Final Exam **FYSS335 Micro- and nanofabrication**

Friday 19.2.2010

1. Explain briefly

   (a) Comformation, step coverage and bottom coverage

   (b) Sputtering

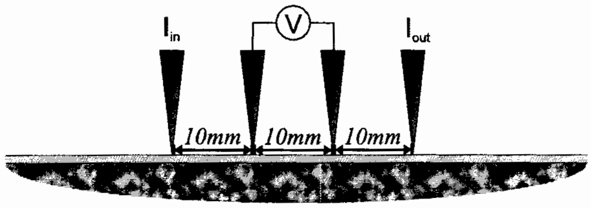
   (c) Growth of silicon by "Float Zone" (FZ) -method

   (d) Spin coating

   (e) Laser ablation

   (f) 'top-down' vs. 'bottom-up' fabrication methods

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^{o}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: $\rho_{\mathrm{Al}} \approx 2.7 \cdot 10^{-8}$ Ωm and $\rho_{\mathrm{Mn}} \approx 185 \cdot 10^{-8}$ Ωm $\Longrightarrow$ $\rho_{1:1} \approx 93.8 \cdot 10^{-8}$ Ωm.



3. Explain in detail the general principle of deposition of thin films by Plasma Enhanced Chemical Vapor Deposition (PECVD) using RF-plasma inside a planar electrode station, where another electrode is grounded and another is capacitively coupled to RF-source. Explain also the tensile and compressive stress, and how can the stress of the formed film be controlled in PECVD processes.

4. Aluminum oxide (Al_2O_3 also known as alumina) is a highly stable coating material in many industrial applications. It is produced by (LP-/AP-)CVD via reaction:

$$2AlCl_3 + 3H_2 + 3CO_2 \longrightarrow Al_2O_3 + 3CO + 6HCl$$

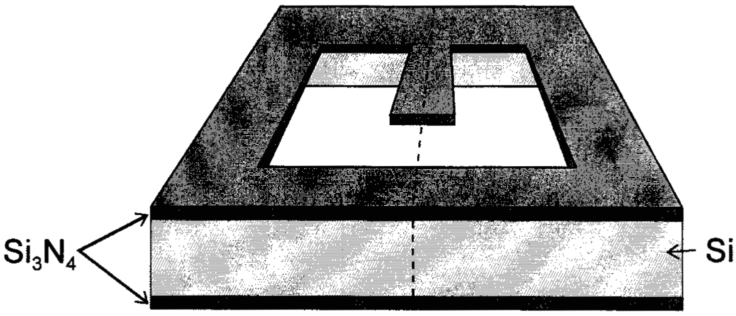
   Typical recipe is of the form: T ≈ 1050°C, P = 10 Torr, and gas flows: $AlCl_3$ = 700 sccm, H_2 = 3300 sccm and CO_2 = 1200 sccm.

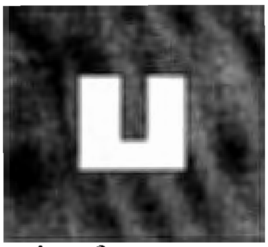
   (a) By using the recipe above, what is the theoretical maximum deposition rate of Al_2O_3, i.e., thickness growth rate, if the total deposition area (quartz tube and wafers) is 2 m^2? Density of aluminum oxide is 3.965 g/cm^3 and gases can be treated as ideal gases.

(b) To characterize process more, the deposition rate was measured in slightly different temperatures. The obtained data is shown below and the activation energy for the chemical reaction above is known to be 704 meV $\approx 1.13 \cdot 10^{-19}$ J. Is the process either *transport limited* or *reaction limited*?

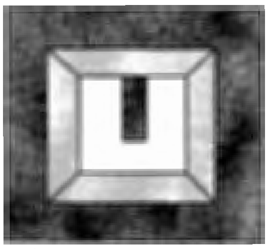
Temperature (°C)	Rate /(Rate at 1050°C)
882	0.841
950	0.904
1050	1.000
1114	1.061

5. Thin Si_3N_4 cantilevers could be used for example as a flow meter in microfluidistic structures. This is realized, e.g., by letting the fluid to flow through a tiny opening in a Si_3N_4 covered silicon chip with Si_3N_4 cantilever attached on a side of the opening and by measuring the bending of the cantilever (see figure below). Develop a process, starting from a plain silicon wafer, to fabricate this structure, shown below. Describe process steps needed. (Patterning by lithography needs not to be described in great detail)





view from up



view from down

Cross-section along the dashed line on the 3D image

Some of these might be useful:

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

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

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

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

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

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

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

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

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

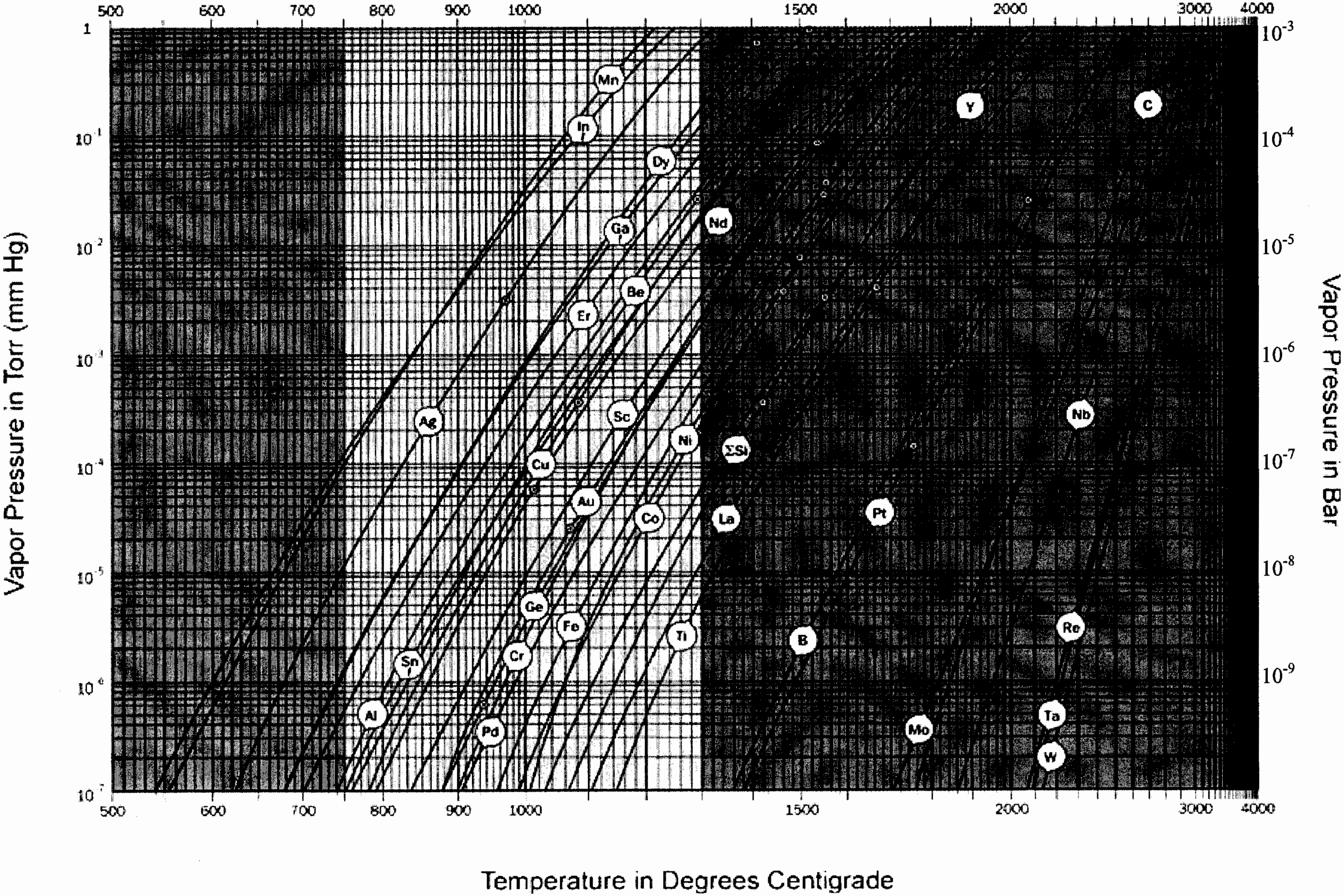
$$\text{ElectronMass} = 9.10938188 \cdot 10^{-31}\ \text{kg} \qquad \text{ElectronCharge} = 1.602176462 \cdot 10^{-19}\ \text{C}$$

$$1\ \text{Torr} = 133.3\ \text{Pa} \qquad \text{R.I.}_{\text{Si3N4}} \approx 2.05 \qquad \rho_{\text{Mn}} \approx 185 \cdot 10^{-8}\ \Omega\text{m}$$

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

1A	2A	3B	4B	5B	6B	7B	8B	8B	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]



1 Torr = 133.3 Pa