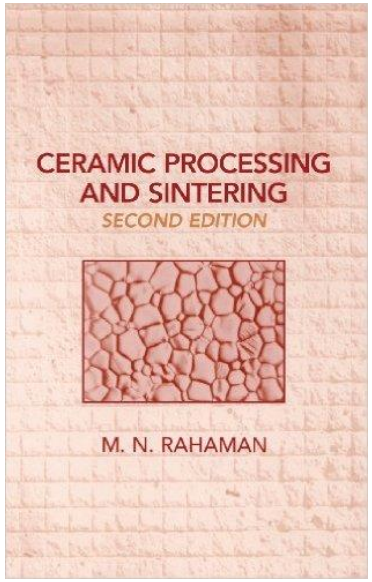
Ceramic Processing
1 Introduction

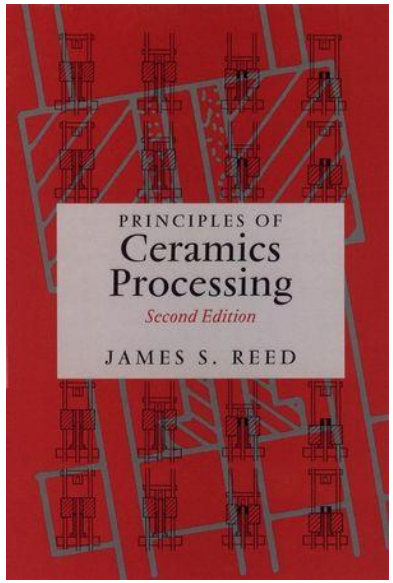
Course Information & Policy

❑ **Zhe Cheng**

❑ **Textbooks & Other References**

- **Textbook:**
  Ceramic Processing and Sintering, M. N. Rahaman, 2nd edition, CRC Press (2003), ISBN 0-8247-0988-8
- Principles of Ceramic Processing, James S. Reed, 2nd edition, Wiley (1995) ISBN 0-471-59721-X.
- Classnotes





More about Dr. Zhe Cheng

- **Education & Experiences:**
  - PhD in Materials Science & Engineering, Georgia Tech, 2008
  - Research scientist, DuPont, Wilmington DE, 2008-2013
- **Research group website**

  https://scholar.google.com/citations?hl=en&user=-3eZMkQAAAAJ

Course Website

- Course Website

Course Policy

❑Policy

- Students can discuss homework problems, but must independently finish it
- Grade discrepancies – resolve in the same day
- Homework will be collected
- Accommodate “make-up” quiz, tests, or delayed term paper if proven medical necessity
- Accommodate disability and religious holidays
- NO cheating or plagiarizing in ANY form (Check with me if questions)
  - No excuses will be accepted
  - Will be reported and handled according to policy

Exams & Grading - Graduate

- **Quiz (20%)**
- **Homework (30%)**
- **"Mini research proposal" (50%)**
- **Grading Scale**
  - A:>=90; A-:87-89.9;
  - B+:84-86.9; B:80-83.9; B-:77-79.9;
  - C+:74-76.9; C:70-73.9; C-: <67-69.9;
  - D: 60-66.9;
  - F: <60

Exams & Grading - Undergraduate

- **Quiz (20%)**
- **Homework (30%)**
- **"Mini term paper" (20%)**
- **Final project (30%)**
- **Grading Scale**
  - A:>=90; A-:87-89.9;
  - B+:84-86.9; B:80-83.9; B-:77-79.9;
  - C+:74-76.9; C:70-73.9; C-: <67-69.9;
  - D: 60-66.9;
  - F: <60

Course Objective & Outcome

❑Objectives

- Introduce scientific principles and engineering practices of conventional as well as new, unconventional processing techniques for technical ceramics and glass materials

❑Related Program Outcomes

a) Ability to apply knowledge of mathematics, science, and engineering

e) Ability to identify, formulate, and solve engineering problems

g) Ability to communicate effectively

i) Recognition of the need for, and a ability to engage in life-long learning

k) Ability to use the techniques, skills and modern engineering science necessary for engineering

What are Ceramics?

- https://en.wikipedia.org/wiki/Ceramic

"A ceramic is an **inorganic**, **nonmetallic** **solid** material comprising metal, nonmetal or metalloid atoms primarily held in ionic and covalent bonds"

- W. D. Kingery et al., *Introduction to Ceramics* (1976), p. 3

"We define ceramics as the art and science of making and using **solid** articles which have as their essential components, and are composed in large part of, **inorganic** **nonmetallic** materials"

- M. N. Rahaman, *Ceramic Processing & Sintering* (2003), p. 1

"Chemically, *with the exception of carbon*, ceramics are **non-metallic**, **inorganic** **compounds**"

- M. D. Barsoum, *Fundamentals of Ceramics* (2003), p. 2

"**Solid** **compounds** that are formed by the application of heat, and sometimes heat and pressure, comprising at least two elements provided one of them is **a non-metal or nonmetallic elemental solid**. The other element(s) may be a metal(s) or another nonmetallic elemental solid(s)."

