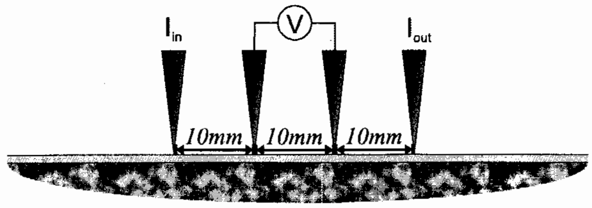
Final Exam **FYSS335 Micro- and nanofabrication**

Friday 6.5.2011 at 12:00

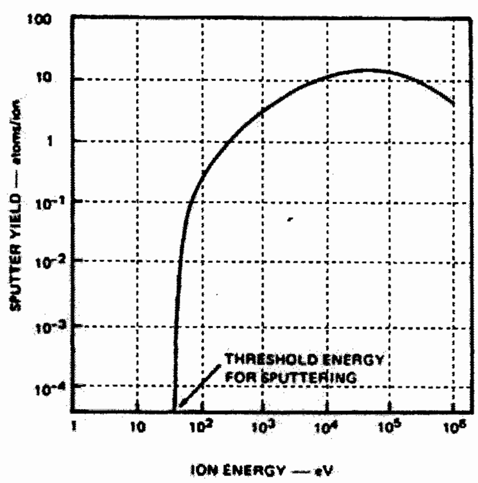
You can answer either in english or in finnish

1. Explain briefly
   (a) Tensile and compressive stress. (1p)
   (b) Langmuir Blodget deposition. (1p)
   (c) Atomic Layer Deposition (ALD). (1p)
   (d) Isotropicity and anisotropicity in wet and dry etching. (1p)
   (e) Different doping methods for silicon. (2p)

2. One evaporates an Al/Mn-alloy film on a 15.6 cm diameter Si wafer by using resistive heating of 1:1-mixture of aluminium (Al) and Manganese (Mn) inside a UHV chamber. Metals are heated to a constant temperature of 1200°C, yielding a high enough vapour pressure $P_v > 10^{-2}$ mbar for both metals to be evaporated. After the evaporation, the film thickness was measured to be 80 nm and the electrical four probe measurement of the film, by using the probe configuration shown below, yielded 302 mV with 60 mA current. Calculate the sheet resistance and the resistivity of the film and explain by formulas, i.e. by calculating, why the resistivity deviates from the expected resistivity of the 1:1-mixture of the two metals: $\rho_{\mathrm{Al}} \approx 2.7 \cdot 10^{-8}\ \Omega\mathrm{m}$ and $\rho_{\mathrm{Mn}} \approx 185 \cdot 10^{-8}\ \Omega\mathrm{m} \Longrightarrow \rho_{1:1} \approx 93.8 \cdot 10^{-8}\ \Omega\mathrm{m}$.



3. Gold (Au) film is sputtered inside a sputtering chamber of a volume of 20 litres. Ar^+-plasma with ionization level of $n_{\mathrm{ions}}/n_{\mathrm{atoms}} \approx 10^{-5}$ is utilized in the process yielding plasma potential of 75 V. Other parameters are $T = 300$ K and $P = 10^{-2}$ mbar which induce the self-biasing of the capacitively coupled cathode to be -9925 V. What is the theoretical maximum film growth rate? Sputtering yield, i.e. sputtered atoms per arriving ion, as a function of ion energy is plotted on the image right. Gases can be dealed as ideal gases.

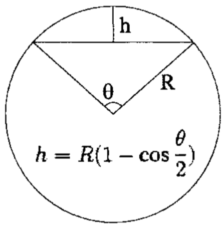


4. Explain in detail the general principles of Chemical Vapour Deposition (CVD) and at least *free different types* of CVD. Briefly explain also the uses and advantages/disadvantages of the different types of CVD.

5. Develop a process, starting from a plain silicon wafer, to fabricate a photonic crystal shown below. Briefly describe every process step needed. (Patterning by lithography needs not to be described in detail)

Some of these might be useful:

$$F = \frac{1}{4} n_0 \langle v \rangle \qquad \langle v \rangle = \sqrt{\frac{8 k_B T}{\pi m}} \qquad R_{\text{sheet}} = \frac{V}{I} \frac{\pi}{\ln 2}$$



$$\cos(x) = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \ldots \qquad \lambda = \frac{k_B T}{\sqrt{2} P \pi a^2} \qquad \langle v^2 \rangle = \frac{3 k_B T}{m}$$

$$\sin(x) = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \ldots \qquad F = \frac{P_v}{\sqrt{2 \pi M k_B T}}$$

$$P_v = \frac{1}{3} m n_0 \langle v^2 \rangle \qquad \sigma = \frac{E_S t_S^2}{6 t_F (1 - \nu_S)} \left(\frac{1}{R} - \frac{1}{R_0} \right) \qquad \rho = \frac{V}{I} 2 \pi s$$

$$V = -\frac{k_B T}{2e} \ln \left(\frac{T_e m_i}{T_i m_e} \right) \qquad t = \frac{d^2}{2 D C_s V} + \frac{d}{k C_s V} \qquad \text{Rate} = Z(T) \exp \left(-\frac{E_a}{k_B T} \right)$$

$$F = -D \frac{\partial C}{\partial x} \qquad E_{\text{Si}} = 190\,\text{GPa} \qquad \rho_{\text{Si}} = 2.33\,\text{g/cm}^3 \qquad \nu_{\text{Si}} = 0.27$$

