MS115b. Fundamentals of Materials Science:
Focus on Mechanical Behavior of Materials

General Scope. Review of Fundamentals in Structure and Bonding. Basic properties: Functional vs. Structural. Introduction to the mechanical behavior of solids, emphasizing the relationships between microstructure, defects, and mechanical properties. Elastic, anelastic, and plastic properties of crystalline and amorphous materials. Polymer and glass properties: viscoelasticity, flow, and strain rate dependence. The relations between stress, strain, strain rate, and temperature for deformable solids. Application of dislocation theory to strengthening mechanisms in crystalline solids. The phenomena of creep, yielding, and fracture, and their controlling mechanisms. Mechanical properties relevant to modern day: photovoltaic devices, thin films will be covered in MS/ME162.

Instructor. Julia R. Greer jrgreer@caltech.edu Office: Steele 221

TAs. Viki Chernow (vchernow@caltech.edu) Office: Steele 223

Lectures. TR 2:30 PM - 3:55 PM Watson 104

Sub Lectures. Viki Chernow (highlighted dates)

Office Hours To be arranged with TA

Website http://jrgreer.caltech.edu/teaching.php.
Please download your homework, assignments, solutions, and handouts from this website.

Homework. There will be weekly problem sets to be turned in on Fridays at 3pm. There will be no problem set due the week after midterm and the week before final. NO LATE HOMEWORKS WILL BE ACCEPTED. While collaborative work is encouraged, please write your own individual solutions.

Exams. There will be 1 take-home midterm exam and 1 take-home final. You are welcome to use any of your notes and books recommended for this class during these exams. You **may not** collaborate with others on any of the problems and you **may not** work past the allotted amount of time. Each exam will last 3 hours.

Class Schedule (subject to change).

Week/Date	Section	Topic
Wk 1/Jan 7 Wk 1/Jan 9	**SSASW** Ch. 8-8.2.4 **BNT** Secs. 5-1 through 5-5	**Introduction** to properties and structures of materials: crystallographic structures and coordinates, types of lattices, defects. **Review of thermodynamics**: phase diagrams of solutions, phase transitions, solidification

Wk 2/Jan 14 Wk 2/Jan 16	**SSASW** Ch. 8.3 **P&E** Sec. 4.2, 4.3, 5.1-5.5	**Thermodynamics review**: reaction rate theory, interface stability, non-equilibrium cooling, time-temperature-transformation (TTT) diagrams, solid-solid transformations. **HW1 due 01/17**
Wk 3/Jan 21 Wk 3/Jan 23	**C** 2.1-2.5 **C** 2.6-2.8	**Fundamentals of Mechanical Properties**: stresses and strains, coordinate conversion Elasticity: isotropy, elasticity and bonding, effects of temperature and composition on elastic properties **HW2 due 01/24**
Wk 4/Jan 28 Wk 4/Jan 30	**Dislocations: C** 3.1-3.4, **W&W** Ch. 1-3, **B&H** Ch. 1-4; Tensile test: **M&A**, Ch. 8	**Dislocations and Yielding in crystalline solids:** Schmid's law, slip systems, twinning, deformation of single crystals. Mechanical testing, stress-strain curves, instabilities, yield criteria, ductility. **HW3 due 01/31**
Wk 5/Feb 4 Wk 5/Feb 6	Same as above +**C** 3.5-3.10, **C** 4.1-4.4, **W&W** Ch. 4-6, **H&B** Ch. 5-8	**Dislocations/Yield cont'd:** crystallographic slip, motion, geometry of dislocations: forces, interactions and properties, mechanics of testing, three stages of yielding, dislocation mobilities, kinetic and structure evolution laws **Midterm NO HW!**
Wk 6/Feb 11 Wk 6/Feb 13	**C** 5.1-5.7, 5.9; **A** Ch. 3-6; **H&B** Ch. 10	**Strengthening Mechanisms:** self force on a curved dislocation, Peierls mechanism, dislocation-point defect interactions, self force on a curved dislocation, Hall-Petch, solid solution strengthening, precipitation hardening, **HW4 due 02/14**
Wk 7/Feb 18 Wk 7/Feb 20	Entire Ch. 6 in **C**	**Simple Mechanical Models:** Maxwell, Voigt, and Standard Linear (SLS) solids, damping and phase angle, mechanisms constants, rubber elasticity **Composites:** fiber composites, statistics of failure, discontinuous fibers, statistical failure, composites for technological applications **HW5 due 02/21**
Wk 8/Feb 25 Wk 8/Feb 27	**C** 9.1-9.5, 10.1-10.11	**Fracture Mechanics:** Griffith's fracture theory, crack propagation modes, stress intensity factor, fracture toughness, ductile vs. brittle fracture, fracture in specific crystals **HW6 due 02/28**
Wk 9/March 4 Wk 9/March 6	**F&S** overview of entire book, lecture notes	**Fracture in Solids, cont'd:** fracture toughness, ductile vs. brittle fracture, fatigue failure **HW7 due 03/07**
Wk 10/Mar 11	**F&S**	**Mechanics of Thin Films:** stresses in thin films, curvature, effects of passivation, relaxation mechanisms, thin films for photovoltaics **(no HW on this but will be on the final)**

Lecture Topic Outline.