- W. D. Callister, *Materials Science & Engineering – An Introduction* (2010), p. 6

"Ceramics are **compounds** **between metallic and nonmetallic elements**"

Traditional Ceramics & Glass

❑Examples

Stone/Mineral



http://www.granitecountertops.net/

http://www.gettyimages.com/detail/photo/stone-statue-of-the-people-republic-of-high-res-stock-photography/128039733

http://www.neobits.com/vwr_89037_496_caseof5_vwr_mortars_and_pestles_p4152098.html?atc=gbp&gclid=CNKn6vq89MYCFdUUHwodTzEDkg

Pottery or Porcelain



https://en.wikipedia.org/wiki/Porcelain

http://mfg.regionaldirectory.us/pottery/

http://www.linea-aqua.com/shop/LineaAqua-Caraway-One-Piece-Siphonic-Toilet-28-x-15-x-30-Luxury-White-Porcelain-Toilet-with-S-Trap-and-Soft-Closing-Seat-pr-17486.html

Glass (bulk)



http://www.rainbow-rental.com/party/dinnerware/

http://www.theculturemap.com/colourful-buildings-street-art-reykjavik-iceland/stained-glass-window-church-reykjavik/

https://talkingarchitecture.files.wordpress.com/2012/03/glass-building.jpg

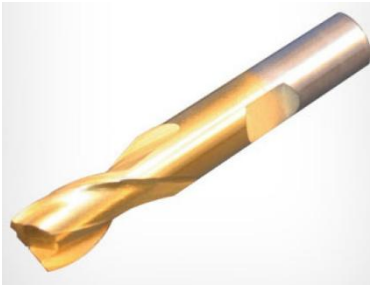
Glaze/Enamel (glass layer)

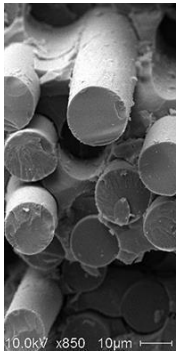

https://www.qualitylogoproducts.com/custom-mugs/enamel-ceramic-mug-17-oz-superextralarge-383936.jpg

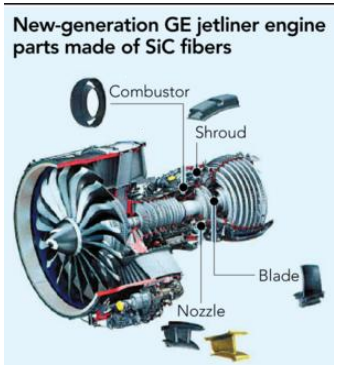
http://www.ganoksin.com/borisat/nenam/ajm-metals_under_fire.htm

Structural Ceramics - Mechanical

Mechanical Properties & Applications	Examples
High hardness - cutting, grinding, polishing, armor…	c-BN, B_4C, SiC, Si_3N_4, WC…
Low hardness - lubrication, fillers	Talc, MoS_2, Graphite…
Low toughness (Brittle)	Glass, Most ceramics…
Higher toughness – bearings, engine parts	MAX phase (Ti_3SiC_2), Si_3N_4, toughened ZrO_2
High modulus	C or SiC fibers







http://vercomaterialsllc.com/gallery/

https://www.ngkntk.co.jp/english/product/cutting_tools/cubic_boron_nitride.html

http://www.intelcoatings.com/product/titanium-nitride/

http://www.chemodex.co.uk/product/mos2-molybdenum-disulphide-dry-film-lubricant/

https://www.gcferrules.com/ecommerce/product/164/

ceramics.org/wp-content/uploads/2013/03/bulletin042013_maxphases.pdf

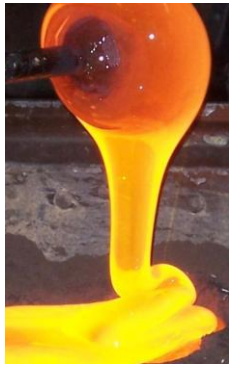
https://www.lily-bearing.com/ceramic-bearings/zirconia-bearings/

https://asia.nikkei.com/Business/SiC-fibers-find-their-way-into-aircraft-engines

https://www.compositesworld.com/articles/ceramic-matrix-composites-heat-up

Structural Ceramics - Thermal

Thermal Properties & Applications	Examples
Low thermal conductivity - Thermal barrier or insulation material	Al_2O_3, SiO_2, ZrO_2, …
High thermal conductivity - Heat sink for electronics	AlN; diamond…
High melting point - Refractories	Al_2O_3, SiO_2, SiC, ZrB_2, HfC…
Low melting point	Glass (frit); Salts…



http://www.trymaxgroup.com/enquiry-form-10019.htm?product_slno=1343015

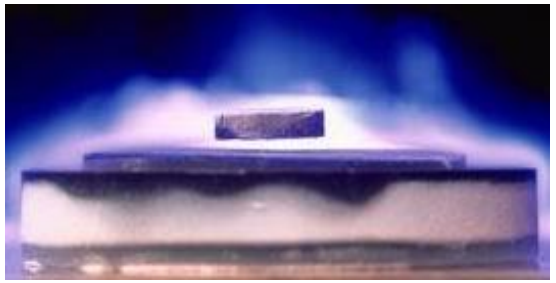
https://www.outotec.com/company/newsletters/smelting-newsletter/smelting-issue-2--2016/refractory-lining-materials-testing/

