Spring 2005

UNIVERSITY OF CALIFORNIA

College of Engineering

Department of Electrical Engineering and Computer Sciences

EECS130 Midterm I

Last Name______________________ **First Name** SOLUTIONS

Instructions:

Print your name on the cover page CLEARLY now

Show major intermediate steps on exam pages to facilitate grading

Make sure your copy of the exam paper has 7 pages (including cover page)

Information that may be useful

$q = 1.6 \times 10^{-19}$ coulombs

Boltzmann constant $k = 8.62 \times 10^{-5}$ eV/ K

n_i of Si= 10^{10} cm^{-3} at 300K

Problem 1 (14 points) _______________

Problem 2 (28 points) _______________

Problem 3 (17 points) _______________

Problem 4 (41 points) _______________

TOTAL (100 points) __________________

Problem 1 (14 points)

A donor-doped silicon sample at 300K has resistivity of 0.1 Ω-cm.

a) What is the doping density? (3 points)

Given $\rho = 0.1\ \Omega\text{-cm}$

From Resitivity versus Doping chart,

$N_D = 7\times10^{16}\ cm^{-3}$

b) What is the hole concentration? (2 points)

$$p = \frac{n_i^2}{n} = \frac{10^{20}}{7\times10^{16}}$$

$$= 1.42\times10^{3}\ cm^{-3}$$

$n_i = 1.45\times10^{10}\ cm^{-3}$ OK

c) What is electron diffusion constant? (4 points)

$$D_n = \frac{kT}{q}\mu_n$$

$\mu_n = 830\ cm^2/V\text{-}s$

$$D_n = \frac{kT}{q}\mu_n = \frac{8.62\times10^{-5}\ eV}{e} \times 300 \times 830\ \frac{cm^2}{V\text{-}s} = 21.46\ cm^2/s$$

Or read from the chart.

d) Now acceptor density, $N_A=3\times10^{16}$ cm^{-3} is added to above sample. What is conductivity of the sample? (5 points)

$N_A = 3\times10^{16}$, $N_D = 7\times10^{16}$

$N_A + N_D = 10^{17}\ cm^{-3}$

$n = N_D - N_A = 4\times10^{16}\ cm^{-3}$

$$p = \frac{n_i^2}{n} = \frac{10^{20}}{4\times10^{16}} = 2.5\times10^{3}\ cm^{-3}$$

$\sigma = q\mu_n n + q\mu_p p$ → $q\mu_p p$: small contribution

$\sigma \approx q\mu_n n$

$\mu_n @ 10^{17}\ cm^{-3} = 720\ cm^2/V\text{-}s$

$$\sigma = 1.6\times10^{-19}\ Col. \times 720\ \frac{cm^2}{V\text{-}s} \times 4\times10^{16}\ cm^{-3}$$

$$= 4.6\ \frac{1}{ohm\text{-}cm}$$

$\sigma = 4.6\ [ohm\text{-}cm]^{-1}$

Problem 2 (14×2=28 points)

Answer each with one or two sentences, or phrases or define with an equation. Unless otherwise specified answer the questions for Si at 300K. You may assume that commonly used parameters are given.

a) What is the electron concentration given $N_A=N_D=5\times10^{15}$ cm^{-3}?

$n = n_i$

b) Is silicon a donor or an acceptor in GaAs? (Ga is group III and As is Group V).

both Acceptor and Donor (Si is IVth Group)

c) What is the recombination rate, given n'?

$\frac{n'}{\tau}$ where τ is recombination time

d) Give an expression for Einstein relationship.

$\frac{D}{\mu} = \frac{kT}{q}$

e) What is the "excess carrier concentration"?

$n' \equiv n - n_0$

or Difference between carrier concentration and the equilibrium value.

f) What is wet lithography technology?

Use liquid to reduce the light wavelength in lithography process.

or Add water to the space between the lens and the water

or Use liquid to improve lithography resolution.

g) What is 'end-point detection' in etching process?

