Section 31
MOSFET Non-Idealities

31.3 Physics of interface traps

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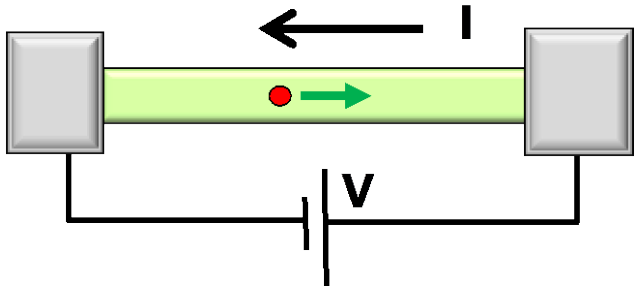
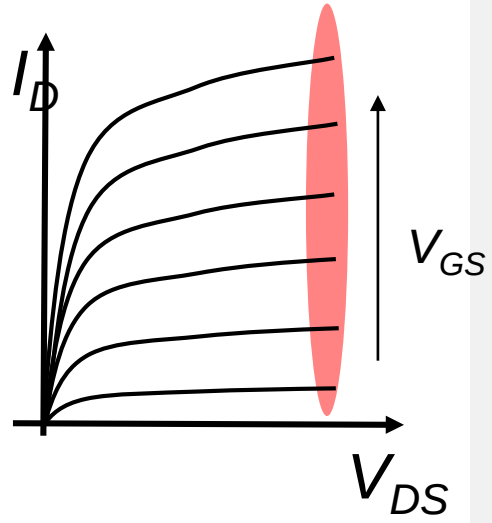


$$I = G \times V$$
$$= q \times n \times v \times A$$

charge density velocity area



1 • 31.1 Flat band voltage - What is it and how to measure it?

2 • 31.2 Threshold voltage shift due to trapped charges

3 • 31.3 Physics of interface traps

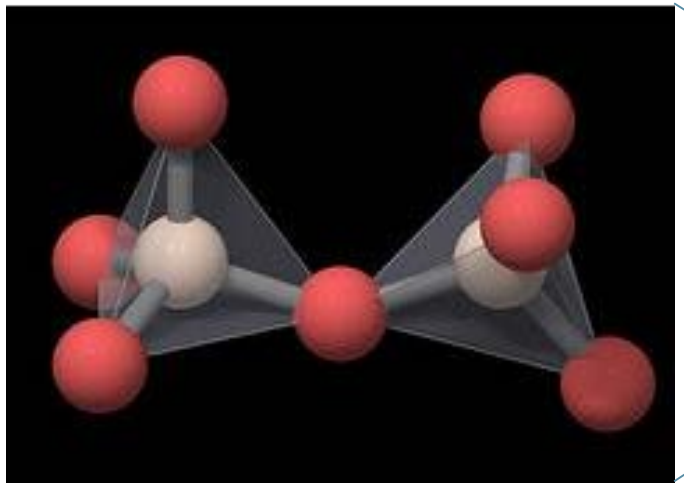
$$I_D(V_D = V_{DD}) \sim (V_G - V_{th})^{\alpha}$$
$$1 < \alpha < 2$$

$$V_{th} = V_{th,ideal} + \phi_{MS} - \frac{\gamma_M Q_M}{C_O} - \frac{Q_F}{C_O} - \frac{Q_{IT}(\phi_s)}{C_O}$$

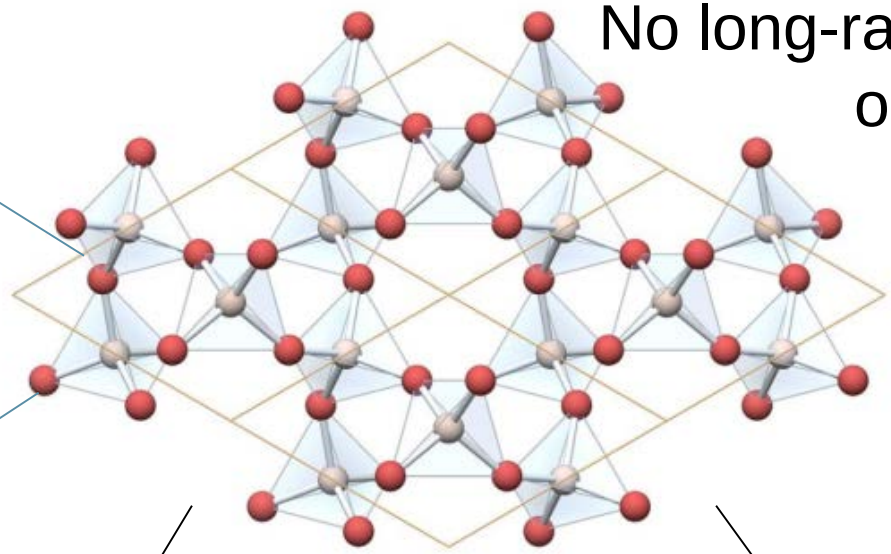
Metal contact Charge in oxide Fixed charge interface traps

