = \sqrt{1 + \frac{V_G}{V_\delta}} - 1$$

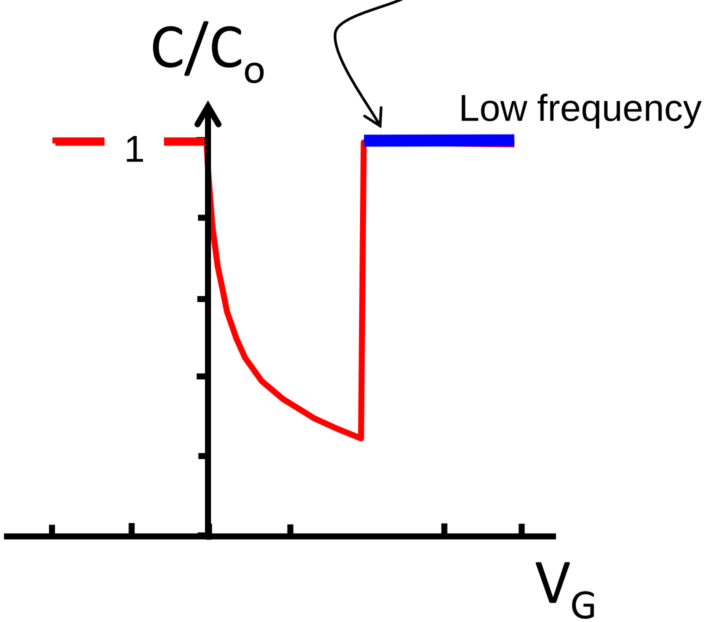


Junction capacitance *in inversion*



$$C_{j,inv} \approx \frac{\kappa_s \varepsilon_0}{x_0} \equiv C_0$$

$$C_{j,inv} = \frac{C_o C_{inv}}{C_o + C_{inv}} \qquad C_{inv} \equiv \frac{\kappa_s \varepsilon_0}{W_{inv}}$$

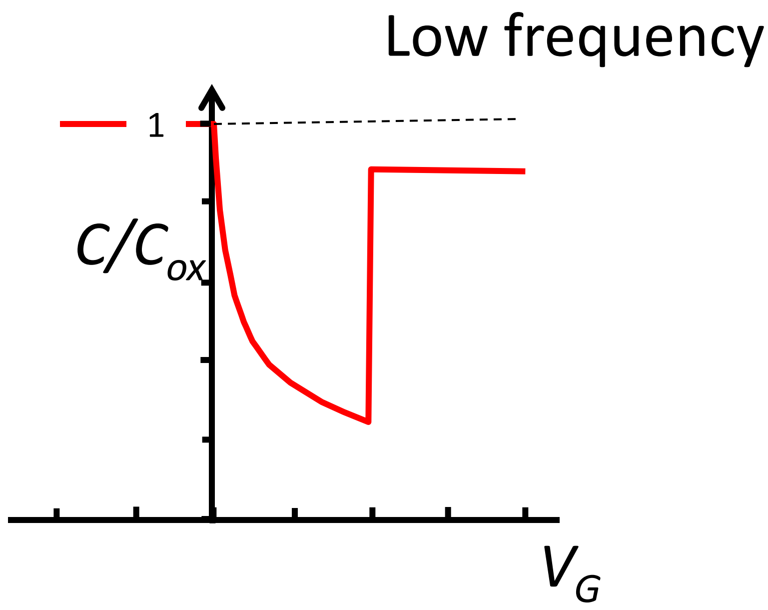


Equivalent Oxide Thickness

$$Q_i = -C_G\left(V_G - V_T\right)$$

$$C_G = C_{j,inv} = \frac{C_o C_{inv}}{C_{inv} + C_o} < C_o$$

$$C_o = \frac{\kappa_o \varepsilon_o}{x_0} \qquad C_{inv} \equiv \frac{\kappa_s \varepsilon_o}{W_{inv}}$$

