

Problem 1 (from Prof. Ali Javey)

What are the advantages/disadvantages in using metal drain and source? Draw the band diagram for the case of on and off states.

Topics to discuss:

Formation of channel (band bending)

Effective Mobility (mobility degradation at high  $V_{gs}$ )

subthreshold leakage current/subthreshold swing

how to lower swing?

1. increase  $C_{ox}$
2. decrease  $C_{dep}$
3. Decrease Temp

Question: Can the subthreshold swing ever be better than 60 mV/dec?

Velocity saturation (scattering in channel)

$V_T$  roll-off

series resistance

Problem 2: Dynamic Threshold MOSFET

- (a) How can the threshold voltage of a MOSFET be adjusted? (Describe 3 ways.)
- (b) Describe the  $V_T$  design trade-off for short-channel MOSFETs. (Why is it desirable to have low  $V_T$ ? Why is it desirable to have high  $V_T$ ?)
- (c) One way to improve the  $V_T$  design trade-off for a short-channel MOSFET is to change the  $V_T$  dynamically (that is, to adjust its value during circuit operation) by changing the body bias. Consider a very short channel NMOSFET, designed to operate at relatively low power-supply voltage ( $V_{DD} < 0.6$  V). Suppose the body bias ( $V_B$ ) can be varied between 0V and  $V_{DD}$ :
  - i. When the NMOSFET is in the ON state ( $V_{GS} = V_{DD}$ ), what should  $V_B$  be, in order to maximize the transistor current?
  - ii. When the NMOSFET is in the OFF state ( $V_{GS} = 0V$ ), what should  $V_B$  be, in order to minimize the sub-threshold leakage current?
  - iii. Considering your answers to parts (i) and (ii) above, what is the advantage of connecting the body to the gate?
  - iv. What is the disadvantage of connecting the body to the gate?

## Problem 2: Dynamic Threshold MOSFET

a) Three ways to adjust  $V_T$ :

- adjust  $T_{ox}$
- adjust channel doping
- adjust the gate material work function

b) It is desirable to have a low  $V_T$  in order to maximize the transistor current when it is ON, to maximize  $I_{dsat}$

It is desirable to have a high  $V_T$  in order to minimize the transistor leakage current when it is OFF, to reduce the static power consumption.

c) i)  $V_B$  should be connected to VDD to reduce  $V_T$  and hence increase  $I_{dsat}$

ii)  $V_B$  should be connected to GND in order to maximize  $V_T$  and hence minimize sub-threshold leakage current

ii) The main advantage of connecting  $V_B$  to  $V_G$  is to dynamically optimize  $V_T$  for high speed (in the ON state) and low static power consumption (in the OFF state).

iii) The disadvantage of connecting  $V_B$  to  $V_G$  is an increase power consumption when the transistor is turned ON, due to the forward-bias pn-junction diode current associated with the source and drain regions. If the area of the source and drain junctions is small (e.g. if SOI technology is used), this power consumption penalty will be small.