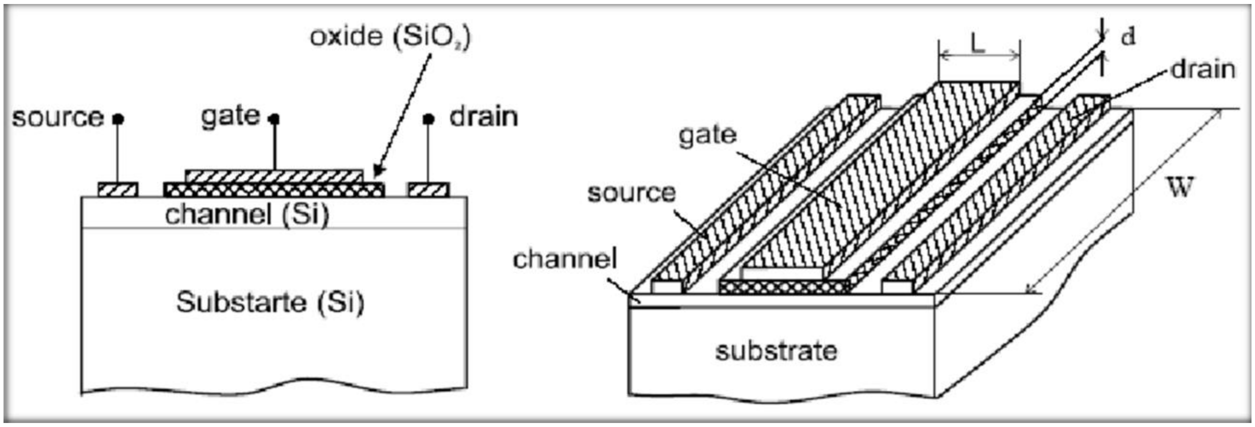
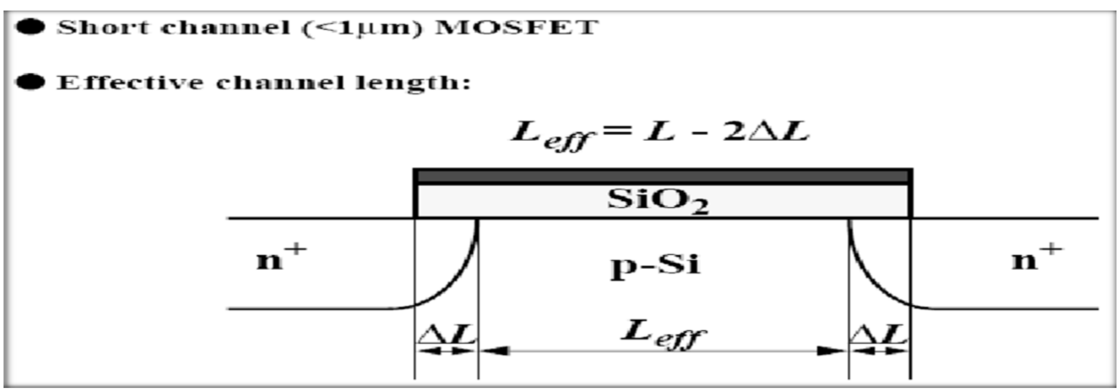
# Second order effects in MOSFET




**1) Channel Length Modulation:**

There are some subtleties to the operation of the transistor in the saturation region. The length of the channel changes with changing values of VDS. As the value of VDS is increased, it causes the depletion region of the Drain junction to grow. This reduces the length of the channel which impacts current.



