Advanced MOSFETs and Novel Devices

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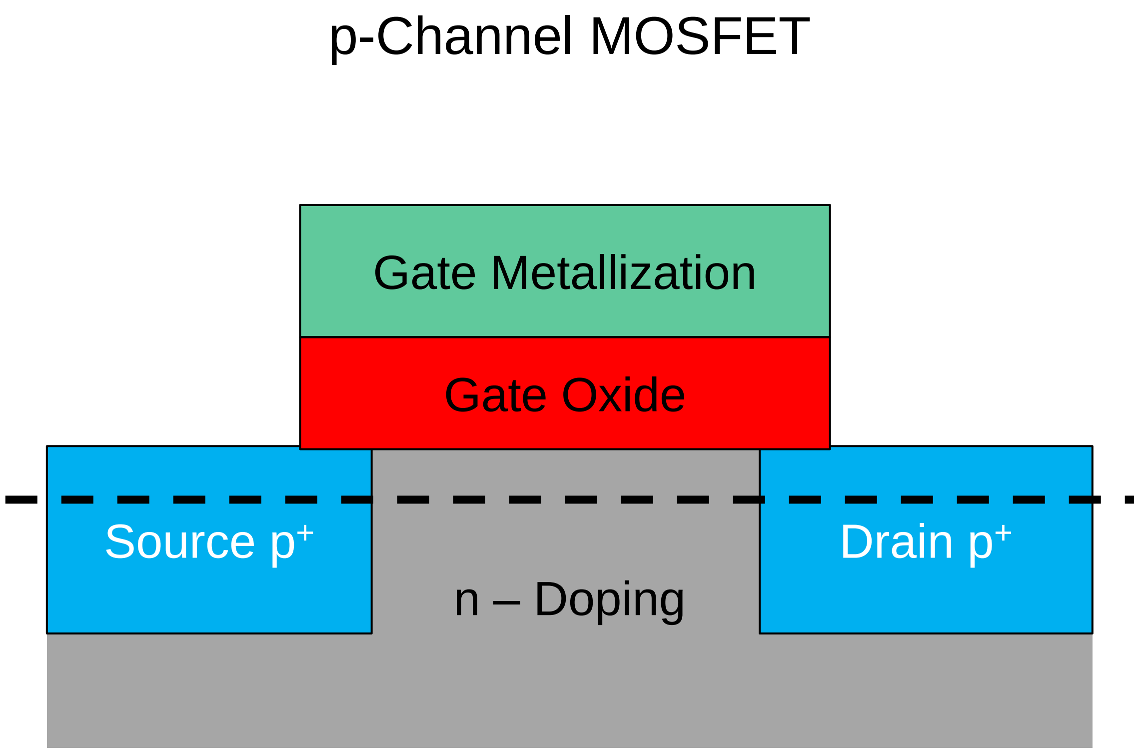
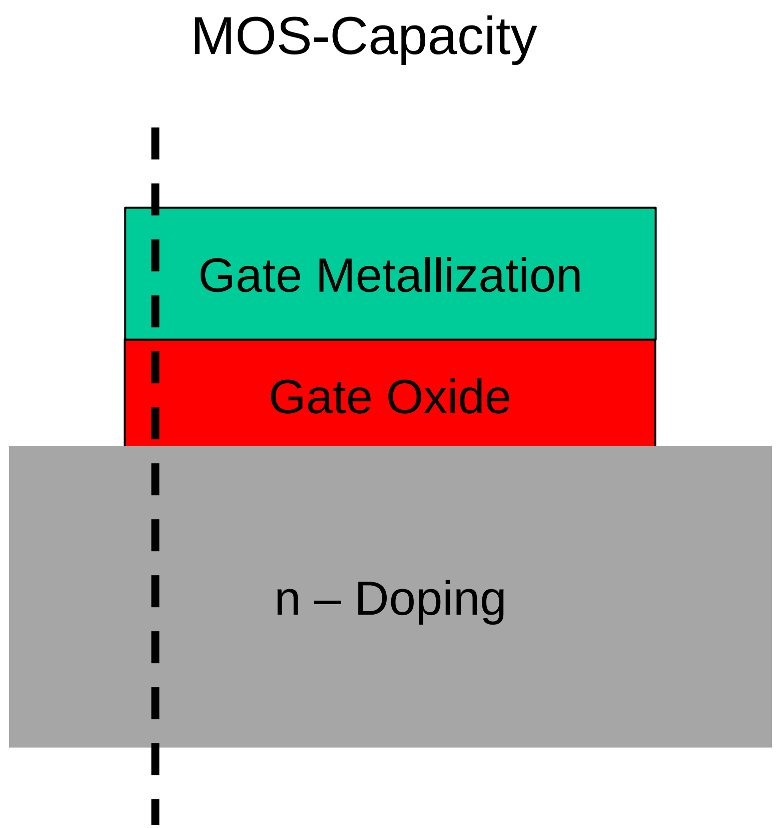
3. Tutorial & Exercise