Ref: Sec. 16.4 of SDF Chapter 18, SDF

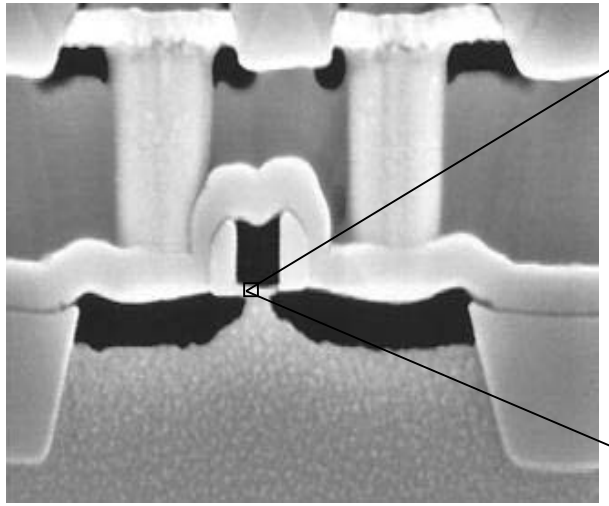
SiO and SiH Bonds

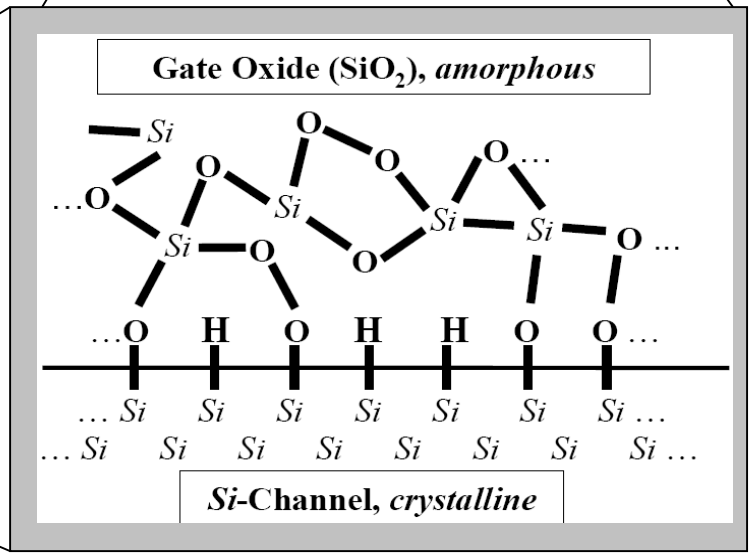


Local ordering tetrahedra

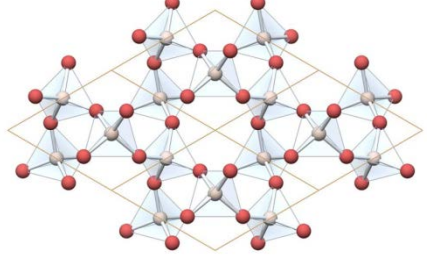


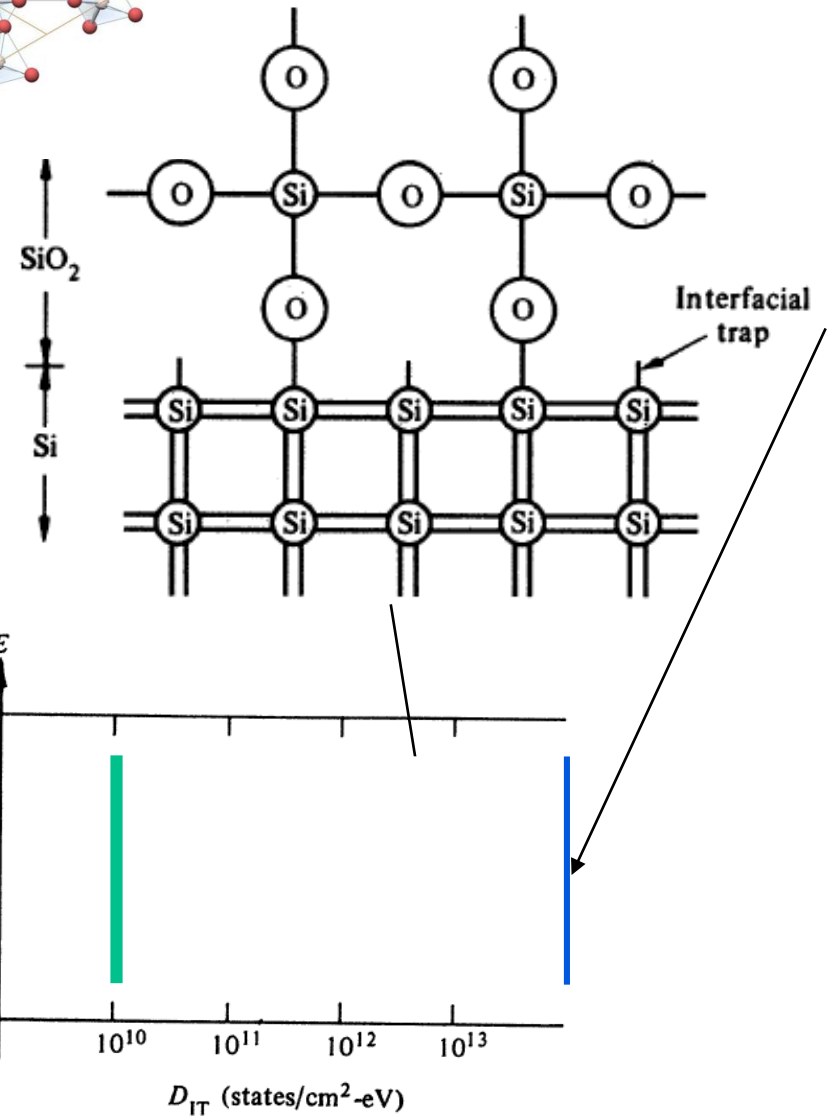
