UNIVERSITY OF CALIFORNIA, BERKELEY
College of Engineering
Department of Electrical Engineering and Computer Sciences

Final
EE 130/230A: Spring 2016
Time allotted: 75 minutes

NAME: Solution ______________ ______________

STUDENT ID#: ______________

INSTRUCTIONS:

1. **Unless otherwise stated, assume**
   a. **temperature is 300 K**
   b. **material is Si**

2. **SHOW YOUR WORK. (Make your methods clear to the grader!)**
   - Specially, while using chart, make sure that you indicate how you have got your numbers. For example, if reading off mobility, clearly write down what doping density that corresponds to.
   - Clearly write down any assumption that you have made.

- **Clearly mark (underline or box) your answers.**

3. **Specify the units on answers whenever appropriate.**

SCORE: 1 ________ **/ 20**

2 ________ **/ 20**

3 ________ **/ 20**

Total ________ **/ 60**

PHYSICAL CONSTANTS

Description	Symbol	Value
Electronic charge	q	$1.6\cdot10^{-19}$ C
Boltzmann's constant	k	$8.62\cdot10^{-5}$ eV/K
Thermal voltage at 300K	$V_T = kT/q$	0.026 V

PROPERTIES OF SILICON AT 300K

Description	Symbol	Value
Band gap energy	E_G	1.12 eV
Intrinsic carrier concentration	n_i	10^{10} cm^{-3}
Dielectric permittivity	ε_{Si}	$1.0\cdot10^{-12}$ F/cm

USEFUL NUMBERS

V_T ln(10) = 0.060 V at T=300K

Law of the Junction: $np = n_i^2\left(e^{qV_D/kT}\right)$

$N_c=2.8\times10^{19}/cm^3$

$N_V=1.04\times10^{19}/cm^3$

Depletion region Width:

$$W = \sqrt{\frac{2\varepsilon}{q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right)\left(V_{bi}-V_{Applied}\right)}$$

MOSFET:

$V_g-V_{fb}=V_{ox}+V_{semiconductor}$;

at threshold: $V_{semiconductor}=2(kT/q)\log(N/n_i)$

$$I_D = \frac{W}{L}\mu_n C_{ox}\left[\left(V_g-V_t\right)V_D-\frac{V_D^2}{2}\right]$$

$$I_{Dsat} = \frac{W}{2L}\mu_n C_{ox}\left(V_g-V_t\right)^2;$$

Current in a PN junction:

$$I = A\left(q\frac{D_p}{L_p}p_{n0}+q\frac{D_n}{L_n}n_{p0}\right)\left(e^{qV_D/kT}-1\right)$$

