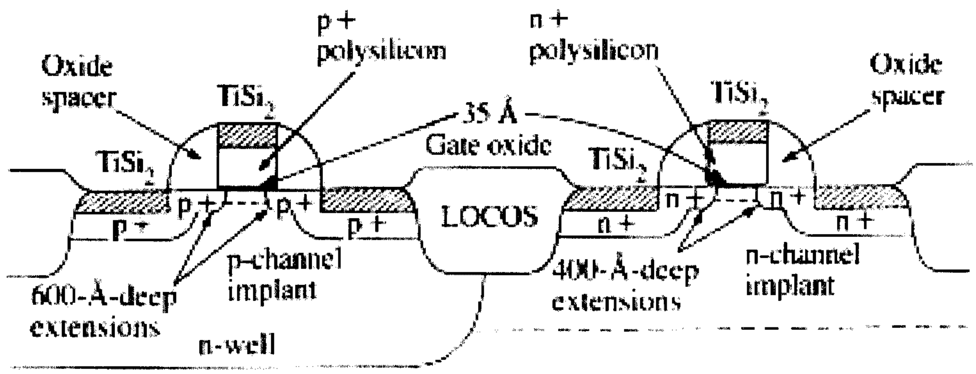
Choose any 5 questions (5 × 6 points = 30 points max).

You can write your answers in English or Finnish!

Make sure that your answers are coherent and self-consistent. Structure of the answer is even more important than individual facts. Fix linewidths and film thicknesses, and stick to your selections! Draw figures and small graphs when suitable. Give examples. Use lists when practical.

Problems? Victor Ovtchinnikov, ☎ 4988 or 050-352 3319

1. Explain step-by-step the fabrication process for the CMOS shown below. You can start from the step following LOCOS isolation step.



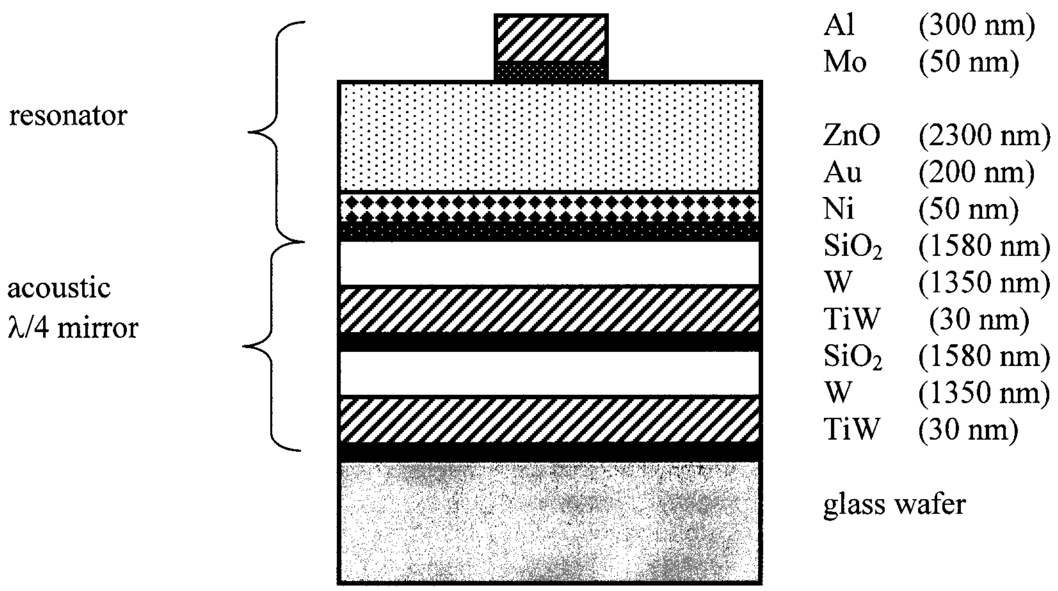
2. World silicon wafer consumption is ca. 5 km^2 annually. Based on this datum and your own assumptions (write them down!) calculate the following:
   a) how many wafers are used annually ? (1 p)
   b) how many silicon crystal pulling systems are there in the world ? (1 p)
   c) how many 10 000 WPM (wafer starts per month) wafer fabs are there in the world ? (1 p)
   d) how many paper clips would destroy all the wafers in the world if iron spec is 2 ppt ? (1 p)
   e) if 30% of wafers are epiwafers, how many single wafer epireactors are needed to produce those epiwafers (1 p)
   f) if the fabrication of one chip takes 3 liters of water, how much water is consumed by a 25 000 WPM fab daily ? (1 p)

