ECE 6450 Introduction to Microelectronics Technology

Exam 2

October 16, 2017

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Note to Future Classes: Due to a short time Between exam 1 + 2 this exam is easier/shorter than most.

Print your name clearly: Solutions

Instructions:
Read all the problems carefully and thoroughly before you begin working. **DO NOT SEPARATE ANY PAGES OF THIS EXAM.** You are allowed to use 2 sheets of hand written notes (4 faces, 1 page front and back, total) which you must turn in as well as a calculator. There are 100 total points. Observe the point value of each problem and allocate your time accordingly. **SHOW ALL WORK ON THE PROVIDED SHEETS AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED**. Write legibly. No work should be done on any other paper. If I cannot read it (including tiny writing), it will be considered to be a wrong answer. Do all work on the paper provided. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. Good luck!

Sign your name on **ONE** of the two following cases:

I did not observe any ethical violations during this exam:

I observed an ethical violation during this exam:

Problem 1. (30 points total in 15, 2 point parts):

True/False - Circle your answer. Double points will be deducted if you are silly enough to not answer a true false question (and I will put in a petition for you to be removed from Ga Tech ☺).

a.) True or [✓ False] (circle the correct answer)
Rapid thermal anneals are not used often because they result in long characteristic diffusion lengths

b.) [✓ True] or False (circle the correct answer)
Excimer lasers are good choices for projection lithography systems because they provide abundant fluxes of high energy collimated light.

c.) True or [✓ False] (circle the correct answer)
In commercial RTP systems, the outer edge of the wafer is often cooler than the center due to excess energy lost at the edges.

d.) [✓ True] or False (circle the correct answer)
A wafer with a large emissivity will result in more radiative heat loss than one with a smaller emissivity.

e.) [✓ True] or False (circle the correct answer)
A wafer absorbing 200 watts of radiant heat and emitting 200 watts of radiant heat will remain at constant temperature regardless of what the emissivity of the wafer is.

f.) [✓ True] or False (circle the correct answer)
When heating wafers with an RTP system, one has to be MORE careful to maintain temperature uniformity than when heating a wafer with a large traditional furnace.

g.) True or [✓ False] (circle the correct answer)
RTP makes temperature measurement easier because the wafer can be directly probed with a thermocouple.

h.) True or [✓ False] (circle the correct answer)
Extreme Ultraviolet (EUV) Lithography is a nice idea for improving the lithography resolution by lowering the optical wavelength significantly but will never be practical because EUV sources with enough power cannot be created.

i.) [✓ True] or False (circle the correct answer)
RTP systems can, but rarely do, use the absorption photon energy to perform photochemistry not possible in a traditional furnace.

j.) [✓ True] or False (circle the correct answer)
Many photoresists share the same basic "glue" compounds found in plywood.

k.) [✓ True] or False (circle the correct answer)
The chemical process by which a positive photoresist works is based on the destabilization of an otherwise stable molecule by high energy photons and the subsequent dissolving of that destabilized molecule in a developer solution.

l.) True or [✓ False] (circle the correct answer)
Manufacturers of Photoresists rarely add custom molecules because this destabilizes the photoresist.

m.) True or [✓ False] (circle the correct answer)
It is impossible to print any feature smaller than the diffraction limit of the laser wavelength chosen for lithography.

n.) True or [✓ False] (circle the correct answer)
Projection lithography systems always have higher optical resolution than a contact lithography (mask aligner) system

o.) True or [✓ False] (circle the correct answer)
A small wafer to mask spacing on the order of a few microns are used in projection lithography systems to maximize resolution by meeting the Fresnel diffraction limit conditions.

Problem 2. (55 points total in 8 parts):

As an engineer for Doolittle Inc, the most prestigious semiconductor company on the planet, you are asked to develop an arsenic (As) implant into Si. The implanter your company uses has a large total beam current of 7.06858 mA through a 300 mm diameter aperture into a 300 mm wafer along the highest density atomic direction (<111>)and a source to wafer spacing of 2 meters. If the voltage on the Implanter is set to 90,000 Volts, and the implant lasts for 20 seconds:

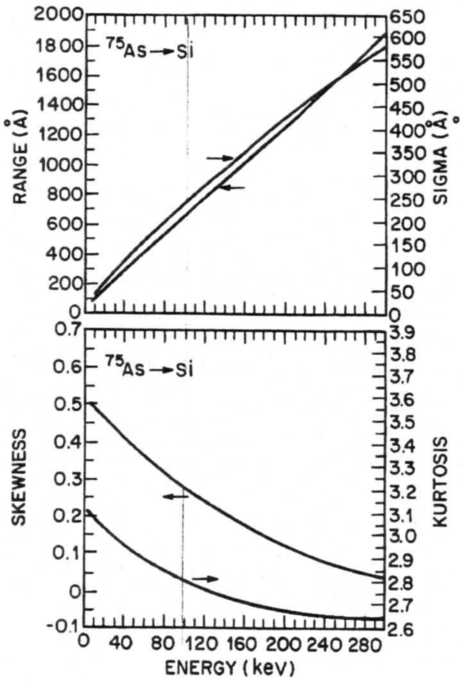


FIGURE 7 (CONTINUED)

see next page

a) (a- 5 points) the **implant energy?**

$$\boxed{90\ \text{keV}}$$

b) (b-10 points) Assuming only a simple Gaussian model, what is the depth from the surface for which the As concentration is half that of the peak concentration?

Clearly indicate and circle your values used from the charts.

$R_p \sim 700\,\text{Å}$

$\sim 70\,\text{nm}$

$\sim 70\text{e-}7\,\text{cm}$

$\sigma_p \sim 250\,\text{Å}$

$\sim 25\,\text{nm}$

$\sim 25\text{e-}7\,\text{cm}$

$$\frac{1}{2} = e^{\frac{-(x-R_p)^2}{2\sigma_p^2}}$$

$$x = R_p \pm \sqrt{-\ln\left(\tfrac{1}{2}\right) 2\sigma_p^2}$$

$$= 29.4\ \text{nm} + R_p$$

$$-29.4 \quad + R_p$$

Or

$$x = R_p \pm \sqrt{\ln(2)\, 2\sigma_p^2}$$

$$\boxed{X_{1/2} = 40.1\,\text{nm} \text{ or } 99.4\,\text{nm}}$$

c) (c-10 points) Assuming only a simple Gaussian model, what is the peak concentration?

$$n_0 = \frac{Q_T}{\sigma\sqrt{2\pi}}$$

$$Q_T = \frac{1}{q\,\text{Area}} \int_0^{20} 7.06858\,\text{mA}$$

$$(\pi 15^2) = 706.858\ \text{cm}^2$$

$$Q_T = 1.25 \times 10^{15}\ \text{cm}^{-2}$$

$$n_0 = \frac{1.25 \times 10^{15}}{\sigma\sqrt{2\pi}}$$

$25 \times 10^{-7}\,\text{cm}$

$$\boxed{n_0 = 2\text{e}20\ \text{cm}^{-3}}$$

d) (d- 5 points) If we looked at the actual implant profile (i.e. not the simple Gaussian model) **is the implant not skewed, skewed toward, away from the surface**?

Circle one: [✓ Away] / Toward / Not Skewed $\quad Y_z \;\overset{+}{=}\; 0.25$

e) (e-5 points) If the same implant from parts a-c (assuming a simple Gaussian model) was performed into germanium (Ge), an element heavier than Si, would the implant peak concentration be located at the same depth, farther from or closer to the surface?

Circle one: Same Depth / Farther From the Surface / [✓ Closer to the Surface]

f) (f-5 points) If the same implant from parts a-c (assuming a simple Gaussian model) was performed into Silicon (Si) but along the lowest atomic density direction (<100>), would the implant peak concentration be located at the same depth, farther from or closer to the surface?

Circle one: Same Depth / [✓ Farther From the Surface] / Closer to the Surface

g) (g-10 points) If the same implant from parts a-c (assuming a simple Gaussian model) was annealed such that the characteristic diffusion length of the anneal is 50 nanometers, what is the new peak concentration and where is it located?

$$n_0' = \frac{Q_T}{\sqrt{2\pi}\sqrt{\underset{\uparrow\; 25e\text{-}7}{\sigma_p}^2 + 2D\tau}}$$

$\sqrt{D\tau} = 50\,nm$

$D\tau = \left[(50e\text{-}7)\,cm\right]^2$

$$\boxed{n_0' = 6.65e19\ cm^{-3} \quad @\ x = 70\,nm}$$

h) (h- 5points, Circle One) If we looked at the speed of As as it diffused at the beginning and end of the Rapid Thermal Anneal, would the initial diffusion velocity be:

- [✓ a. Faster at the beginning of the anneal?]
- b. Faster at the end of the anneal?
- c. The same speed at all times during the anneal?