Electron and Hole Mobilities in Silicon at 300K

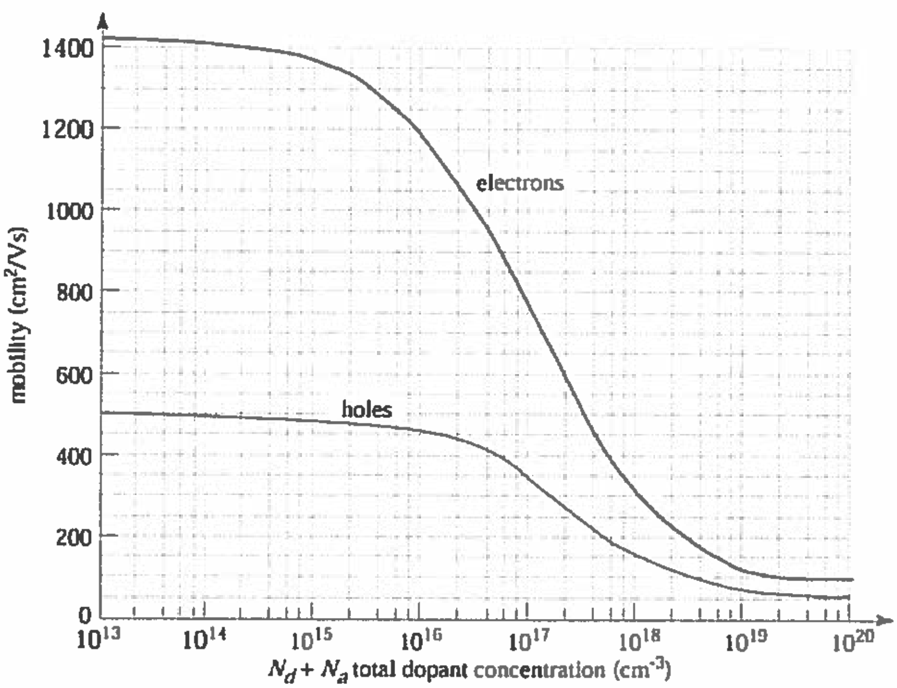


Table1: Barrier Heights of Different Metals to Si

Metal	Mg	Ti	Cr	Ni	W	Mo	Pd	Au	Pt
ϕ_{Bn} (V)	0.4	0.5	0.61	0.61	0.67	0.68	0.77	0.8	0.9
ϕ_{Bp} (V)		0.61	0.5	0.51		0.42		0.3	
Work Function ψ_m (V)	3.7	4.3	4.5	4.7	4.6	4.6	5.1	5.1	5.7

Table 2:Barriet Heights of Different Silicide Alloys to Si

Silicide	$ErSi_{1.7}$	HfSi	$MoSi_2$	$ZrSi_2$	$TiSi_2$	$CoSi_2$	WSi_2	$NiSi_2$	Pd_2Si	PtSi
ϕ_{Bn} (V)	0.28	0.45	0.55	0.55	0.61	0.65	0.67	0.67	0.75	0.87
ϕ_{Bp} (V)		0.45	0.55	0.49	0.45	0.45	0.43	0.43	0.35	0.23

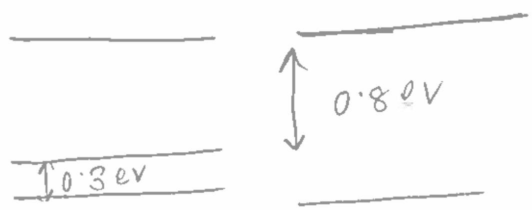
Prob 1a.[10 pts] Consider a Si PN junction diode whose N-side is heavily doped such that the E_f aligns with the conduction band. From C-V measurement, the built in potential is found to be 0.8eV.

(i) What is the doping on the p-side?

(ii) Draw the energy band diagram for the diode when a large reverse bias has been applied. Clearly show the Fermi levels on each side.

(iii) What is the mechanism of current flow under the condition specified in (ii)? Clearly show which direction the particles (electrons or holes or both) are flowing.

(i)

