MAT 214: Processing and Properties of Ceramic Materials

Introduction to Ceramic Materials

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Materials Science and Engineering

Lehigh University

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Learning Objectives

- Understand the difference classes of materials. What makes a ceramic a ceramic?

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- Understanding of the diverse types of properties that ceramics can exhibit
- Appreciation for applications and growth opportunities for ceramic materials and industries

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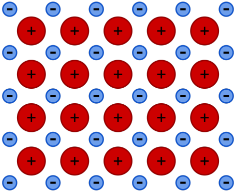
Semiconductors, composites, and biomaterials are defined by their properties

Metals



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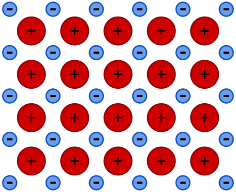

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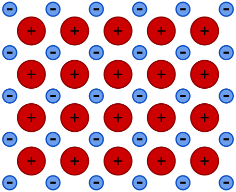

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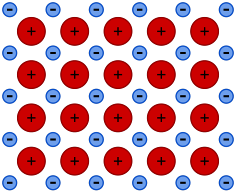

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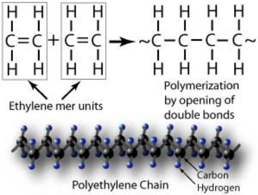
- Metallic bonding allows for closed-packed crystal structures that permit plastic deformation

Polymers



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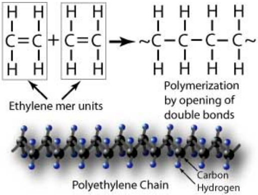

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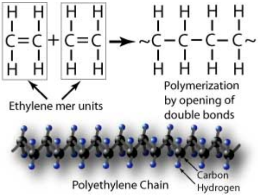

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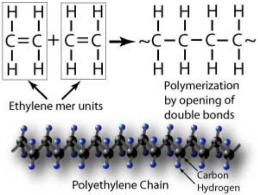

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- Many of the plastics that we are familiar with are actually combinations of polymers and often include fillers and other additives to give the desired properties and appearance

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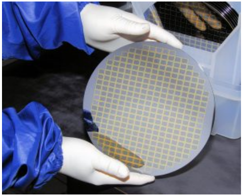
Most solid materials that are not metal, plastic, or derived from plants or animals are ceramics

Semiconductors



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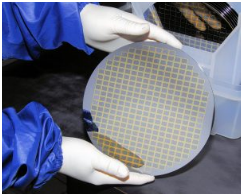

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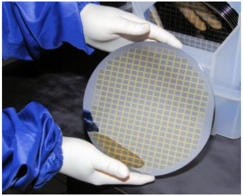

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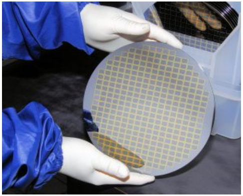

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- The conductivity is strongly dependent upon the presence of small amounts of impurities
- Classically, semiconductors have been limited to materials with a band gap $< 3eV$, but there is growing commercial interest in large band gap semiconductors for high-temperature electronics.

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- It is quite common to have ceramic composites

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- Glasses live in a gray area - it is really a supercooled liquid

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Ceramics cannot be defined based on their properties

- We can't say "ceramics are brittle" because some can be superplastically deformed and some metals can be more brittle: a rubber hose or banana at 77 K shatters under a hammer

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- We can't say "ceramics are insulators" unless we put a value on the band gap (Eg) where a material is not a semiconductor.
- We can't say "ceramics are poor conductors of heat" because diamond has the highest thermal conductivity of any known material. Porous ceramics have some of the lowest thermal conductivity of any known materials.