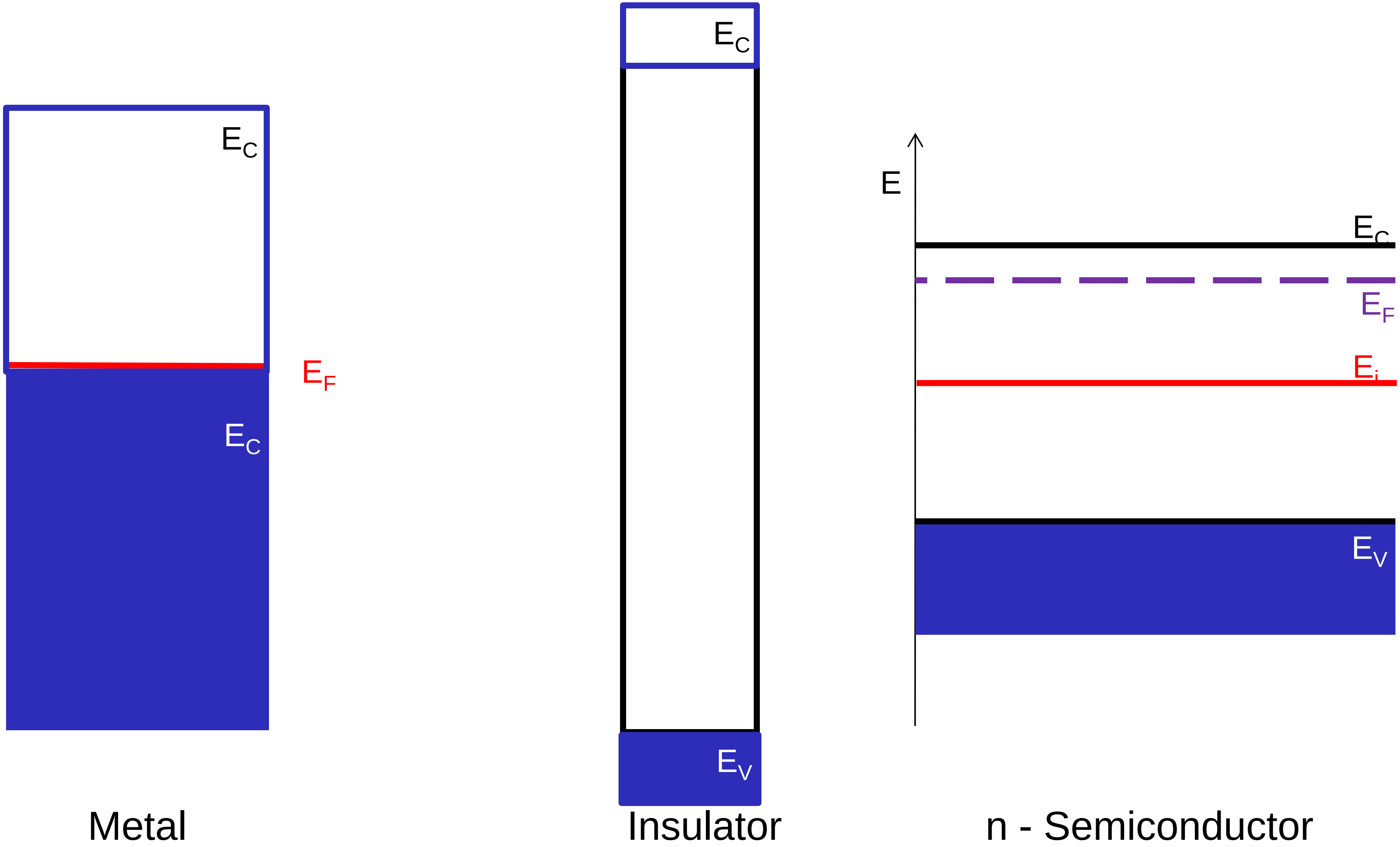
Threshold Voltage

Threshold Voltage – Band diagram MOSFET

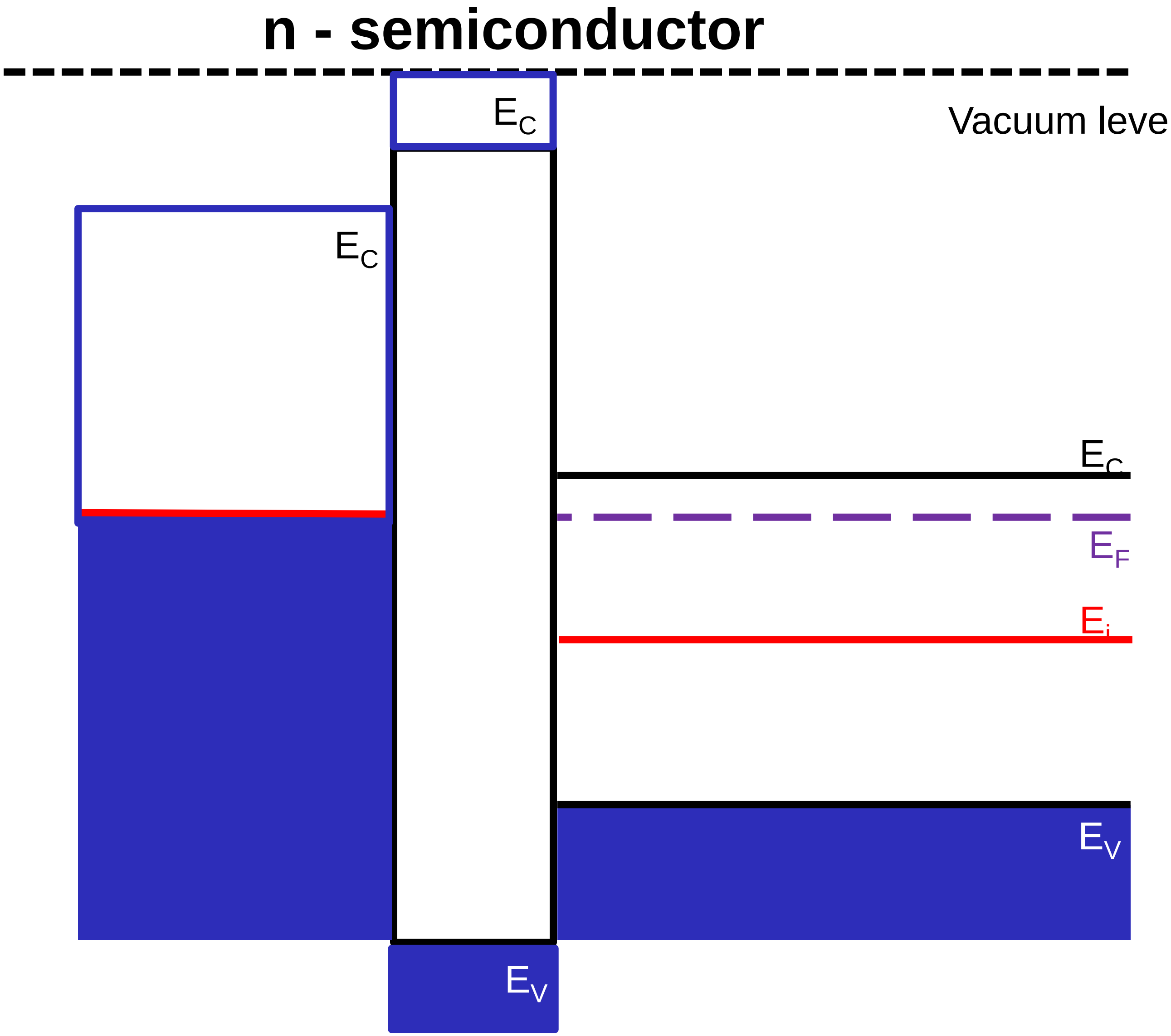




Threshold Voltage – Band diagram MOS-Capacity



Threshold Voltage – Band diagram MOS-Capacity

