Name: _____

Amorphous Materials
Exam I
90 min Exam

Problem 1 (25 Points) _____

Problem 2 (25 Points) _____

Problem 3 (25 Points) _____

Problem 4 (25 Points) _____

Total (100 Points) _____

Happy exam! And may the odds be ever in your favor.

Problem 1 Appetizers

Please briefly justify your choice using ONE sentence.

1) All metastable solids are amorphous.

NOT CORRECT

Diamond.

2) Laboratory glasses always have a smaller density than their supercooled liquid counterparts due to the presence of free volume.

NOT CORRECT

Silica.

3) Laboratory glasses always have higher enthalpy compared to their supercooled liquid counterparts. As a result, isothermal crystallization of glass is an exothermic reaction.

CORRECT

Laboratory glassy states have higher potential energy compared to the supercooled liquid state.

4) A stretched exponential relaxation kinetics suggests that multiple microscopic relaxation mechanisms co-exist.

CORRECT

A sum of exponential decay functions can be approximated by a stretched exponential function.

5) A research paper proposes to mold tunable infrared optical lenses out of the commercial phase change memory alloy $Ge_2Sb_2Te_5$. When the lens piece is heat treated to switch between the crystalline/amorphous states, its optical property is reversibly adjusted. Do you think the approach is technically sound?

There is a problem here…

The typical crystallization time for commercial GST alloys is in the order of 100 ns, and therefore there is no way to control the phase composition in a bulk optical element.

Problem 2 Soup

1) [Part A] Briefly explain why glasses prepared using different processing routes exhibit different macroscopic properties.
[Part B] Consider a glass thin film deposited via vacuum vapor deposition and a bulk glass sample of identical chemical composition prepared using air quench. Both samples are amorphous. Which one do you expect to have larger molar enthalpy at standard conditions (15 °C and 1 atm)?

Solution:
[Part A] There are multiple local minima in the potential energy landscape for a glass material. The processing history dictates which minimum the glass structure will reside in. The different microscopic structures therefore yield different macroscopic glass properties. (10 Points)

[Part B] Vacuum deposition has a much higher effective cooling rate and therefore samples deposited from vapor should have larger molar enthalpy (5 Points).

2) Briefly explain the key difference(s) between viscoelasticity and viscosity.

Solution:
Unlike viscous liquids, the response of viscoelastic materials to external stimuli (stress) has an elastic component that results in an instantaneous elastic strain which slowly relaxes. On the other hand, deformation (strain) in viscous liquids has to build up over time (10 Points).

Problem 3 Main course

You have been hired as a research group leader by a start-up company Gninroc Inc.. The company focuses on developing new display glasses for Orange Inc., a leading manufacturer of smart phones. After some preliminary research, your team has recommended the following candidate compositions for the company's next-generation chemically toughened glass product (all are given in atomic/molar fractions):

$3MgO \cdot 21Al_2O_3 \cdot 76SiO_2$
$12Na_2O \cdot 3MgO \cdot 11Al_2O_3 \cdot 74SiO_2$
$10Cs_2O \cdot 8CaO \cdot 10Al_2O_3 \cdot 72SiO_2$
$20K_2O \cdot 3CaO \cdot 2PbO \cdot 5Al_2O_3 \cdot 70SiO_2$

i) Among the four compositions, which one would you pick to move on to the next stage of R&D? Why?
ii) Use your own words, briefly explain the strengthening mechanism.
iii) If you want to batch 1 kg of the glass composition you selected for lab testing, specify the amount (in gram) of raw materials needed for the synthesis. You can pick raw materials from the following list:

Sand [SiO_2], soda [Na_2CO_3], limestone [$CaCO_3$], albite [$Na_2O \cdot Al_2O_3 \cdot 6SiO_2$], feldspar [$K_2O \cdot Al_2O_3 \cdot 6SiO_2$], potassium carbonate [$K_2CO_3$], cesium nitrate [$CsNO_3$], lead metal [Pb], barringtonite [$MgCO_3 \cdot 2H_2O$].

