ECE 6450 Introduction to Microelectronics Technology

Exam 2

October 21, 2002

Dr. W. Alan Doolittle

Solutions

Print your name clearly:

Instructions:
Read all the problems carefully and thoroughly before you begin working. You are allowed to use 1 new sheet of notes (2 pages front and back), your sheet from previous exams as well as a calculator. There are 100 total points in this exam. Observe the point value of each problem and allocate your time accordingly. SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED. Write legibly. If I can not read it, 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, 2 points each):
True/False and Multiple Choice:

a.) Channeling ...
   1.) ... results from nuclear collisions
   2.) ... is more dominant at high implant energy
   3.) ... results in negative skewness
   4.) ... results in positive skewness

b.) For an image to be transferred to the wafer, ...
   1.) ... the contrast must be greater than 1.
   2.) ... the MTF>CMTF.
   3.) ... the MTF<CMTF.
   4.) ... the image must be diffracted.

c.) Higher implant energy results in more nuclear displacement at the wafer surface?
True or False (circle the correct answer)

d.) A resist spun on at 3000 revolutions per minute (RPM) is thicker than the same resist spun on at 4000 rpm
True or False (circle the correct answer)

e.) Damascene processing is meant to compensate for small depth of fields in modern lithography systems.
True or False (circle the correct answer)

f.) Polymers such as the resins in photoresist are made up of long chains of molecules.
True or False (circle the correct answer)

g.) In a positive resist, the photoactive compound (PAC) reconfigures itself by splitting in half.
True or False (circle the correct answer)

h.) An RF plasma can not have a net DC bias between the gas and the wafer.
True or False (circle the correct answer)

i.) An increasing mean free path results in a more anisotropic etch.
True or False (circle the correct answer)

j.) An increasing mean free path results from higher pressures.
True or False (circle the correct answer)

k.) A wet etch has less undercut than a reactive ion etch.
True or False (circle the correct answer)

l.) Since the vacuum "sucks" gases , the gas throughput is higher at lower pressure
True or False (circle the correct answer)

m.) Using a tube in front of a pump increases throughput.

True or False (circle the correct answer)

n.) The plasma sheath is the region of the plasma where the potential changes.

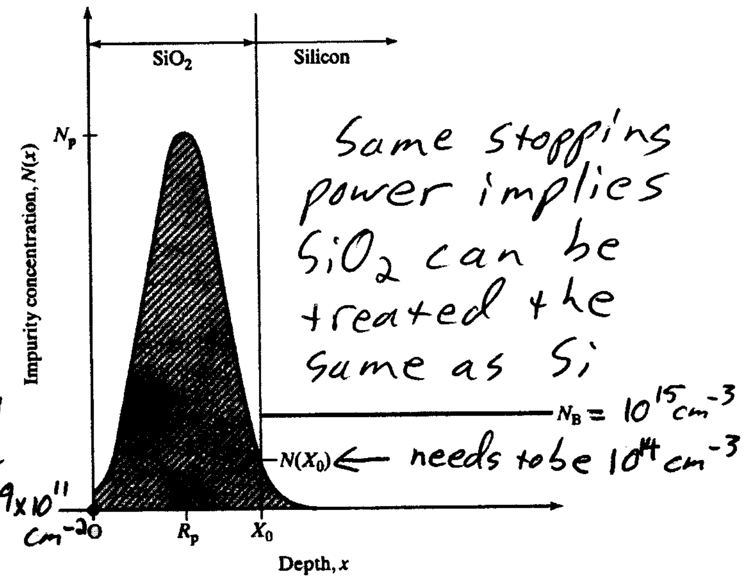
True or False (circle the correct answer)

o.) In a standard silicon wet etch consisting of nitric : hydrofluoric : acetic acid the nitric acid oxidizes the wafer while the hydrofluoric acid removes the oxide.