No long-range order

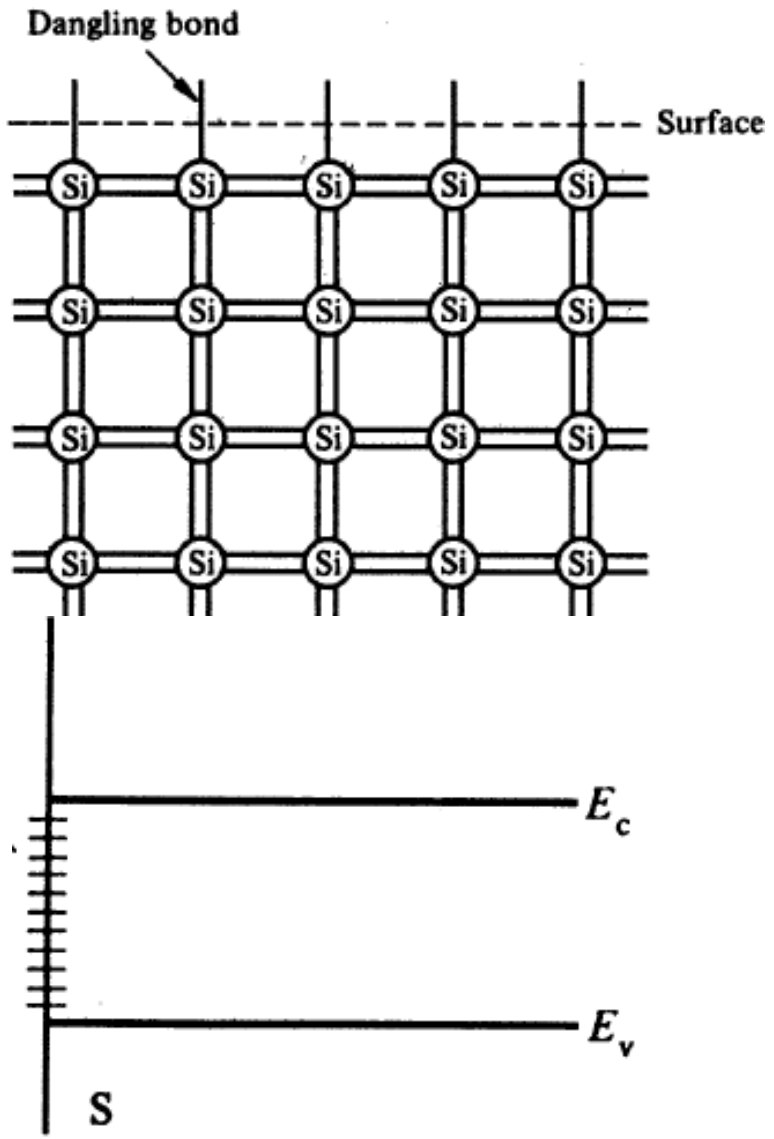




Interface States







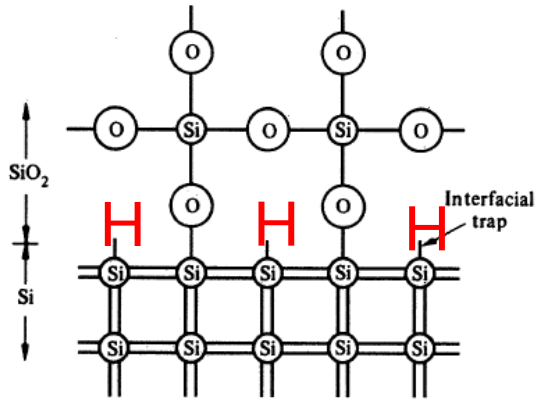
With annealing technology

Unpassivated bonds ~10^{10} cm^{-2}

Unpassivated bonds ~10^{14} cm^{-2}

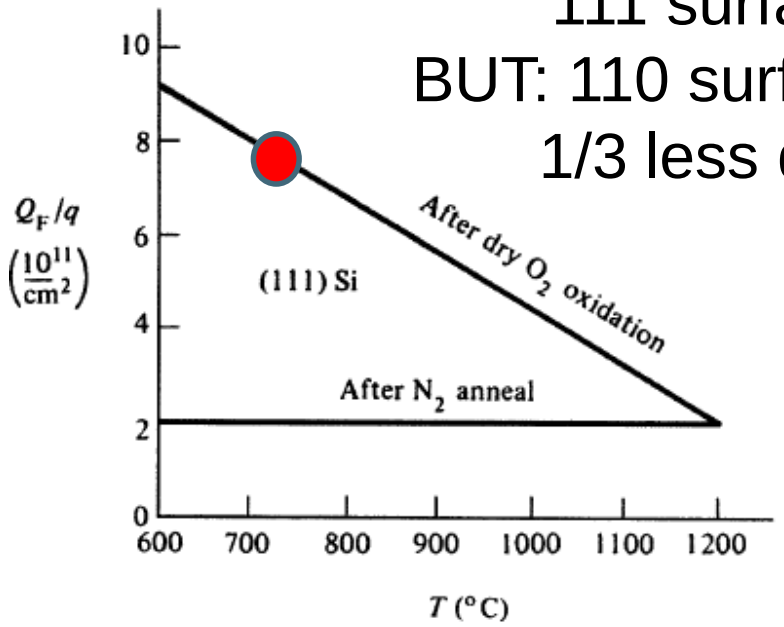
