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

EE 143 Professor Ali Javey

Spring 2014
Exam 1

Name:

SID: **Solution**____________________

Closed book. One sheet of notes is allowed.
There are a total of 12 pages on this exam, including the cover page.

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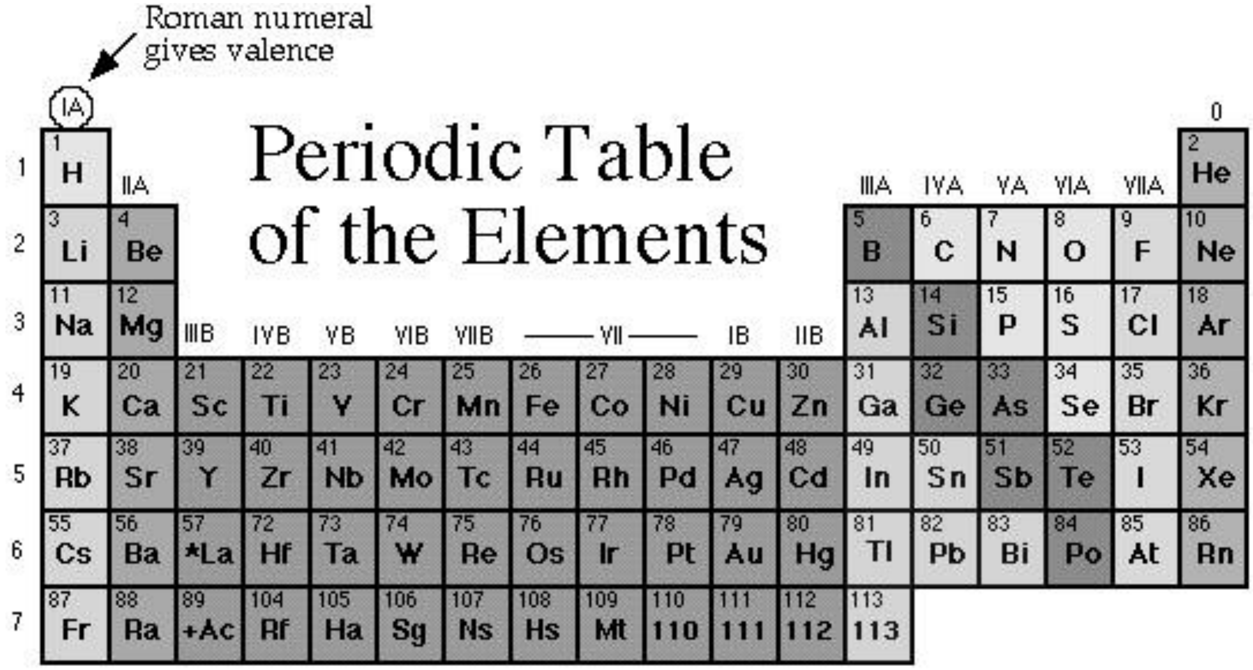
Total	100



Roman numeral gives valence

Periodic Table of the Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VII			IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110 110	111 111	112 112	113 113					

Physical Constants

Electronic charge	q	$1.602\square10^{-19}$ C
Permittivity of vacuum	$\square_0$	$8.845\square10^{-14}$ F cm^{-1}
Relative permittivity of silicon	$\square_{Si}/\square_0$	11.8
Boltzmann’s constant	k	8.617×10^{-5} eV/ K *or*
		$1.38\square10^{-23}$ J K^{-1}
Thermal voltage at T = 300K	kT/q	0.026 V
Effective density of states	N_c	2.8×10^{19} cm^{-3}
Effective density of states	N_v	1.04×10^{19} cm^{-3}

Problem 1 – Device Physics (25 pts)

Consider a wafer of InAs, (E_g=0.36 eV, $N_C=9\text{x}10^{16}$ cm^{-3}, $N_V=6\text{x}10^{18}$ cm^{-3}, n_i = 10^{15} cm^{-3})

a) If we were to introduce carbon into the InAs would it behave as an n- or p-type dopant? Why? Explain your answer with 2-3 sentences. [5 pts]

