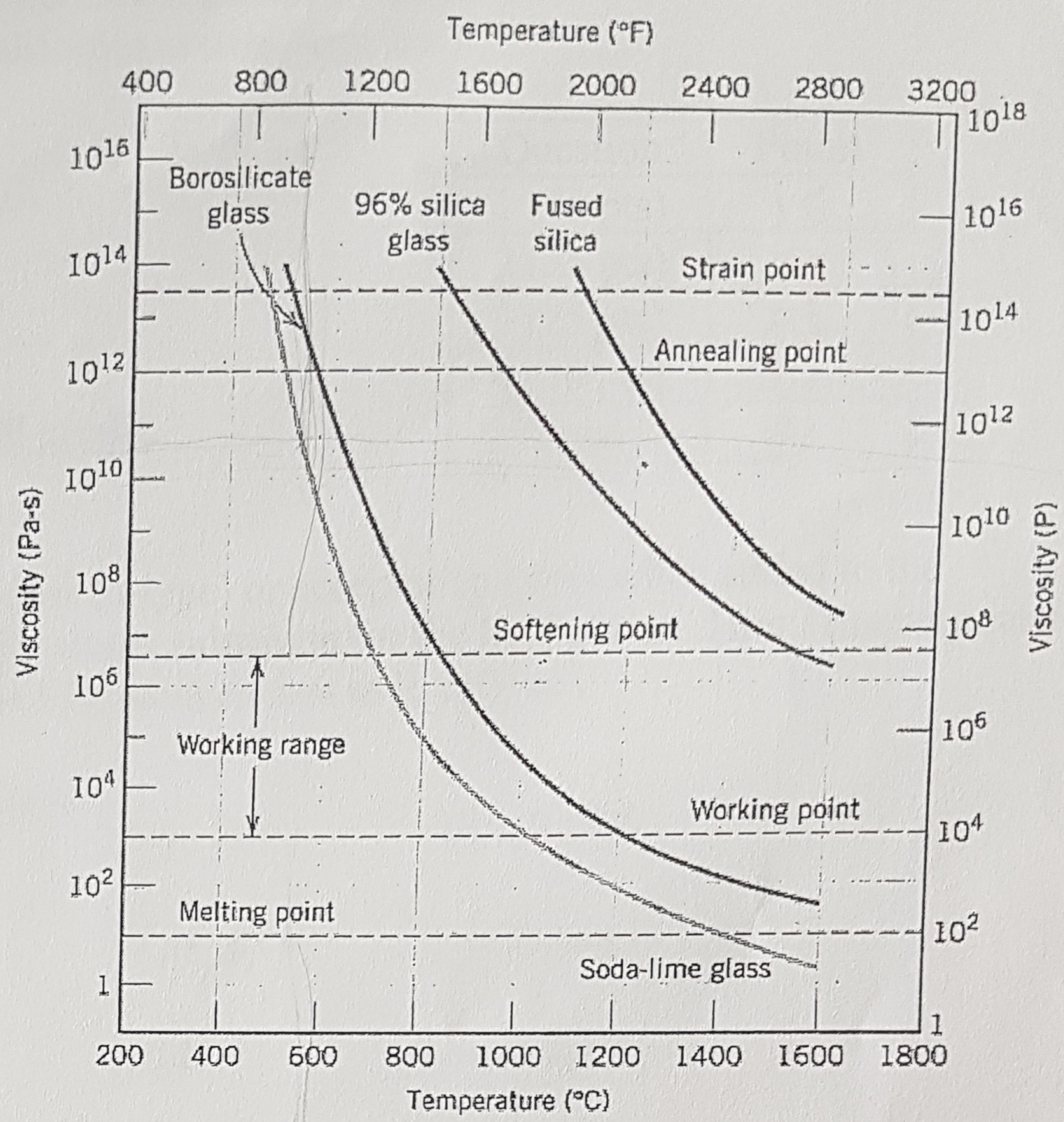
MSE104 Fall 2017 Quiz 2 Review

1. (a) For many viscous materials, the viscosity η may be defined in terms of the expression: $\eta = \sigma/(d\varepsilon/dt)$, where σ and $d\varepsilon/dt$ are, respectively, the tensile stress and the strain rate. A cylindrical specimen of a borosilicate glass of diameter 4 mm and length 125 mm is subjected to a tensile force of 2N along its axis. If its deformation is to be less than 20 mm over 28 hours, using the figure, determine the maximum temperature to which the specimen may be heated.