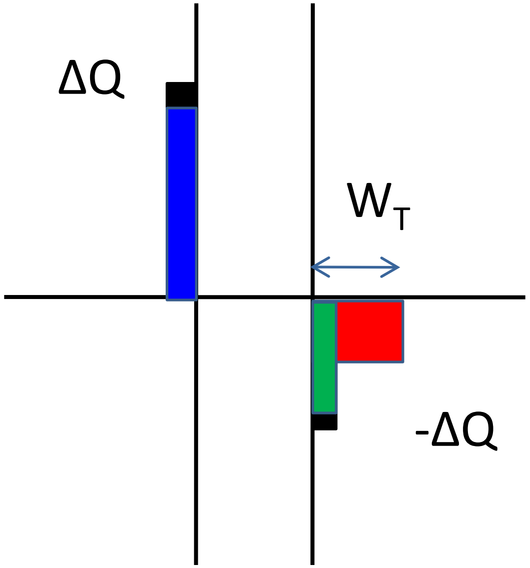


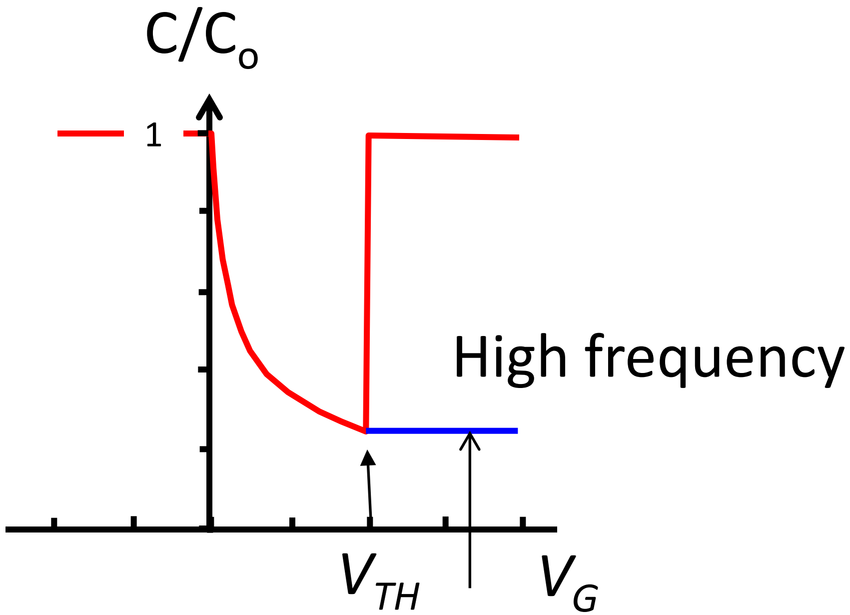
$$C_G = \frac{\kappa_{ox}\varepsilon_O}{EOT_{elec}} \qquad EOT_{elec} = x_O + \left(\frac{\kappa_{ox}\varepsilon_O}{\kappa_s \varepsilon_O}\right) W_{inv} > x_O$$

'Equivalent oxide thickness - electrical '

High frequency curve *at inversion*

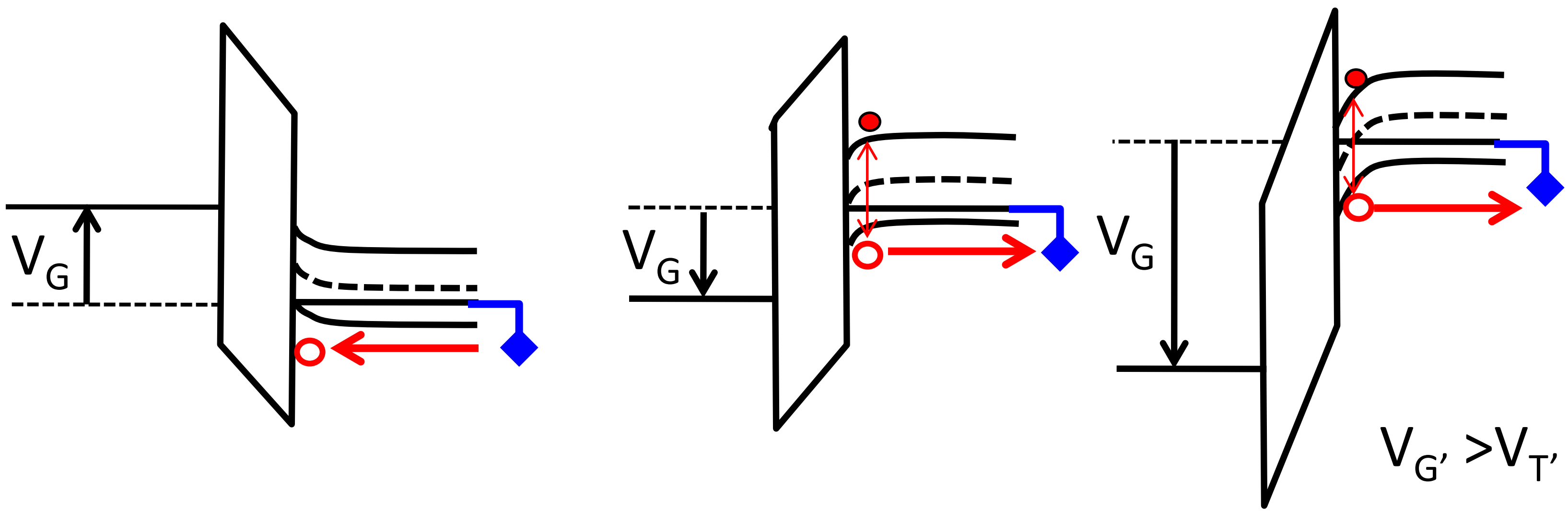
$$C_{j,inv} \approx \frac{\kappa_s \varepsilon_0}{x_0} \equiv C_0$$