3. Explain possible applications, advantages and shortcomings of the next characterization methods:
   a) XPS (=ESCA) (x-ray photoelectron spectroscopy) (1 p)
   b) SEM (Scanning electron microscopy) (1 p)
   c) XRD (x-ray diffraction) (1 p)
   d) AFM (atomic force microscopy) (1 p)
   e) EMPA (=EDX) (electron microprobe analysis; energy dispersive X-ray analysis) (1 p)
   f) SIMS (secondary ion mass spectrometry) (1 p)

4. If you were to buy a RIE (Reactive Ion Etching) system for Si etching in manufacturing environment, what kind of test runs would you make at equipment makers' factory? Assuming 200 wafers available, describe both the type of runs, wafers, processes and measurements that you would carry out to evaluate the RIE system.

5. Compare thermal diffusion and ion implantation.

6. What methods and why can be used for deposition of film stack of BAW (bulk acoustic wave) resonator? Explain process problems (deposition rate, temperature, thickness control) and possible interactions between layers (interdiffusion, stresses).



Semiconductor Technology II: silicon-in-aid

Note on notations:

<Si>	single crystal material
c-Si	single crystal material
α-Si	amorphous material
a-Si:H	amorphous material with imbedded hydrogen (at% usually given)
nc-Si	nanocrystalline (grain size a few nanometers)
μc-Si	microcrystalline material (grain size in the range of tens of nanometers)
mc-Si	multicrystalline (= large grained polycrystalline, grain size >> film thickness)
Al-0.5%Cu	alloy with 0.5 % copper
W_2N, Si_3N_4	stoichiometric compounds
SiN_x,x≈0.8	non-stoichiometric compound
W:N	stuffed material, nitrogen at grain boundaries (non-stoichiometric)
WF_6 (g)	material in gas phase
W (s)	material in solid phase
TiW	exception: TiW is not a compound but pseudoalloy with 30 atom% Ti
$Si/SiO_2/Si_3N_4$	film stacks are marked with substrate or bottom film on the left

CVD reaction types:

pyrolysis	SiH_4 (g) ==> Si (s) + 2 H_2 (g)
reduction	$SiCl_4$ (g) + 2 H_2 (g) ==> Si (s) + 4 HCl (g)
hydrolysis	$SiCl_4$ (g) + 2 H_2 (g) + O_2 (g) ==> SiO_2 (s) + 4 HCl (g)
compound formation	3 SiH_2Cl_2 (g) + 4 NH_3 (g) ==> Si_3N_4 (s) + 6 H_2 (g) + 6 HCl (g)

Table 5.2: Some widely used CVD processes

Material/method	Source gases	Temperature	Stability
LTO	$SiH_4 + O_2$	425°C	densifies
HTO	$SiCl_2H_2 + N_2O$	900°C	loses Cl
TEOS	TEOS+O_2	700°C	stable
PECVD OX	$SiH_4 + N_2O$	300°C	loses H
LPCVD poly	SiH_4	620°C	grain growth
LPCVD a-Si	SiH_4	570°C	crystallizes
LPCVD Si_3N_4	$SiH_2Cl_2+NH_3$	800°C	stable
PECVD SiN_x	$SiH_4 + NH_3$	300°C	loses H
CVD-W	WF_6+SiH_4	400°C	grain growth

