

### Homework Assignment 3, Due at start of class, Thursday, Feb 26

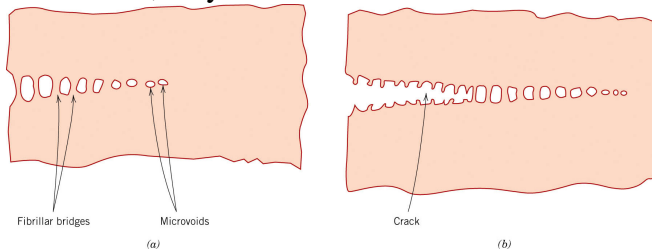
Solve Questions 14.11, 15.12, 15.31 (a,b only), 15.39, 16.8, 16.15, 16.22,  
AND solve the following:

22 pts total.

EX1) Describe the mechanisms for failure/fracture with: 3 pts total, 2 pts for part a (1 of these for using the word crazing, 1 for the concept of bridges), 1 pt for part b.

- thermoplastics
- crosslinked polymers

a) As thermoplastics are loaded, local composition inhomogeneities cause localized stress intensification and therefore strong local deformations. This leads to 'crazing,' which is the formation of microcracks and microvoids. With continued loading, crazes connect to form proper cracks and later failure of a thermoplastic. The bridges that remain connecting both sides of a crack still impart some strength, though (somewhat like a fiber composite), improving fracture toughness. Overall, they exhibit a ductile character.



b) Crosslinked polymers fail like brittle ceramics (i.e. catastrophically), but generally at lower loads. The failure points initiate at local scratches, voids, etc. which are stress amplification points just as with ceramics.

EX2) For **one** of the following, note 4 key details.

Not graded.

- Sol gel
- Single crystal
- Thermal evaporation
- Sputtering
- CVD
- PLD
- Semiconductor microfabrication
- MEMS

**NOTE: Students are only supposed to answer ONE of these options. Roughly 75% of the following should be addressed for full credit, otherwise proportionately less credit should be given.**

a) Sol gel

- Prepare a liquid "sol" that is mostly colloidal
  - Inorganic metal salts or metal alkoxides (metal organics)

- Hydrolize and polymerize to form a colloidal suspension (“sol”)
- Spray, dip, or spin onto a substrate, forming a “gel” as it dries
- Bake to remove the rest of the H<sub>2</sub>O
- Anneal to burn off the organic groups remaining
- Anneal at higher temperatures to densify
- This is a primary process for preparing small, pure particles of most performance ceramics.
- If the sol is cast before the gel has set, then a porous, low density material can be made (“aerogel”).
  - Excellent thermal insulator
  - Lousy mechanical strength
- Fibers can also be drawn from the sol under certain conditions.

#### b) Single crystal

- Most common method for semiconductor substrates, but also optical materials.
- Usually grown by Czochralski growth
  - Melt starting materials in a crucible
  - Introduce a seed crystal
  - Rotate and slowly extract the seed crystal
  - Large diameter, dislocation free
- Like growing rock candy

#### c) Thermal Oxidation

- Heat it up, usually around 600C for less than a minute.
- Oxidize the surface.
- Oxide extends into the sample depending on time and temperature (diffusion).
- Possible with N as well.
  - Most commonly used for SiO<sub>2</sub> formation.
  - ***NOT LINE OF SIGHT (thus easier batch processing)***

#### d) Sputtering

- Bombard a target with inert ions
- Sputters target ions into the vacuum.
- Substrate mounted nearby is coated with these target ions.
- Common industrial process.
  - ***Line of sight.***
  - ***(Best for flat surfaces)***

#### e) CVD

- Start with gaseous molecules (precursor)
- Expose to a substrate
- Molecules adsorb
- Molecular components chemically bond to the surface
- Byproducts desorb back into gas phase and are removed
- Film growth can be carefully controlled.
  - Common industrial process.