Can be either n-type or p-type depending upon In or As sites are replaced by C. If In is replaced, C acts as donor and would behave as a n-type dopant; if As is replaced, then it would behave as a p-type dopant.

b) For a piece of InAs doped with 2x10^{16} cm^{-3} acceptors, find the hole concentration at room temperature. Assume total ionization of acceptors [5 pts]

$$p = 2 \times 10^{16}$$

c) Find E_c-E_f for the sample in part b. [5 pts]

$$E_f - E_i = kT \times \ln\left(\frac{p}{n_i}\right) = 0.078eV \quad E_c - E_f = \frac{E_g}{2} + \left(E_f - E_i\right) = 0.258eV$$

Do doped semiconductors become more insulating or conducting at low temperatures? Briefly explain. [5 pts]

More insulating. Lowered thermal energy at low temperatures reduces band-to-band generation and freezes out dopant and in turn results in reduced free carrier concentration.

c) For space applications, do you think InAs provides an advantage over Si? Briefly explain. [5 pts]

No. space applications require materials with wide band gaps to be able to tolerate the extreme temperature ranges without breakdown.

Problem 2 – Etching (25 pts)

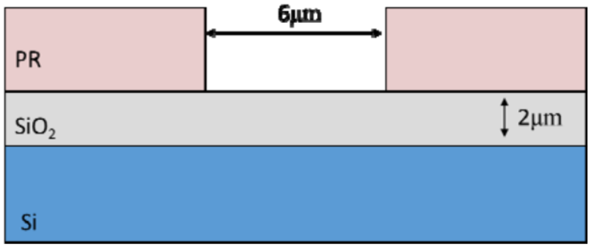
a) List the three main mechanistic steps involved in wet etching. [5 pts]

1. Reactant transport to surface
2. Selective and controlled reaction of etchant with the film to be etched
3. Transport of by-products away from surface

b) A student is etching SiO_2 with a 10:1 buffered HF, but soon realizes the etching is taking too long. List three ways the student could do to speed up the SiO_2 etch rate using buffered HF and briefly explain your reasoning for each. [5 pts]

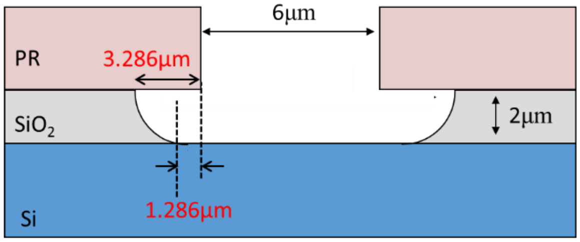
1. Heat up the HF – to increase the reaction, transport, and desorption rates
2. Etch in HF with higher concentrations such as 5:1 BHF or straight HF – increase the reaction and transport rates
3. Agitate the solution – increase transport and desorption rates

c) Consider a wafer cross-section shown below. A SiO_2 film of 2 μm is known to have a thickness variation factor δ of 0.15. Assume HF has an isotropic oxide etch rate of 100 nm/min with a variation factor of 0.3. How long should the wafer be submerged in HF to completely remove oxide from the exposed regions, across the entire wafer? [5 pts]



hf(max)=hf*(1+δ) = 2.3μm, E.R.(min)=E.R.*(1-0.3) = 70 nm/min.
therefore an etch time of 2300/70 = 32.86 mins is needed.

e) Draw the nominal cross-section after the wafer has been etched for the time computed above. Be sure to label all known dimensions. [5 pts]



f) List three benefits of using wet etching over dry etching. [5 pts]

