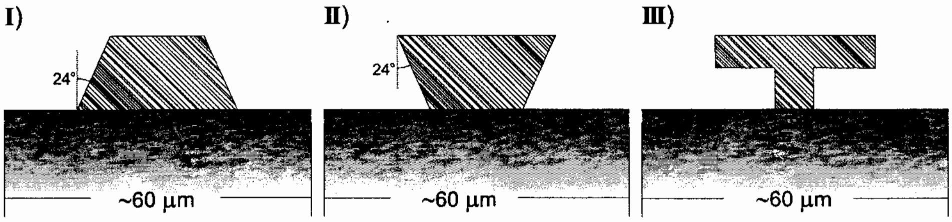
Final Exam **FYSS335 Micro- and nanofabrication**

Friday 17.12.2010

You can answer either in english or in finnish

1. Explain briefly
   (a) Comformation, step coverage and bottom coverage
   (b) Molecular beam epitaxy (MBE)
   (c) Nanoimprint lithography (NIL)
   (d) "Infinite dopant supply" and "Limited dopant supply" -methods in Si doping by diffusion
   (e) Isotropicity and anisotropicity in both wet and dry etching
   (f) 'Bottom-up' & 'top-down'

2. Draw schematic film coverages and calculate film thicknesses in different faces of the structure on figures I), II) and III) when nominally 100 nm thick film of Ti is deposited by:
   (a) Evaporation (perpendicularly to the surface from a long distance away)
   (b) ALD (Atomic Layer Deposition)
   (c) Evaporation (from the angle of 45° respect to the surface, from a long distance away).

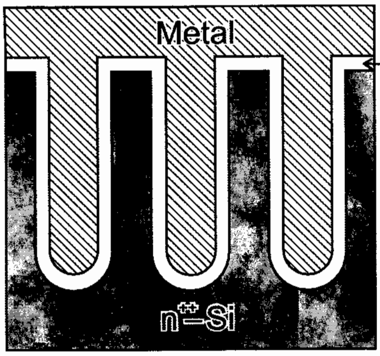


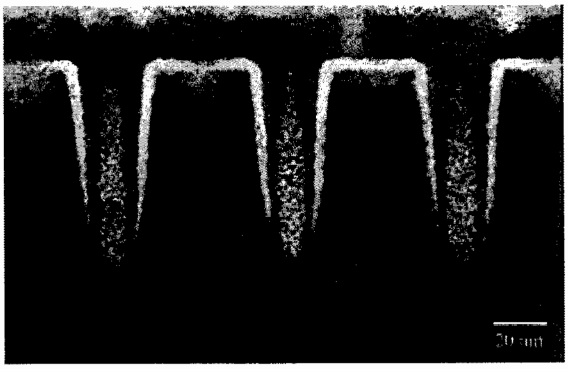
3. Explain in detail the general principles of formation of the RF-plasma inside a planar electrode station, where another electrode is grounded and another is capacitively coupled to RF-source. Draw qualitatively the potential distribution inside the chamber. Explain briefly at least *three different fabrication processes* where this kind of plasma is utilised and *describe the purposes of the plasma in each.*

4. Layer of Si_3N_4 was deposited on top of a 400 μm thick, 10 cm diameter silicon wafer by using LPCVD with process parameters: 370 sccm (cm^3/min) flow of silane/argon mixture, SiH_4/Ar (5%/95%); 710 sccm flow of ammonia, NH_3; temperature of 1000 °C; and pressure of 0.5 Torr.
   (a) Write down the chemical reaction of the process. What is the theoretical maximum deposition rate of Si_3N_4 if the total deposited area (quartz tube and wafers) is 1.0 m^2? In that case, what is the outflow of the by-product, i.e., hydrogen (H_2)? Gases can be treated as ideal gases.
   (b) After deposition the wafer was characterized by basic measurements: Ellipsometer, yielding the Si_3N_4-film thickness of 140 nm and refractive index (R.I.) of 1.93, and profilometer, which showed that the surface of the wafer is at 5 μm lower position at the center of the wafer compared to the edges. Calculate the stress of the Si_3N_4-film.

5. In modern IC-technology high capacitances, needed for example in coupling of DRAM nodes, are obtained by a so-called trench structure. This means a deep hole in a doped (highly conducting) silicon covered with an insulating material, usually SiO_2, and filled with, e.g., metal, as shown in the figure below. This allows a large capacitance area and dense spacing of the capacitances.

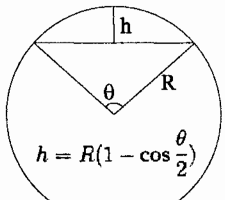
   Develop a process, starting from a plain undoped silicon wafer, to fabricate this structure shown below. Describe process steps needed. (Patterning by lithography needs not to be described in detail, and the exact shape of the bottom of the holes is not important)





Cross-sectional TEM image of a completed shallow-trench-array MOS decoupling capacitor [IBM]

Some of these might be useful:



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

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

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

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

$$V = -\frac{k_BT}{2e} \ln\left(\frac{T_e m_i}{T_i m_e} \right) \qquad t = \frac{d^2}{2DC_sV} + \frac{d}{kC_sV} \qquad R = Z(T) \exp\left(-\frac{E_a}{k_BT} \right)$$

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

$k_B = 1.3806503 \cdot 10^{-23}$ 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.$_{\text{Si3N4}} \approx 2.05 \quad PV = nRT$