(b) Why is the permanent dipole lost in $BaTiO_3$ when it is heated above its Curie temperature (~120°C)?

2. (a) Will the dielectric constant of diamond vary with field frequency when alternating current (ac) is applied? (assume maximum frequency is 10^{15} Hz). Yes or no answer will be sufficient.

(b) Consider a parallel plate capacitor with an area of 3200 mm^2, a plate separation of 1 mm, with a material having a dielectric constant of 3.5 positioned between the plates. Determine the following – remember to include units.

i. The capacitance of this capacitor
ii. The electric field that must be applied for 2 x 10^{-8} C to be stored on each plate
iii. If the dielectric constant of the material was 7.0 instead of 3.5, what electric field can be applied for 2 x 10^{-8}C to be stored on each plate
iv. The surface charge density (also referred to as the dielectric displacement) for this capacitor with 2 x 10^{-8} C stored on each plate and material with a dielectric constant of 3.5 between the plates.

3. (a) ZnSe has a bandgap of 2.70 eV, over what wavelength region of visible light will it be opaque? Visible light is from 400nm to 700 nm.

(b) Consider the group II metal magnesium (Mg), which has an atomic weight of 24.31 g/mole, a density of 1.74 g/cm^3 and room temperature electrical *resistivity* of 43.9 x 10^{-9} (Ω-m).

(i) Calculate the electron mobility (m^2/V-s) in Mg.
(ii) If the magnesium is heated to 100°C, will the electrical *resistivity* increase, decrease or have no change?

4) A pure elemental semiconductor (group IV) has a room temperature electrical *conductivity* of 4 x 10^{-4} (Ω-m)$^{-1}$, electron mobility of 0.145 m^2/V-s and hole mobility of 0.05 m^2/V-s. If the number of free electron per valence electron is 6.4 x 10^{-14}, answer the following questions. Assume for dopants that dopant atoms substitute for host atoms, saturation/exhaustion is reached and intrinsic conduction is negligible.

(i) What is the number of density of elemental *atoms* (m^{-3}) in this pure semiconductor?
(ii) What atomic % of n-type dopant must be used to increase the electrical conductivity by factor of 100?
(iii) What atomic % of p-type dopant must be used to increase the electrical conductivity by factor of 100?
(iv) If this semiconductor were heated to 100°C, would the electrical conductivity increase, decrease or have no change?

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MSE 104, Fall 2017
Quiz No. 2, November 29, 2017

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Question	Points
1 (20 pts)	15.
2 (25 pts)	21
3 (25 pts)	25
4 (30 pts)	30
Total	91

Show all work and must include units to receive full credit.
Check that all parts are answered.

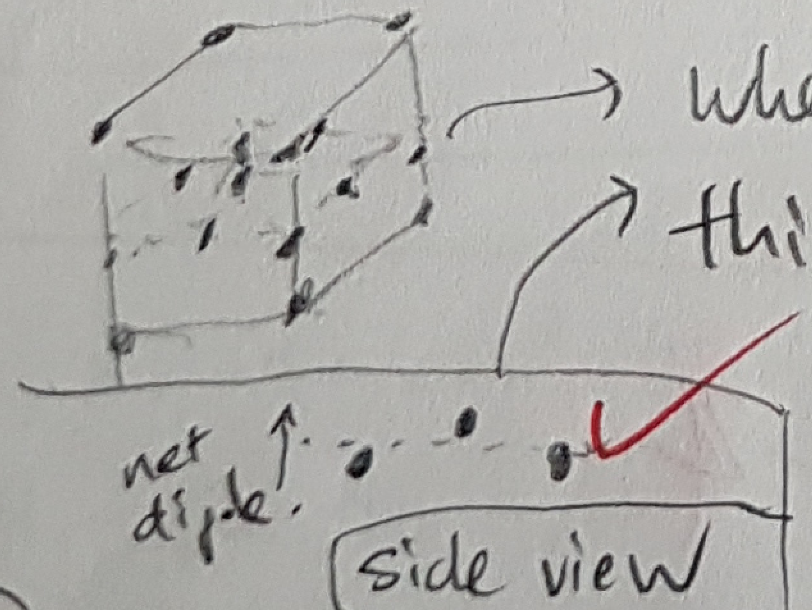
1. (a) Will each of the following elements act as a donor (n-type) or acceptor (p-type) when added to the indicated host semiconductor. Assume impurity atoms substitute for the host atoms. Hint: In compound semiconductors, the impurity atom replaces the host atom closest to it. (10 pts)

Impurity	Host semiconductor		
P	Si	Donor.	n-type
Ga	Ge	Acceptor	p-type.
Se	InSb	Donor	n-type.
In	CdS	Donor	n-type
As	ZnTe	acceptor	p-type.