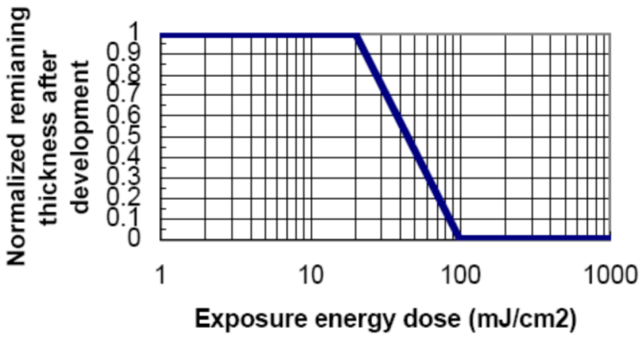
1. Excellent Selectivity

2. Isotropic etching may be beneficial (i.e. MEMS release)

3. Cheaper and easier than dry etching

Problem 3. Photolithography & Etching (30 pts)

For this question assume a g-line photoresist (436nm) that has the exposure/development characteristic shown below.



(a) Is this PR positive or negative? Briefly explain (1 sentence). [5 pts]

High expose dose removes the P.R. so it is a positive resist.

(b) Find the resist contrast. [5 pts]

$$contrast = \frac{1}{\log(\frac{Q_f}{Q_0})} = \frac{1}{\log(\frac{100}{20})} = 1.43$$

(c) What are the main advantages and disadvantages of positive PR as compared to negative PR? [5 pts]

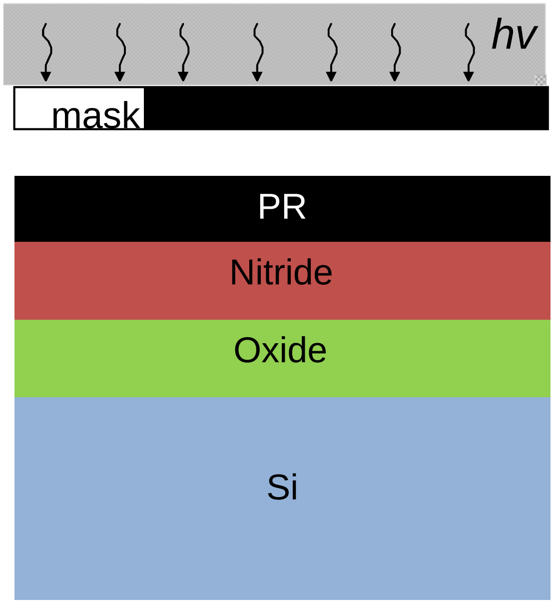
Advantages:

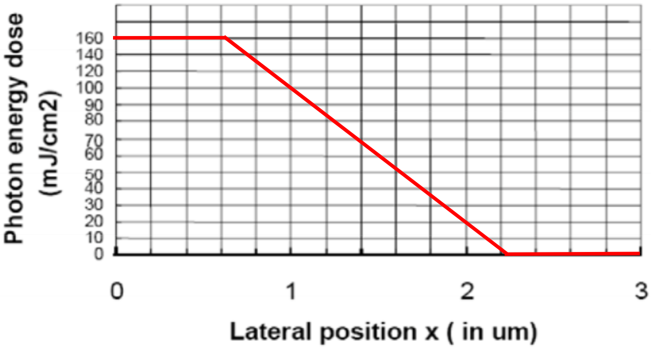
- Higher resolution
- Aqueous-based solution