$k_B = 1.3806503 \cdot 10^{-23}$ J/K $\quad \pi = 3.141592654 \quad \rho_{\text{Al}} \approx 2.7 \cdot 10^{-8}\,\Omega\text{m}$

$\rho_{\text{Si3N4}} \approx 3.1\,\text{g/cm}^3 \quad$ AtomicMassConstant $= 1.66053873 \cdot 10^{-27}$ kg

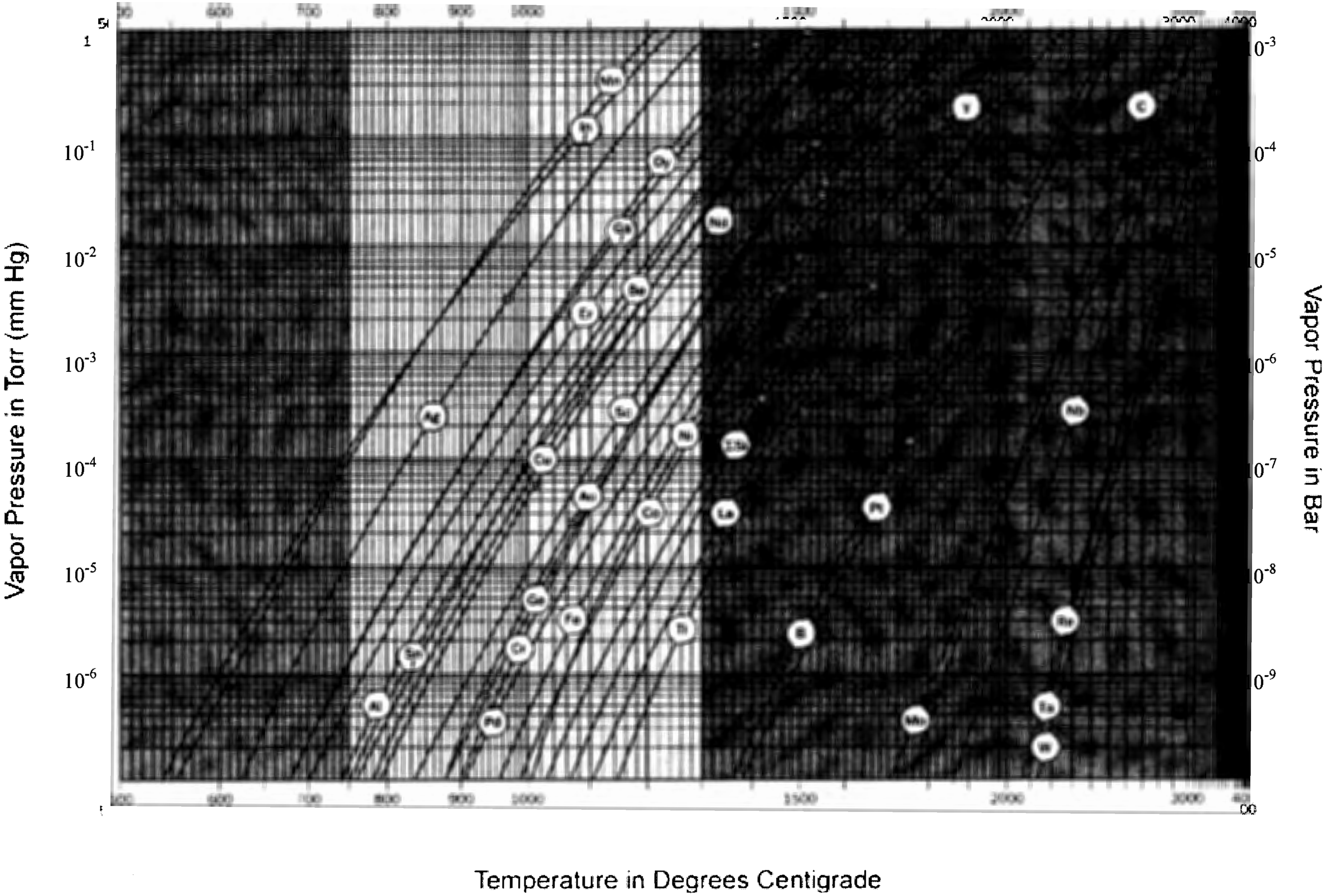
AvogadroConstant $= N_A = 6.02214199 \cdot 10^{23} \quad \nu_{\text{Si}} = 0.27$

