Metal Oxide Semiconductor Transistor (MOST)

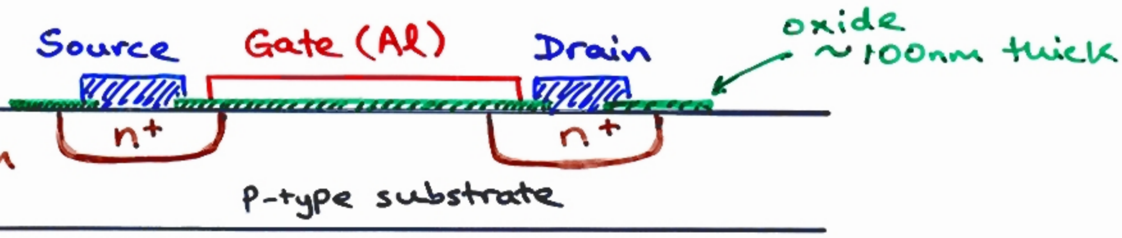
Also MOSFET – field effect transistor, **IGFET** insulated gate

Induced Channel MOST

This has a metal gate electrode, completely isolated from a semiconducting layer by an insulating layer (oxide). But Vg on the gate can induce a conducting channel and influence its resistance:

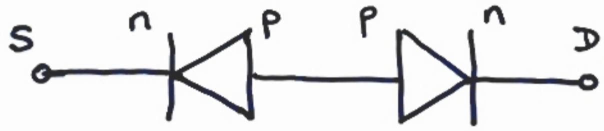
(S+D ohmic)

heavily doped n+ regions form S + D

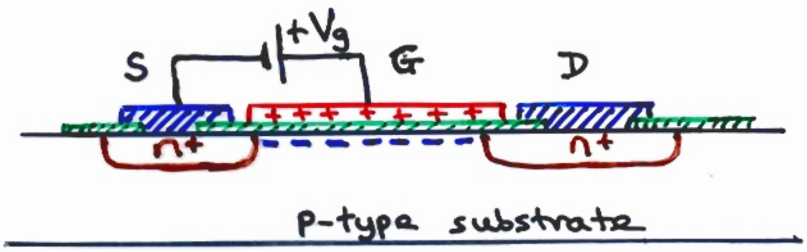


* Assume no surface effects – Si passivated

When Vg=0, I_d=0 because there are two 'back-to-back' diodes.

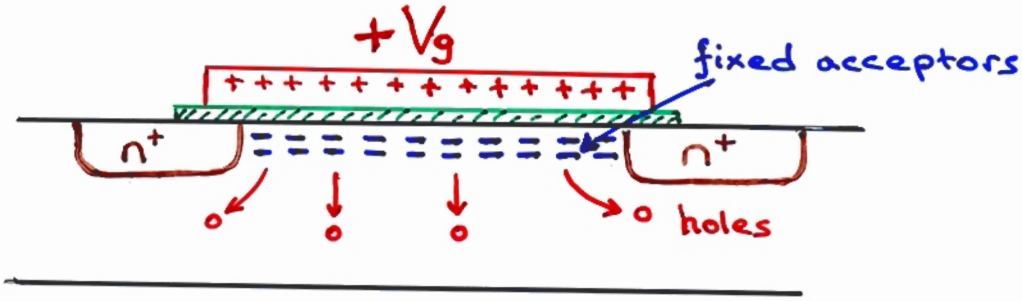


Now apply $+V_g$ with respect to the source:-



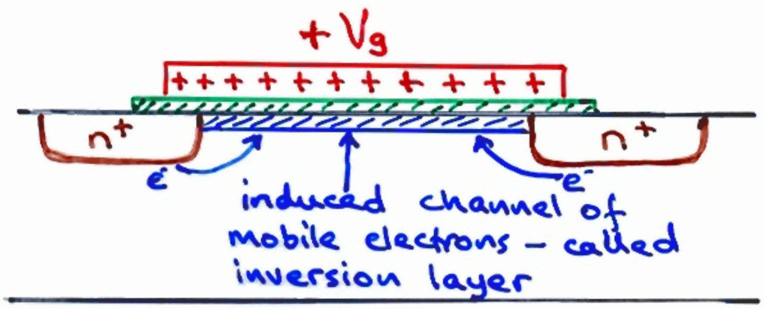
A –ive charge is induced in the p-type material under the gate to balance the +ive charge of the gate; like a capacitor. But **where** does –ive charge come from?

