Section 30
MOSFET Introduction

30.4 Comments on bulk charge theory & small transistors

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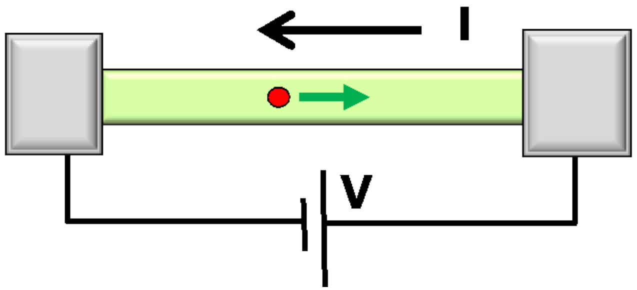


$$I = G \times V$$
$$= q \times n \times v \times A$$

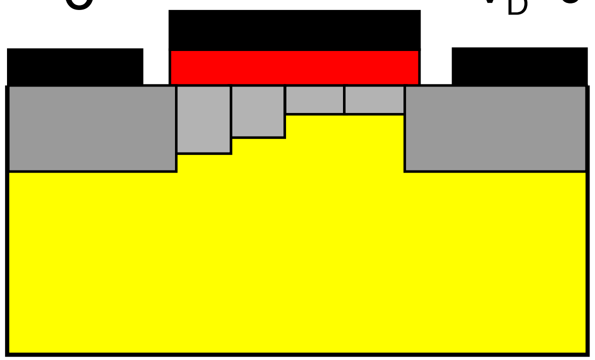
charge density velocity area

- 30.1 Sub-threshold (depletion) current
- 30.2 Above-threshold, inversion current
- 30.3 Velocity saturation in simplified theory
- 30.4 Comments on bulk charge theory & small transistors

Ref: Sec. 16.4 of SDF Chapter 18, SDF

Approximations for Inversion Charge

$$\sum_{i=1,N} \frac{J_i dy}{\mu(y)} = \sum_{i=1,N} Q_i dV$$



$$Q_i = -C_O(V_G - V_{th} \; - V) + qN_A\left(W_T(V) - W_T(V=0)\right)$$

$$Q_i = -C_O(V_G - V_{th} - V) + \sqrt{2q\kappa_S\varepsilon_o N_A(2\varphi_B + V)} - \sqrt{2q\kappa_S\varepsilon_o N_A(2\varphi_B)}$$

Approximations:

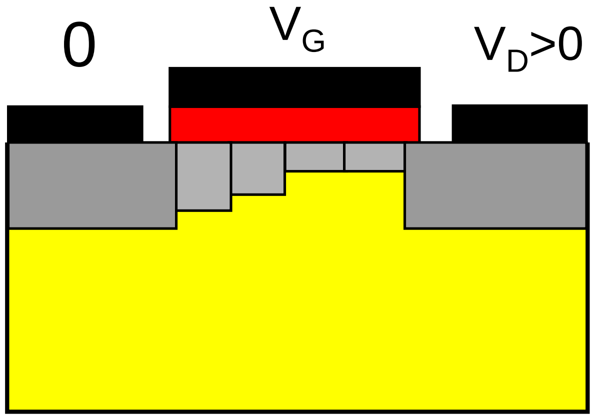
$Q_i \approx -C_{ox}(V_G - V_{th} \; - V)$ Square law approximation …

$Q_i \approx -C_{ox}(V_G - V_{th} \; - mV)$ Simplified bulk charge approximation …

One could substitute the expression for Q_i above explicitly instead of using m to simplify the equation, resulting in a more complete bulk charge expression

Complete Bulk-charge Theory

$$Q_i = -C_O(V_G - V_{th} - V) + \sqrt{2q\kappa_S\varepsilon_o N_A(2\varphi_B + V)} - \sqrt{2q\kappa_S\varepsilon_o N_A(2\varphi_B)}$$



$$\sum_{i=1,N} \frac{J_i dy}{\mu(y)} = \sum_{i=1,N} Q_i dV$$

$$\frac{J_D}{\mu_0}\sum_{i=1,N} dy = \int_0^{V_D} C_O(V_G - V_{th} - V)dV + \int_0^{V_D}[..........]dV$$