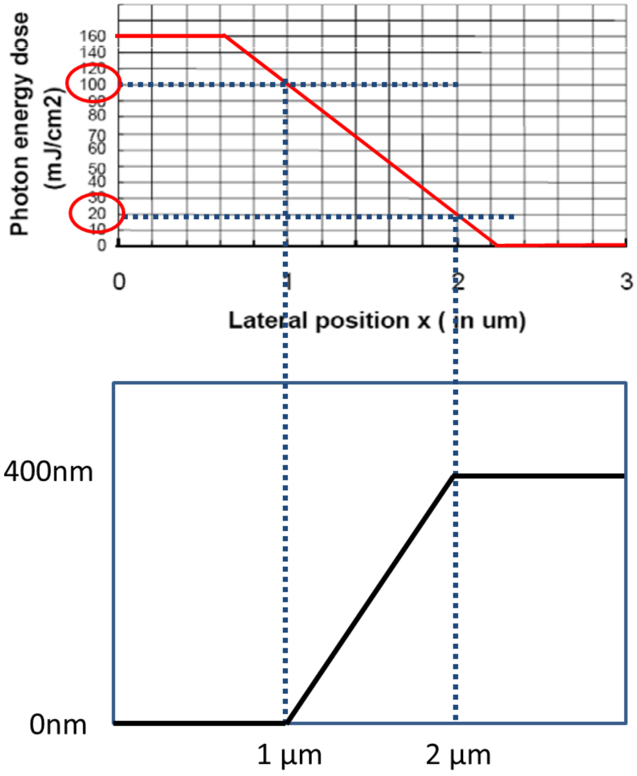
Disadvantages:

- Less sensitive (lower exposure throughput)
- Less tolerant of developing conditions
- Less chemically resistant

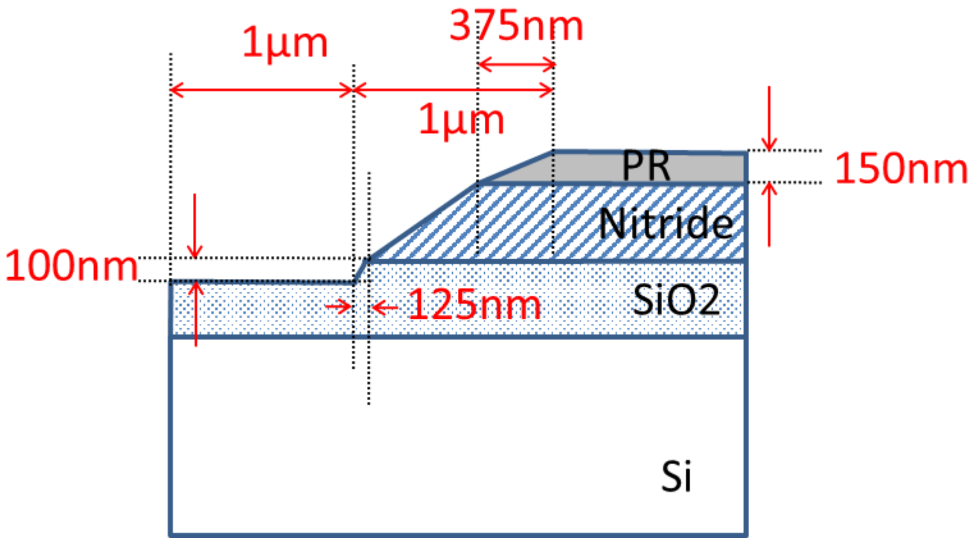
(b) The PR from part (a) is coated over a wafer which has an oxide and a nitride layer as shown below. The thickness of each layer is 400nm. The image profile that is projected on the PR is shown below. Draw the expected PR profile (PR thickness versus lateral position) after exposure and development. (Hint: assume linear slope in your profile.) [5 pts]