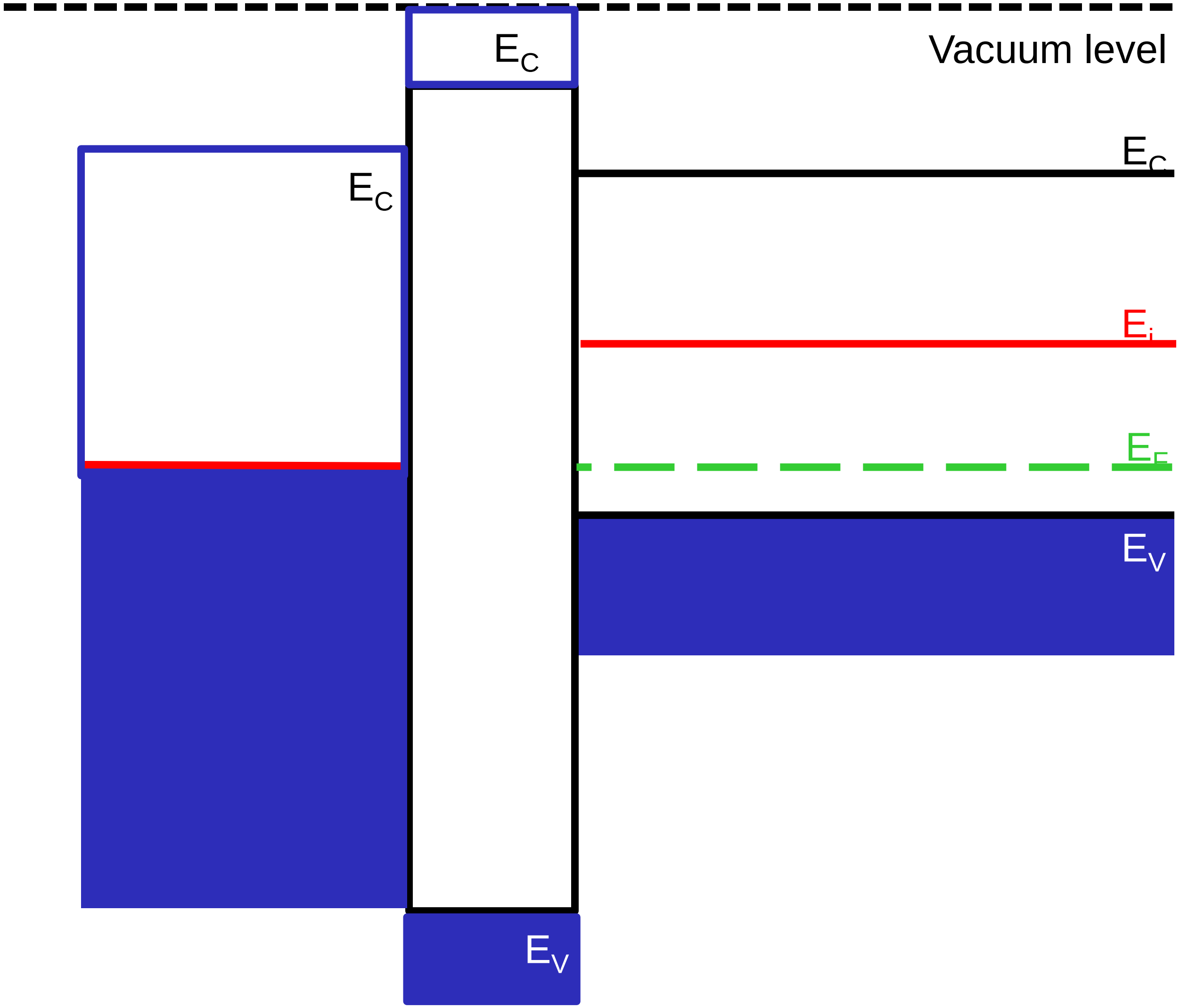


Assume:

- No work function difference between metal and semiconductor.
- Resistivity of the insulator is infinite.
- No oxide charges.

Threshold Voltage – Band diagram MOS-Capacity

p - semiconductor



