

# MAT 214: Processing and Properties of Ceramic Materials

Introduction to Ceramic Materials

Prof. Joshua C. Agar

jca318@lehigh.edu

**Materials Science and Engineering**  
**Lehigh University**

January 24, 2022



# 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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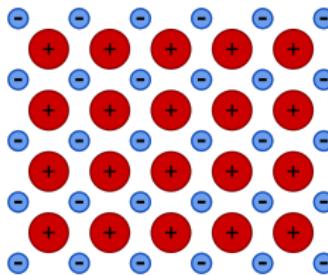
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Semiconductors, composites, and biomaterials are defined by their properties

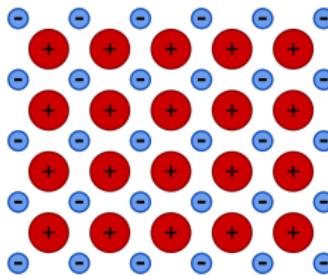


# Metals



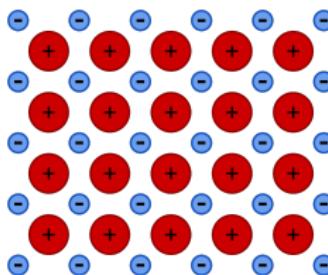
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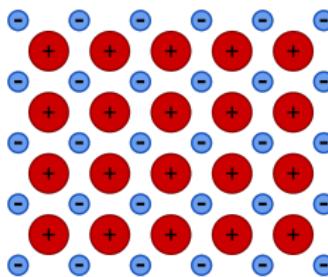
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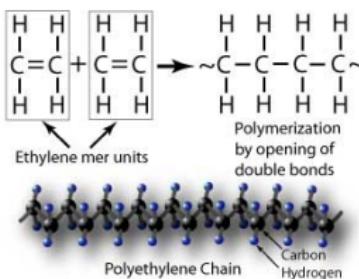
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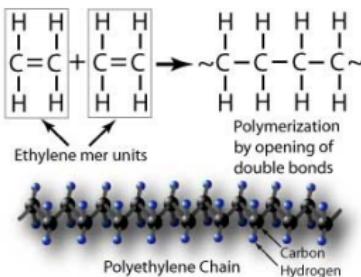
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- Metallic bonding allows for closed-packed crystal structures that permit plastic deformation

# Polymers



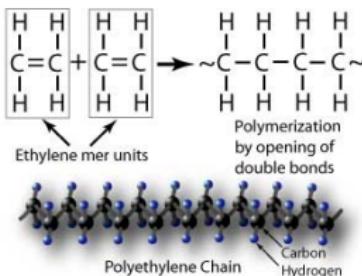
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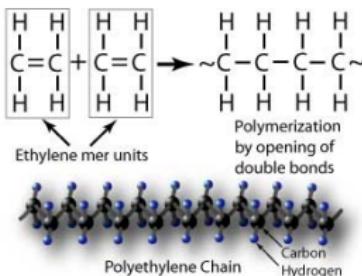
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- Many of the plastics that we are familiar with are actually combinations of polymers and often include fillers and other additives to give the desired properties and appearance

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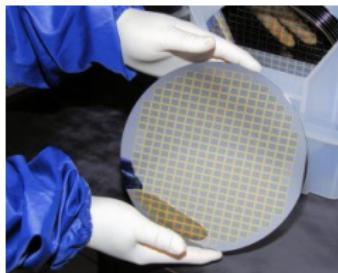
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**Most solid materials that are not metal, plastic, or derived from plants or animals are ceramics**