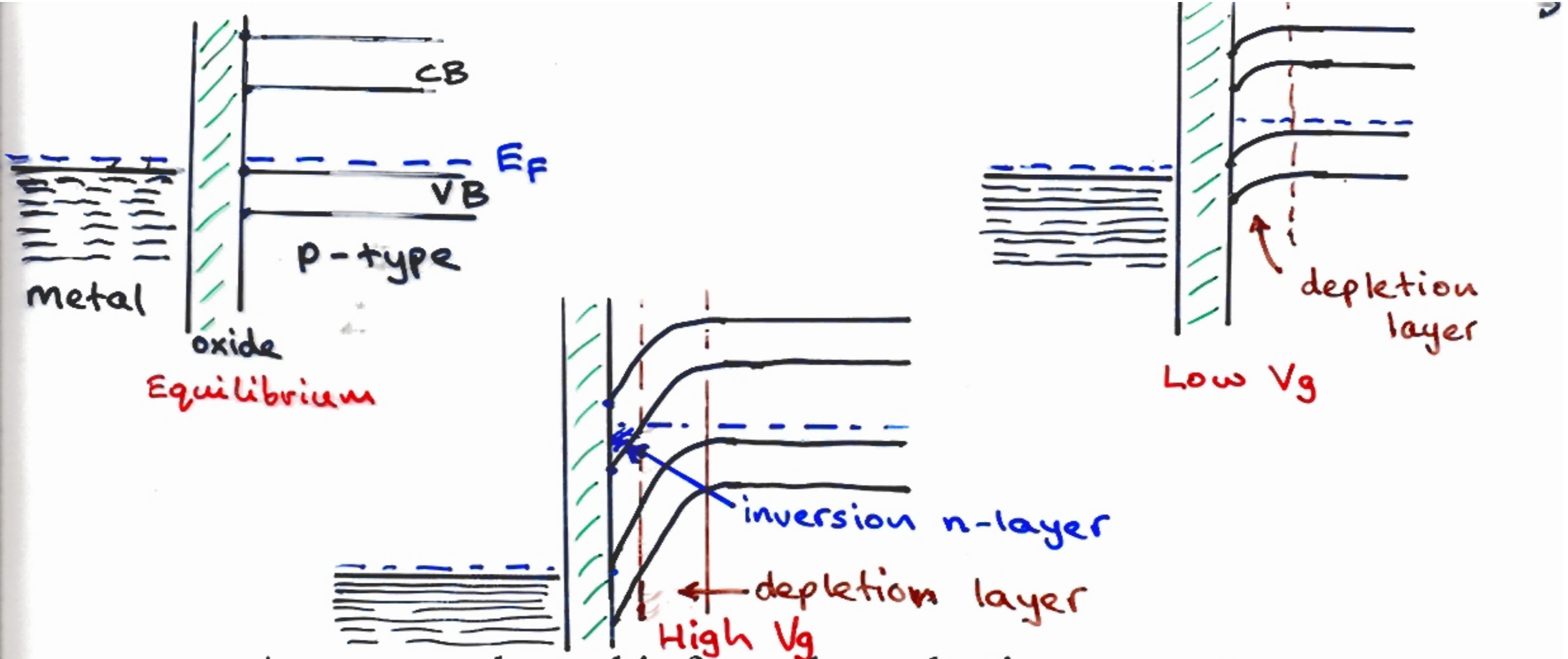
1) For low Vg's; the –ive charge is provided by a depletion layer in the p-type material consisting of –ive exposed fixed acceptors



No free carriers in channel region so I_d still equals 0

2) For large Vg's; all –ive charge cannot be provided by a depletion layer so additional charge comes from electrons (from S & D) drawn to the surface to balance the +ive gate charge. An n-type layer is <u>induced</u> on the surface.