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Threshold Voltage – Band diagram MOS-Capacity

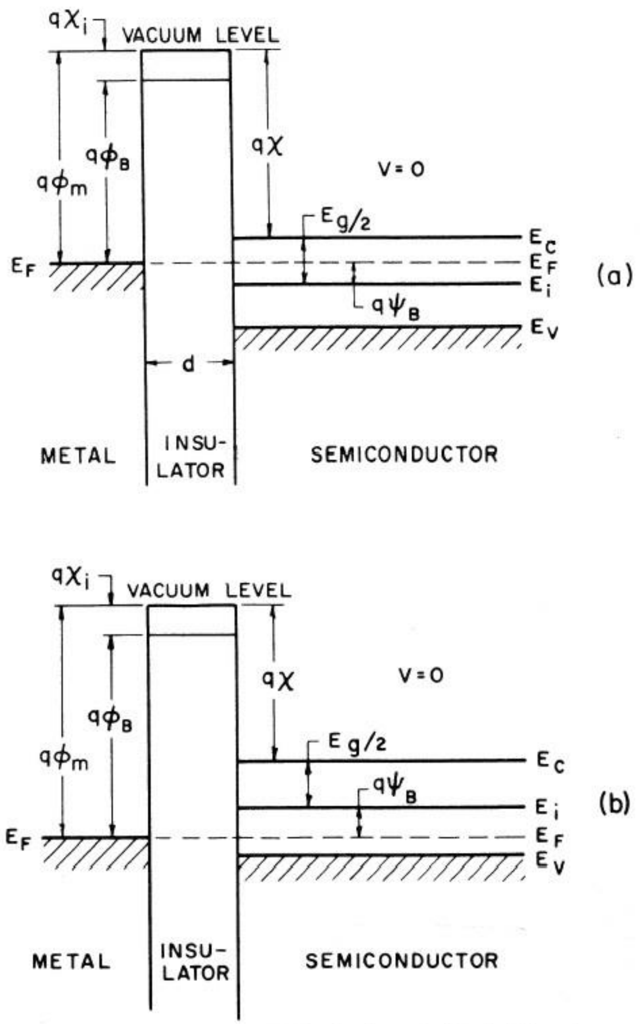


Fig. 2 Energy-band diagrams of ideal MIS diodes at $V = 0$. (*a*) *n*-type semiconductor. (*b*) *p*-type semiconductor.