What about high frequency part of the curve?

Response Time



Dielectric Relaxation

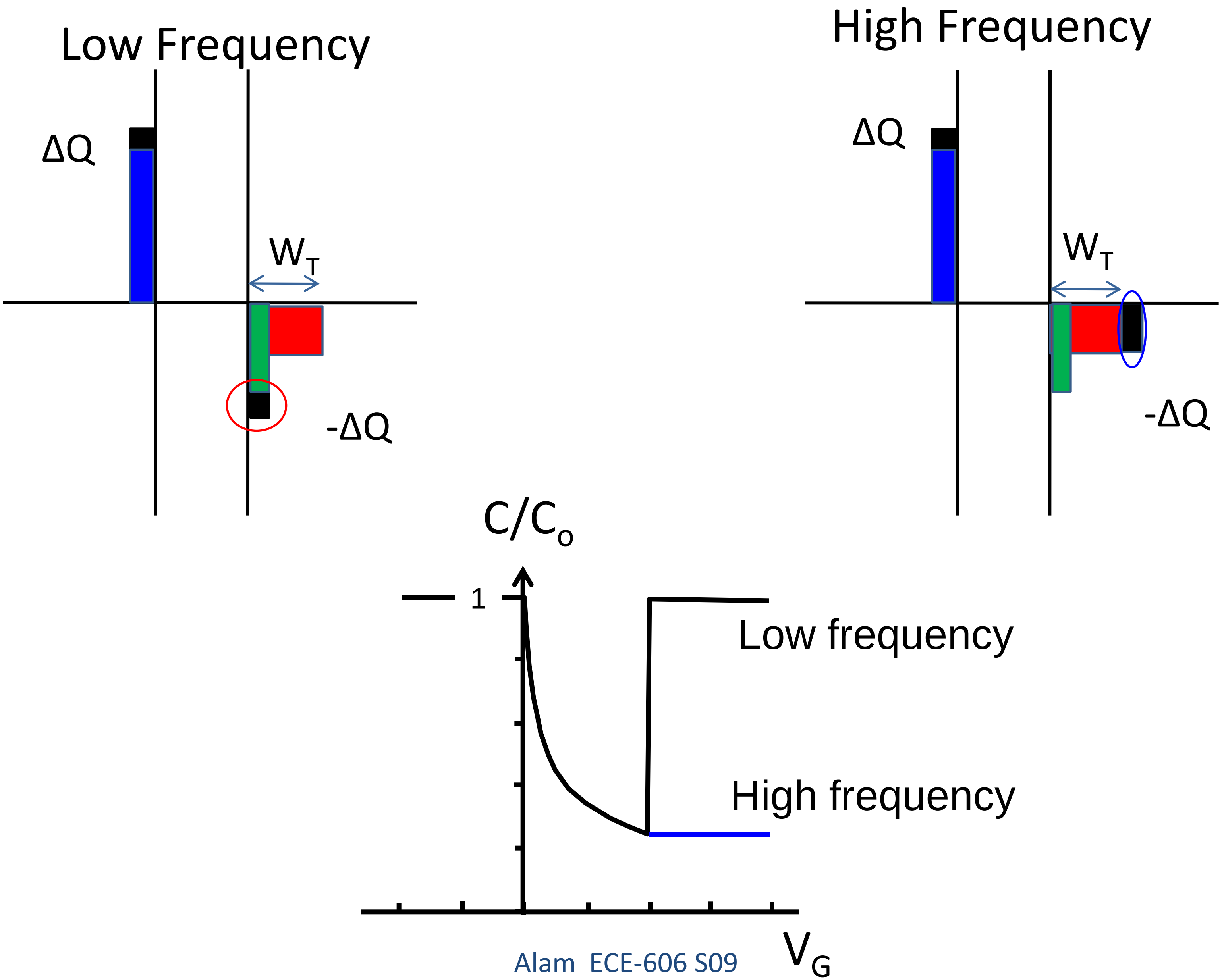
$$\tau = \frac{\sigma}{\kappa_s \varepsilon_0}$$