True or False (circle the correct answer)

Problem 2. (30 points total):

An arsenic ion implantation is used to dope the channel of a MOSFET (this is done to adjust the threshold voltage of the device). It is desired to have a very shallow implant, so the implant is performed through a SiO_2 layer with the range chosen to be inside the oxide. We want the concentration of the implant to be 1/10th the wafer's bulk doping concentration. ~~The bulk~~ wafer concentration is 1×10^{15} cm^{-3}, the energy is 100KeV and the dose is 2.69 $\times10^{11}$ cm^{-2}. This results in a low concentration tail in the silicon channel as depicted in the figure. We assume the stopping power of SiO_2 is the same as Si and the range and straggle can be assumed to be,



Same stopping power implies SiO_2 can be treated the same as Si

$$R_p = \frac{1025\ A}{200\ KeV} = 512.5\ \mathring{A} \ @\ 100\ keV \qquad \Delta R_p = \sigma_p = \frac{215\ [redacted] A}{200\ KeV} = \quad @\ 100\ keV$$

What is the required oxide thickness to position the implant as described above?

$$n(x) = \frac{Q_T}{\sigma_p\sqrt{2\pi}} e^{-(x-R_p)^2/2\sigma_p^2}$$

$$n(x_0) = 10^{14} = 10^{17} e^{-(x_0-R_p)^2/2\sigma_p^2}$$

$$X_0 = R_p + \sqrt{2\sigma_p^2 \ln\left(\frac{10^{17}}{10^{14}}\right)}$$

$$X_0 = \frac{1.025e{-5}}{200\ keV} E + \frac{2.15e{-6}}{200\ keV} E \sqrt{2\ln(1000)}$$

$$E = 100\ keV$$

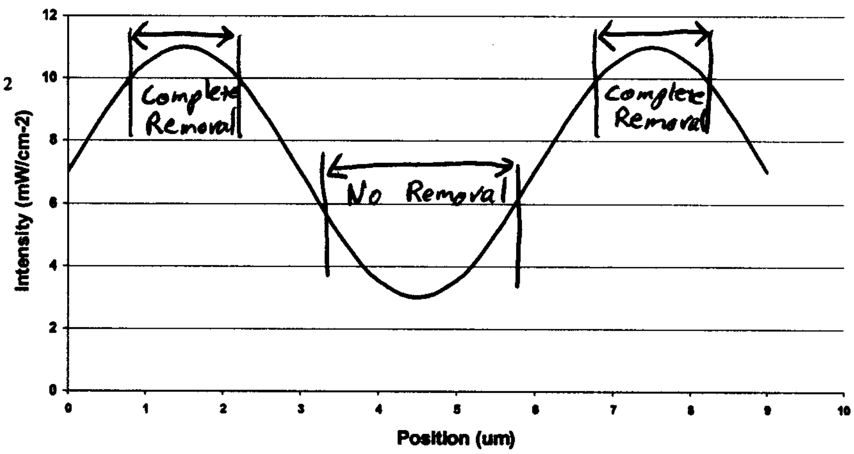
$$X_0 = 5.125e{-6}\ cm + 1.075e{-6}\ (3.716)\ cm$$

$$\boxed{X_0 = 912\ \mathring{A}}$$

Problem 3. (40 points total):

A fictional proximity printer has an "areal image" as shown below and described by the equation,

$$I(x) = 7 + 4\sin\left(\frac{\pi x}{3\,\mu m}\right) \quad mW/cm^2$$



A positive photoresist with a contrast of 4.5 at i-line (365 nm) is to be used. The photoresist requires a dose of 400 mJ/cm² to be completely removed in the developer solution, and the exposure time is 40 seconds.

a. 30 points) ~~Draw~~ ok and label the photo resist pattern on the wafer. Label all points that indicate transitions from where no photoresist is removed and where the photoresist is completely removed.

b. 5 points) If the lithography process has a "k" of 0.75 and a numerical aperture of 0.5, what is the minimal feature the system can resolve.

c. 5 points) What is the depth of field?