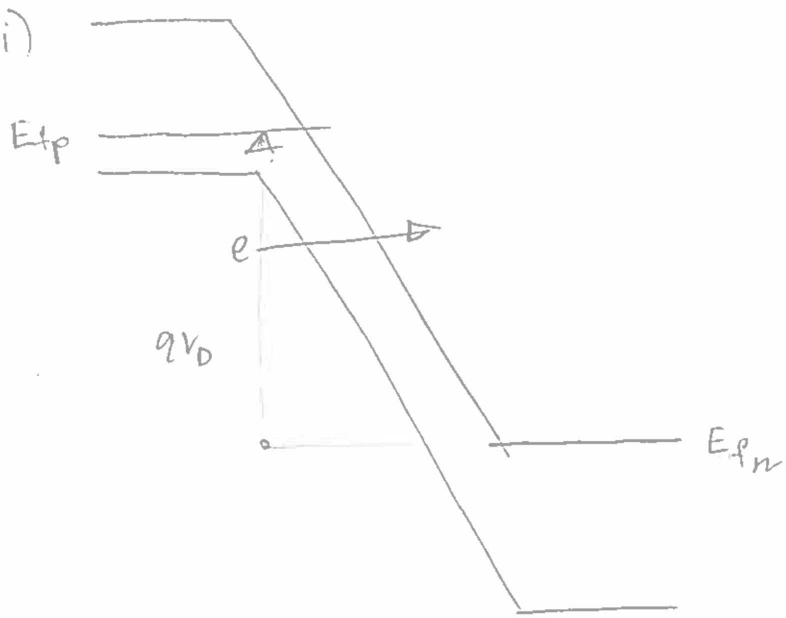


$$p \cong N_A = N_v \, e^{\frac{E_V - E_f}{k_B T}}$$

$$= 10^{19} \times e^{-\frac{0.3}{0.0259}}$$

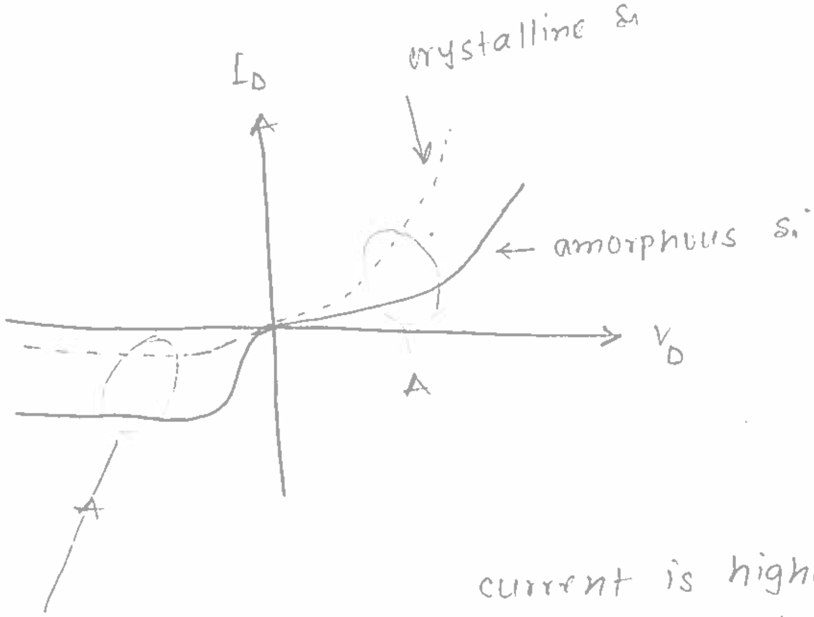
$$\approx 10^{14}/cm^3$$

(ii)



(iii) Tunneling. Electrons flow from p-side to n-side.

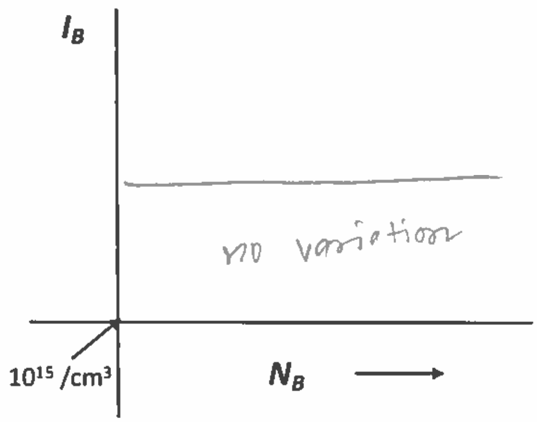
Prob 1b [10 pts] Consider a PN junction diode has been fabricated but rather than using crystalline Si, it is made of ***amorphous Si***. Draw the current-voltage characteristics of this device. In the same diagram also draw the current-voltage characteristics of a diode that has exactly the same doping levels for the N and P side but made of crystalline silicon. Clearly point out any differences and the rationale for those differences.

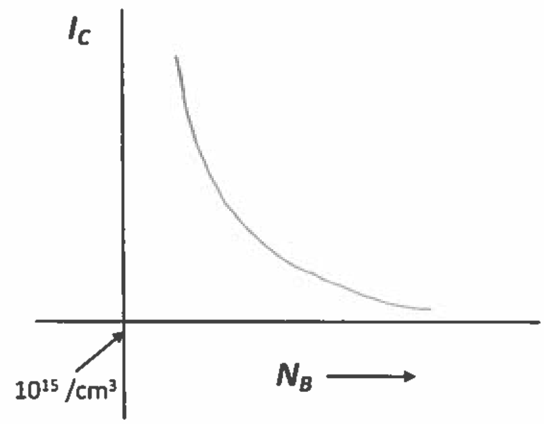


current is higher because μ and so D is larger for crystalline Si.

reverse bias current is larger because of increased junction leakage which happens due to larger defect density in amorphous Si.

Prob 2a [5pts] Consider a few NPN transistors are made where the base doping is varied over a certain range. In the following, plot how I_C and I_B will vary as a function of base doping if all the transistors are biased in the forward active mode. Justify your answer.





$$I_B \propto \frac{n_i^2}{N_E}$$

$$I_C \propto \frac{n_i^2}{N_B}$$

Prob 2b [5 pts] Consider, for a NPN BJT, the emitter has been replaced by a material which has a larger bandgap compared to base and collector. Discuss how this will change (increase/decrease/no effect) I_C and I_B. If the collector is further replaced by a larger bandgap material than the base how would that affect I_C and I_B?