SRH Recombination-Generation

$$R = \frac{np - n_i^2}{\tau_n(p + p_1) + \tau_p(n + n_1)} \rightarrow \frac{-n_i}{\tau_n + \tau_p}$$

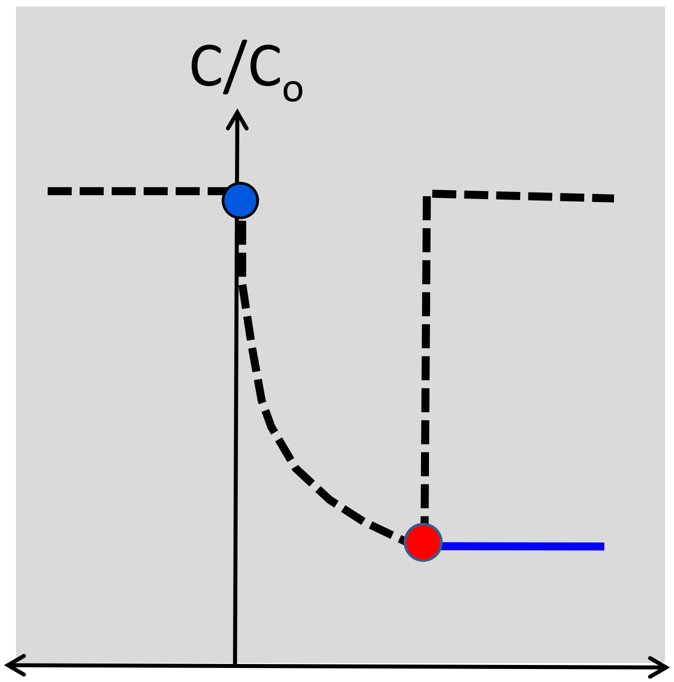
Ref. Lecture no. 15

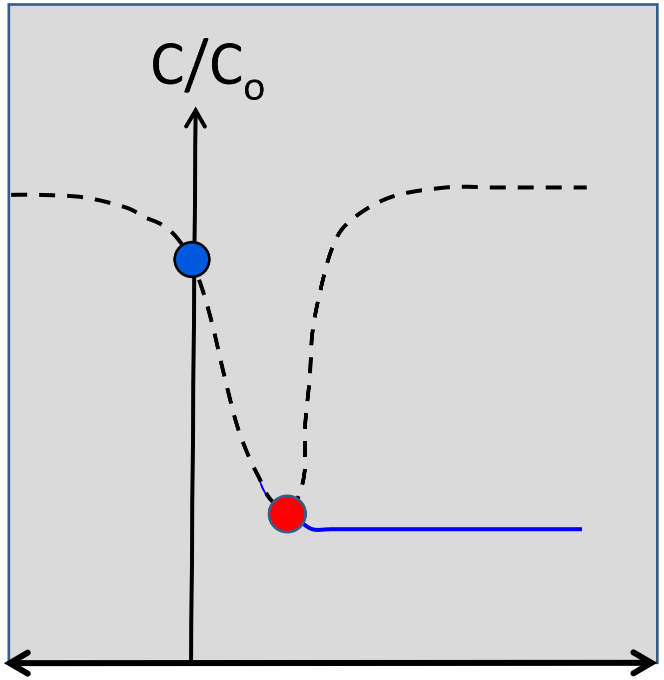
High frequency response in MOS-C



Ideal vs. Real C-V Characteristics

Flat band voltage …





Threshold voltage …

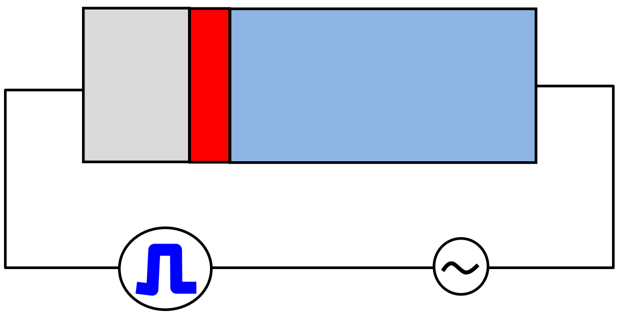
Outline

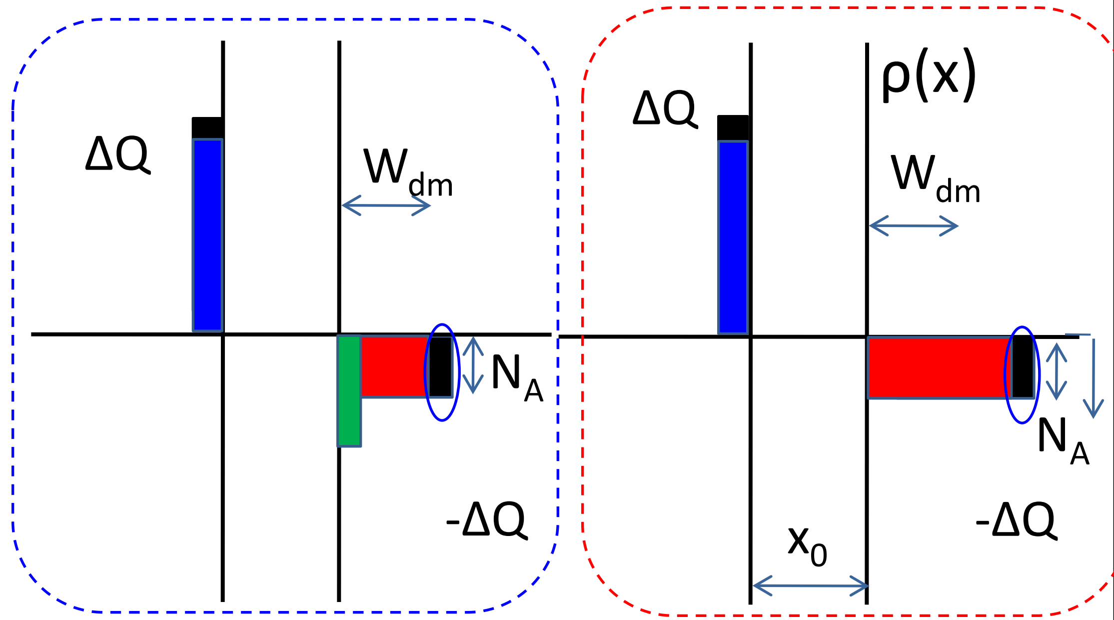
1. Background
2. Small signal capacitances
3. **Large signal capacitance**
4. Conclusion

Topic Map

	Equilibrium	DC	Small signal	**Large Signal**	Circuits
Diode					
Schottky					
BJT/HBT					
MOS					