✓

(b) Why is the permanent dipole in $BaTiO_3$ lost when it is in the cubic phase? (5 pts)

The permanent dipole is only present in the tetragonal structure → where atomic positions are slightly off-center, and this off-centering creates the dipole effect.



Cubic phase centers all atoms in the unit cell, so dipole is lost.

(c) Would you expect $SrTiO_3$ to have a permanent dipole as $BaTiO_3$? (Yes or no answer is sufficient) (5 pts)

No

-5.

2. (a) Name all polarization mechanisms possible in NaCl? (Hint: possibilities are electronic, ionic and orientation polarization). (5 pts)

electronic, ionic

(b) A charge of 2.0 x 10^{-10} C is to be stored on each plate of a parallel plate capacitor having an area of 650 mm and a plate separation of 4.0 mm. Determine the following – remember to include units.

i. What electric field must be applied if a material with dielectric constant of 4.5 is positioned within the plates? (4 pts)
ii. What is the capacitance of the capacitor in part (i)? (4 pts)
iii. What is the polarization for the capacitor in part (i) (4 pts)
iv. What is the surface charge density (also referred to as the dielectric displacement) for the capacitor in part (i). (4 pts)
v. Which material will have the higher dielectric constant, pure SiO_2 or MgO-SiO_2? (4 pts) (No explanation necessary)

b) i)

$Q = 2.0\times10^{-10}$ C

$A = 650(10^{-3})^2$

$l = 4\times10^{-3}$

$C = \epsilon\frac{A}{l} = \epsilon_r\epsilon_0\frac{A}{l} = \frac{Q}{V}$

$V = \frac{Ql}{\epsilon_r\epsilon_0 A}$

$\mathcal{E} = \frac{V}{l} = \frac{Q}{\epsilon_r\epsilon_0 A}$

$= \frac{2\times10^{-10}}{(4.5)(8.85\times10^{-12})(650\times(10^{-3})^2)}$

$\mathcal{E} = 7726$ V/m ✓

ii)

$C = \epsilon_r\epsilon_0\frac{A}{l}$

$= 4.5\times8.85\times10^{-12}\times\frac{650(10^{-3})^2}{4(10^{-3})}$

$C = 6.47\times10^{-12}$ C/V ✓

iii) $D = \epsilon\mathcal{E} = \epsilon_0\mathcal{E} + P$

$P = \epsilon\mathcal{E} - \epsilon_0\mathcal{E}$

$= \epsilon_r\epsilon_0\mathcal{E} - \epsilon_0\mathcal{E}$

$= \epsilon_0\mathcal{E}(\epsilon_r - 1)$

$= (8.85\times10^{-12})(7726)(4.5-1)$

$P = 2.39\times10^{-7}$ C/m^2 ✓

iv) $D = \epsilon\mathcal{E} = \epsilon_r\epsilon_0\mathcal{E}$

$= 4.5(8.85\times10^{-12})(7726)$

$D = 3.077\times10^{-7}$ C/m^2 ✓

v) SiO_2 ✗ higher. −4

2

GaP has a band gap of 2.25 eV, over what wavelength region of visible light will it be transparent? Visible light is from 400nm to 700 nm. (5 pts)

Transparent → light pass through, NOT absorbed.

$E_g = 2.25eV$ → light corresponds to E_g region

$E = \frac{hc}{\lambda} < E_g = 2.25 eV$

$\frac{4.13\times10^{-15} \times 3\times10^{8}}{\lambda} < 2.25 \rightarrow \lambda > \frac{4.13\times10^{-15} \times 3\times10^{8}}{2.25}$

$\lambda > 550$ nm

answer: $550nm < \lambda < 700$ nm ← upper limit of visible

+5

3 ~~(b) At room~~ temperature, the electrical conductivity and the electron mobility for Al are 3.8 x 10^7 $(\Omega\text{-m})^{-1}$ and 0.0012 $m^2/V\text{-}s$, respectively. (20 pts)

(i) Calculate the number of free electrons per m^3 for Al at room temperature.