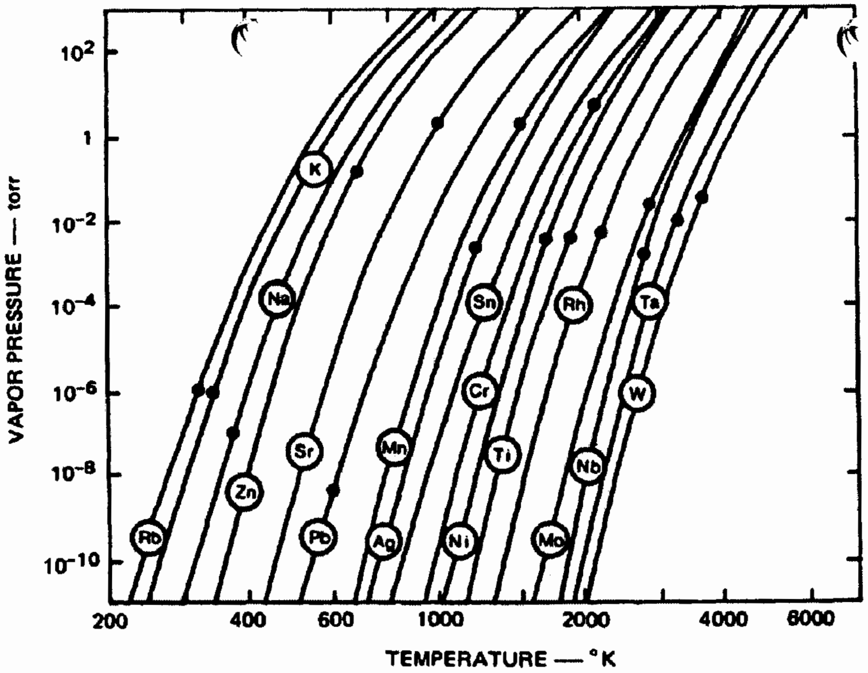
ElectronMass $= 9.10938188 \cdot 10^{-31}$ kg $\quad$ ElectronCharge $= 1.602176462 \cdot 10^{-19}$ C

1 Torr $= 133.3$ Pa $\quad$ R.I.$_{\text{Si3N4}} \approx 2.05 \quad \rho_{\text{Au}} = 19320\ \text{kg/m}^3$

$R_{(\text{Molar gas constant})} = 8.314472\ \text{J/(Kmol)}$

1 Torr = 133.3 Pa





1A	2A	3B	4B	5B	6B	7B	8B			1B	2B	3A	4A	5A	6A	7A	8A
1 H 1.0079																	2 He 4.0026
3 Li 6.941	4 Be 9.0122											5 B 10.811	6 C 12.0107	7 N 14.0067	8 O 15.999	9 F 18.9984	10 Ne 20.1797
11 Na 22.9898	12 Mg 24.305											13 Al 26.9815	14 Si 28.0855	15 P 30.9738	16 S 32.065	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.078	21 Sc 44.9559	22 Ti 47.867	23 V 50.9415	24 Cr 51.9961	25 Mn 54.9380	26 Fe 55.845	27 Co 58.9332	28 Ni 58.6934	29 Cu 63.546	30 Zn 65.38	31 Ga 69.723	32 Ge 72.64	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.798
37 Rb 85.468	38 Sr 87.62	39 Y 88.9058	40 Zr 91.224	41 Nb 92.906	42 Mo 95.96	43 Tc [98]	44 Ru 101.07	45 Rh 102.905	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 26.9045	54 Xe 131.293
55 Cs 132.905	56 Ba 137.33	57-71 Lanthanides	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.217	78 Pt 195.084	79 Au 196.9666	80 Hg 200.59	81 Tl 204.3833	82 Pb 207.2	83 Bi 208.9804	84 Po [209]	85 At [210]	86 Rn [222]
87 Fr 223	88 Ra [226]	89-103 Actinides	104 Rf [267]	105 Db [268]	106 Sg [271]	107 Bh [272]	108 Hs [270]	109 Mt [276]	110 Ds [281]	111 Rg [280]	112 Uub [285]	113 Uut [284]	114 Uuq [289]	115 Uup [288]	116 Uuh [293]	117 Uus [294]	118 Uuo [294]

Lanthanides	57 La 138.90547	58 Ce 140.116	59 Pr 140.90765	60 Nd 144.242	61 Pm [145]	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.92535	66 Dy 162.500	67 Ho 164.93032	68 Er 167.259	69 Tm 168.93421	70 Yb 173.054	71 Lu 174.9668
Actinides	89 Ac [227]	90 Th 232.03806	91 Pa 231.03588	92 U 238.02891	93 Np [237]	94 Pu [244]	95 Am [243]	96 Cm [247]	97 Bk [247]	98 Cf [251]	99 Es [252]	100 Fm [257]	101 Md [258]	102 No [259]	103 Lr [262]