Because $I_B \propto n_{iE}^2$; larger bandgap in the emitter will decrease I_B.

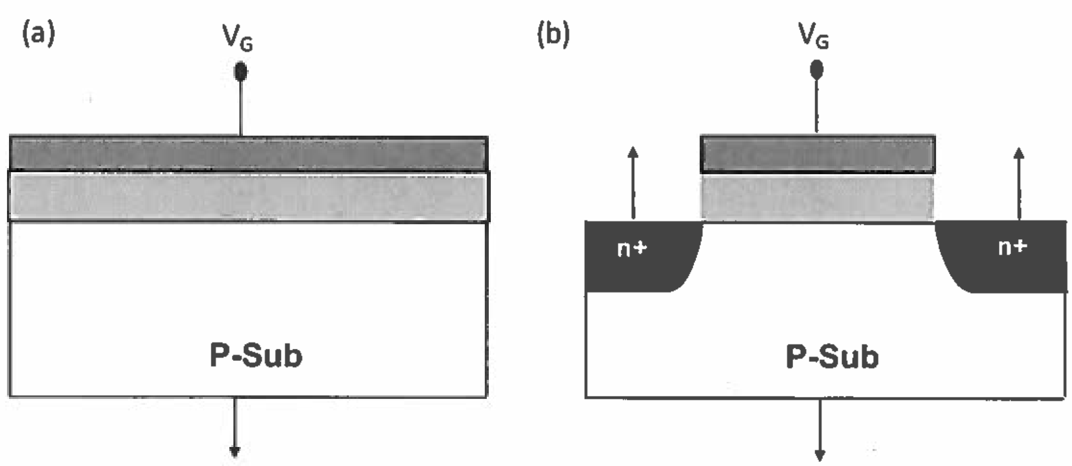
There is no effect on I_C.

Larger bandgap in collector:

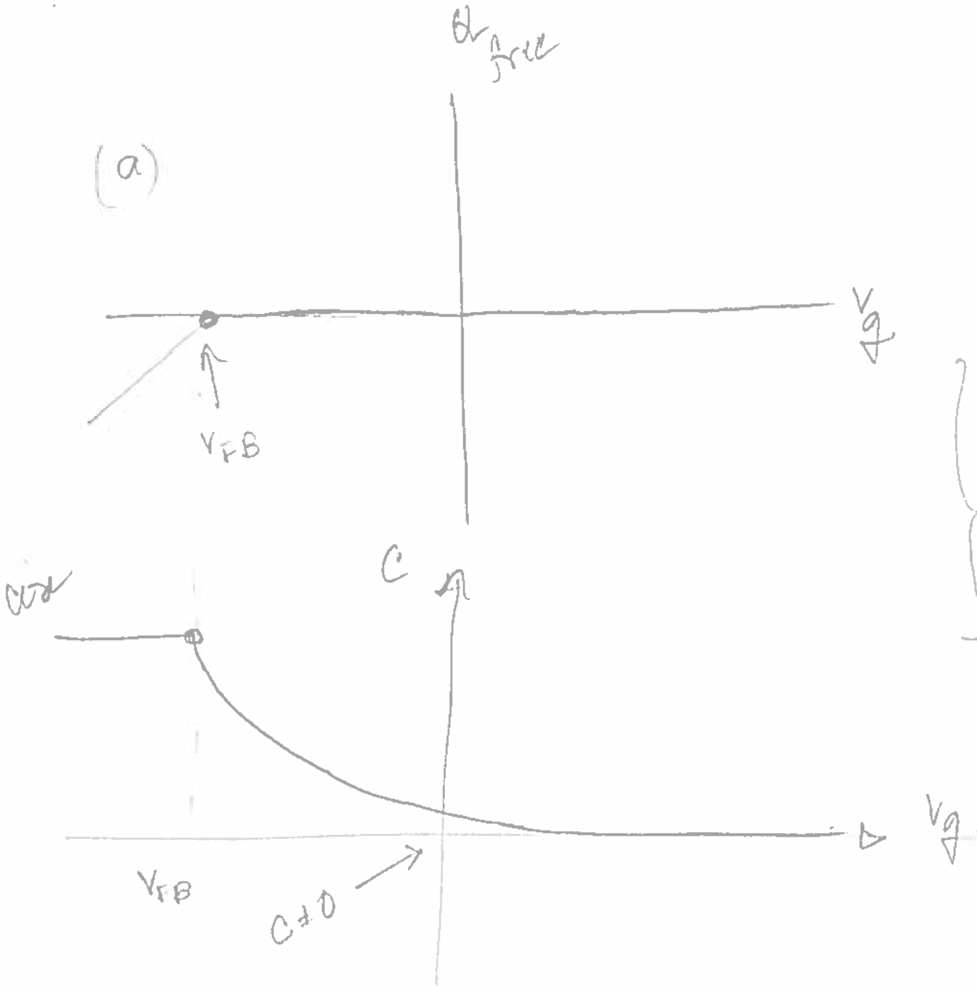
There is no effect on I_B and I_C to the first ordr