‘Annealing’ of Interface States

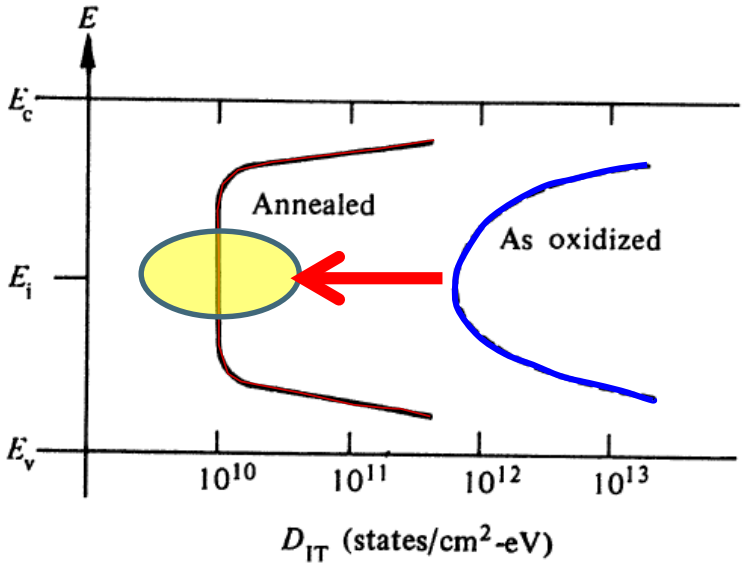
Forming gas anneal



Good MOSFET requires about $10^{10}/cm^2$

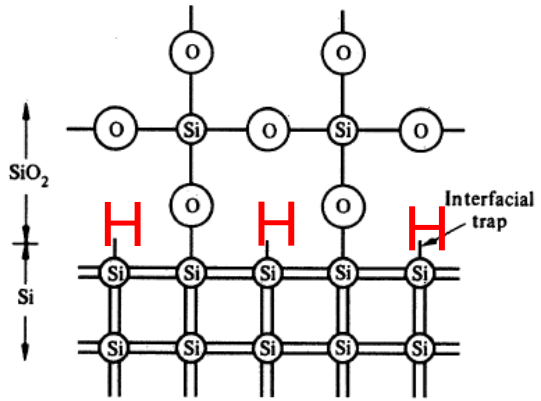
111 surface data
BUT: 110 surface has 1/3 less dangling bonds