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- Most ceramics are brittle at room temperature but not necessarily at elevated temperatures – they can become viscous

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- The mixed oxide $YBa_2Cu_3O_7$ is an HTSC; it has zero resistivity below 92 K

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- Ceramics generally have a low degree of toughness, although combining them in composites can dramatically improve this property

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- Example Pyrex: resistant to many corrosive chemicals, stable at high temperatures (does not soften until 1,100 K),and resistant to thermal shock because of its low coefficient of thermal expansion ($33x10^{-7}K^{-1}$)

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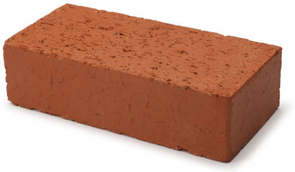
- Glass optical fibers have percent transmission > 96%/km
- "Clearly" not all ceramics are transparent

Traditional Ceramics

High volume items such as bricks, tiles, toilet bowls (whitewares), and pottery



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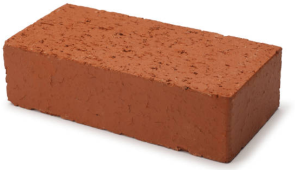
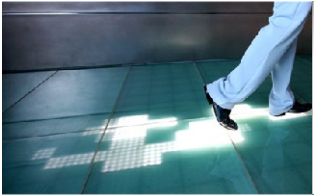
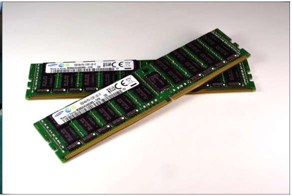


- Generally based on clay or silica
- can require complex processing or tooling

Advanced or Technical Ceramics

Advanced Ceramics Advanced ceramics are newer materials, such as laser host materials, piezoelectric ceramics, and ceramics for dynamic random access memories (DRAMs), among others, which are often produced in small quantities at higher prices.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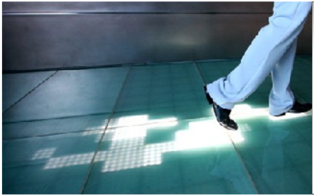
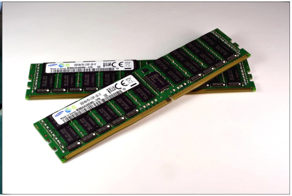



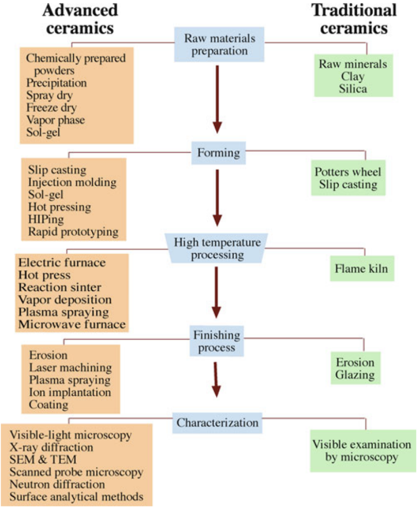

- They exhibit superior mechanical properties, corrosion/oxidation resistance, or electrical, optical and/or magnetic properties.
- Emerged primarily over the last 100 years

Properties and Applications of Ceramics

TABLE 1.1 Properties and Applications for Ceramics

Property	*Example*	*Application*
Electrical	$Bi_2Ru_2O_7$	Conductive component in thick-film resistors
	Doped ZrO_2	Electrolyte in solid-oxide fuel cells
	Indium tin oxide (ITO)	Transparent electrode
	SiC	Furnace elements for resistive heating
	$YBaCuO_7$	Superconducting quantum interference devices (SQUIDs)
	SnO_2	Electrodes for electric glass melting furnaces
Dielectric	α-Al_2O_3	Spark plug insulator
	$PbZr_{0.5}Ti_{0.5}O_3$ (PZT)	Micropumps
	SiO_2	Furnace bricks
	$(Ba,Sr)TiO_3$	Dynamic random access memories (DRAMs)
	Lead magnesium niobate (PMN)	Chip capacitors
Magnetic	γ-Fe_2O_3	Recording tapes
	$Mn_{0.4}Zn_{0.6}Fe_2O_4$	Transformer cores in touch tone telephones
	$BaFe_{12}O_{19}$	Permanent magnets in loudspeakers
	$Y_{2.66}Gd_{0.34}Fe_{4.22}Al_{0.68}Mn_{0.09}O_{12}$	Radar phase shifters
Optical	Doped SiO_2	Optical fibers
	α-Al_2O_3	Transparent envelopes in street lamps
	Doped $ZrSiO_4$	Ceramic colors
	Doped (Zn,Cd)S	Fluorescent screens for electron microscopes
	$Pb_{1-x}La_x(Zr_zTi_{1-z})_{1-x/4}O_3$ (PLZT)	Thin-film optical switches
	Nd doped $Y_3Al_5O_{12}$	Solid state lasers
Mechanical	TiN	Wear-resistant coatings
	SiC	Abrasives for polishing
	Diamond	Cutting tools
	Si_3N_4	Engine components
	Al_2O_3	Hip implants
Thermal	SiO_2	Space shuttle insulation tiles
	Al_2O_3 and AlN	Packages for integrated circuits

Advanced vs. Traditional Ceramics



Overall Market Finances

Ceramics is a multibillion-dollar industry. Worldwide sales are about \$100 billion per year; the U.S. market alone is over \$35 billion annually.

55%	Glass
17%	Advanced ceramics
10%	Whiteware
9%	Porcelain enamel
7%	Refractories
2%	Structural clay

- Bricks and glass, the commodity ceramics have the largest market

Advanced Ceramics

36%	Capacitors/substrates/packages
23%	Other electrical/electronic ceramics
13%	Other
12%	Electrical porcelain
8%	Engineering ceramics
8%	Optical fibers

- More than half of this sector is comprised of electrical and electronic ceramics and ceramic packages

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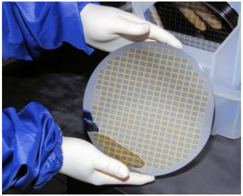
Key Issues

- Reducing the cost of the final product
- Improving reliability
- Improving reproducibility

Electrical Ceramics



- Include barium titanate ($BaTiO_3$), zinc oxide (ZnO), lead zirconate titanate [$Pb(Zr_x Ti_{1-x})O_3$], aluminum nitride (AlN), and high-temperature superconductors

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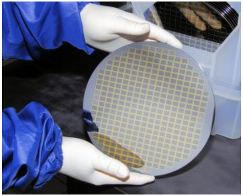

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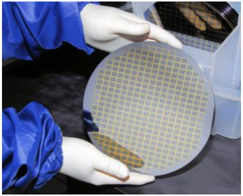
- They are used in applications as diverse as capacitor dielectrics, varistors, micro-electro-mechanical systems (MEMS), substrates, and packages for integrated circuits

Electrical Ceramics



- Include barium titanate ($BaTiO_3$), zinc oxide (ZnO), lead zirconate titanate [$Pb(Zr_x Ti_{1-x})O_3$], aluminum nitride (AlN), and high-temperature superconductors
- They are used in applications as diverse as capacitor dielectrics, varistors, micro-electro-mechanical systems (MEMS), substrates, and packages for integrated circuits

Key Issues

- Integrating with existing semiconductor technology
- Improving processing
- Enhancing compatibility with other materials
- Improved electrical resistivity in thin films

Bioceramics

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Key Issues

- Matching mechanical properties to human tissues
- Enhancing compatibility with other materials
- Improving processing methods and reliability

Coating and Films

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- Thin film properties can be better, the transport properties of thin films of HTSCs, which are improved over the bulk

Key Issues

- Understanding film deposition and growth
- Improving film/substrate adhesion
- Increasing reproducibility

Composites

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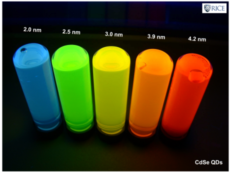
Key Issues

- Reducing processing costs
- Developing compatible combinations of materials (e.g., matching coefficients of thermal expansion)
- Understanding interfaces

Nanoceramics



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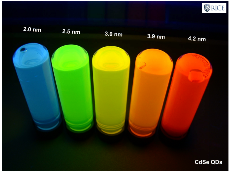

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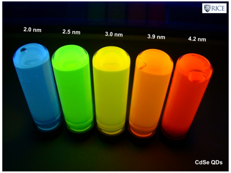

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Key Issues

- Making them
- Integrating them into devices through either top-down or bottom-up approaches
- Ensuring that they do not have a negative impact on society

Important Concepts to Master

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- A working knowledge of what applications ceramic materials are used for. What about their properties makes them useful for these applications?