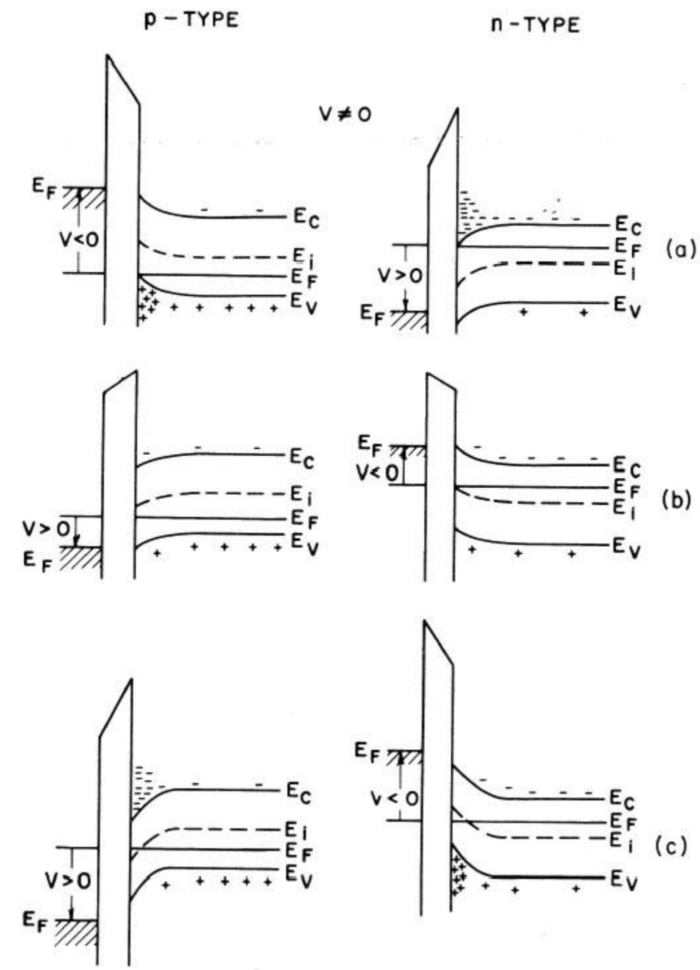
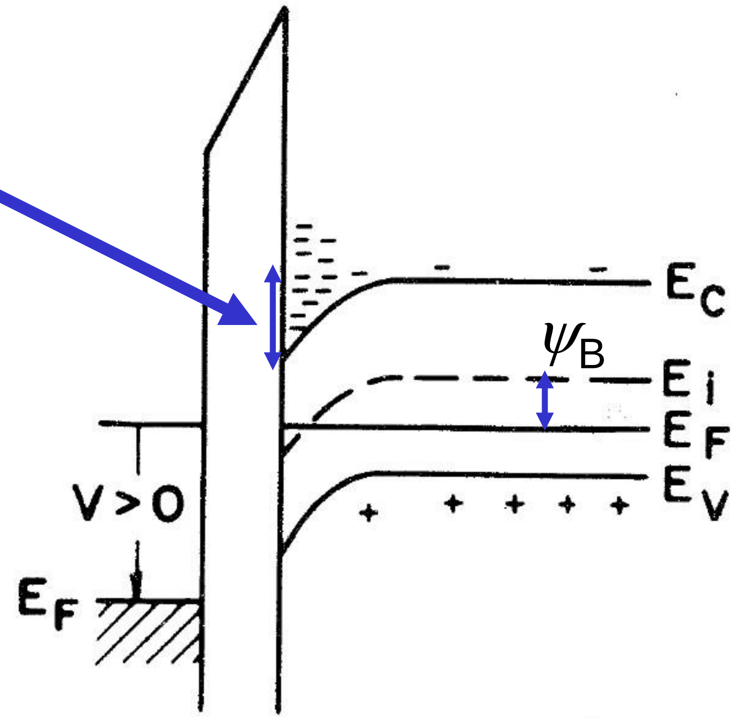
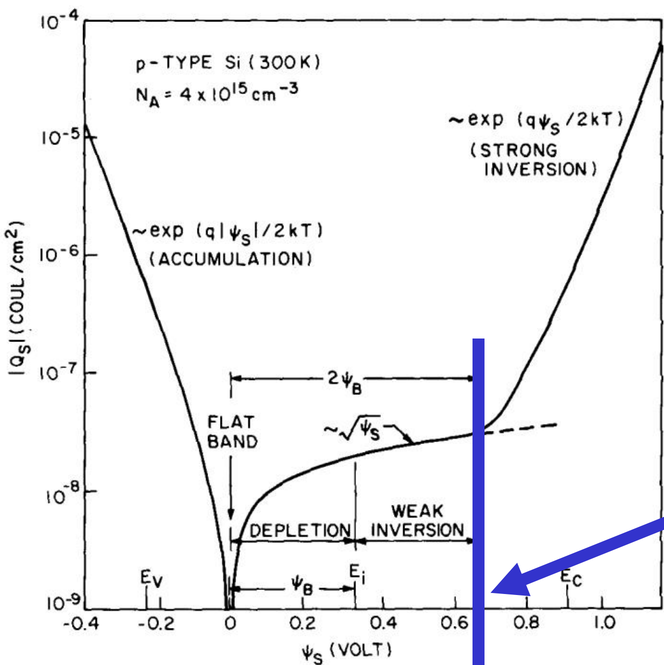