Detecting the exposed substrate film after the removal of the desired film.

or A way to know when etching is done.

or Detection of completion of the (desired) etch process.

h) What type of CVD process is used to deposit oxide at the lowest temperature?

PECVD

i) What is 'sputtering'?

Depositing a film by kicking atoms of the film material out of a "target" with plasma (or ions).

j) Why is wet oxidation sometimes preferred over dry oxidation?

Wet oxidation is faster than dry oxidation.

Or Wet oxidation can be performed at lower temperature

k) Give two reasons for 'thermal annealing' after ion-implantation even when the shallowest possible junction depth is desirable.

1. Damage removal
2. Dopant activation

l) Give two reasons why the industry switched from *Al* to *Cu* as interconnect material in advanced silicon technology.

1. Electromigration
2. Low contact resistance
3. Low RC delay
4. Faster circuits
5. better reliability

m) What is the depletion region approximation?

There is a region in PN junction where electrons and hole concentrations are low.

or Mobile carriers are negligible in the depletion region.

Or $n \approx 0$, $p \approx 0$ in the depletion region.

n) What is a one-sided junction?

One side of the junction is heavily doped as compared to the other side.

Problem 3 (17 points)

Design a sequence of process steps by using the available process options from the given menu to go from Fig. 1 to Fig. 2.

Process Menu
Annealing
Gas Source doping
Wet etching
Deposition of oxide
Dry etching
Ion Implantation
Sputtering
Solid source diffusion
Lithography

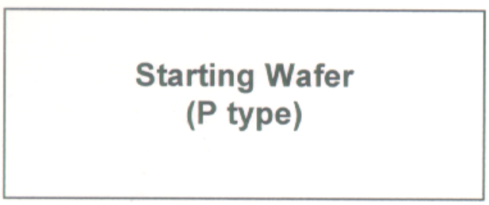

Fig. 1

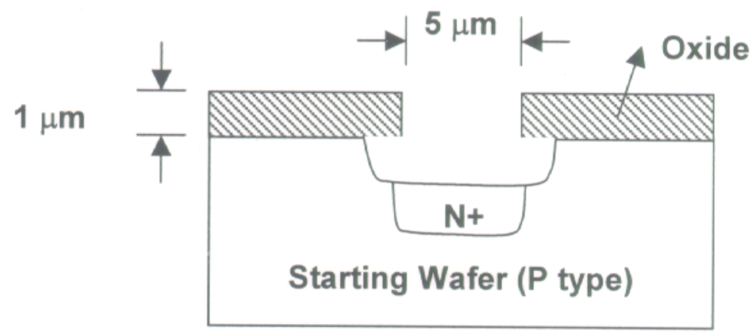

Fig. 2

- Deposition of oxide
- Lithography
- Dry etching (For oxide)
- Wet etching (for substrate)
- Ion Implantation
- (Annealing) ⇐ optional

OR

- Deposition of oxide
- Lithography
- Dry etching (for oxide)
- Ion Implantation
- Wet etching (for substrate)
- (Annealing) ⇐ optional

OR

- Deposition of oxide
- Lithography
- Dry etching
- Ion Implantation
- (Annealing) ⇐ optional
- Wet etching

PROBLEM #4

1.

