ECE/ME 449 Spring 08, Prof. Feinerman, Test #1 2/19/08 solutions, Closed Book and Closed Notes

Undergraduates $\bar{x}$ = 53.9, σ =19.1, Graduates $\bar{x}$ = 68.3, σ = 20.2

Element	Molecular weight, grams	Atomic number	Density, gm/cc	Resistivity, $\mu\Omega$*cm
Hydrogen (H)	1.00794	1	Gas	Insulator
Carbon (C)	12.0107	6	1.8 (graphite)	1100$\mu\Omega$cm
Oxygen (O)	15.9994	8	Gas	Insulator
Silicon (Si)	28.0855	14	2.33	10^{11} or less
Argon	39.948	18	Gas	insulator

Avogadro's Number, $N_{Av} = 6.022*10^{23}$ atoms/mole, Boltzmann's constant, $k_B = 1.3807*10^{-23}$ J/^{o}K

Ideal gas law, $P*V = N * k_B * T$, $Z = \frac{n*\bar{c}}{4}$, gas mean velocity $\bar{c} = \sqrt{\frac{8*k_B*T}{\pi * m}}$, $0^oC = 273.15^oK$

$[h_1k_1l_1] = h_1\hat{x} + k_1\hat{y} + l_1\hat{z}$, $[h_2k_2l_2] = h_2\hat{x} + k_2\hat{y} + l_2\hat{z}$, $[h_1\ k_1\ l_1] \bullet [h_2\ k_2\ l_2] = h_1*h_2 + k_1*k_2 + l_1*l_2$

$\|[h_1k_1l_1]\| = \sqrt{h_1^2 + k_1^2 + l_1^2}$ $\qquad \cos(\theta) = \frac{[h_1k_1l_1]\bullet[h_2k_2l_2]}{\|[h_1k_1l_1]\| \times \|[h_2k_2l_2]\|}$

1 atmosphere = $1.013*10^5$ Pa = $1.013*10^5$ N/m^2 = 760.0 torr = 14.696 pounds/in^2.

1 foot = 12 inches, 1 inch = 2.54 cm, 1 cm = 10 mm = 10^4 μm = 10^7 nm

MEMS = <u>M</u>icro<u>E</u>lectro<u>M</u>echanical <u>S</u>ystems, NEMS = <u>N</u>ano<u>E</u>lectro<u>M</u>echanical <u>S</u>ystems

1) List one advantage <u>and</u> one disadvantage MEMS/NEMS has for society (that means you, your relatives, their friends, …)? $\bar{x}$ = 8.0, σ = 2.5

2) List one advantage <u>and</u> one disadvantage for electroplating metal instead of using physical vapor deposition in a MEMS/NEMS process. $\bar{x}$ = 6.6, σ = 3.5

Advantages – Precious metal is mainly placed where it is needed there is very little waste, inexpensive process, electroplating can achieve very high aspect ratio wires (up to ~30/1 height/width), pulsed electroplating can deposit metals in corners better than PVD.

Disadvantages – not all metals can be electroplated, non-uniform thickness, poor control of stress, toxic chemicals used in electroplating baths, removal of plating base can complicate the processing.

3) List one advantage dry etching has over wet etching, <u>and</u> one advantage wet etching has over dry etching. $\bar{x}$ = 8.1, σ = 2.9

Advantage – 1) Can etch anisotropically ($v_{vertical}/v_{horizontal} > 1$) important for creating narrow features in thick films, 2) allows us to use a photoresist mask for some aggressive etches (i.e. fluorine based chemistry), 3) generates far less toxic waste, 4) uses less DI water (saves water and energy).

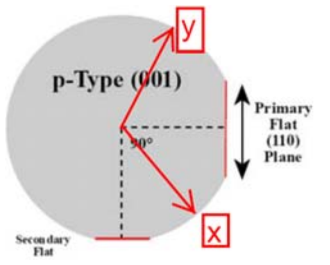
Disadvantage – Can be much less selective to mask and substrate than wet etching (S_{FM}, and S_{FS}), can remove a great deal of material, wet etching is usuall cheaper to implement, some wet etches can preferentially etch certain crystal directions.