- *NOT line of sight.*
- Coating of complex shapes and even internal pores is possible
- Used for
  - IC's, optoelectronics, and sensors
  - Catalyst deposition
  - Powder preparation
  - Protective coatings
  - Coolant lines in aircraft engine components
  - Space telescope sun shield (reflector)

f) Pulsed Laser Deposition (PLD)

- Intense laser pulses vaporize a small region of the target.
- Like sputtering, target atoms are then ejected onto a substrate.
- This time, short duration, high energy pulses locally vaporize the target.
- Atomic layers/second or minute can be grown.
  - Common research lab process.
  - Great for epitaxial growth (single xtal).
  - *Line of sight.*
- Heating rates up to 100 degrees/sec

g) Lithography (IC processing)

- Design
- Coat
- Mask
- Expose
- Develop
- Fabricate
  - Oxidize
  - Deposit (industrially usually sol-gel or cvd)
  - Etch (for MEMS, deep reactive ion etch, "RIE")
- Lift-off
- Repeat to complete multiple layers if necessary
- Bonding of dissimilar parts if necessary

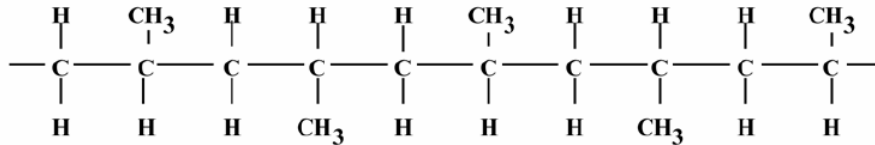
h) Micro-Electro-Mechanical Systems (MEMS)

- Very similar to Si IC microfabrication, with exception of more aggressive etching to make 3-dimensionaility
  - Design
  - Masking
  - **Etching (deep reactive ion etch, "RIE")**
  - Oxidizing
  - Coating (usually sol-gel or cvd).
  - Repeat to complete multiple layers if necessary
  - Bonding of dissimilar parts if necessary

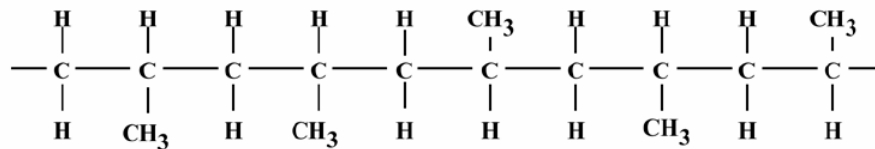
14.11 4 pts total: 1 pt. for polypropylene being a polymer chain of repeating units of -CHH-CHCH<sub>3</sub>- 1 pt. each for noting in sketch or in words that syndiotactic is opposite sides, atactic is random, and isotactic is all on the same side.

14.11 We are asked to sketch portions of a linear polypropylene molecule for different configurations (using two-dimensional schematic sketches).

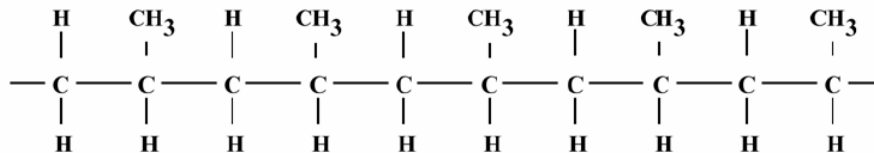
(a) Syndiotactic polypropylene



(b) Atactic polypropylene



(c) Isotactic polypropylene



15.12: 4 pts. total, 1 pt each.

(a) The tensile strength of a semicrystalline polymer increases with increasing molecular weight. This effect is explained by increased chain entanglements at higher molecular weights.

(b) Increasing the degree of crystallinity of a semicrystalline polymer leads to an enhancement of the tensile strength. This is due to enhanced interchain bonding and forces; in response to applied stresses, interchain motions are thus inhibited.

(c) Deformation by drawing increases the tensile strength of a semicrystalline polymer. This effect is due to the highly oriented chain structure that is produced by drawing, which gives rise to higher interchain secondary bonding forces.

(d) Annealing an undeformed semicrystalline polymer produces an increase in its tensile strength.

15.31 (a,b only): **not graded**

15.31 (a) Yes, it is possible to determine which polymer has the higher melting temperature. The linear polyethylene will most likely have a higher percent crystallinity, and, therefore, a higher melting temperature than the branched polyethylene. The molecular weights of both materials are the same and, thus, molecular weight is not a consideration.