(ii) What is the number of free electrons *per aluminum atom*? Assume a density of 2.7 g/cm^3, and the atomic weight of Al is 26.98 g/mol

(iii) What is ratio of free electrons/valence electrons per aluminum atom?

Aluminium

i) $\sigma = 3.8\times10^7$

$\mu_e = 0.0012\ m^2/V \cdot s$

$\sigma = n|e|\mu_e$

$n = \frac{\sigma}{|e|\mu_e} = \frac{3.8\times10^7}{1.602\times10^{-19} \times 0.0012}$

$n = 1.9767\times10^{29}\ e/m^3$

+8

ii) $\rho = 2.7\ g/cm^3 \rightarrow 2700000\ g/m^3$

$A_r = 26.98\ g/mol$

Aluminium: $mole/m^3 = \frac{2700000}{26.98} = 100074\ mole/m^3$

$atom/m^3 = mole/m^3 \times 6.02\times10^{23}$

$= 6.02\times10^{28}\ atoms/m^3$

$\therefore \frac{\text{free electron}}{\text{al atom}} = \frac{1.9767\times10^{29}}{6.02\times10^{28}} = 3.28$

+7

iii) Aluminum: Valency = 3+

$\therefore \frac{\text{free electron}}{\text{valence electron}} = \frac{3.28}{3}$

$= 1.0937$

at room temp.

+5

30

4) A Si sample was found to have residual boron (B). The room temperature electrical conductivity of this Si sample with residual B was found to be 0.080 $(\Omega\text{-m})^{-1}$. B has a density of 2.34 g/cm^3. Si has a density of 2.33 g/cm^3, intrinsic conductivity of 4 x 10^{-4} $(\Omega\text{-m})^{-1}$, with $\mu_e = 0.19$ m^2/V-sec and $\mu_h = 0.0425$ m^2/V-sec at room temperature. Atomic weights can be found in the periodic table on the last page. Assume that B atoms substitute for Si atoms and saturation is reached.

(i) What was the *atomic%* of residual boron in this Si sample? (15 pts)
(ii) If this sample was further doped with additional 5 x 10^{18} m^{-3} of B atoms, what would be its electrical conductivity? (15 pts)

$Ar_{Si} = 28.086$ g/mol
$Ar_B = 10.811$ g/mol

$\sigma = 0.080\ (\Omega\text{-m})^{-1}$

$B = \rho = 2.34\ g/cm^3$

$Si: \rho = 2.33\ g/cm^3$

$\sigma_{Si} = 4\times10^{-4}\ (\Omega\text{-m})^{-1}$

$\mu_{e\,(Si)} = 0.19\ m^2/V\text{-}s$

$\mu_{h\,(Si)} = 0.0425\ m^2/V\text{-}s$

i) 15

$\sigma_{total} \approx p|e|\mu_h$ → Because Boron is acceptor dopant.

$0.08 = p(1.6\times10^{-19})(0.0425)$

$p = \frac{0.08}{1.6\times10^{-19}\times0.0425} = 1.17\times10^{19}$ carrier/volume.

$\therefore \frac{\text{Boron atoms}}{\text{volume}} = 1.17\times10^{19}\ at/m^3$.

Pure silicon: $\frac{at}{m^3} = 6.02\times10^{23}\times\frac{\rho_{Si}}{Ar_{Si}}/(10^{-2})^3$

$= \frac{6.02\times10^{23}\times2.33}{28.086\times(10^{-2})^3}$

$= 4.99\times10^{28}\ atom/m^3$.

→ Substitution ∴

atomic % B $= \frac{1.17\times10^{19}}{4.99\times10^{28}}\times100 = 2.35\times10^{-8}$ % at ✓

ii) 15

$\sigma_{tot} \approx p|e|\mu_h$

$= (p_{initial} + p_{additional})|e|\mu_h$

$= [(1.17\times10^{19}) + (5\times10^{18})](1.6\times10^{-19})\times0.0425$

$= 0.114\ (\Omega\text{-m})^{-1}$ σ_{new} ✓