Large Signal Deep Depletion

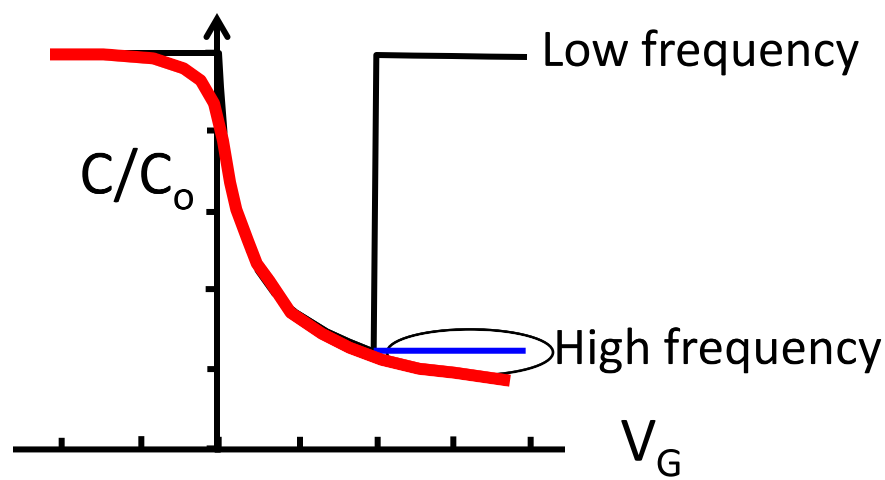




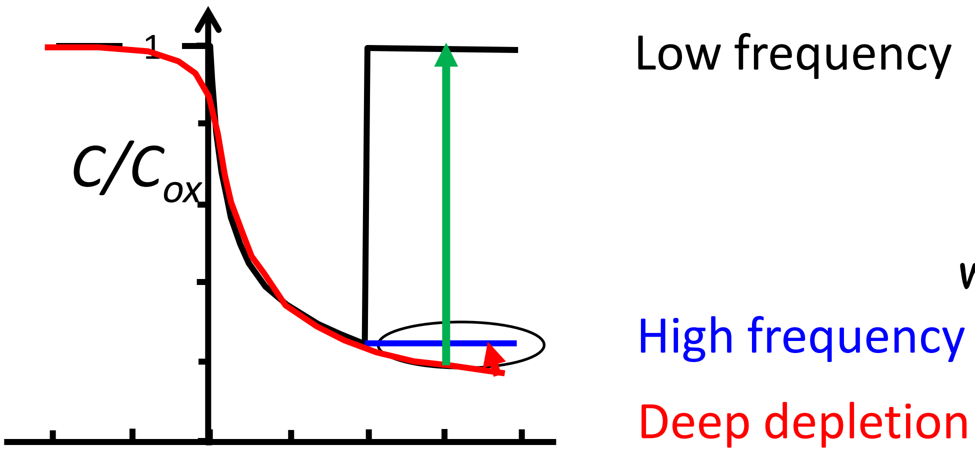
$$C_{j,dep} = \frac{C_0 C_s}{C_0 + C_s} = \frac{C_0}{1 + \frac{\kappa_{ox}}{\kappa_s}\frac{W}{x_0}}$$