(b) Yes, it is possible to determine which polymer has the higher melting temperature. Of these two polytetrafluoroethylene polymers, the PTFE with the higher density ( $2.20 \text{ g/cm}^3$ ) will have the higher percent crystallinity, and, therefore, a higher melting temperature than the lower density PTFE. The molecular weights of both materials are the same and, thus, molecular weight is not a consideration.

15.39 **1 point**

15.39 The distinction between dye and pigment colorants is that a dye dissolves within and becomes a part of the polymer structure, whereas a pigment does not dissolve, but remains as a separate phase.

16.8: **4 pts, 1 pt each for equation and value in a and b (units must be correct).**

16.8 This problem calls for us to compute the longitudinal tensile strength and elastic modulus of an aramid fiber-reinforced polycarbonate composite.

(a) The longitudinal tensile strength is determined using Equation 16.17 as

$$\begin{aligned}\sigma_{cl}^* &= \sigma_m'(1 - V_f) + \sigma_f^*V_f \\ &= (35 \text{ MPa})(0.55) + (3600)(0.45) \\ &= 1640 \text{ MPa} \quad (238,000 \text{ psi})\end{aligned}$$

(b) The longitudinal elastic modulus is computed using Equation 16.10a as

$$\begin{aligned}E_{cl} &= E_mV_m + E_fV_f \\ &= (2.4 \text{ GPa})(0.55) + (131 \text{ GPa})(0.45) \\ &= 60.3 \text{ GPa} \quad (8.74 \times 10^6 \text{ psi})\end{aligned}$$

16.15: 2 pts total: 1 pt for figuring out that  $l$  is  $> l_c$ , 1 pt for final value (units must be correct).

16.15 In this problem, for an aligned carbon fiber-epoxy matrix composite, we are given the volume fraction of fibers (0.20), the average fiber diameter ( $6 \times 10^{-3}$  mm), the average fiber length (8.0 mm), the fiber fracture strength (4.5 GPa), the fiber-matrix bond strength (75 MPa), the matrix stress at composite failure (6.0 MPa), and the matrix tensile strength (60 MPa); and we are asked to compute the longitudinal strength. It is first necessary to compute the value of the critical fiber length using Equation 16.3. If the fiber length is much greater than  $l_c$ , then we may determine the longitudinal strength using Equation 16.17, otherwise, use of either Equation 16.18 or Equation 16.19 is necessary. Thus, from Equation 16.3

$$l_c = \frac{\sigma_f^* d}{2\tau_c} = \frac{(4.5 \times 10^3 \text{ MPa})(6 \times 10^{-3} \text{ mm})}{2(75 \text{ MPa})} = 0.18 \text{ mm}$$

Inasmuch as  $l \gg l_c$  (8.0 mm  $\gg$  0.18 mm), then use of Equation 16.17 is appropriate. Therefore,

$$\begin{aligned}\sigma_{cl}^* &= \sigma_m'(1 - V_f) + \sigma_f^* V_f \\ &= (6 \text{ MPa})(1 - 0.20) + (4.5 \times 10^3 \text{ MPa})(0.20) \\ &= 905 \text{ MPa} \quad (130,700 \text{ psi})\end{aligned}$$

16.22: 4 pts total, 2 for a, 1 for b, and 1 for c.

a) 4 reasons are that:

- i) glass fibers are easily drawn into fibers from molten glass
- ii) widely available and easy to manufacture
- iii) fibers are strong with high strength/weight ratio
- iv) chemically inert

16.22 (a) The four reasons why glass fibers are most commonly used for reinforcement are listed at the beginning of Section 16.8 under "Glass Fiber-Reinforced Polymer (GFRP) Composites."

(b) The surface perfection of glass fibers is important because surface flaws or cracks act as points of stress concentration, which will dramatically reduce the tensile strength of the material.

(c) Care must be taken not to rub or abrade the surface after the fibers are drawn. As a surface protection, newly drawn fibers are coated with a protective surface film.