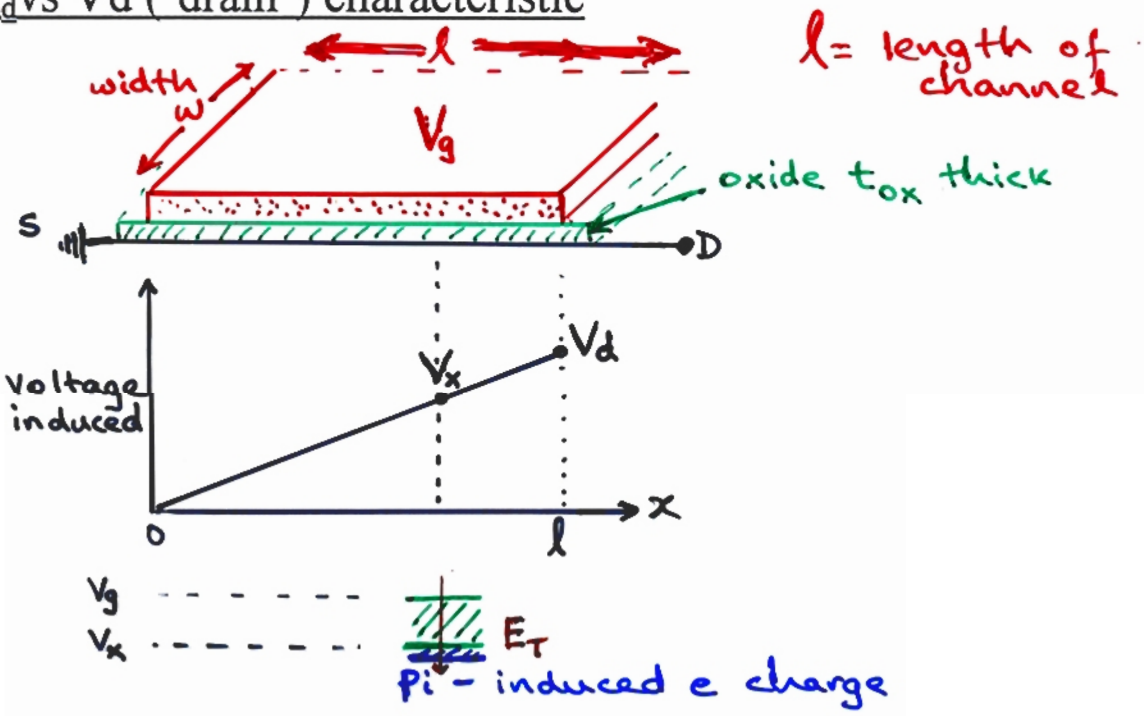




As soon as channel is formed, conduction can occur between S & D. If Vd is applied, I_d flows.

For a fixed Vd, if Vg ↑, $n_{channel}$ ↑, $\sigma_{channel}$ ↑ and so I_d↑
Since I_d ↑ as Vg↑, this is called enhancement mode

<u>$I_d$vs Vd ('drain') characteristic</u>



Voltage across oxide at x = Vg-Vx
Oxide is t_{ox} thick so transverse electric field is E_T = (Vg-Vx)/t_{ox}

Suppose induced surface charge in channel is $\rho_I(x)$ Cm^{-2}
E_T and ρ_i related by Gauss Law:

$$\rho_i = \varepsilon_{r0} E_T = \varepsilon_{r0}\varepsilon_0 (Vg-Vx)/t_{ox} \qquad (1)$$

Not all this charge is available for conduction. At low Vg's, only a depletion layer is formed.
At some minimum Vg = V_T (the 'turn-on' voltage, ≈3V), the mobile charge is <u>just</u> sufficient for channel to form.

Hence, the effective voltage across the oxide for producing mobile charge is:-

$$(Vg-Vx) - V_T$$

So, effective mobile surface charge density from eqn.(1) is:

$C = \frac{\varepsilon A}{d} = \frac{Q}{V}$

$$\rho_{ieff} = \varepsilon_{r0}\varepsilon_0 (Vg-Vx - V_T)/t_{ox} \qquad (2)$$

$\rho_i = \frac{Q}{A} = \frac{CV}{A}$

$\rho_{ieff} = e.\Delta n(x)$ is the surface density of electrons in channel.