$$= \frac{C_o}{\sqrt{1 + \frac{V_G}{V_\delta}}}$$

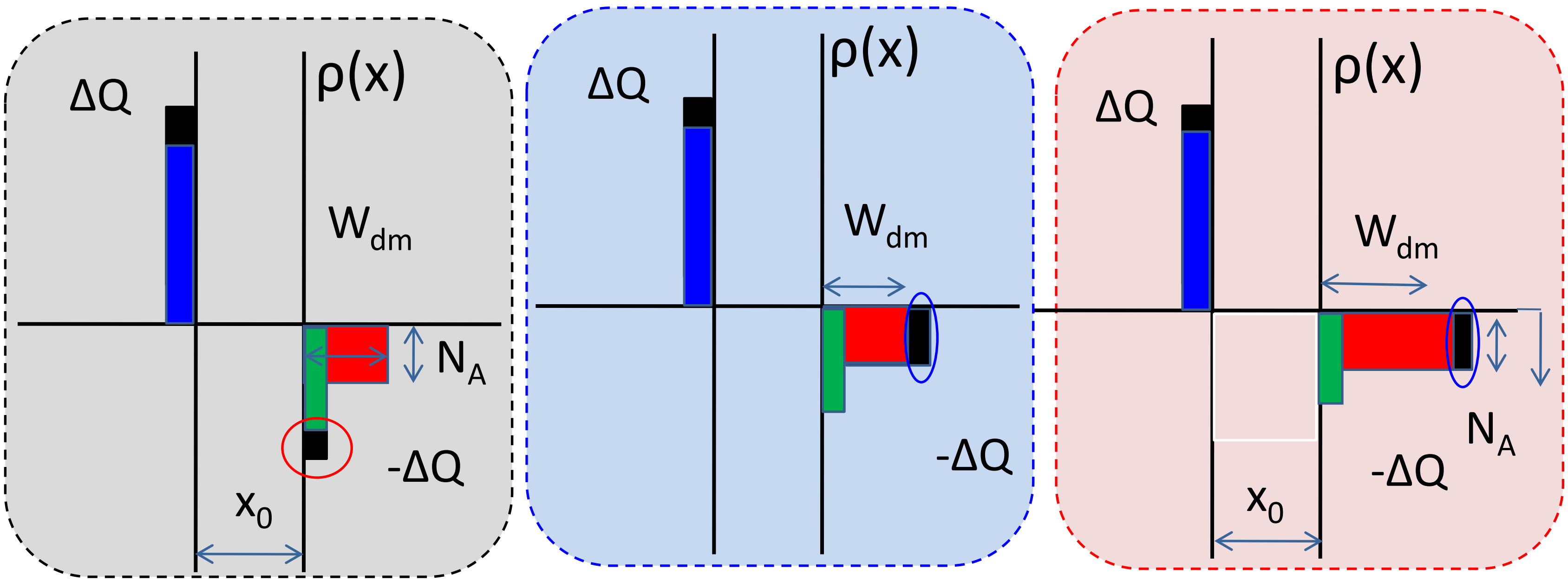
(even beyond threshold)