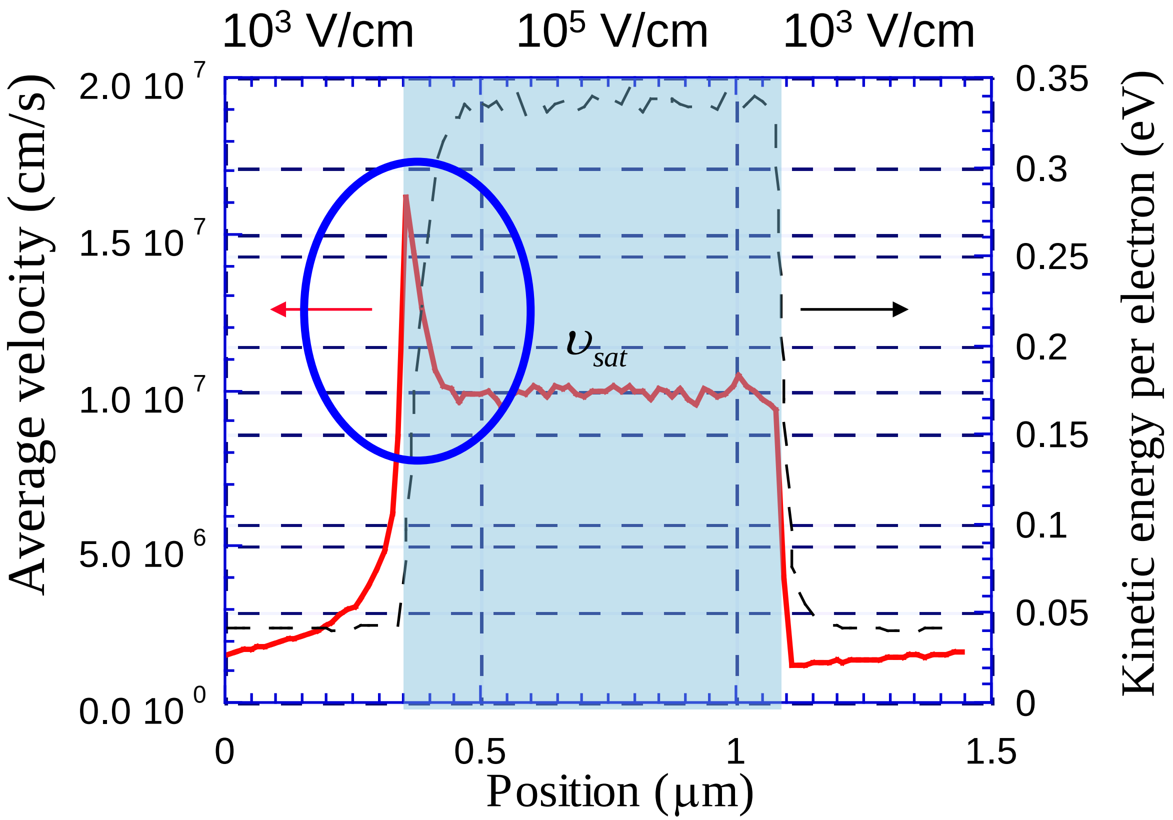
Additional V dependent terms abstracted into m previously

$$\frac{J_D}{\mu_0}\int_0^{L_{ch}} dy = \int_0^{V_D} C_O(V_G - V_{th} - V)dV + \int_0^{V_D}[..........]dV$$

$$J_D = \frac{\mu_0 C_{ox}}{L_{ch}}\left[(V_G - V_{th})V_D - \frac{V_D^{\,2}}{2} - \frac{4}{3}\frac{qN_A W_T}{C_O}\phi_F\left\{\left(1+\frac{V_D}{2\phi_F}\right)^{3/2} - \left(1+\frac{3V_D}{4\phi_F}\right)\right\}\right]$$

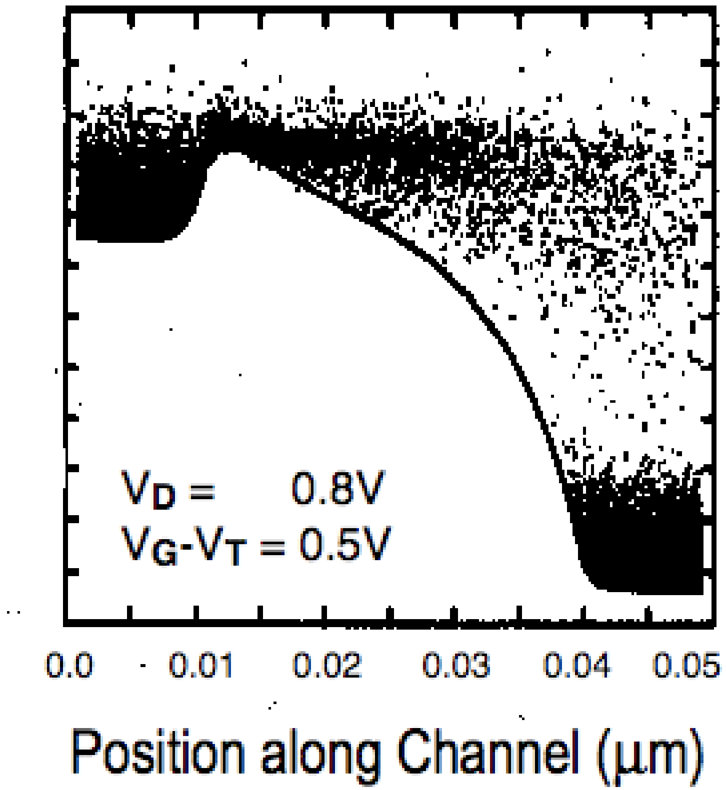
(Eq. 17.28 in SDF) .... Explicit dependence on bulk doping