Fig. 3 Energy-band diagrams for ideal MIS diodes when $V \neq 0$, for the following cases: (*a*) accumulation; (*b*) depletion; (*c*) inversion.

Definition: band bending at the Si-SiO_2-Interface is equal to $2^*\psi_B$

=> concentration of minority exceeds outnumbers the concentration of majority carriers in the bulk silicon

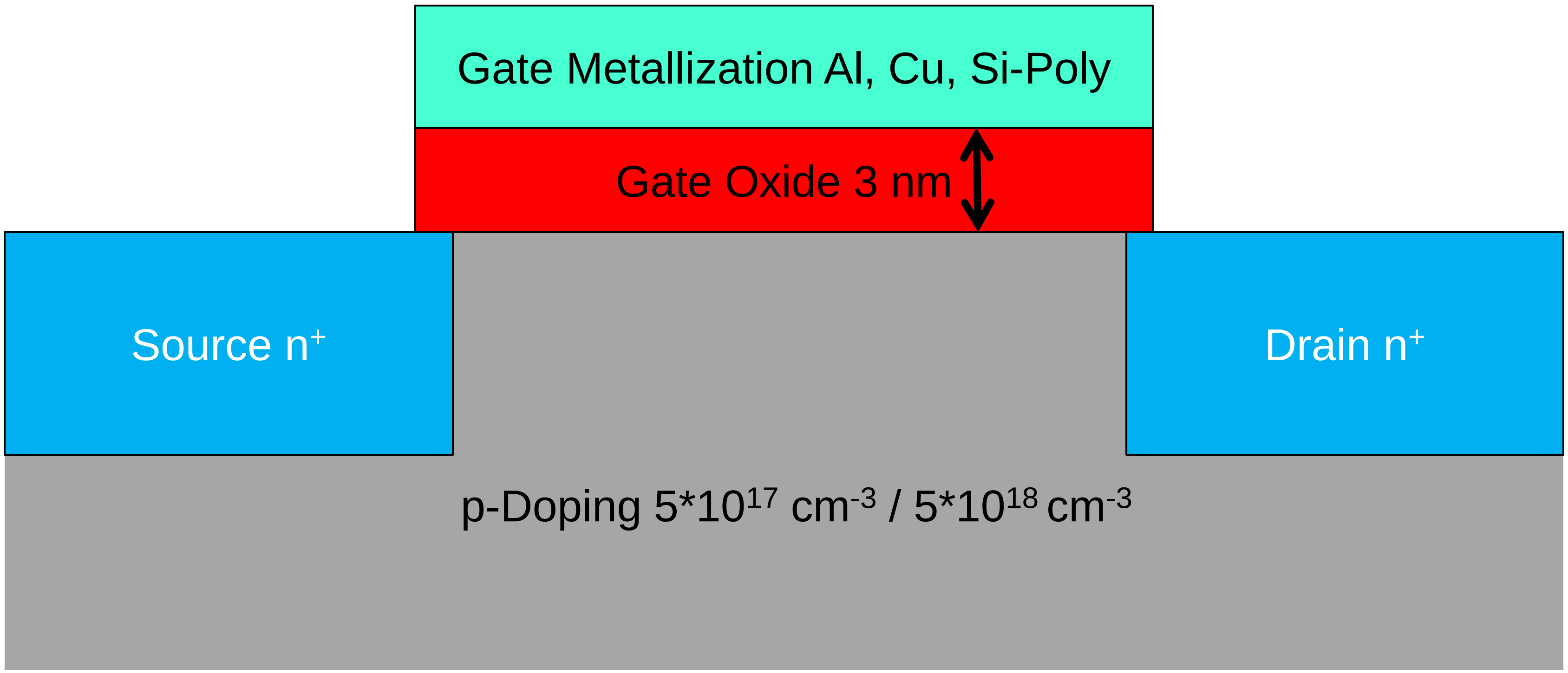




$$V_T = \phi_{MS} \pm \frac{Q''_{OX}}{C''_{OX}} \pm \frac{Q''_{Depl}}{C''_{OX}} \pm |2\psi_B|$$

Threshold Voltage – Exercise

Determine the threshold voltage V_T for a *n*-channel MOSFET with different gate metallization (Al, Cu, *n*- and *p*-poly Si) for two different channel dopings (5e17 cm^{-3} and 5e18 cm^{-3}) at room temperature. The thickness of the gate oxide is 3 nm. Oxide charges can be considered zero.