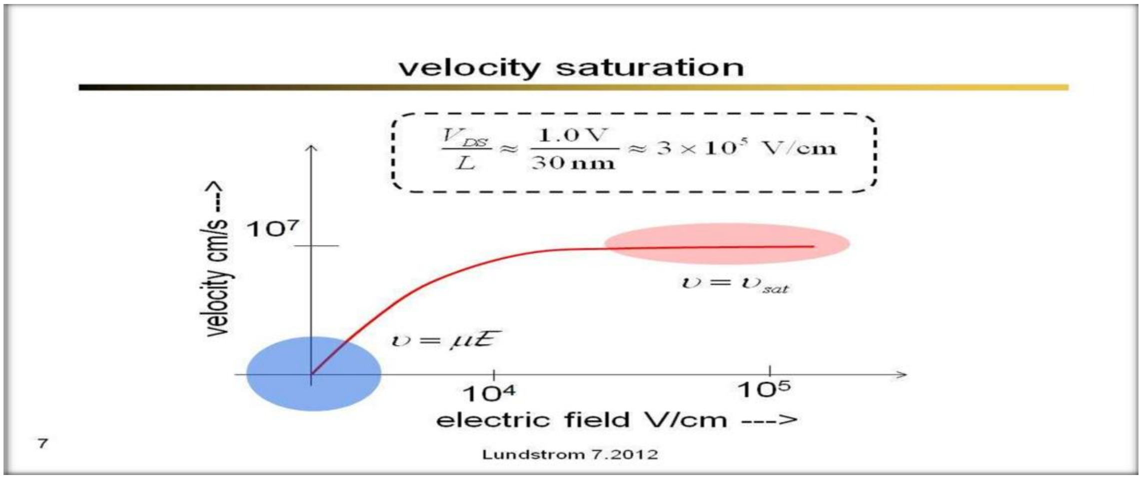

The model current equation must be modified to

$$I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_t)^2 (1 + \lambda V_{DS})$$

In general, lambda is proportional to channel length. The effects of channel length modulation become more pronounced for smaller feature sizes. Thus, when a high impedance current source is required, longer channel transistors are used.

**2) Velocity Saturation:**

For high VDS, carriers experience higher lateral electric fields. Carrier velocity increases with increasing lateral electric fields. However, once the critical lateral electric field is reached, the velocity of the carriers does not increase any further. This is caused by an increased rate of collision and carrier scattering. The current does not increase at the expected rate. Rather, the current increases very little, if at all.




**3) Mobility Degradation:**

With increasing VGS, vertical electric fields increase. This increase causes a rise in the number of carrier collisions, which degrades carrier mobility. The current flowing through the transistor is therefore than that expected by the ideal models. Mobility decreases with increasing temperature.

**4) Threshold Voltage:**

The threshold voltage is the value of gate voltage (VGS) at which strong inversion occurs. In other words, this is the voltage at which the transistor begins to conduct current. The Threshold Voltage depends on:

1.Thickness of the oxide layer: 2.Charge of the impurities trapped between the silicon and the oxide 3.Dosage of ions implanted for threshold adjustment 4.Source to Bulk Voltage

The channel strength and the threshold voltage can be changed through application of appropriate voltage to the body terminal of the MOSFET. This is known as the body effect.

$$V_t = V_{t0} + \gamma\left(\sqrt{V_{SB} - 2\phi_F} - \sqrt{|2\phi_F|}\right)$$

For gate voltages less than threshold voltage, current drops off exponentially and as feature sizes decrease the way MOSFETs behave in this region becomes important. The transistor conducts some current before VGS = Vt. This is called sub-threshold conduction.

**5) Temperature Dependence:**

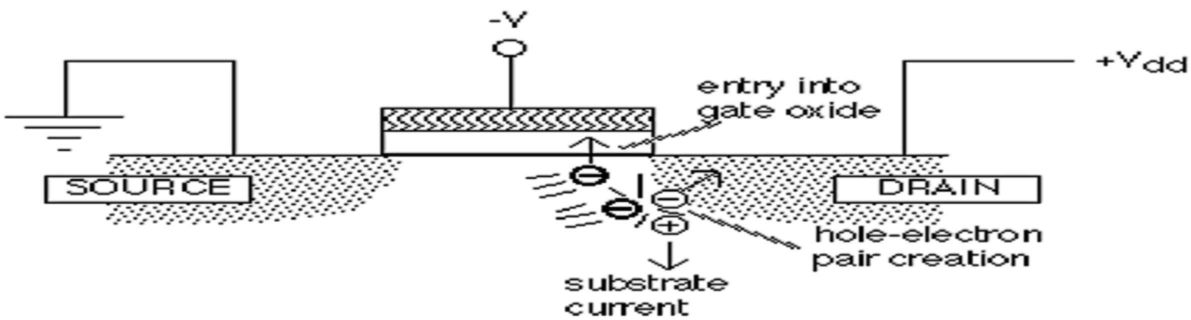
1. Carrier Mobility: Decreases with temperature
2. Threshold Voltage: Decreases with temperature

3. Junction Leakage: Increases with temperature
4. Velocity Saturation: Occurs sooner with higher temperature
5. Sub-threshold conduction: Increases exponentially with temperature. This means that at low temperatures, lower threshold voltages can be used.

Most wear out mechanisms are temperature dependent so transistors are more reliable at lower temperatures.

**6) Hot-Carrier Effects:**

The hot carrier effect can cause the threshold voltage of a device to drift over time. Smaller devices mean that carriers experience higher electric fields. This is because while device sizes have scaled, power signal voltages have not scaled at the same rate. These high electric fields can cause electrons to become hot. These electrons have very high energy, and can tunnel into the gate oxide. These electrons, trapped in the gate oxide, can cause a rise in the Vt of a device.




To avoid this, designers use specially engineered drain and source regions to ensure that the strength of the electric fields are limited so as to avoid the generation of hot carriers.