LTO = Low Temperature Oxide
HTO = High Temperature Oxide
TEOS = TetraEthylOxySilane, $Si(OC_2H_5)_4$

Table 5.3: Properties of metals

Metal	**Resistivity** μΩ-cm	**CTE** ppm	**Thermal cond.** W/cmK	**Melting point** °C
Al	3	23	2.4	650
Cu	1.7	16	4	1083
Mo	5.6*	5	1.4	2610
W	5.6*	4.5	1.7	3387
Ta	12*	6.5	0.6	3000
Ti	48*	8.6	0.2	1660
Co	6.2*	12.5	0.7	1500
Ni	6.8*	13	0.9	1455
Cr	13*	6	0.7	1875
Pt	10	9	0.7	1769
Au	1.7	14	3	1064

* Thin film resistivity is much higher than bulk value: as a rule of thumb, 1.5-2 times the bulk value can be used as an guestimate for thin film resistivity.

Table 5.4: Properties of silicon dioxide and silicon nitride

	SiO_2	Si_3N_4 (LPCVD)
Resistivity (Ω-cm), 25°C	10^{16}	10^{16}
Density (g/cm^3)	2.2	2.9-3.1
Dielectric constant	3.8 – 3.9	6-7
Dielectric strength (V/cm)	$12 \cdot 10^6$	$10 \cdot 10^6$
Thermal expansion coefficient (ppm/°C)	0.5	1.6
Melting point (°C)	1700	1800
Refractive index	1.46	2.00
Specific heat (J/g°C)	1.0	0.7
Young's modulus (GPa)	87	~300
Yield strength (GPa)	8.4	14
Stress in film on Si (MPa)	200-400 C	1000 T
Thermal conductivity (W/cm K)	0.014	0.19
Etch rate in Buffered HF (nm/min)	100	1

Table 5.9: Silicide properties

Silicide	**Resistivity**	**Formation**	**selective metal:silicide etch**
$TiSi_2$	15-20 µOhm-cm	Ti/Si reaction at ca. 750°C	$NH_4OH:H_2O_2$
$TiSi_2$	15-20 µOhm-cm	CVD $TiCl_4/SiH_2Cl_2/H_2$	--
$CoSi_2$	15-20 µOhm-cm	Co/Si reaction at 500°C	$HCl:H_2O_2$ 3:1
NiSi	15-20 µOhm-cm	Ni/Si reaction at 400°C	HNO_3
WSi_2	30 µOhm-cm	CVD WF_6/SiH_2Cl_2 at 400°C	--
PtSi	30 µOhm-cm	Pt/Si reaction	$HCl:HNO_3$ 3:1

Table 4.1: Properties of silicon at 300K

Structural and mechanical

Atomic weight	28.09	
Atoms, total (cm^{-3})	4.995×10^{22}	
Crystal structure	diamond (fcc)	
Lattice constant (Å)	5.43	
Density (g/cm^3)	2.33	
Electrical		
Energy gap (eV)	1.12	
Thermal		
Coefficient of thermal expansion (°C^{-1})	2.6×10^{-6}	
Melting point (°C)	1414	
Optical		
Index of refraction	3.42	$\lambda = 632$ nm
	3.48	$\lambda = 1550$ nm
Energy gap wavelength	1.1 µm	(transparent at larger wavelengths)

Basic wafer specifications for 100 mm wafers

	IC	MEMS
Growth Method	CZ	CZ
Type / Dopant	P / boron	P/boron
Orientation	100	100
Off-orientation	0.0 ± 1.0°	0.0 ± 0.2°
Resistivity	16 – 24 Ohm-cm	1-10 Ohm-cm
Diameter	100.0 ± 0.5 mm	100.0 ± 0.5 mm
Thickness	525 ± 25 µm	380 ± 10 µm
Front side	Polished	Polished
Back side	Etched	Polished
Primary flat	± 1°	± 0.2°
Oxygen level	13 -16 ppma	11-15 ppma
Particles	<20 @ 0.3 µm	<20 @ 0.3 µm