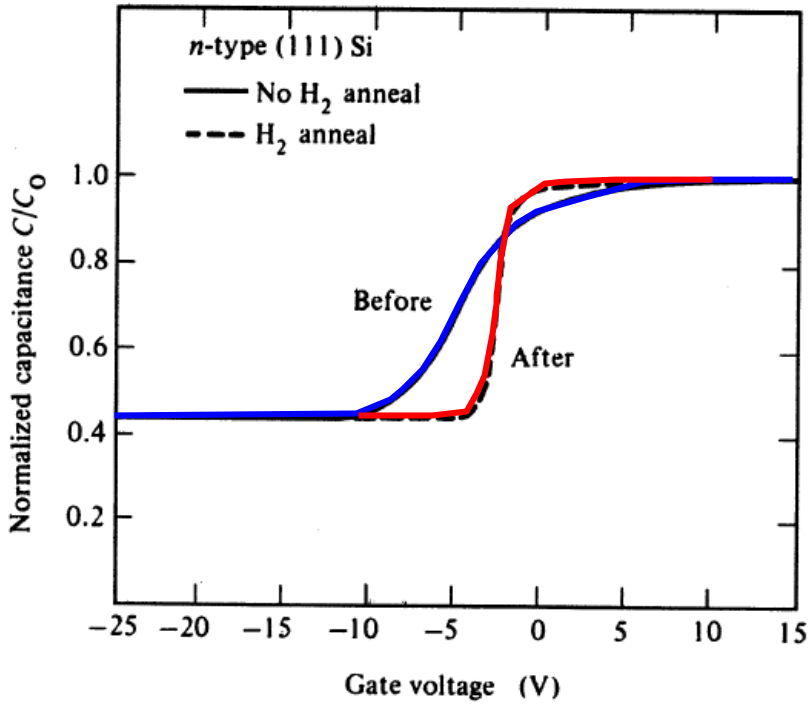


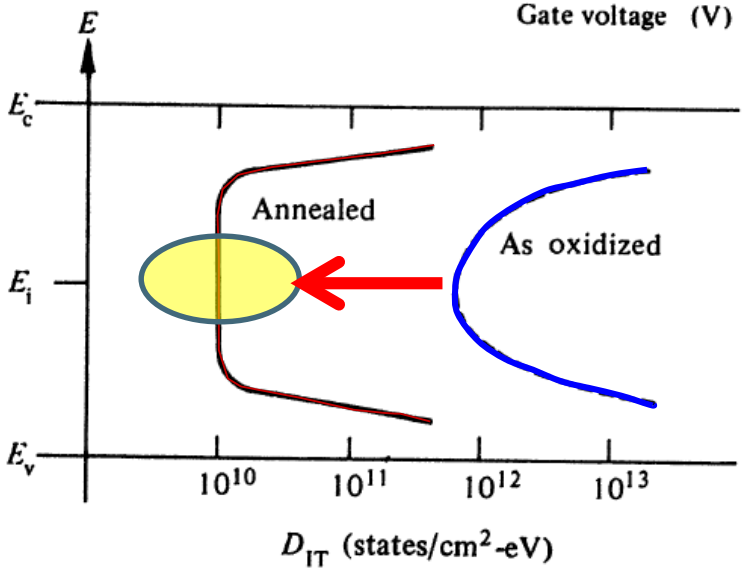
C-V Stretch Out

Forming gas anneal

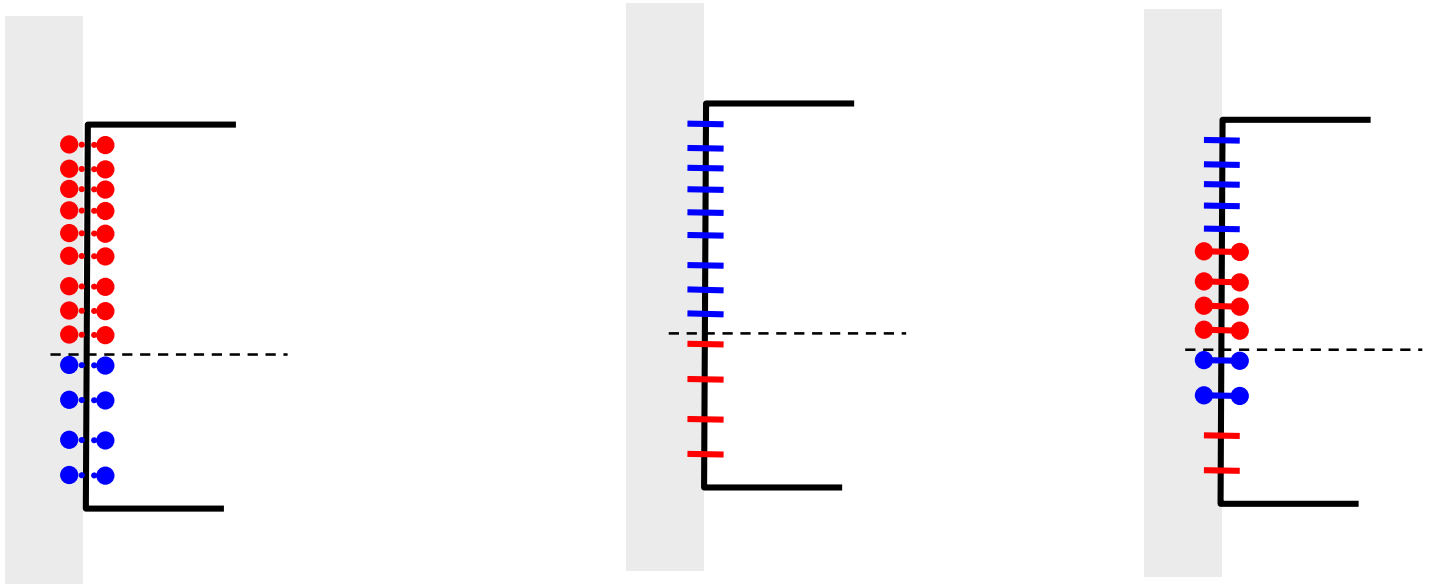


Good MOSFET requires about $10^{10}/cm^2$





Nature of Donor and Acceptor Traps



Donor level
Positive when empty
Neutral when full

Acceptor level
Neutral when empty
Negative when full

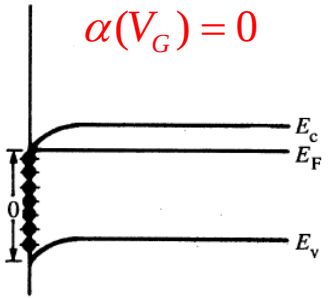
Combination when
both are present

Now the surprising part:
Hydrogen passivation can act as a donor and as an acceptor leve
Depends on details of bond configuration

Donor like Interface States

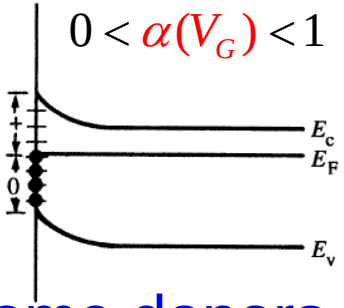
$$V_{th} = V_{th}^{*} - \frac{1}{C_{ox}x_0}\int_0^{x_0} x \times \alpha(V_G) \times Q_{ox}(x)\delta(x - x_o)dx = V_{th}^{*} - \frac{\alpha(V_G)Q_{ox}(x_0)}{C_{ox}}$$