1. Properties
   - Structural vs. functional
   - Crystalline structure and structure types
   - Defects
2. Thermodynamics Review
   - Binary Phase Diagrams
   - Nucleation and Reaction rate theory
   - Interface Stability

- Solidification
- Time-Temperature-Transformation (TTT) diagrams

3. Solid-Solid transformations
    - Nucleation and growth
    - Diffusional phase transformation
    - Phase transformations

4. Mechanical Fundamentals
    - Force, moment, stress, equilibrium
    - Coordinate transformations
    - Mohr's circle
    - Principal Stress Axes
    - Displacements and strain
    - Infinitesimal Strains

5. Elastic Behavior of Materials
    - General formulation of Hooke's law
    - Strain energy
    - Elastic anisotropy: properties in particular directions and planes
    - Average elastic constants, composites
    - Atomic bonding basis for elastic behavior
    - Rubber elasticity

6. Time-dependent Behavior: Anelasticity and Damping
    - Simple models for solids: Maxwell, Voigt, and Standard Linear Solid (SLS)
    - Viscoelasticity: mechanical models, damping and relaxation
    - Mechanisms of anelasticity and damping

7. Yielding and Plasticity
    - Tensile test for metals
    - Generalized yield criteria
    - Strain rate sensitivity
    - Plastic instability
    - Ductility

8. Defects and imperfections in Crystalline Solids (DISLOCATIONS)
    - Crystallographic slip
    - Dislocation properties, interactions, and motion
    - Taylor hardening
    - Yielding from crystalline solids perspective
    - Single crystals – polycrystals deformation relation

9. Deformation in Specific Crystals
    - Independent slip systems and plasticity
    - Hexagonal Close-Packed (hcp)
        i. Twinning

- Face-centered cubics (fcc)
    i. Stress-strain curve
    ii. Deformation mechanisms
    iii. Kinetic and structure evolution laws
    iv. Theory of yielding and hardening
    v. Dislocation density, mobility, and multiplication
- Body-centered cubic (bcc) and others
- Strain hardening

10. Strengthening Mechanisms
    - Peierls mechanism
    - Double kink formation
    - Dislocation-point defect interactions
    - Precipitation hardening
    - Cottrell interaction and Orowan bowing
    - Hall-Petch
    - Size-dependent strength
11. Composites
    - Reinforcement with particles and fibers
    - Continuous vs. discontinuous fibers: shear lag model
    - Statistical failure
    - Microstructural effects
    - Modern composites: Kevlar, biomedical, blast protection, etc.

12. Fracture of Materials
    - Types of fracture
    - Stress concentration, stress intensity factor
    - Linear Elastic Fracture Mechanics (LEFM)
    - Plastic zones and small-scale yielding
    - Fracture toughness and resistance curves
    - Physical basis for fracture and toughening concepts

13. Mechanics of Thin Films
    - Stresses in thin films on substrates: rigid vs. flexible
    - Bending, curvature, and stress relations
    - Measurements of stresses: X-ray, beam deflection, wafer curvature, buckling
    - Physical origins of stresses
    - Nanoindentation (maybe, if there is time)

14. Cellular Solids
    - Properties of cellular solids, cell size and geometry
    - Deformation mechanisms in honeycombs
    - Mechanics of foams: stress-strain curves
    - Bending vs. stretching dominated deformation
    - Relationship between stress, stiffness, and relative density
    - Energy absorption

Books. Required class text:

1. Schaffer, Saxena, Antolovic, Sanders and Warner "The Science & Design of Engineering Materials" (**SSASW**)
2. T.H. Courtney "Mechanical Behavior of Materials" (McGraw-Hill, 2nd edition, 2000) (**C**)
3. Barrett, Nix, and Tetelman "The Principles of Engineering Materials" (**BNT**)

Additional Recommended Texts

4. F.A. McClintock and A.S. Argon "*Mechanical Behavior of Materials*" Addison-Wesley(1966) – a REALLY good fundamentals book! (**M&A**)
5. A.S. Argon "Strengthening Mechanisms in Crystal Plasticity" Oxford University Press (2008) (**A**)
6. S. Suresh "*Fatigue of Materials*" Cambridge (1991) (**S**)
7. T. L. Anderson "*Fracture Mechanics- Fundamentals and Applications"* CRC Press (1991)
8. L.B. Freund and S. Suresh "Thin Films Materials," Cambridge University Press (2003) (we will not have time to cover this material as much, but it is a terrific book specifically for the mechanical properties of thin films) (**F&S**)
9. J. Weertman and J.R. Weertman "Elementary Dislocations Theory" Oxford University Press (1992) (**W&W**)
10. D. Hull and D.J. Bacon "Introduction to Dislocations" 3rd Ed. Pergamon Press, New York (1984) (**H&B**)
11. "Dislocations bible": J.P. Hirth and J. Lothe "Theory of Dislocations" 3rd Ed., John Wiley, New York (1982).
12. L.J. Gibson and M.F. Ashby "Cellular Solids: Structure and Properties" 2nd Ed., Cambridge University Press (1997) (**G&A**)