$\gamma = 4.5 \quad I_{100} = \frac{D_{100}}{time} = \frac{400\,mJ/cm^2}{40\,sec} \Rightarrow I_{100} = 10\,mW/cm^2$

$\gamma = 4.5 = \frac{1}{\log_{10}\left(\frac{D_{100}}{D_0}\right)}$

$\frac{D_{100}}{D_0} = 10^{1/4.5} = \frac{400\,mJ/cm^2}{D_0}$

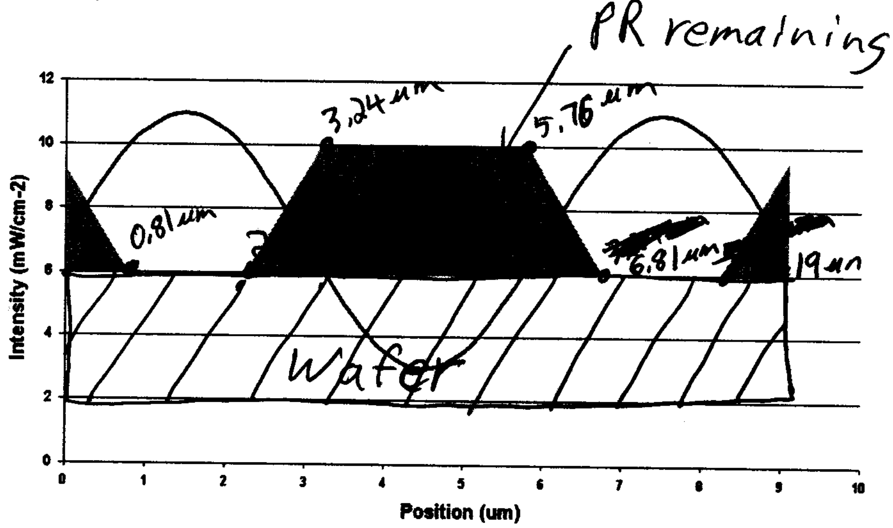
$\Rightarrow D_0 = 240\,mJ/cm^2$

$I_0 = \frac{240\,mJ/cm^2}{40\,sec} = 6\,mW/cm^2$

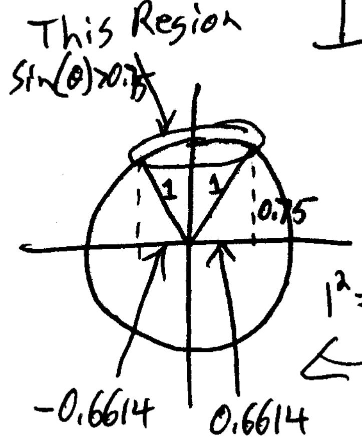
Thus, the Regions exposed to $I > 10\,mW/cm^2$ are completely removed while the regions with $I < 6\,mW/cm^2$ are not removed at all.

Thus, ...

The PR pattern looks something like:



Fully Removed:



$$I(x) = 7 + 4\sin\left(\frac{\pi x}{3\,\mu m}\right) mW/cm^2 \geq 10 mW/cm^2$$

$$\sin\left(\frac{\pi x}{3\,\mu m}\right) > 0.75$$

$1^2 = (.75)^2 + (0.6614)^2$

$\Downarrow$

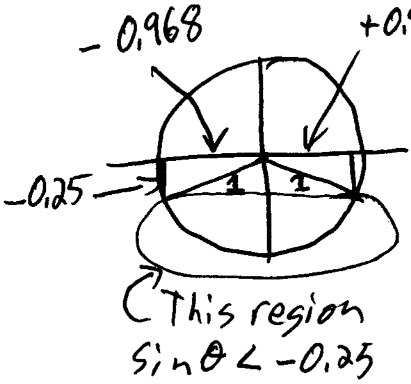
$$\boxed{0.81\,\mu m \leq x \leq 2.19\,\mu m}$$

$\frac{3}{\pi}\cos^{-1}(0.6614)$ $\qquad$ $\frac{3}{\pi}\cos^{-1}(-0.6614)$

also $(x + 6\,\mu m)$

$$\boxed{6.81\,\mu m \leq x \leq 8.19\,\mu m}$$

No Removal:



$$I(x) = 7 + 4\sin\left(\frac{\pi x}{3\,\mu m}\right) mW/cm^2 \leq 6 mW/cm^2$$

$$\sin\left(\frac{\pi x}{3\,\mu m}\right) \leq -0.25$$

$\Downarrow$

$$\boxed{3.24\,\mu m \leq x \leq 5.758\,\mu m}$$

$\frac{3}{\pi}\left(\pi + \sin^{-1}(0.25)\right)$ $\qquad$ $\frac{3}{\pi}\left(\pi + \cos^{-1}(-0.968)\right)$

3rd Quadrant