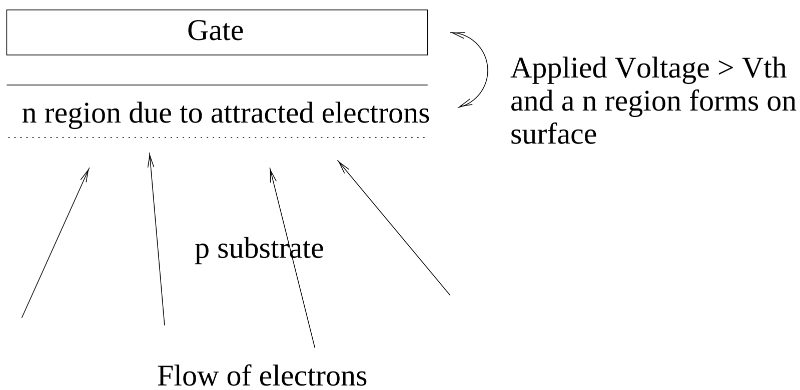
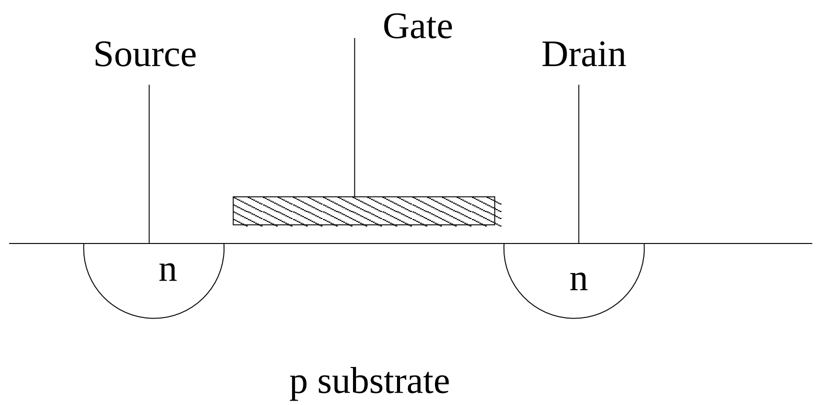
MOSFET transistors

The MOSFET (Metal Oxide Silicon Field Effect Transistor) is a device that controls a current between two contacts (Source and Drain) using a voltage contact (Gate). The device uses a surface effect to create a n-type region in a p-type substrate (or the converse).

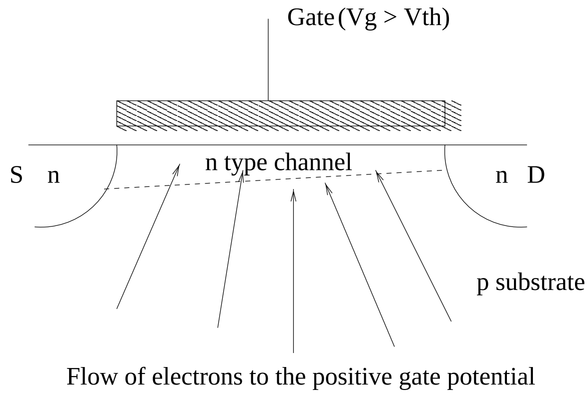


To understand this we take a simple capacitor structure using a p-type substrate a oxide layer and a metal gate. If we apply a positive potential to the gate (the substrate is grounded) electrons will be attracted to the gate and will pile up at the surface underneath the gate.

At some voltage V_{th} called the threshold voltage the region under the gate will have enough additional electrons that $n > p$ and the material will be n-type not p-type. The oxide is very important as it stops the current flow towards the gate and forces the electrons to “pile up” underneath the gate and turn the material n-type.



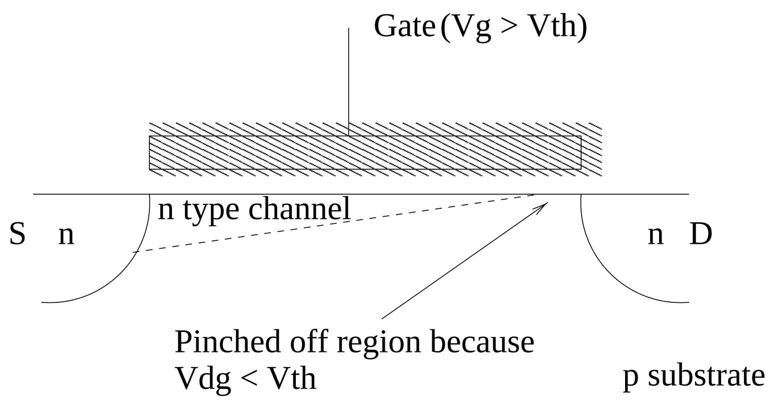
The basic MOSFET structure uses the capacitor structure above with n type regions placed at either edge, known as the source and drain. The basic operation of the device is to bias the gate with $V_G > V_{th}$ and form a n-type region between the source and the drain. This provides a simple n-type path between the n-type source and drain regions for electrons to flow. This region is called a channel. Note that with out forming the channel there are two back to back diodes formed which will not allow appreciable current to flow.



The formation of this channel provides a simple resistive path between the source and the drain. The thickness of the channel is function of the difference between the gate potential and the potential in the substate near the surface.

We can place a voltage between the source and the drain and cause a current to flow. Typically we ground the source and bias the drain with V_ds. The ability to change the thickness of the channel using the gate potential provides a means of controlling the current from the source to the drain. We basically can form a voltage controlled resistor.

One thing to note is that the appliction of a drain voltage raises the potential of the region of the substrate at the surface near the drain. This results in a thinner channel at that end (as the gate to substrate potential is reduced).



A new condition arises if we increase the drain voltage substantially ($V_{DS} > V_{DS,sat}$ – $V_{DS,sat}$ is called the saturation voltage). The drain voltage becomes large enough that the gate to substrate potential at the drain is smaller than threshold. Therefore the channel thickness at this end goes to zero. We call this pinch off.

Electrically, the effect of pinch off is that the channel no longer acts like a simple resistor. The current I_{DS} becomes fixed (saturated) at the value just prior to pinch off.

Therefore the equations for the MOSFET are:

1. The triode region — $V_{GS} > V_{th}$, $V_{DS} < V_{DS,sat}$

$$I_{DS} = I_0 \left[(V_{GS} - V_{th}) V_{DS} - V_{DS}^2/2 \right] \tag{1}$$

   The $V_{DS}^2/2$ term takes the narrowing of the channel at the gate region into account as V_{DS} approaches $V_{DS,sat}$.

2. The saturation region — $V_{GS} > V_{th}$, $V_{DS} > V_{DS,sat}$

   It can be shown that $V_{DS,sat} = V_{GS} - V_{th}$ and

$$I_{DS,sat} = I_0 \frac{(V_{GS} - V_{th})^2}{2} \tag{2}$$

In saturation the MOSFET acts like a nonlinear voltage controlled current.