$\alpha(V_G) = 0$



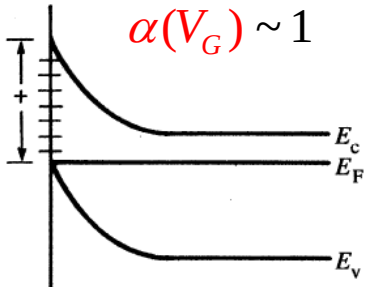
All donors full - neutral

$0 < \alpha(V_G) < 1$

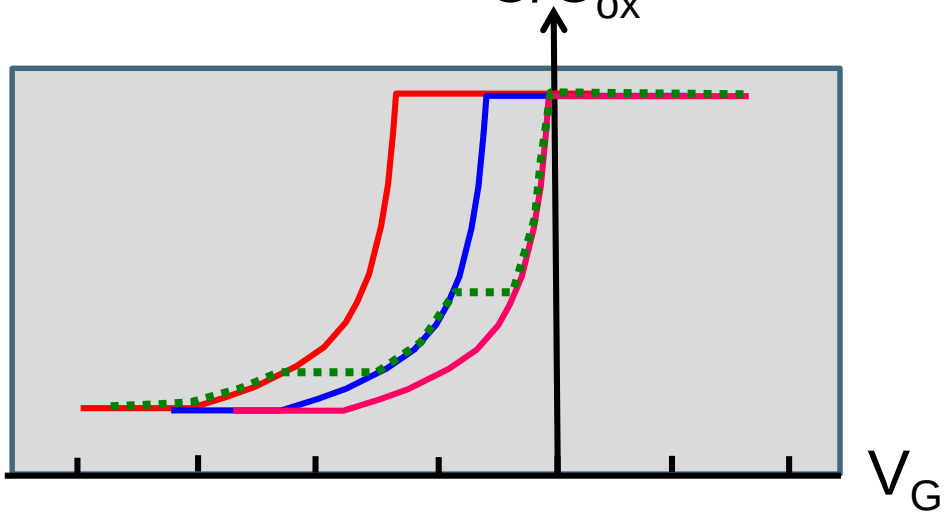


Some donors empty

$\alpha(V_G) \sim 1$



All donors empty



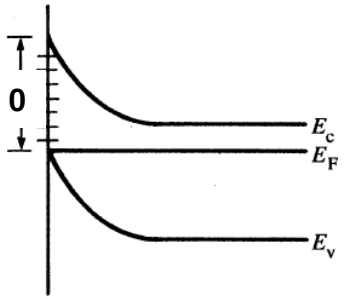
Assume the charges would NOT be voltage dependent
=> solid shift

BUT: charges change with voltage
=> smooth shift

There are no discrete steps – it is just stretched out.