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Physical Constants	**e**	ε_0	k_B
	1.6E(-19) As	8.85E(-14) F/cm	8.6E(-5) eV/K

Parameters	E_g	χ	ε_r	n_i
Si	1.12 eV	4.05 V	11.9	1.45e10 cm^{-3}
SiO_2	8.8 eV	1.00 V	3.9	-

Metal	**Al**	**Cu**	***n*-poly Si**	***p*-poly Si**
$\phi_M-\chi_{Si}$	- 0.06 V	0.63 V	0.0 V	1.12 V

V_T Results

	Al	Cu	*n*-poly Si	*p*-poly Si
$N_A = 5e17\ cm^{-3}$				
$N_A = 5e18\ cm^{-3}$				

Major Design Parameters for V_T:

- Channel doping
- Work function of gate metallization
- Oxide thickness

Threshold Voltage – Solution

Threshold voltage: $V_T = |\frac{Q''_{Depl}}{C''_{ox}}| + |2\Psi_B| + \Phi_{MS} - \frac{Q''_{Ox}}{C''_{Ox}}$ N-channel MOSFET

Oxide charges: $Q''_{Ox} = 0 \Rightarrow \frac{Q''_{Ox}}{C''_{Ox}} = 0$

Workfunction difference: $\Phi_{\mathrm{MS}} = \Phi_M - \left(\mathrm{X}_{si} + \frac{E_g}{2\, q} + |\Psi_B| \right)$

Electrostatic bulk potential: $\Psi_B = \frac{k_B\, T}{q} \cdot \ln(\frac{N_{dop}}{n_i})$

Normalized Capacitor:

$C = \epsilon_0\, \epsilon_r\, \frac{A}{d}$ $C''_{Ox} = \frac{C_{Ox}}{A} = \frac{\epsilon_0\, \epsilon_{SiO_2}}{d_{ox}}$

Space charge:

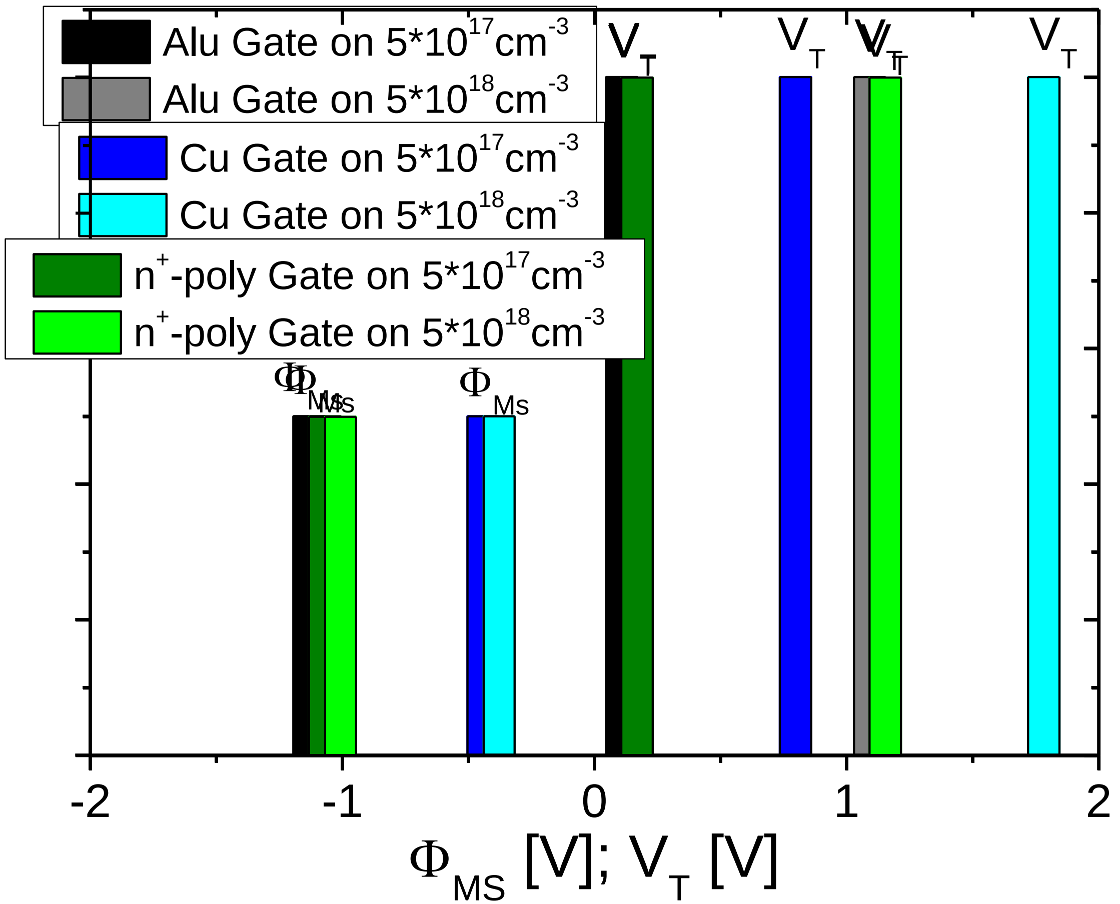
$$Q''_{Depl} = \int_0^{w_{max}} \rho_S(x)dx = w_{max} e\, N_A$$