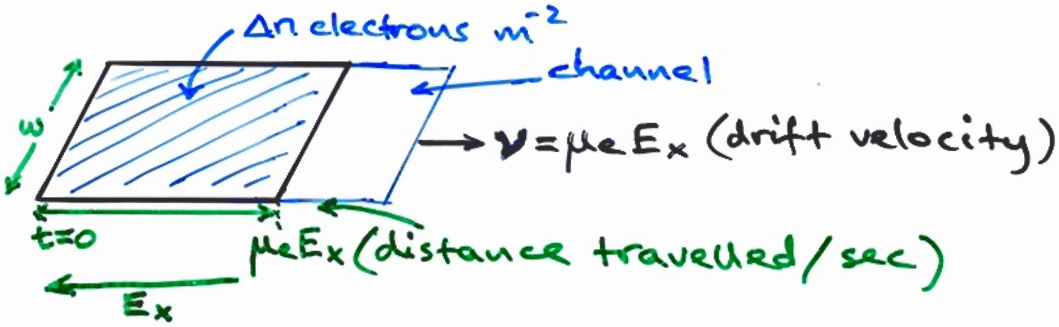
The gate-oxide-channel combination behaves as a capacitor Cg.

$$Cg = \varepsilon_{r0}\varepsilon_0 (W\ell)/t_{ox}$$

So eqn.(2) becomes.

$$\left.\begin{aligned} \rho_{ief} &= e.\Delta n(x) = \frac{Cg}{\omega l}(Vg - Vx - V_T) && \text{for } Vg - Vx > V_T \\ \rho_{ief} &= 0 && \text{for } Vg - Vx < V_T \end{aligned}\right] \quad (3)$$

Now we know the charge Δn m^{-2} so we need to find resistance of the thin channel :-



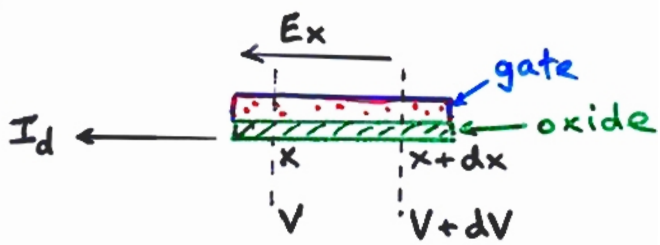
Number of electrons passing through t=0 plane per second is (Area/sec). Δn,

i.e. $(\mu_e E_x\ W)\ \Delta n$

Therefore charge/sec. passing through the plane =

$$(\mu_e E_x\ W)e\ \Delta n = Id \qquad (4)$$

Consider dx of channel:



$E_x = dV/dx$

Subs. in eqn.(4)

$$I_d = \mu_e(dV/dx)\ We\Delta n$$

or,

$$I_d.dx = \mu_e dV\ We\Delta n$$

Subs. from eqn.(3) for $e\Delta n$ *(see JA, pg 248)*

$$I_d.dx = \mu_e \frac{Cg}{\ell}(Vg - V_T - Vx)dV$$

Integrate along channel length,

$$I_d \int_0^{\ell} dx = \mu_e \frac{Cg}{\ell} \int_0^{V_d} (Vg - V_T - Vx)dV$$

*

$$I_d = \frac{\mu_e Cg}{\ell^2}\left[Vg - V_T - \frac{Vd}{2}\right]Vd$$

(5), is the **drain characteristic**

This only applies for ;

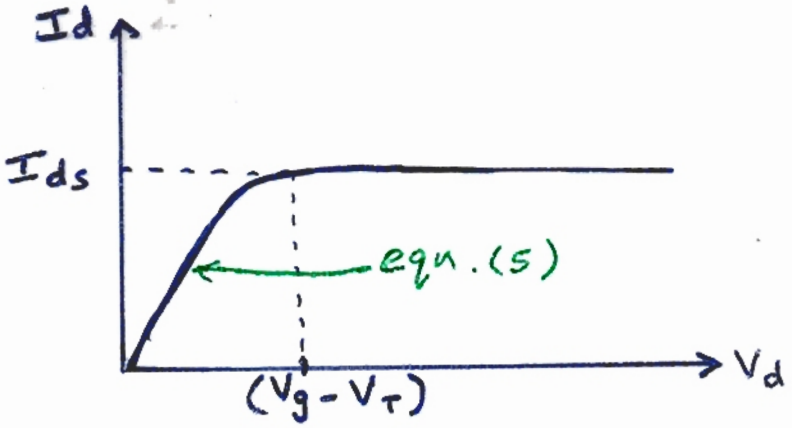
	$Vg - Vx > V_T$	for all x
	$Vg - Vd > V_T$	at drain end
or	$Vg - V_T > Vd$	at drain end