The hole current from base to collector in the reverse biased B-C junction will be affected but it is too small compared to hole current flowing in forward biased B-E junction

Prob 2c [10 pts] For each of the two structures shown in the following draw the (i) *free carriers* vs. V_G and (ii) Capacitance vs. V_G plots looking from the gate. Justify your answers.

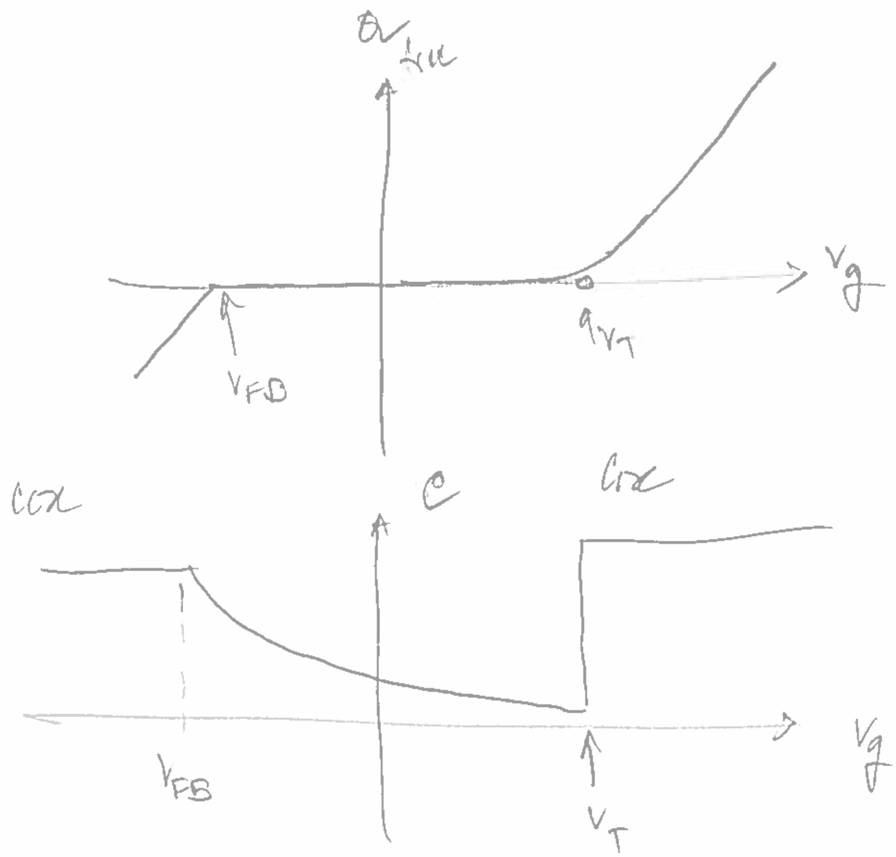


(a)