Eqn. 1: $n_i = \sqrt{N_c N_v}\, e^{-E_g/2kT}$

Eqn. 2: $N_c = 2\left[\frac{2\pi m_n kT}{h^2}\right]^{3/2}$

Eqn. 3: $N_v = 2\left[\frac{2\pi m_p kT}{h^2}\right]^{3/2}$

Eqn. 4: $N_c e^{-(E_c-E_f)/kT} = n$

Changing Parameter \ Affected Parameter	n_i	n	p	E_c-E_f
E_g ↑	From Eqn. 1 w/ $E_g\uparrow \Rightarrow n_i\downarrow$ ↓	For $N_D = 10^{16}\,cm^{-3}$ (N type) n - stays the same →	$p = \frac{n_i^2}{n}$ w/ $n_i\downarrow \Rightarrow p\downarrow$ ↓	From Eqn. 4 n - stays same N_c - stays same No change in E_c-E_f →
m_n ↑	from Eqn. 2 w/ $m_n\uparrow \Rightarrow N_c\uparrow$ n_i ↑ (Eqn. 1)	n - No change →	w/ $n_i\uparrow \Rightarrow p\uparrow$ ↑	n - No change N_c - ↑ from Eqn. 4 ↑
m_p ↑	from Eqn. 3 w/ $m_p\uparrow \Rightarrow N_v\uparrow$ n_i ↑ (Eqn. 1)	n - No change →	w/ $n_i\uparrow \Rightarrow p\uparrow$ ↑	n - No change N_c - No change from Eqn. 4 →
N_D ↑	No effect on n_i →	sample more heavily doped now. ↑	$p = \frac{n_i^2}{n}$ $n\uparrow \Rightarrow p\downarrow$ ↓	from Eqn. 4 ↓ (E_f closer to E_c)
N_A ↑	No effect on n_i →	$n = N_D - N_A$ (compensated) ↓	$p = \frac{n_i^2}{n}$ $n\downarrow \Rightarrow p\uparrow$ ↑	from Eqn. 4 ↑ (E_f moves away from E_c)
T ↑ (assume N_c and N_v remain constant)	From Eqn. 1 ~~no change~~ n_i ↑	upto this temp. (400 K) n does not change →	$p = \frac{n_i^2}{n}$ $n_i\uparrow \Rightarrow p\uparrow$ ↑	from Eqn. 4 $e^{-(E_c-E_f)/kT}$ = const (N_c, n = No change) $T\uparrow \Rightarrow (E_c-E_f)\uparrow$ ↑

Added condition T goes upto 400K

PROBLEM # 4

2.

Eqn. 5: $\mu = \frac{q\tau}{m}$

μ — Impurity scattering component $\propto \frac{T^{3/2}}{N_A + N_D}$

μ — Lattice scattering component $\propto T^{-3/2}$

Eqn. 6: $D = \frac{kT}{q}\mu$

Eqn. 7: $\phi_{bi} = \frac{kT}{q}\ln\left(\frac{N_A N_D}{n_i^2}\right)$

Eqn. 8: $W_{dep} = \sqrt{\frac{2\varepsilon_{si}(\phi_{bi} + V) \times (N_A + N_D)}{q(N_A \cdot N_D)}}$

Changing Parameter \ Affected Parameter	μ_n	D_p	ϕ_{bi} of PN junction with $N_A = 10^{18}$ cm^{-3}	W_{dep}
E_g ↑	$\mu_{lattice}$ and $\mu_{impurity}$: No change. →	from eqn. 6 D_p = No change →	from eqn. 7: $n_i \downarrow \Rightarrow \phi_{bi} \uparrow$ ↑	$\phi_{bi} \uparrow \Rightarrow W_{dep} \uparrow$ (Eqn. 8) ↑
m_n ↑	$m_n \uparrow \Rightarrow \mu_n \downarrow$ (eqn. 5) ↓	μ_p – remains same D_p = No change →	$n_i \uparrow \Rightarrow \phi_{bi} \downarrow$ ↓	$\phi_{bi} \downarrow \Rightarrow W_{dep} \downarrow$ ↓
m_p ↑	$m_p \uparrow \Rightarrow$ No change on μ_n →	$m_p \uparrow \Rightarrow \mu_p \downarrow \Rightarrow D_p \downarrow$ ↓	$n_i \uparrow \Rightarrow \phi_{bi} \downarrow$ ↓	$\phi_{bi} \downarrow \Rightarrow W_{dep} \downarrow$ ↓
N_D ↑	More Impurity scattering μ_n ↓	μ_p also goes down $\mu_p \downarrow \Rightarrow D_p \downarrow$ ↓	$N_D \uparrow \Rightarrow \phi_{bi} \uparrow$ ↑	X
N_A ↑	More Impurity scattering μ_n ↓	$\mu_p \downarrow \Rightarrow D_p \downarrow$ ↓	X	X
T ↑ (assume N_c and N_v remain constant)	X	X	X	X