Vd can be increased until;

$$Vg - V_T = Vd$$

----(6), the **saturation condition**

As Vd increases beyond this value, I_d saturates (i.e. becomes constant) and excess voltage is dropped across high resistance depletion layer. The saturated current is called I_{ds} and occurs when eqn.(6) holds,

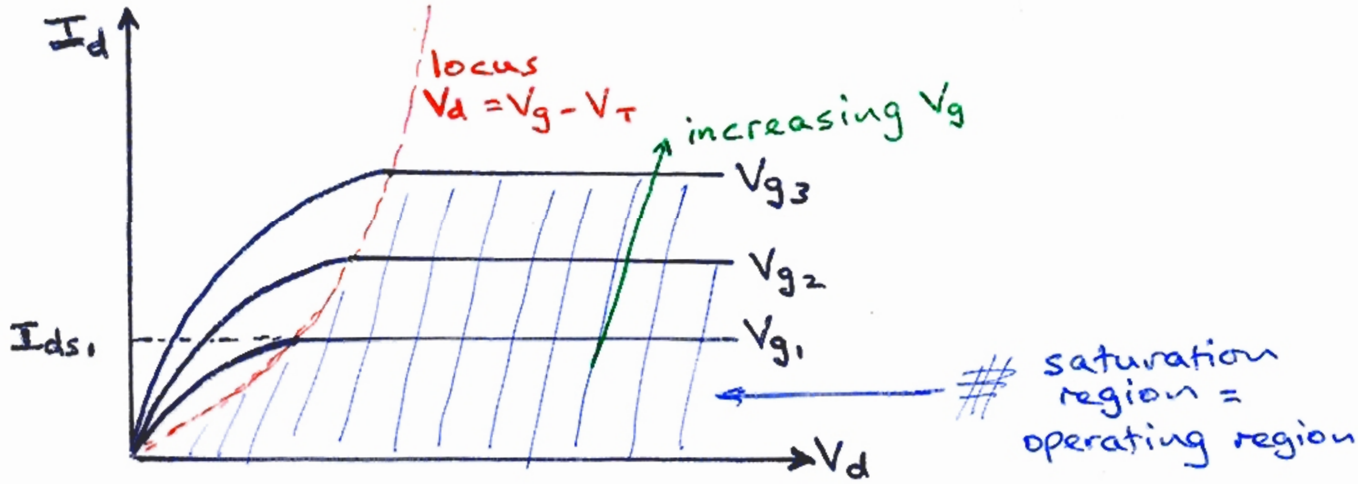


Subs. eqn.(6) into eqn.(5),

$$I_{ds} = \frac{\mu_e Cg}{\ell^2}\left[\left(\frac{Vg - V_T}{2}\right)^2\right]$$

7(a)

$$\text{or,} \qquad I_{ds} = \frac{\mu_e CgVd^2}{\ell^2 2} \qquad 7(b)$$



The transconductance is,

$$g_m = \left.\frac{\partial Id}{\partial Vg}\right|_{Vd\ const.}$$

evaluated in the saturation region, with a constant Vd

From 7(a).

$$g_m = \frac{\mu_e Cg}{\ell^2}[(Vg - V_T)]$$

$$\text{or,} \quad g_m = \frac{\mu_e Cg}{\ell^2}[(Vd)]$$

In reality, measured g_m is less than that predicted by this equation due to,

i) ignoring the parasitic source and drain resistances
ii) reduced channel mobility c.f. that of the channel due to that fact that there is enhanced scattering at the oxide surface.

V_T is defined as the voltage that just causes an accumulation layer to form. It occurs when $n=N_a$. i.e. when the electrons attracted by Vg balances the holes due to the p-type doping. In Fermi-level terms, the conduction band bends sufficiently such that the Fermi-level at the semiconductor surface is below the CB by the same amount as the Fermi-level in the bulk is above the VB.