Problem 3. (15 points total):

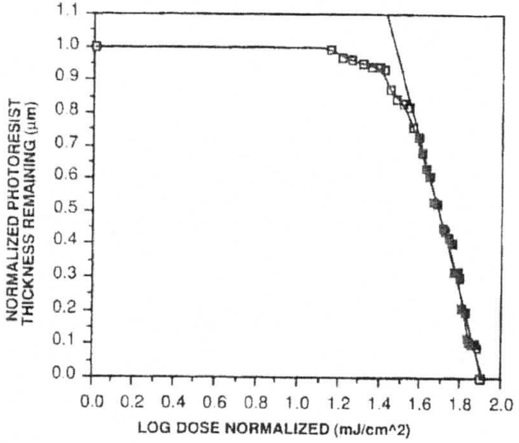
Due to the time constraints imposed by the need to have the second exam earlier in the semester than in years past, this problem is significantly easier than prior problems. Do not read too much into this problem and be prepared for a more representative problem on the final exam.

A common photoresist, Shipley Microposit S1813, has a contrast curve as shown in the figure to the right (taken from actual datasheets). You are asked to specify a projection lithography system that can image this resist. When used alone, it is found that the thickness of the S1813 resist remaining after exposure and development has a slope (as indicated by the linear regression fit line in the figure) of,

$$\text{Thickness Remaining} = 4.3416 - 2.2681\ \mathrm{Log}_{10}(Dose)$$

MICROPOSIT S1813 PHOTO RESIST

Figure 7. Contrast Curve



a) (2 Points) Find S1813 resist's D_0

$$D_o = 10^{((1-4.3416)/-2.2681)}$$

$$\boxed{D_o = 29.73\ mJ/cm^2}$$

b) (2 Points) Find S1813 resist's D_{100}

$$D_{100} = 10^{(4.3416/2.2681)}$$

$$\boxed{D_{100} = 82.07\ mJ/cm^2}$$

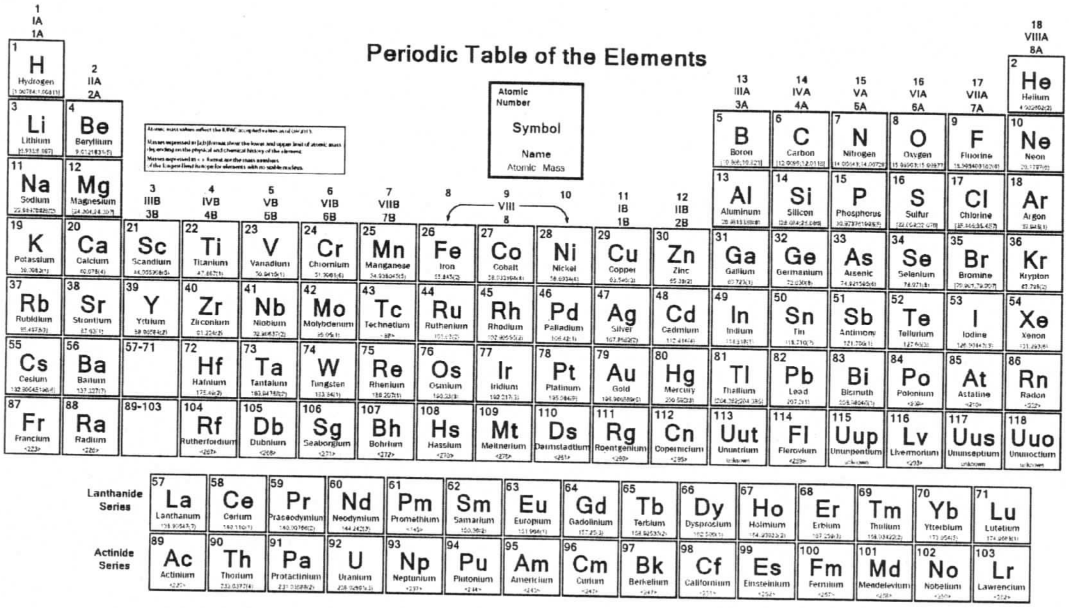
c) (11 Points) What is the minimum MTF the projection lithography system should have to be successfully used with this resist?

$$CTMF = \frac{D_{100} - D_o}{D_{100} + D_o} = \frac{82.07 - 29.73}{82.07 + 29.73}$$

$$= 0.468$$

$$\boxed{MTF > 0.468}$$

You may show your work here



Periodic Table of the Elements

Atomic Number
Symbol
Name
Atomic Mass

1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	57-71	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89-103	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Uut Ununtrium	114 Fl Flerovium	115 Uup Ununpentium	116 Lv Livermorium	117 Uus Ununseptium	118 Uuo Ununoctium

Lanthanide Series	57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
Actinide Series	89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium