

PY2N20

**Material Properties and
Phase Diagrams**

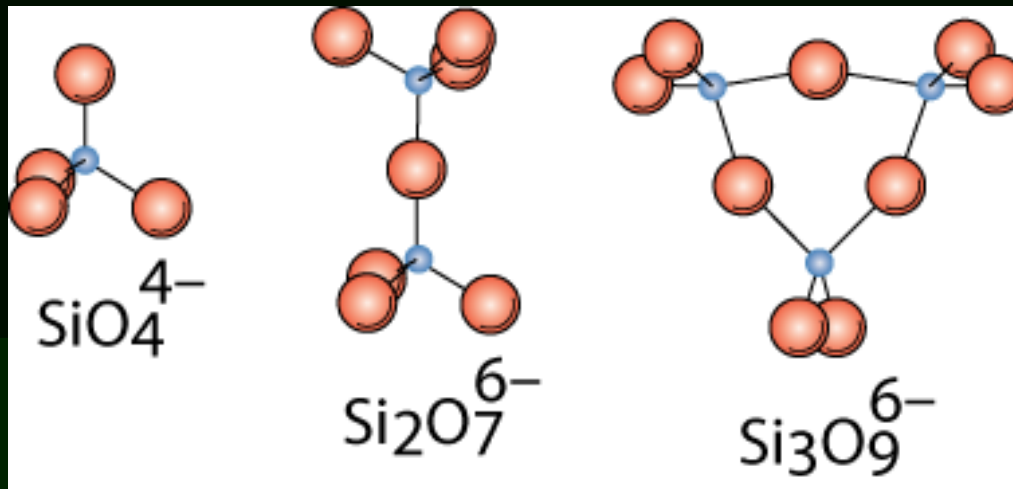
Lecture 11

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Silicates

- Combine SiO_4^{4-} tetrahedra by having them share corners, edges, or faces

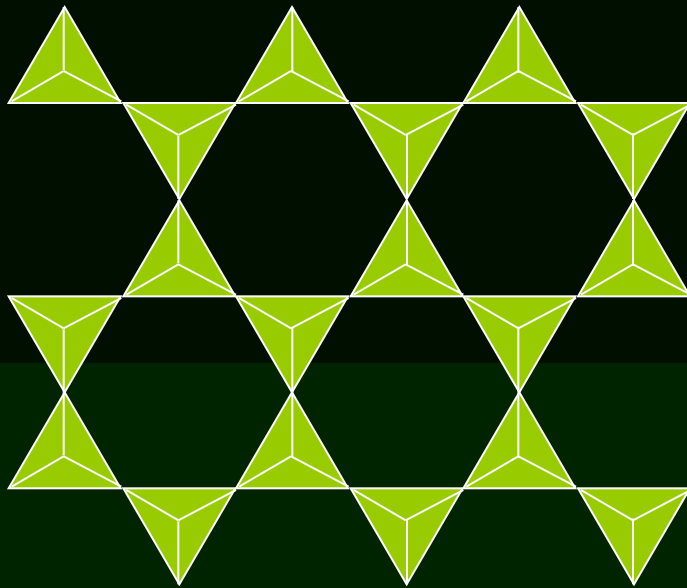


Adapted from Fig. 12.12, Callister 7e.

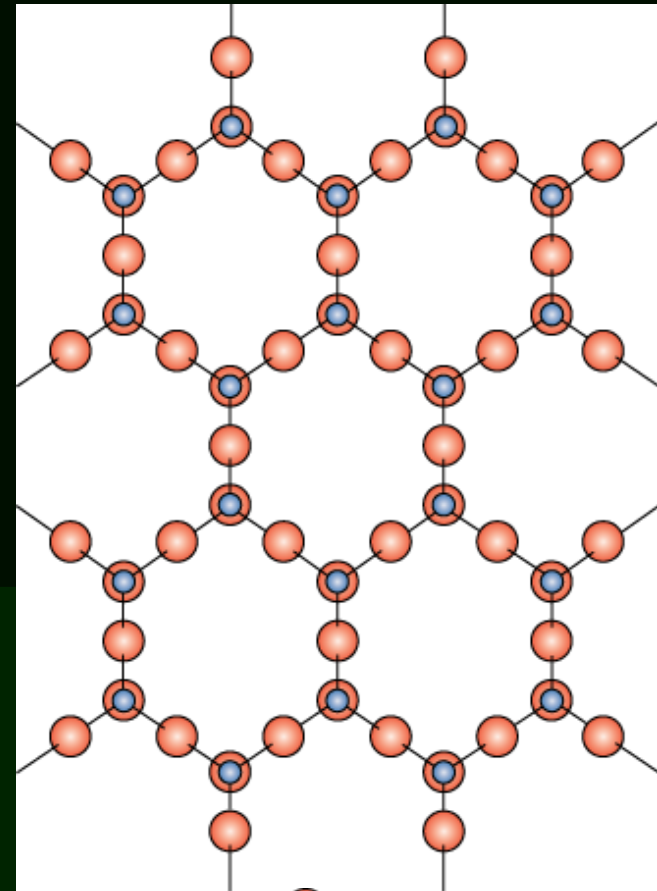
- Cations such as Ca^{2+} , Mg^{2+} , & Al^{3+} act to neutralize & provide ionic bonding

Layered Silicates

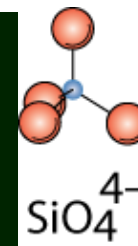
- Layered silicates (clay silicates)
 - SiO_4 tetrahedra connected together to form 2-D plane



- $(\text{Si}_2\text{O}_5)^{2-}$
- So need cations to balance charge



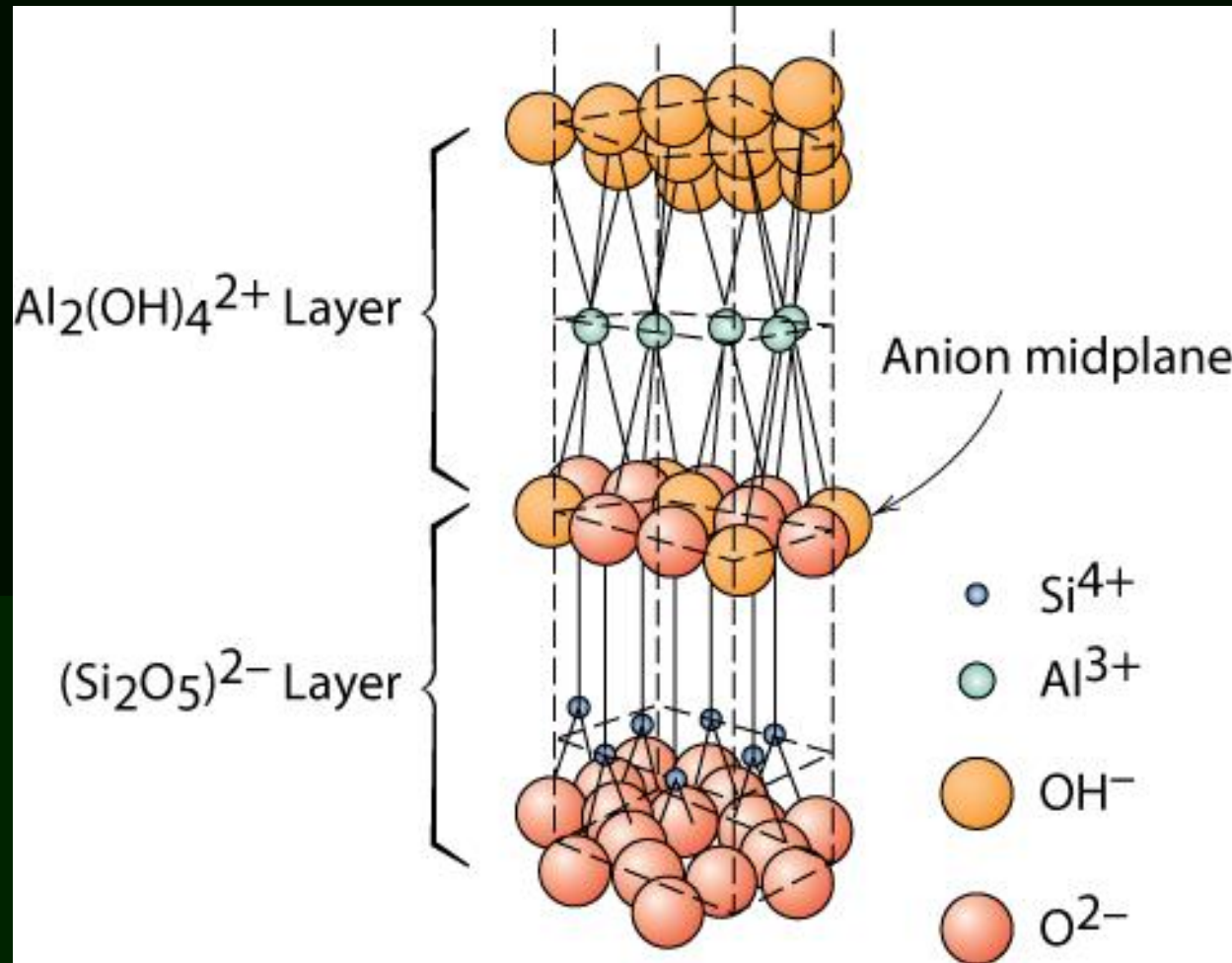
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Adapted from Fig. 12.13, Callister 7e.

Layered Silicates (Porcelain)

- Kaolinite clay alternates $(\text{Si}_2\text{O}_5)^{2-}$ layer with $\text{Al}_2(\text{OH})_4^{2+}$ layer



Adapted from Fig. 12.14, Callister 7e.

Note: these sheets loosely bound by van der Waal's forces

Layered Silicates

- Can change the counterions
 - this changes layer spacing
 - the layers also allow absorption of water
- Micas $\text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$ – some capacitors
- Bentonite (essentially impure clay)
 - used to seal wells
 - general absorber (i.e. for cat litter, etc.)
 - packaged dry
 - swells 2-3 fold in H_2O
 - pump in to seal up dumps so that no polluted ground water seeps out to contaminate the water supply
- Zeolite $\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10}\cdot 2\text{H}_2\text{O}$ (also an excellent absorber)
194 unique forms have been identified, so far!

Machinable Ceramics

- Machined in the unfired or partially sintered state
 - Bisque Alumina
 - Hydrous aluminium silicate
 - Macor™, Cerman™ and other glass-ceramic materials
- Machined in the fully fired state
 - Yttrium stabilized Zirconia
 - Mica-filled ceramics and glass-mica composites

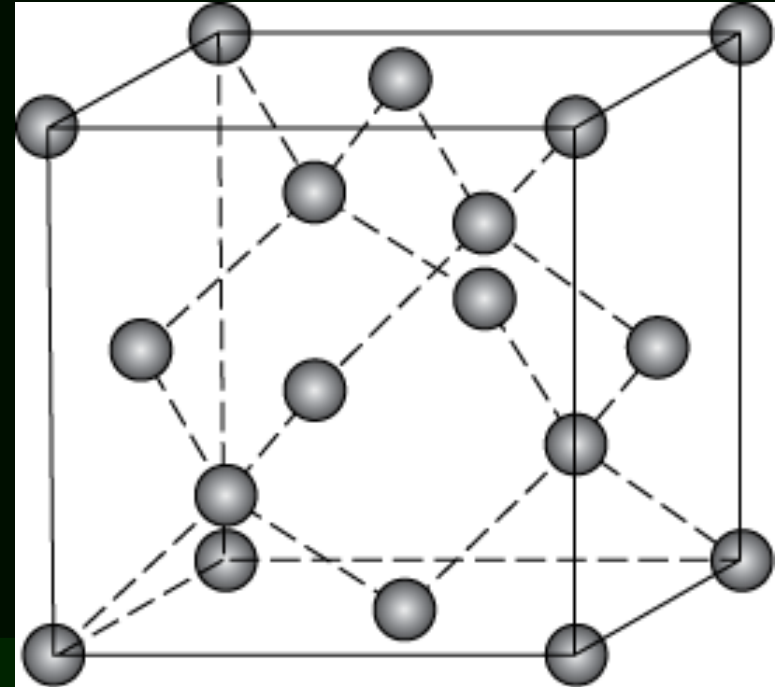
Metal-Ceramics & Metal Glasses

- Metal-Ceramics NiO, BeO, Cr₂O₃ (dentistry, etc.)
 - Powder metallurgy (convenient for hard and brittle metals and for refractory metals – i.e. hi-power electrodes)
 - Metal-ceramic composites – Ti + SiC, Ti + Si₃N₄, Al + SiC, Al + TiB₂, Al + Al₂O₃, etc. – i.e. aircraft and automotive engines
- Metal-Glasses (add B, P, Si, Bi, C and/or Al)
 - Amorphous or glassy state
 - Magnetically soft – sensors
 - Quench-Condensation
 - Melt-Spinning



Carbon Forms

- Carbon black – amorphous – surface area ca. 1000 m²/g
- Diamond
 - tetrahedral carbon
 - hard – no good slip planes
 - brittle – can cut it
 - large diamonds – jewelry
 - currently, often manmade
 - small diamonds
 - often man made - used for cutting tools and polishing
 - diamond films
 - hard surface coat – tools, medical devices, etc.

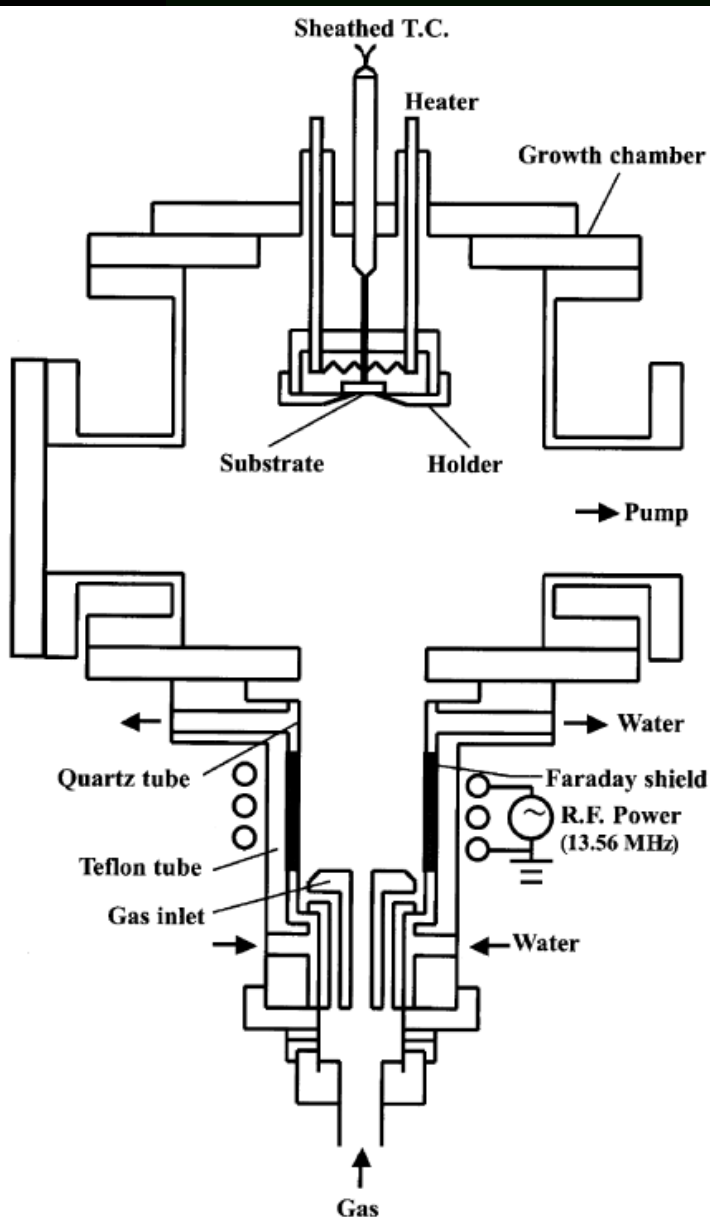


Adapted from Fig. 12.15, *Callister 7e*.

$$E_g = 5.5 \text{ eV}$$
$$n = 2.417$$

Metastable and potentially decaying to graphite

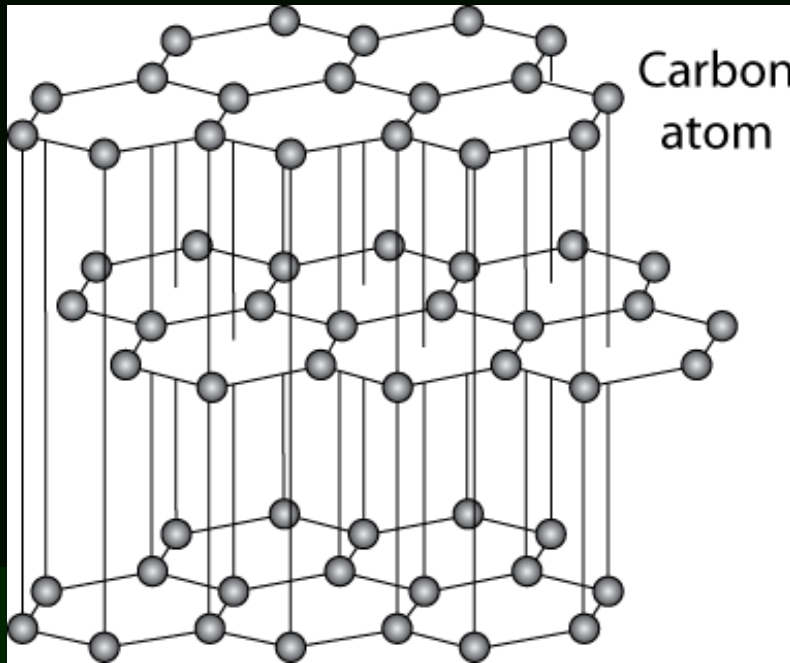
Plasma-Enhanced CVD Process



- $\text{CH}_4 + \text{H}_2$ process gas mixture + RF + Temp.
- Poly-crystalline or epitaxial layers
- Intrinsically or purpose-doped diamond layers
- Heat conduction layers
- Mechanical wear protection

Carbon Forms - Graphite

- layer structure – aromatic layers

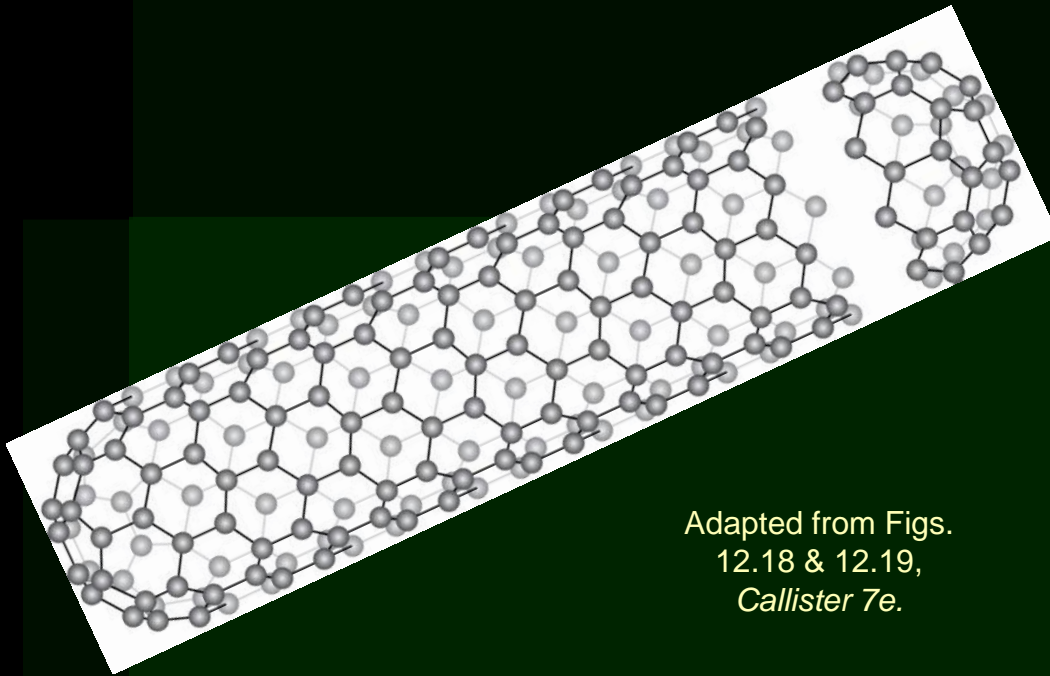


Adapted from Fig. 12.17, Callister 7e.

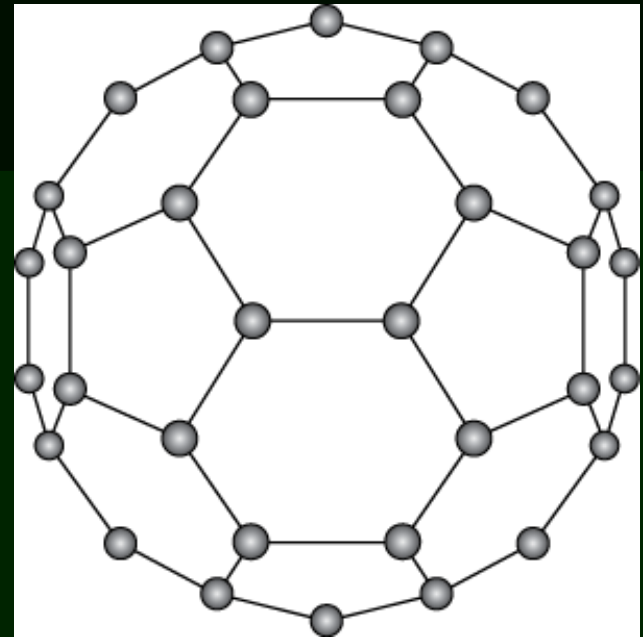
- weak van der Waal's forces between layers
- planes slide easily, good lubricant
- Highly Oriented Pyrolytic Graphite (HOPG) – ZYA ($< 0.4^\circ$), ZYB ($< 0.8^\circ$) and ZYH ($< 3.5^\circ$) – production and use for monochromators

Carbon Forms – Fullerenes and Nanotubes

- Fullerenes or carbon nanotubes
 - wrap the graphene sheet by curving into ball or tube
 - Buckminsterfullerenes – notes on their discovery
 - Like a soccer ball C_{60} - also C_{70} + others



Adapted from Figs.
12.18 & 12.19,
Callister 7e.



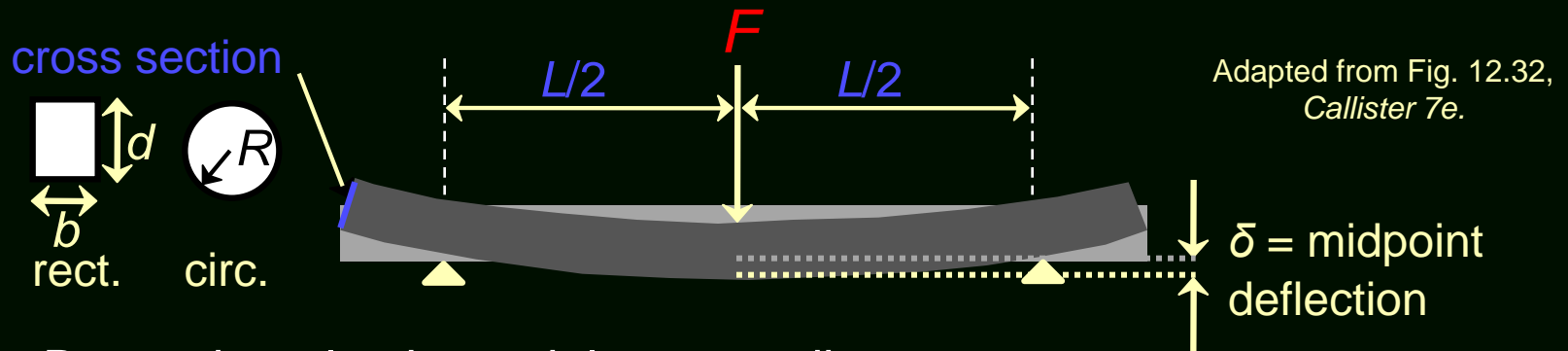
Graphite and CNT Properties

Material	Property	Value	Units	Notes
HOPG	Magnetic susceptibility	$-3.8 \cdot 10^{-7}$	m^3kg^{-1}	Parallel to the <i>c</i> axis, 1.8 K
HOPG	Magnetic susceptibility	$-5 \cdot 10^{-9}$	m^3kg^{-1}	Perpendicular to the <i>c</i> axis
HOPG	Magnetoresistance	2280	%	Field parallel to <i>c</i> , 1.8 K, 5 T
HOPG	Carrier density	$3 \cdot 10^{-4}$	el/atom	At 1.8 K
HOPG	Rel. Phase of HE/MR	$\pi/4$	rad	De-phasing of the oscillations
HOPG	Electron effective mass	0.039	m_e	Majority carriers
HOPG	Anisotropy of m^*	25:1	-	Majority carriers
HOPG	e-Fermi X-section	$4.2 \cdot 10^{16}$	m^2	Majority carriers
HOPG	Fermi level position	12	meV	Bottom of c-band
HOPG	Smallest gap	2	meV	Detected by breakdown
HOPG	Electron-phonon coupling	0.021(2)	k/\hbar	Approximate value
HOPG	Hole-phonon coupling	0.006(1)	k/\hbar	Approximate value
HOPG	e-temperature coefficient	$1.84(6) \cdot 10^{22}$	K^{-1}	Three-carrier model
HOPG	h-temperature coefficient	$1.1(1) \cdot 10^{22}$	K^{-1}	Three-carrier model
HOPG	e-athermal scattering freq.	$2.1(2) \cdot 10^{11}$	Hz	ZYB grade MR&Hall
HOPG	h-athermal scattering freq.	$2.5(2) \cdot 10^{11}$	Hz	ZYB grade MR&Hall
HOPG	Dingle temperature	5	K	Average (ZYB grade) from ShdH
CNT	Magnetoresistance	13	%	Random, 1.8 K, 5 T
CNT	Effective magneton	25	μ_B	Transverse at 1.8 K
CNT	2D band parameter	3	eV	Hopping integral
CNT	Free electron density	$3 \cdot 10^{-5}$	el/atom	At 1.8 K
CNT	Athermal relax. time	100	fs	Ensemble average

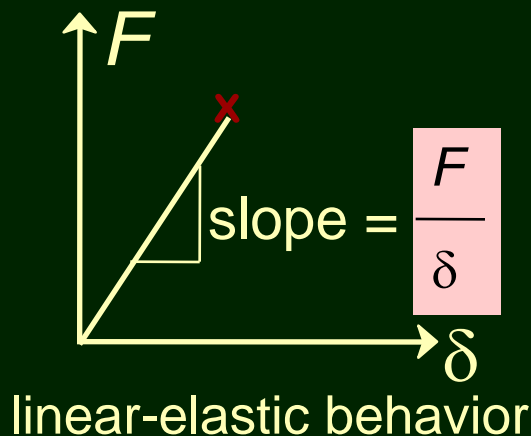
For reference only. Not required for the examination.

Measuring Elastic Modulus

- Room T behavior is usually elastic, with brittle failure.
- 3-Point Bend Testing often used.
 - tensile tests are difficult for brittle materials.



- Determine elastic modulus according to:

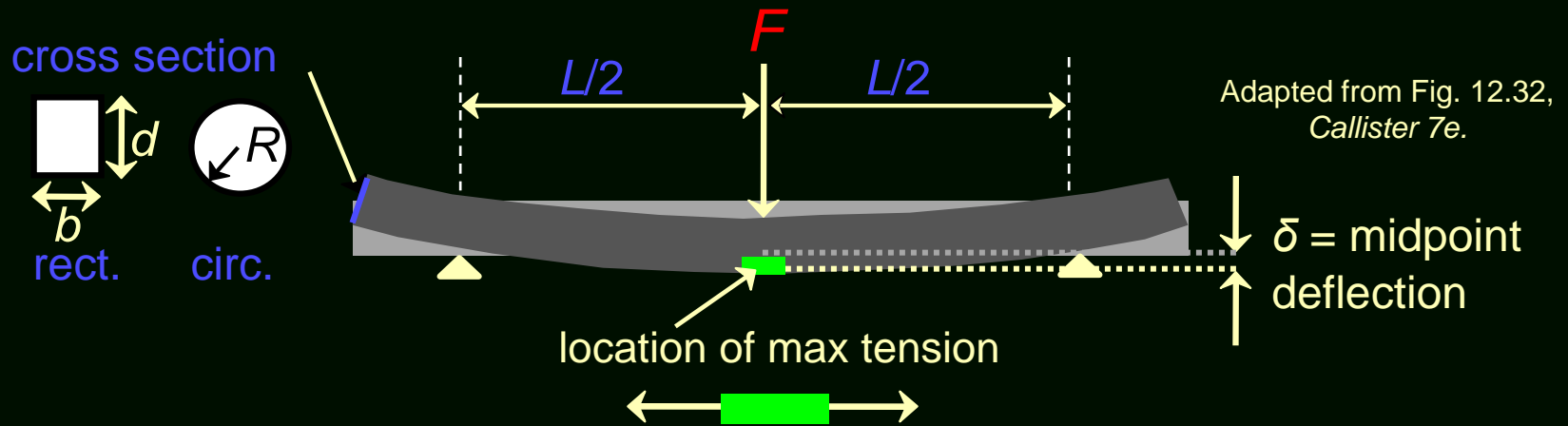


$$E = \frac{F}{\delta} \frac{L^3}{4bd^3} = \frac{F}{\delta} \frac{L^3}{12\pi R^4}$$

	F	L^3		F	L^3
	δ	$4bd^3$	=	δ	$12\pi R^4$
	rect. cross section			circ. cross section	

Measuring Strength

- 3-point bend test to measure room T strength.



- Flexural strength:

$$\sigma_{fs} = \frac{1.5F_f L}{bd^2 \text{ rect.}} = \frac{F_f L}{\pi R^3}$$

- Typical values:

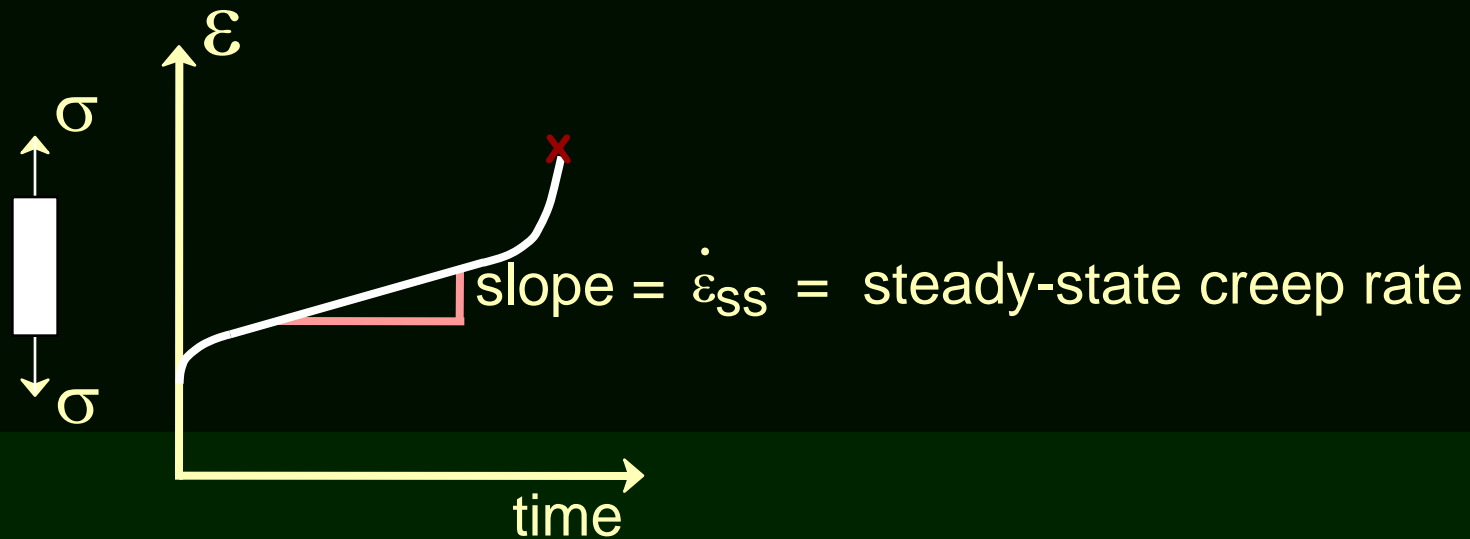
Material	σ_{fs} (MPa)	E (GPa)
Si nitride	250-1000	304
Si carbide	100-820	345
Al oxide	275-700	393
glass (soda)	69	69

Data from Table 12.5, Callister 7e.

Measuring Elevated T Response

- Elevated Temperature Tensile Test ($T > 0.4 T_m$).

creep test



- Machinable ceramics are typically not well -performing at very high temperatures
- Implications on glassy state materials (long-term performance)

Summary of Ceramics

- Ceramic materials have covalent & ionic bonding.
- Structures are based on:
 - charge neutrality
 - maximizing # of nearest oppositely charged neighbors.
- Structures may be predicted based on:
 - ratio of the cation and anion radii.
- Defects
 - must preserve charge neutrality
 - have a concentration that varies exponentially with T .
- Room T mechanical response is elastic, but fracture is brittle, with negligible deformation.
- Elevated T creep properties are generally superior to those of metals (and polymers).