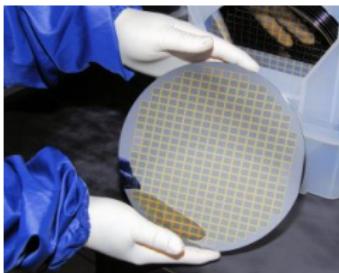


# Semiconductors



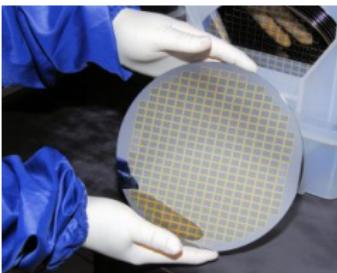
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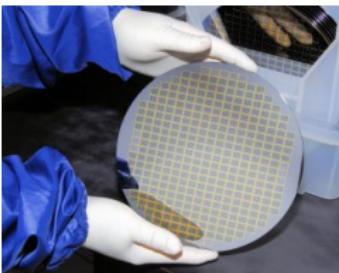
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- The conductivity is strongly dependent upon the presence of small amounts of impurities
- Classically, semiconductors have been limited to materials with a band gap  $< 3\text{eV}$ , but there is growing commercial interest in large band gap semiconductors 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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- We can't say "ceramics are insulators" unless we put a value on the band gap ( $E_g$ ) 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 oxide ceramic  $ReO_3$  has an electrical conductivity at room temperature similar to that of Cu
- 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

# Chemical insensitivity



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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 ( $33 \times 10^{-7} K^{-1}$ )

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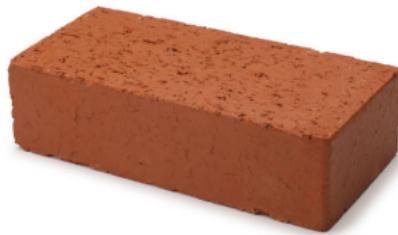
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- Glass optical fibers have percent transmission  $> 96\%/\text{km}$
- "Clearly" not all ceramics are transparent

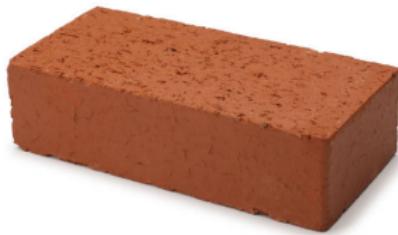
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High volume items such as bricks, tiles, toilet bowls (whitewares), and pottery



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

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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

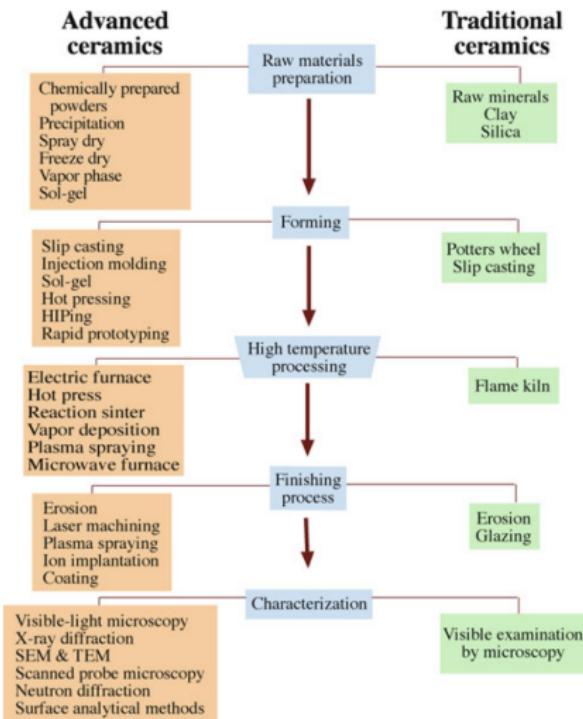
# Properties and Applications of Ceramics

