

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

EE143

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Spring 2016

Exam 1

Name: _____

SID: _____

Closed book. One sheet of notes is allowed.
There are a total of 11 pages on this exam, including the cover page.

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Total	100

Physical Constants

Electronic charge	q	$1.602 \times 10^{-19} \text{ C}$
Permittivity of vacuum	ϵ_0	$8.845 \times 10^{-14} \text{ F cm}^{-1}$
Relative permittivity of silicon	$\epsilon_{\text{Si}}/\epsilon_0$	11.8
Boltzmann's constant	k	$8.617 \times 10^{-5} \text{ eV/K}$ or $1.38 \times 10^{-23} \text{ J K}^{-1}$
Thermal voltage at $T = 300\text{K}$	kT/q	0.026 V
Effective density of states	N_c	$2.8 \times 10^{19} \text{ cm}^{-3}$
Effective density of states	N_v	$1.04 \times 10^{19} \text{ cm}^{-3}$
Intrinsic carrier concentration of Silicon at $T=300\text{K}$	n_i	10^{10} cm^{-3}



Periodic Table of the Elements															
1	2											3	4	5	6
1	H	IIA											7	B	He
2	3	4											8	C	Ne
	Li	Be											9	N	
3	11	12	IIIB	IVB	VB	VIB	VII B	— VII —				IB	IIB	10	O
	Na	Mg											11	F	Ar
4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As
5	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb
6	55	56	57	72	73	74	75	76	77	78	79	80	81	82	83
	Cs	Ba	*La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi
7	87	88	89	104	105	106	107	108	109	110	111	112	113	114	115
	Fr	Ra	+Ac	Rf	Ha	Sg	Ns	Hs	Mt	110	111	112	113		

Problem 1. Introduction to Materials (20 pts)

- a) Suppose we have a piece of silicon doped with Indium at a concentration of $1 \times 10^{17} \text{ cm}^{-3}$. Is this semiconductor p-type, n-type, or intrinsic? Briefly explain in one sentence. [2 pts]

- b) What are the majority and minority carrier concentrations for the semiconductor in part a? [2 pts]

- c) Find $E_c - E_f$ at $T=300\text{K}$ for the semiconductor in part a. [4 pts]

- d) Now we add phosphorous at a concentration of $5 \times 10^{17} \text{ cm}^{-3}$ to the semiconductor in part a. Find $E_c - E_f$ at $T=300\text{K}$. [4 pts]

- e) The wafer is now cooled to 5K. How does the carrier concentration change? Give a qualitative justification. [4 pts]

- f) Do amorphous and crystalline silicon have the same band gap? Briefly explain (2 sentences max). [4 pts]

Problem 2: Photolithography (28 pts)

a. Suppose we choose to use projection lithography for an exposure. The light source is an ArF excimer laser with wavelength of 193nm. For our system assume $k_1=0.5$, $k_2=0.5$, and the half angle of the maximum cone of light that can exit or enter the objective lense is 50 degrees. What is the smallest feature size we can fabricate? (4 pts)

b. What is the depth of focus for this exposure? (4 pts)

c. Water has a refractive index of 1.33. Suppose we performed an exposure using immersion lithography in water. What is the smallest feature size? (4 pts)

d. How does a phase-shift mask allow us to resolve smaller lines? You may use drawings to illustrate your point. (2 sentences max) (4 pts)

e. Briefly explain (3 sentences max) how using a partially coherent light may change the image contrast for projection lithography. (4 pts)

f. Photolithography tools must be kept at temperature regulated rooms. Briefly explain why. (3 sentences max) (4 pts)

g. Describe three techniques one can use to minimize the proximity effect in optical lithography. (4 pts)

Problem 3. Oxidation (26 pts)

The Deal-Grove model relates growth time and oxide thickness as:

$$X_o^2 + AX_o = B(t + \tau)$$

Where X_o is the total oxide thickness after time t , and τ is the time required to grow the initial oxide, X_i .