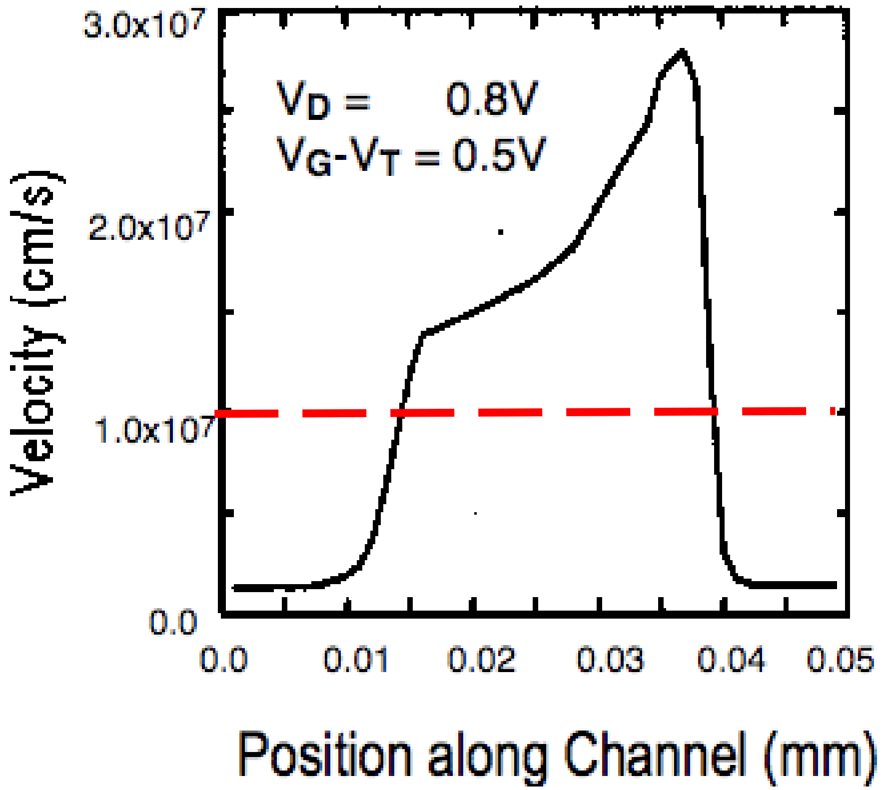
Velocity Overshoot



$$\upsilon \neq \mu_n(E)E$$ → Valid for bulk semiconductors, not valid at top of the barrier

Velocity Overshoot in a MOSFET





Frank, Laux, and Fischetti, IEDM Tech. Dig., p. 553, 1992

MOSFET Intermediate Summary

1) Velocity saturation is an important consideration for short channel transistors (e.g., V_D=1V, L_{ch}=20nm). Therefore, $\alpha \sim 1$ for most modern transistors.
2) Bulk charge theory explains why MOSFET current depends on substrate (bulk) doping. In the simplified bulk charge theory, doping dependence is encapsulated in ***m***.
3) Additional considerations of velocity overshoot could complicate calculation of current.
4) Good news is that for very short channel transistors, electrons travel from source to drain without scattering. A considerably simpler ‘Lundstrom theory of MOSFET’ applies.

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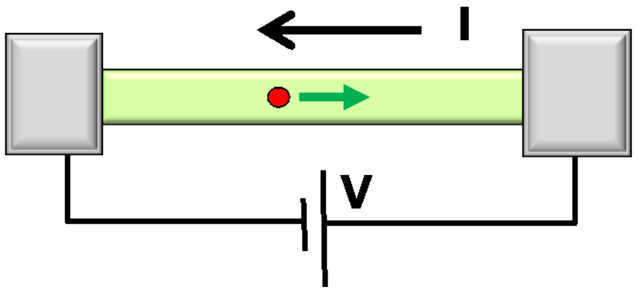

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status

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

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