Depletion region:

$$w_{max} = \sqrt{\frac{4\, \epsilon_0 \epsilon_{Si} |\Psi_B|}{e\, N_A}}$$

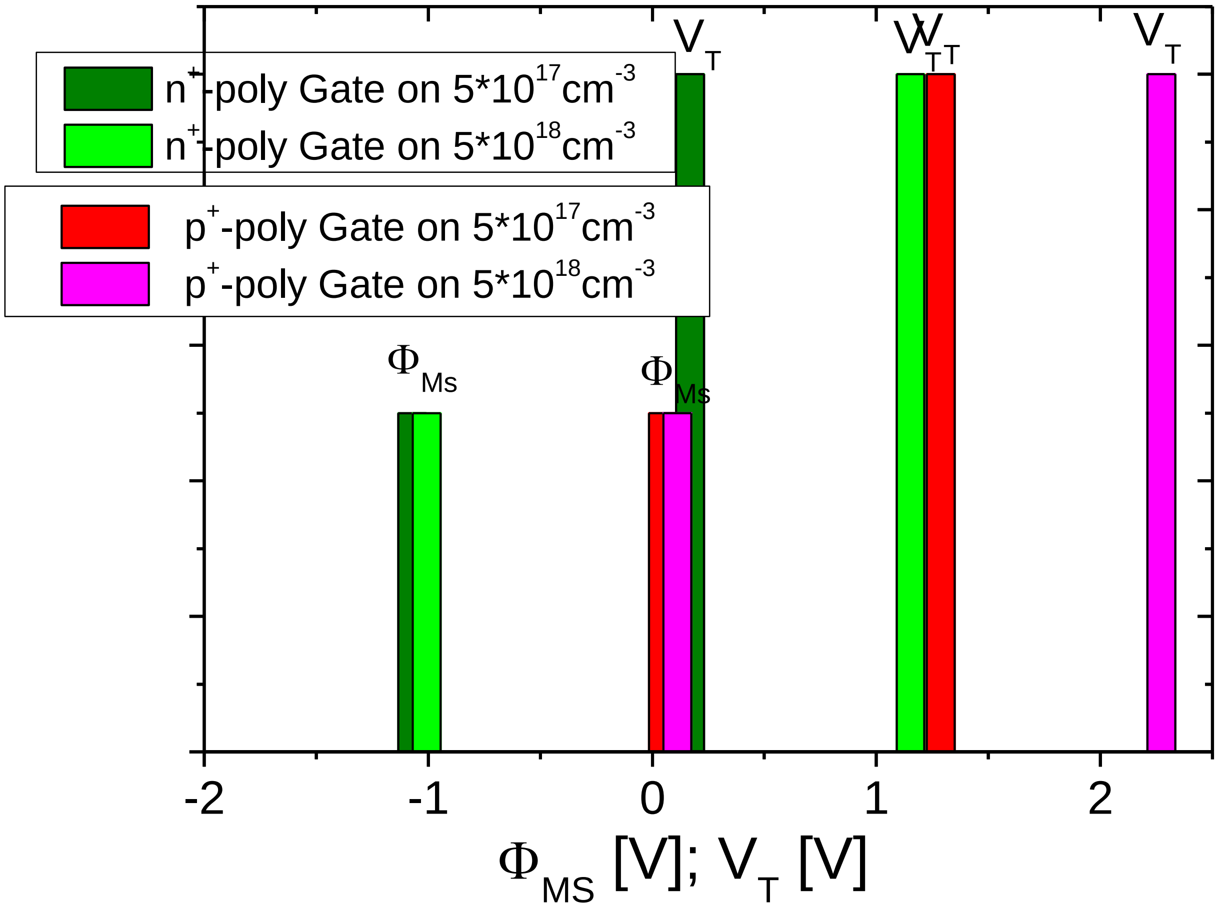
Threshold Voltage – Solution

Using different gate metals



We can see that the threshold voltage can be adjusted by the metal

Changing the doping of the polysilicon gate



V_T calculations for a symmetric CMOS-Inverter