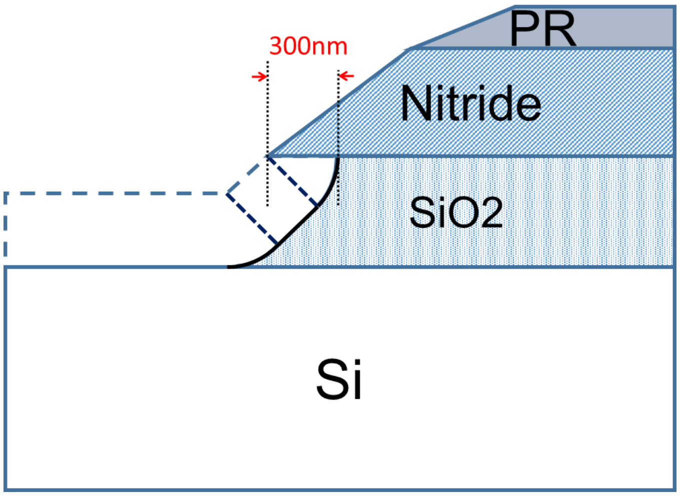




(e) Now, the nitride layer is dry-etched. Degree of anisotropy, A_f is 1 for all materials. Etching selectivity is PR:nitride:oxide = 0.5:1:1. Assuming the etching rate for nitride is 100nm/min, draw the cross-section after 5min etching. Clearly label the relavent length scales. [5 pts]

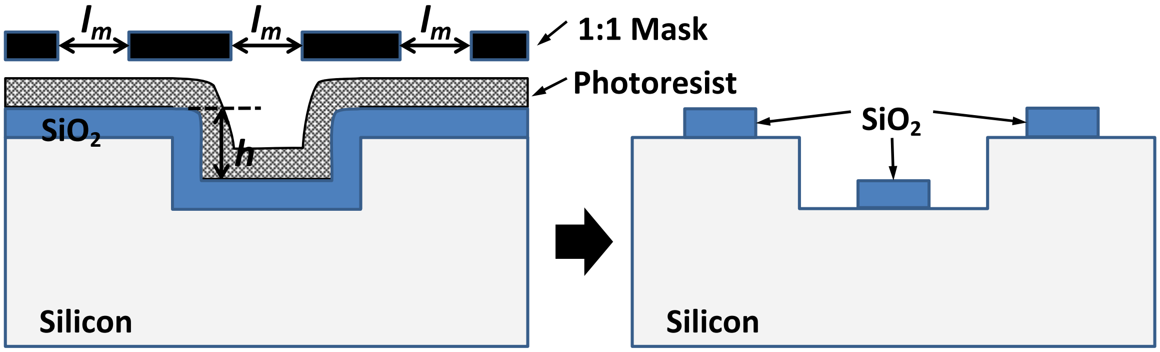


(f) Next, the sample is treated with buffered HF (BOE). Generally, BOE is assumed to have an infinite selectivity with A_f=0. Draw the cross-section after 3min BOE etching. The BOE is diluted to have 100nm/min etching rate. Clarly label the relavent length scales. [5 pts]



Problem 4- Photolithography (20 pts)

1. Suppose that a photolithography step and a fully anisotropic SiO_2 etching (100% selective to Si) are performed sequentially on a 6-inch wafer (diameter = 150 mm) to achieve patterns as illustrated in the figures below, where l_m is the minimum feature size of 0.25 µm. Assume that the initial SiO_2 layer was uniform in thickness on the surface of the Si substrate.



(a) What type of photoresist was used here? Justify your answer. [5 pts]

Negative resist was used since negative resist remains on clear regions of the mask after development to protect oxide from being etched.

(b) Now, suppose a 10:1 projection stepper with a numerical aperture of lenses $NA = 1$ is used for this photolithography step, what wavelength illumination is required to achieve the 0.25µm minimum resolution? Assume k1=0.6 and k2=0.5.[5 pts]

$$l_m = k1\frac{\lambda}{NA} = 250nm \quad \lambda = 250 \times \frac{NA}{K1} = 416.7nm$$

(c) Continuing from (b), what is the maximum step height, h (marked in the figure), that is allowed to ensure that the patterns with minimum feature sizes can all be resolved? Assume NA=1. Assume k1=0.6 and k2=0.5. [5 pts]

$$DOF = k2\frac{\lambda}{NA^2} = \frac{h}{2} \quad h = 2 \times k2 \times \frac{\lambda}{NA^2} = 416.7nm$$

(d) Continuing from (b), what is the minimum feature size that needs to be achieved on the photomask plate for this 10:1 project stepper in order to yield the 0.25-µm image resolution? [5 pts]

2.5 µm (10× magnification)