TABLE 1.1 Properties and Applications for Ceramics

Property	Example	Application
Electrical	$\text{Bi}_2\text{Ru}_2\text{O}_7$	Conductive component in thick-film resistors
	Doped $\text{ZrO}_2$	Electrolyte in solid-oxide fuel cells
	Indium tin oxide (ITO)	Transparent electrode
	$\text{SiC}$	Furnace elements for resistive heating
	$\text{YBaCuO}_7$	Superconducting quantum interference devices (SQUIDs)
Dielectric	$\text{SnO}_2$	Electrodes for electric glass melting furnaces
	$\alpha\text{-Al}_2\text{O}_3$	Spark plug insulator
	$\text{PbZr}_{0.5}\text{Ti}_{0.5}\text{O}_3$ (PZT)	Micropumps
	$\text{SiO}_2$	Furnace bricks
	$(\text{Ba}, \text{Sr})\text{TiO}_3$	Dynamic random access memories (DRAMs)
Magnetic	Lead magnesium niobate (PMN)	Chip capacitors
	$\gamma\text{-Fe}_2\text{O}_3$	Recording tapes
	$\text{Mn}_{0.4}\text{Zn}_{0.6}\text{Fe}_2\text{O}_4$	Transformer cores in touch tone telephones
	$\text{BaFe}_{12}\text{O}_{19}$	Permanent magnets in loudspeakers
Optical	$\text{Y}_{2.66}\text{Gd}_{0.34}\text{Fe}_{4.22}\text{Al}_{0.68}\text{Mn}_{0.09}\text{O}_{12}$	Radar phase shifters
	Doped $\text{SiO}_2$	Optical fibers
	$\alpha\text{-Al}_2\text{O}_3$	Transparent envelopes in street lamps
	Doped $\text{ZrSiO}_4$	Ceramic colors
	Doped $(\text{Zn}, \text{Cd})\text{S}$	Fluorescent screens for electron microscopes
Mechanical	$\text{Pb}_{1-x}\text{La}_x(\text{Zr}_z\text{Ti}_{1-z})_{1-x/4}\text{O}_3$ (PLZT)	Thin-film optical switches
	Nd doped $\text{Y}_3\text{Al}_5\text{O}_{12}$	Solid state lasers
	TiN	Wear-resistant coatings
	SiC	Abrasives for polishing
	Diamond	Cutting tools
Thermal	$\text{Si}_3\text{N}_4$	Engine components
	$\text{Al}_2\text{O}_3$	Hip implants
	$\text{SiO}_2$	Space shuttle insulation tiles
	$\text{Al}_2\text{O}_3$ and AlIN	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.

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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

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

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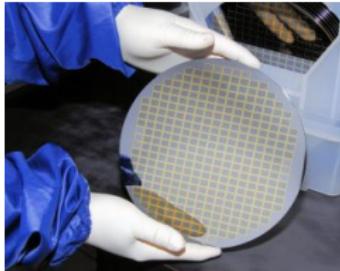


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## Key Issues

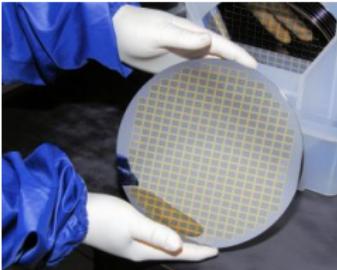
- Reducing the cost of the final product
- Improving reliability
- Improving reproducibility

# Electrical Ceramics



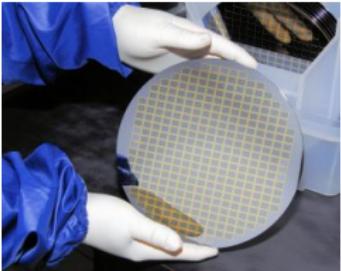
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- Integrating with existing semiconductor technology
- Improving processing
- Enhancing compatibility with other materials
- Improved electrical resistivity in thin films

# Bioceramics



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- Nearly inert bioceramics include alumina ( $Al_2O_3$ ) and zirconia ( $ZrO_2$ )

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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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- Economic reasons: Apply a coating of an expensive material on a lower cost substrate rather than make the component entirely from the more expensive material → An example is applying a diamond coating on a cutting tool
- 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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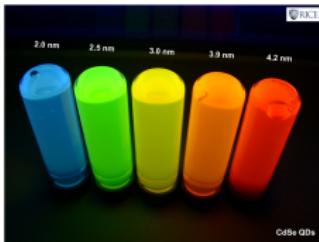


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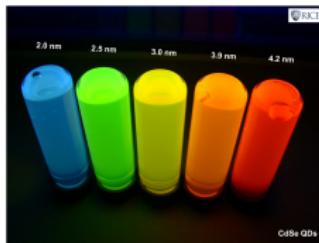
- Reducing processing costs
- Developing compatible combinations of materials (e.g., matching coefficients of thermal expansion)
- Understanding interfaces

# Nanoceramics



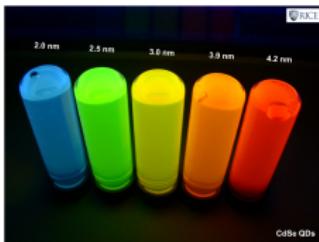
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## Key Issues

- 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

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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?