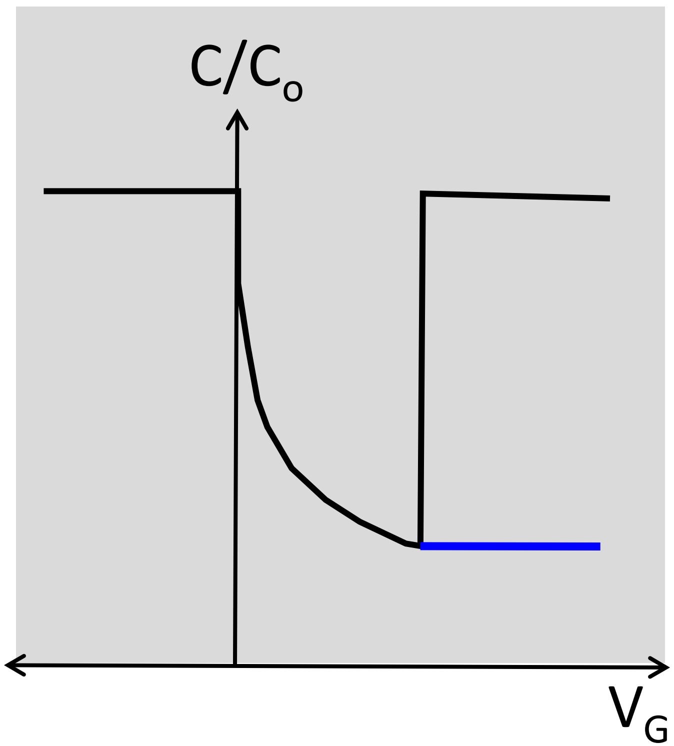
Relaxation from Deep Depletion



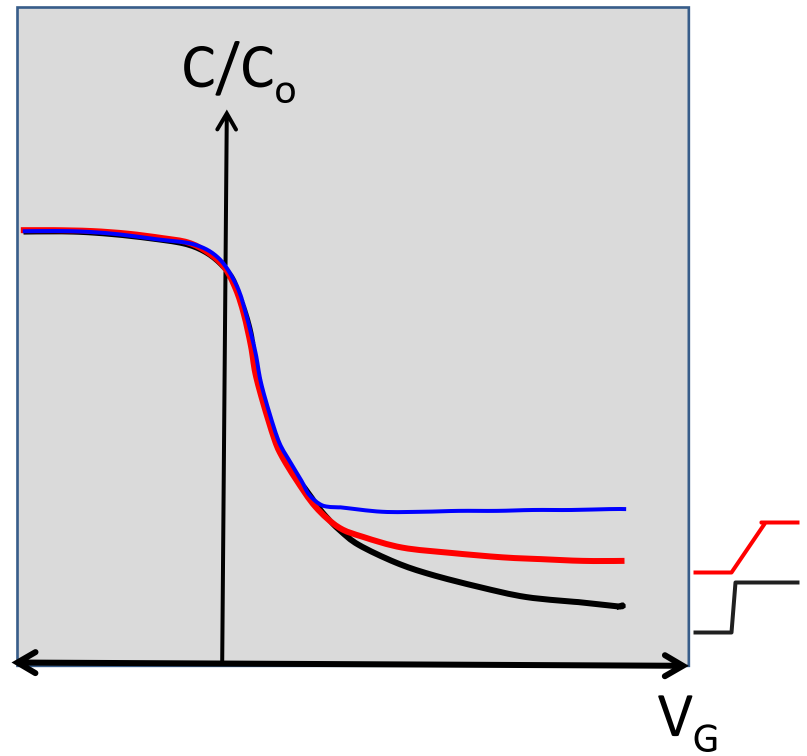
Depending on the measurement frequency, it will either merge with low-freq. or high-freq. curve.



Ideal vs. Real C-V Characteristics

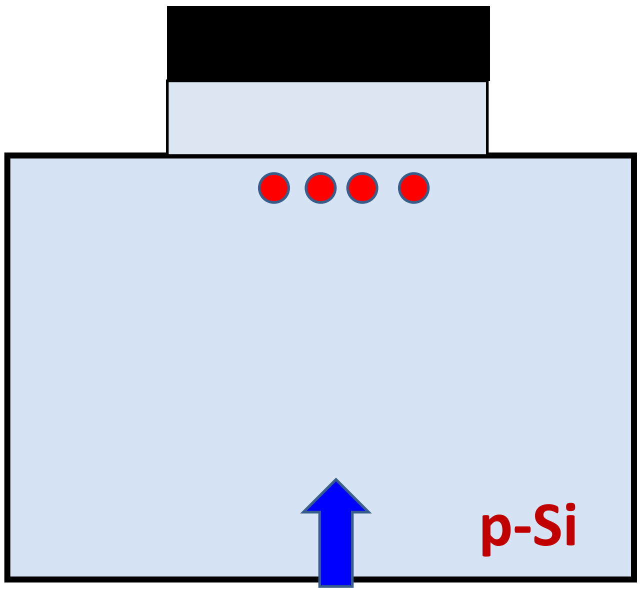


Flat band voltage …



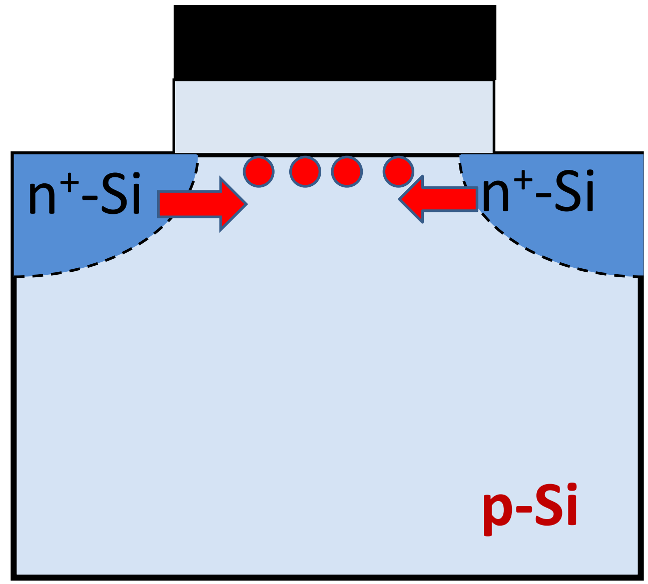
Threshold voltage …

Low or High frequency?



typically observe hi-frequency CV

$$G = \frac{n_i}{2\tau}$$



typically observe low-frequency CV
No deep-depletion as well

What happens if I shine light on a MOS capacitor?

Summary

1) Since current flow through the oxide is small, we are primarily interested in the junction capacitance of the MOS-capacitor.
2) High frequency of MOS-C is very different than low-frequency C-V. In MOSFET, we only see low frequency response.
3) Deep depletion is an important consideration for MOS-capacitor that does not happen in MOSFETs.