4) List <u>two</u> reasons why UIC should invest in a XeF_2 etcher for a MEMS process. $\bar{x}$ = 5.4, σ = 3.8

Isotropic etch for silicon that can be patterned with photoresist. Less chemical waste than Acetic/Nitric/HF, since etchant is a gas – etch can diffuse with smaller openings better than a liquid can, etch is very selective to SiO_2, photoresist, …

5) *List an argument to micro or nanofabricate a particular device and an argument to build that device using conventional manufacturing methods. (indicate which device you are considering in your answer – you can use two different devices).* $\bar{x}$ = 7.2, σ = 2.6

6) *What is the orientation of the secondary flat? Assume coming out of paper toward you is [001] or* $+\vec{z}$ *direction, and the wafer flat is in the [110] direction or* $+\vec{x}+\vec{y}$ *direction.* $\bar{x}$ = 6.5, σ =4.7



If the wafer normal is [001] then a right handed coordinate system means x and y vectors are as shown, so the flat must be $[1\bar{1}0]$.

Another way to do this is to use the cross product, [110] x [001] = $[1\bar{1}0]$

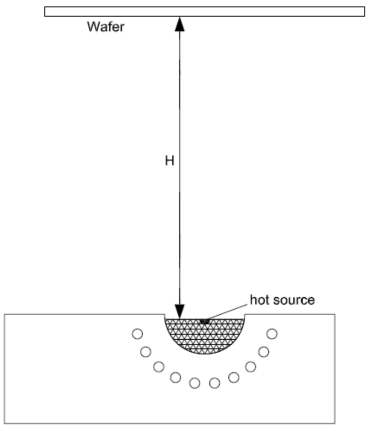
7) *An 8" diameter glass wafer is held at -10°C in an atmosphere containing water (H_2O) vapor at 2 torr. How long will it take to deposit 1mm thick coating of ice? Assume ρ_{ice} = 0.92 gm/cc, and that every water molecule that hits the glass wafer sticks to it.* $\bar{x}$ = 9.0, σ =8.7

mH_2O=(2*1.0008+15.999)*gm/(mole*Nav)=2.992*10^{-26} kg. $\bar{c}=\sqrt{\frac{8*k_B*T}{\pi*mH_2O}}=556\frac{m}{s}$, #$H_2O$ molecules/cc of ice is n_ice=0.92(gm/cc)*(Nav/MW_H_2O)=3.075*10^{22}/cc, #H_2O molecules/cc of vacuum is N_ice=(2 torr)/(k_BT)=7.339*10^{16}/cc. Solving Z*Area*τ = 0.25*N_ice*c*Area* τ = n_ice*1mm*Area, or τ =3.01*s (clearly in freezer every H_2O molecule doesn't stick to surface !)
Grading 5 points each for mH_2O, c, N_ice, n_ice, and τ.

8) *A 1.00 μm thick amorphous silicon film on a SiC wafer is completely converted to SiO_2 during a high temperature oxidation. How thick is the SiO_2 film? The SiC does not react during the oxidation. Assume $\rho_{Silicon}$ = 2.33gm/cc, ρ_{SiO2} = 2.2gm/cc and ρ_{SiC} = 3.21gm/cc.* $\bar{x}$ = 15.9, σ =10.7

$\rho_{Silicon}$*$t_{Silicon}$*N_{av}/MW_Silicon = ρ_{SiO2}*t_{SiO2}*N_{av}/MW_SiO2, or
t_{SiO2} = t_{Si}*(MW_SiO2* $\rho_{Silicon}$)/(MW_Silicon* ρ_{SiO2}) = 2.27*t_{Si} = 2.27 μm.
Grading reason for equation, units, correct formula, and correct answer.

9) *A company needs to electron beam deposit a 1.000 +/- 0.001μm thick film on a silicon wafer for a lift off process. Their wafers are (100) orientation, 200mm in diameter, 0.5mm thick and centered over the electron beam source as shown in the following diagram. How far do they need to position each wafer above the source in order to achieve this tolerance? What is an advantage and a disadvantage of positioning the wafer further than this distance from the source?* $\bar{x}$ = 14.2, σ =6.4

	$D = \frac{R_e * A_e}{\pi * r^2} * \cos(\vartheta) * \cos(\varphi)$ Maximum thickness will be in center, $D = \frac{R_e * A_e}{\pi * H^2} = \frac{1.001}{1.000}$, Minimum thickness at wafer edge where cos(ϑ)=cos(φ), $D = \frac{R_e * A_e}{\pi * \left(H^2 + \frac{W^2}{4}\right)} * \left(\frac{H}{\sqrt{H^2 + \frac{W^2}{4}}}\right)^2 = \frac{.999}{1.000}$. These can be solved for H = 15.8*W = 3160mm. If the wafer is further from the source, the deposition will be more uniform (advantage) but slower (disadvantage).