Solution:
i) (10 Points)
$3MgO \cdot 21Al_2O_3 \cdot 76SiO_2$ No alkali
$12Na_2O \cdot 3MgO \cdot 11Al_2O_3 \cdot 74SiO_2$ Good (aluminosilicate with Al:Na ~ 1:1, contains MgO to accelerate ion diffusion)
$10Cs_2O \cdot 8CaO \cdot 10Al_2O_3 \cdot 72SiO_2$ Cs is the largest alkaline ion
$20K_2O \cdot 3CaO \cdot 2PbO \cdot 5Al_2O_3 \cdot 70SiO_2$ Al:K ratio << 1, and it is rare to use potassium silicate glass in chemical strengthening (Rb and Cs are rarely used in glass products); contains lead

ii) Big ions (K^+) diffuse into the surface of the glass to replace the small ions (Na^+) in the original glass, leading to large surface compressive stress that inhibits surface crack initiation and growth (5 Points).

iii) (10 Points)
Sand [SiO_2], soda [Na_2CO_3], albite [$Na_2O \cdot Al_2O_3 \cdot 6SiO_2$], barringtonite [$MgCO_3 \cdot 2H_2O$]

Molar mass (g/mol):
Glass components: Na_2O: 62; Al_2O_3: 102; MgO: 40; SiO_2: 60
Batch components: Na_2CO_3: 106; $Na_2O \cdot Al_2O_3 \cdot 6SiO_2$: 526; $MgCO_3 \cdot 2H_2O$: 120; SiO_2: 60

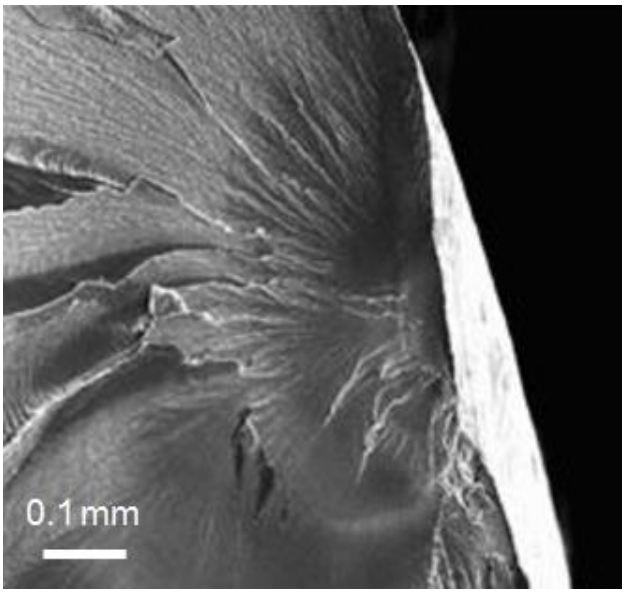
Moles	wt%	For 1 kg of glass	Mineral mass
MgO: 3	1.7	17 g	17 g * (120 / 40) = 51 g
Al_2O_3: 11	16.1	161 g	161 g * (526 / 102) = 830 g Also contains Na_2O: 830 g * (62 / 526) = 98 g Contains SiO_2: 830 g * (6*60 / 526) = 568 g
Na_2O: 12	18.3	183 g	183 g * [106 / 62] - 98 g = 215 g
SiO_2: 74	63.9	639 g	639 g - 568 g = 71 g

Problem 4 Dessert

Gninroc has developed a number of glass products under your leadership with overwhelming market success. Impressed by your technical prowess and leadership skills, Orange Inc. has appointed you as their corporate research VP heading their R&D efforts on bulk metallic glass (BMG) smart phone cases. The cases will be made of the BMG composition Vitreloy-1 ($Zr_{41.2}Be_{22.5}Ti_{13.8}Cu_{12.5}Ni_{10}$).

i) Your engineering team has proposed manufacturing the cases using compressive molding at a viscosity value of $10^{7.6}$ Poise. Determine the molding temperature and processing time window before crystallization occurs.

ii) After a few test molding runs, your team reports that fracture toughness of the molded case falls well below expectation. The following figure shows an exemplary fracture surface. What do you think is the likely cause of the material's subpar performance?



Solution:

i) The molding temperature read out from the Angell plot is ~ 790 K. The corresponding processing time read out from the TTT diagram is ~ 200 s. (10 Points)

ii) The microscope image exhibits a characteristic brittle fracture surface with clearly discernable mirror and hackle regions. Thermal embrittlement, a common issue for thermoplastic formed BMG parts, is likely the culprit. Since there is no plastic deformation in brittle materials to absorb energy during crack propagation, the fracture toughness reduces as a result of thermal embrittlement (15 Points).

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