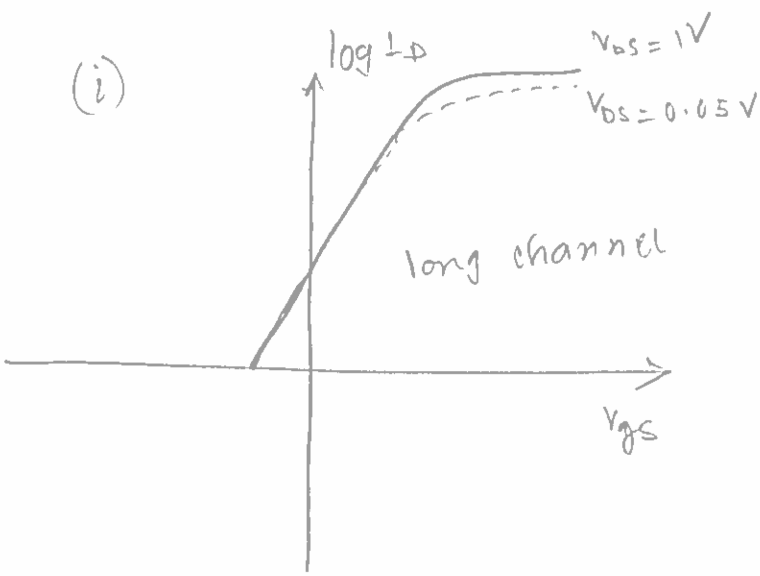


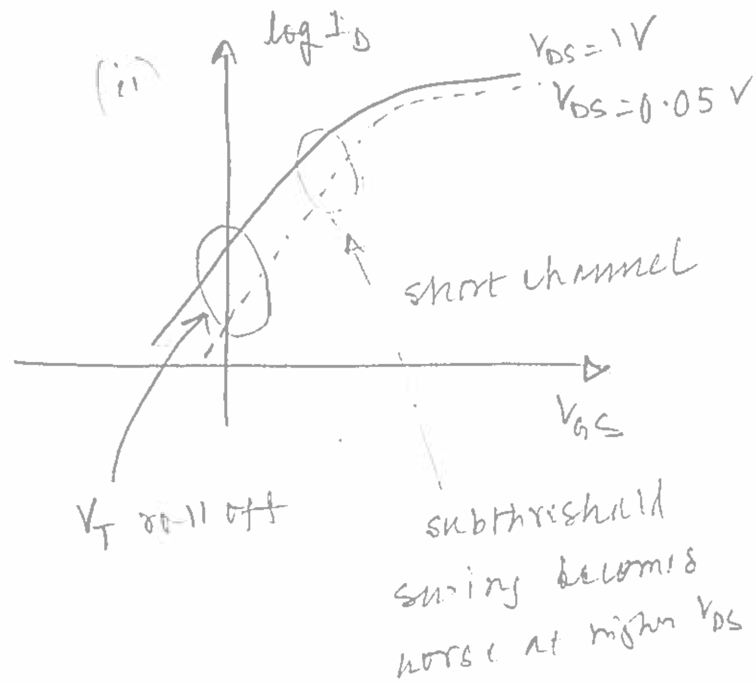
because there are no S/D regions, p-type Si cannot invert.

(b)



Prob 3a [8 pts] Draw the log I_D-Vgs plot for (i) a long channel and a (ii) short channel transistor. In each case draw two curves, one for Vds=0.05 V and one for Vds=1 V. Clearly point out the differences and the reasons for those differences.





Two main differences:

(i) short channel transistors I_{off} goes up exponentially at high V_{DS} due to DIBL

(ii) subthreshold swing gets worse at high V_{DS}. This is because ψ_s has a larger contribution from drain at high V_{DS}.

Prob 3b. [4 pts] Consider two MOSFETs one with a higher body doping than the other. For the same substrate bias, which one will have a larger shift in the threshold voltage? Why?

charge contained in the depletion region,

$$Q_{fixed} = q N_A W$$

$$= q N_A \sqrt{\frac{2\epsilon_{si}}{q N_A} \phi_s}$$

$$= \sqrt{2\epsilon_{si} q N_A \phi_s}$$

$\therefore$ Q_{fixed} increases with increasing N_A.

This means for the same bias, increase in V_T will be larger for more heavily doped body. Note that increased Q_{fixed} means decreased Q_{free}.

Prob 3c [4 pts] How does the body doping need to change (increase or decrease) as channel length is scaled down to account for the short channel effects? Does changing body doping affect any other parameter of the MOSFET?

Body doping needs to go up to minimize the encroachment of depletion region inside the channel.

Increasing body doping also increases V_T which means, supply voltage needs to go up.

Problem 2d [4 pts] Put an X mark in the 'True' of 'False' column for each question

	True	False
GIDL current is due to drift of electrons at high electric field at the drain end		X
Using a metal gate increases the effective oxide capacitance	X	
V_T roll off affects the ON current more than the OFF current		X
Once the velocity saturation is reached, the ON current no longer goes up with decreasing channel length.		X