The rate constants for the Deal-Grove model vary with temperature according to an Arrhenius relationship:

$$D = D_0 e^{-E_A/(kT)}$$

Where D is the parameter of interest (e.g. B or B/A) and D_0 and E_A are the particular Arrhenius coefficients for that parameter. T is the temperature in Kelvin and k is Boltzmann's constant.

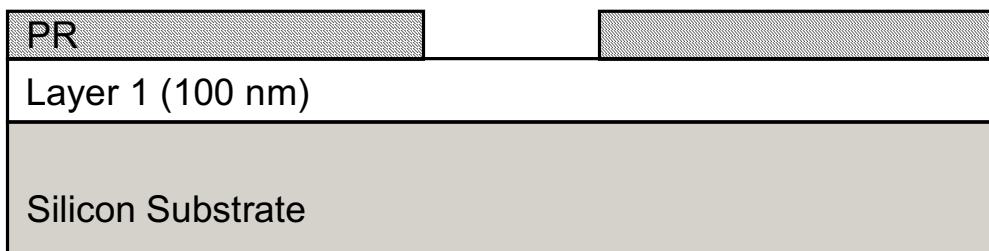
The following Arrhenius coefficients are for the rate constants of oxide thickness for <100> silicon under wet and dry oxidation:

	Wet Oxidation ($X_i = 0$ nm)		Dry Oxidation ($X_i = 25$ nm)	
	D_0	E_A	D_0	E_A
Linear (B/A)	9.70×10^7 $\mu\text{m/hr}$	2.05 eV	3.71×10^6 $\mu\text{m/hr}$	2.00 eV
Parabolic (B)	$386 \mu\text{m}^2/\text{hr}$	0.78 eV	$772 \mu\text{m}^2/\text{hr}$	1.23 eV

- Calculate the linear (B/A) and parabolic (B) rate constants for dry oxidation at 1100°C . [6 pts]
- Calculate the corresponding value of τ for dry oxidation at 1100°C , assuming $X_i = 25$ nm. [4 pts]
- After 2 hours of dry oxidation at 1100°C , a wafer is found to have 200 nm of oxide. Calculate the thickness that the oxide started at just before this step. [4 pts]
- A silicon rod is oxidized at 1100°C such that half of its starting diameter is consumed and converted into SiO_2 . Calculate the volume change after oxidation. [4 pts]
- Dry oxidation is always slower than wet oxidation. Briefly explain why (3 sentences max). [4 pts]
- After oxidation the color of the wafer changes. Briefly explain why. (4 pts)

Problem 4: Etching (26 pts)

- (a) The free electron density in a typical RIE process chamber ranges between 10^9 and 10^{10} cm^{-3} . Assume the RIE chamber is held at a pressure of 200 mTorr and a temperature of 350 K. Calculate (or estimate) the ionization efficiency in the RIE reactor. The ionization efficiency is the ratio of the electron density to the density of the molecules. (Hints: 1 atm = 760 Torr = 101.3 kPa). [4 pts]
- (b) What is one way to improve anisotropy in dry etching? [4 pts]
- (c) Name three advantages and three disadvantages of wet etching compared to dry etching. [4 pts]
- (d) How is the selectivity controlled in dry etching? Be brief, three parameters is sufficient. [4 pts]
- (e) Referring to the figure below for this question. Layer 1 is dry etched with an anisotropy of 1 for 10 minutes at an etch rate of 5 nm/min. Following dry etching, Layer 1 is then wet etched for 3 minutes at an etch rate of 25 nm/min with an anisotropy of 0.3. The selectivity of the wet etch of Layer 1 to the Silicon Substrate is 1:2. The anisotropy for wet etching the Silicon Substrate is 0. Please draw the cross-section (with dimensions for features) after all the etching is completed. [10 pts]



Please assume the following:

- *The opening in the PR is large enough such that an ample supply of reactants is always present at the exposed surfaces.*
- *The PR acts as a hard etch mask that does not etch at all.*