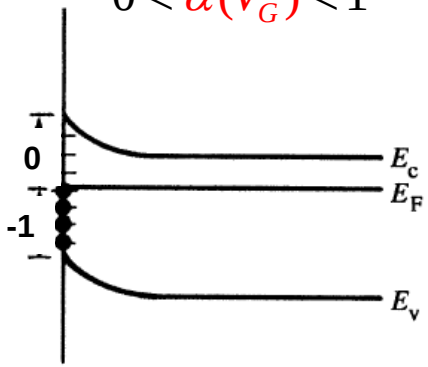
Acceptor like Interface States

$\alpha(V_G) = 0$



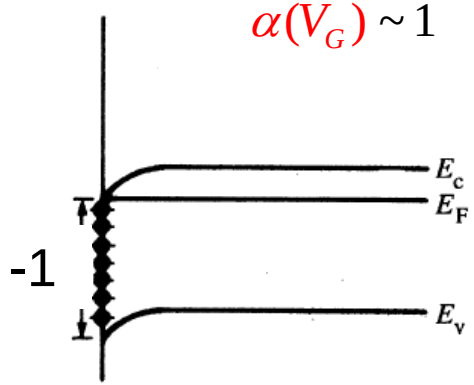
All Acceptors empty - neutral

$0 < \alpha(V_G) < 1$

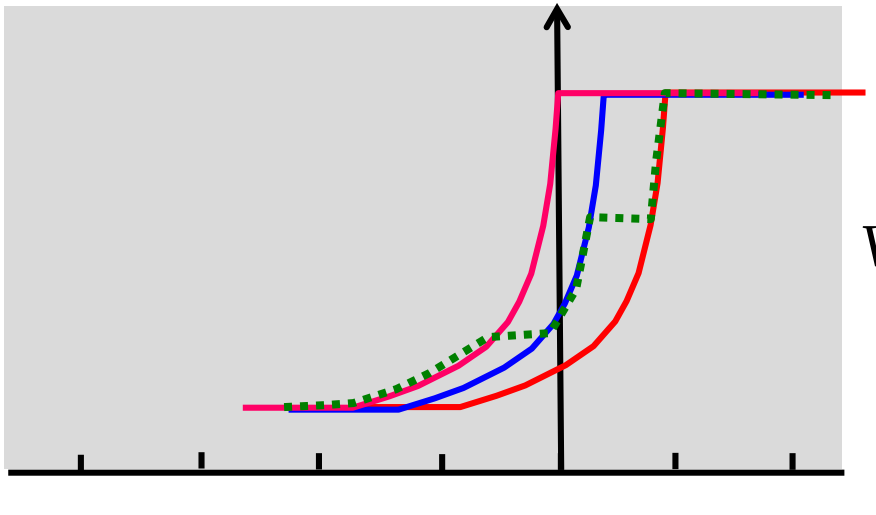


Some acceptors empty

$\alpha(V_G) \sim 1$

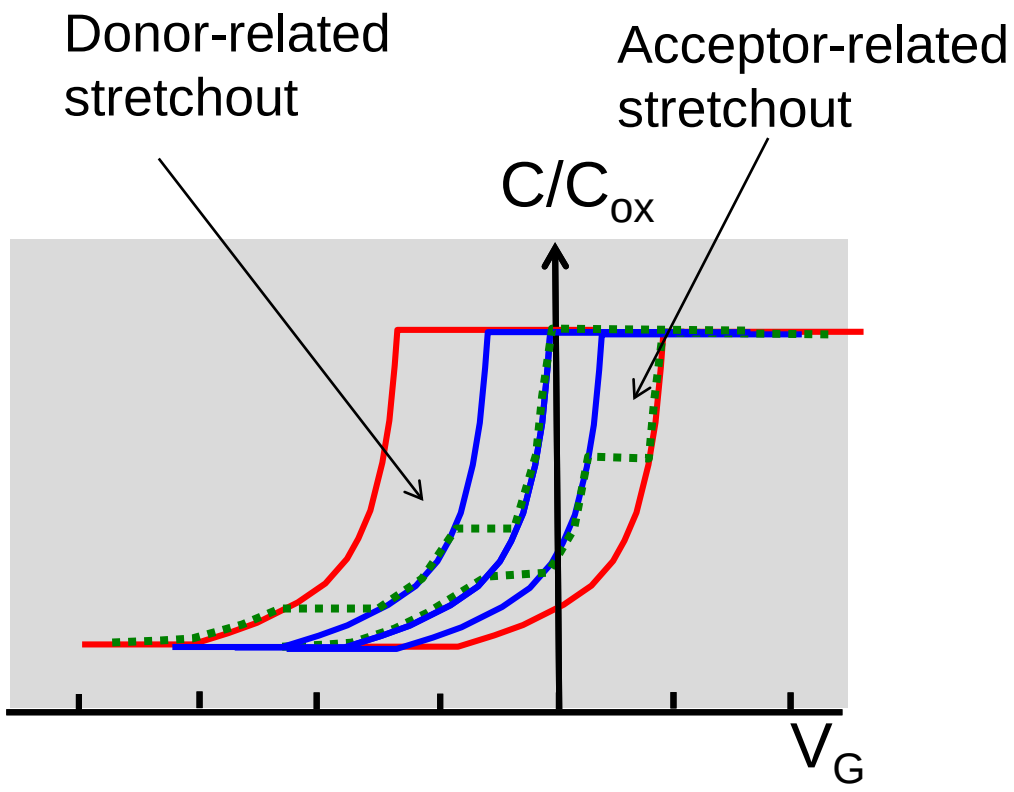


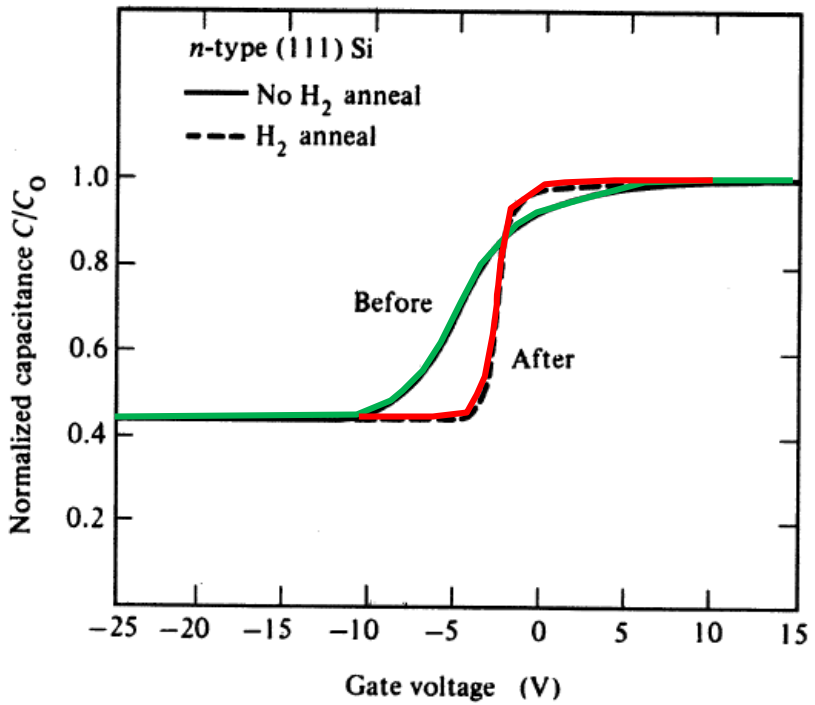
All acceptors empty



$$V_{th}(V_G) = V_{th}^{*} + \frac{\alpha(V_G) Q_{ox}(x_0)}{C_{ox}}$$

Acceptor and Donor Traps Combined





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Metal contact

Charge in oxide

Fixed charge

interface traps

Ref: Sec. 16.4 of SDF Chapter 18, SDF

1) Non-ideal threshold characteristics are important consideration of MOSFET design.

2) The non-idealities arise from differences in gate and substrate work function, trapped charges, interface states.

3) Although non-ideal effects often arise from transistor degradation, there are many cases where these effects can be used to enhance desirable characteristics.