EE 130, Fall 1995
Final
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Electric charge = q =1.602e-19 C
Permittivity of vacuum = **epsilon not** = 8.854e-14 F/cm
Free electron mass = **mo** = 9.11e-31 kg
Boltzman's constant = k = 1.38e-23J/degree K
= 8.62e-5 eV/degree K
Thermal voltage = **Vt** = kt/q = .026 V at 300 K Conversion Factors
1 **A** = 1e-8 cm
1 micrometer = 1e-6 m = 1e-4 cm
1 eV = 1.6e-19 J
1 J = 1e7 erg

Properties of Si at 300 K
Effective density of states for conduction band = **Nc** = 2.8e19 cm e-3
Effective density of states for valence band = **Nv** = 1.04e19 cm e-3
Intrinsic carrier concentration = **ni** = 1.45e10 cm e-3
Relate permittivity = **epsilon r** = 11.7
Relative permittivity of oxide = **epsilon ox** = 3.9

Problem #1a

A uniformly doped Si sample has 10um length and 10um squared cross sectional area. 1V is applied across this sample. Suppose p=1e14 per cm cubed and **mu p** = 500 cm squred/V s. These values are valid for all of #1 Derive the expression **mu p** in terms of **tau p** and **m p**.

Problem #1b

Give two mechanisms of carrier scattering and state whether the rate of scattering for each mechanism increases or decreases as temperature increases.

Problem #1c

Find the drift velocity of the carriers.

Problem #1d

Find the current flowing through this sample.

Problem #1e

What is the approximate hole velocity when 100V is applied

Problem #2a

A simple circuit that functions as a temperature sensor forces a fixed forward-bias current **If** though a pn diode and monitors the resultant diode voltage, **Vf**. Derive an expression for **Vf** as a function of temperature T. The function may contain any semiconductor parameters usually consided known or given, e.g. **Eg**, **Na**, **tau n**, **Nc**, **Nv**, etc. Ignore the T dependence of all these parameters.

Problem #2b
For extra credit, give the answer to (a) in temrs of **Eg**, q, kT, **If**, and **Vf**

Problem #3a
Consider a Schottky diode with this doping profile Sketch the 1/C squared versus V (reverse bias voltage) curve. No need to find numerical values for C.

Problem #3b
Sketch the electric field profile for the bias condition when **x dep** = 2 um. No need to find numercial values of **epsilon**

Problem #3c
What is the applied bias in part (b)

Problem #3d
Derive an expression of C as a function of V for the case of **x d** > 1 um

Problem #3e
Under forward bias, what is the main difference between the I-V characteristic of the Shottky diode and a pn-junction diode? Use 2 sentences or less.

Problem #3f
If you want an ohmic contact instead of a Schottky diode would you change the doping profile?

Problem #4a
Sketch the cross-section of a CMOS inverter in an n-well process. Label the nodes connected to power(VDD) and ground.

Problem #4b
Describe what latch-up is (now how it happens) and why it is a problem in 2 sentences

Problem #4c
Identify the parasitic NPN and PNP transistors in the sketch by connecting the BJT nodes to the corresponding MOSFET node with lines. (Note that not all MOSFET node may be involved.

NPN emitter NMOS source
NPN base NMOS drain
NPN collector n-well
PNP emitter PMOS source
PNP base PMOS drain
PNP collector p-substrate

Problem #4d

In principle latch-up problems can be reduced by depressing the current gains of the BJT's. Indicate by arrows(latch-up reduced, enahced, or unaffected) the effect of each of the following changes. Explain with very short phrases, e.g. base recombination time increses.

Increase n-well depth:
Increase n-well doping:
Increse p+ junction doping:
n+/p+ separation (distance) increase:
Add gold into Si substrate:
Increase gate oxide thickness:

Problem #4e

It has been observed that the latch-up structure can tolerate a large trigger pulse without latching-up if the pulse is very short. Give a one or two sentence simple explanation for why latch-up has a time dependence.

Problem #5a

Qualitatively sketch the C-V, **Id**-**Vg**, and **Id**-**Vd** curves for a NMOSFET in the following conditions. (where the dot line represents the curves before changing each paramter) Add positive charge in oxide:

Problem #5b

Nd decreases:

Problem #5c

x ox increases:

Problem #6a

Consider a NMOSFET with **x ox** = 100 **A**, **Na**=5e16 cm, Assume L=0.5um, W=10um, **mu n**=500 cm squared/V s, **Vg - Vt** = 3V, and **epsilon c** (critical field for velocity saturation) = 2e4 V/cm Without considering velocity saturation, what is **Id** at **Vd**=1V

Problem #6b

What is **Id** at **Vd**=1V with velocity saturation?

Problem #6c

Calculate the subthreshold swing, S

Problem #6d

As a result of the hot-electron effect, 1e-7 could/cm squared of electrons are trapped at the oxide/Si interface. How much will **Vt** change? Will **Vt** increase (become more positive) or decrease?

Problem #6e

If **Vt** decreased by 0.1V as a result of hot-electron effect, by what ratio (factor) will **Id** at **Vg**=0 change? Will **Id** increase of decrease?

Problem #6f

What phenomenon does the following figure illustrate?

Problem #6g

In (f), which company's technology is superior? Why is it considered superior?

Problem #6h

In (g), list two possible ways for this company to achieve this competitive advantage.