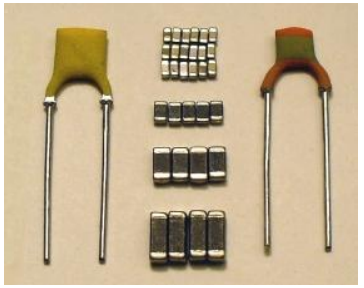
https://www.ceramtec.com/ceramcool/design/

https://www.pinterest.com/pin/294845106829758796

Functional Ceramics - Electronic

Electrical Property & Applications	Examples
Superconductor – NMR analysis, power generation	$YBa_2Cu_4O_{7-x}$, MgB_2…
Metallic conductor – Thick film conductor	TiC, ZrB_2, Ti_3SiC_2, RuO_2, $SrVO_3$, …
Semiconductor – Solar cell, transparent conductor	GaAs, $CuIn_{1-x}Ga_xSe_2$ (CIGS), CdTe, ZnO…
Ionic conductor - Sensors; fuel cells	Y_2O_3-stabilized ZrO_2, AgI…
Mixed conductor (electrodes; catalysts)	$La_{0.5}Sr_{0.5}Co_{0.2}Fe_{0.8}O_3$, $Ce_{1-x}Gd_xO_{2-\delta}$…
Insulator – Electrical insulation	Al_2O_3, SiO_2, MgO…
Piezoelectric/Ferroelectric - capacitor; actuators	$BaTiO_3$, $PbTiO_3$…





Science Photo Library

https://www.solarpowerworldonline.com/2016/05/advantages-flexible-cigs-thin-film-solar-modules/

https://www.likra.nl/index.php?l=_en&id=7&c=58

https://www.tradeindia.com/fp3032293/Electrical-Insulator.html

https://en.wikipedia.org/wiki/Ceramic_capacitor

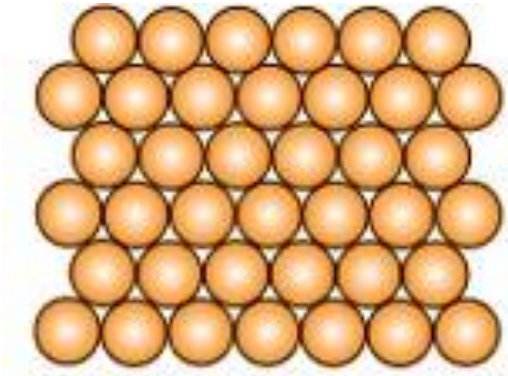
Functional Ceramics - Others

Function	Property & Application	Examples
Magnetic	Ferromagnetic	Fe_3O_4…
	Parromagnetic	Most other
Nuclear	Fuel	UO_2…
	Shield	B_4C…
Optical	Transparent	Al_2O_3 (sapphire), SiO_2 (quartz), many glasses…
	Black	RuO_2, graphite,
	Colored	Doped Al_2O_3, Cr_2O_3, NiO…
	Isotropic	Glass
	Anisotropic	Single crystals
	Special	Laser applications

Atomic-Scale Structure of Ceramics

- **Atomic-scale structure**

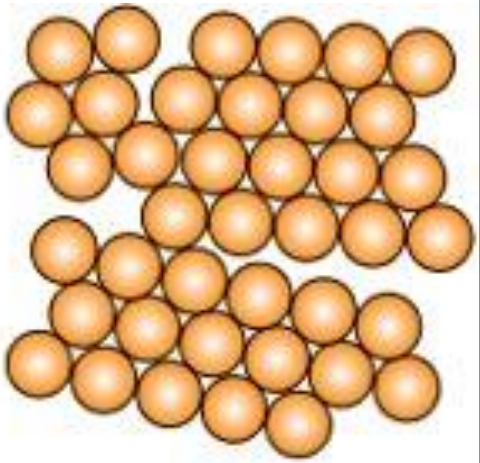
(Single) Crystalline



https://en.wikipedia.org/wiki/Cubic_zirconia

Special applications (e.g., gems, optical parts, semiconductor wafers)

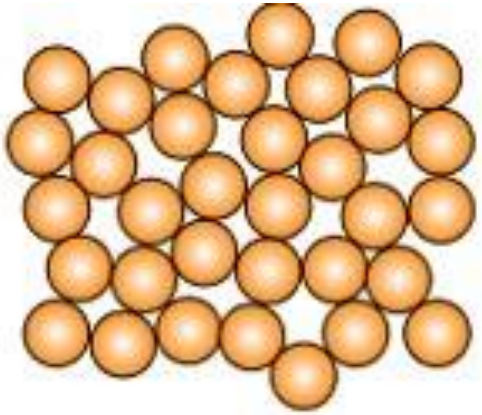
Polycrystalline



http://www.physicscentral.com/explore/action/safer-glass.cfm

most ceramics

Amorphous/Glassy



http://www.physicscentral.com/explore/action/safer-glass.cfm

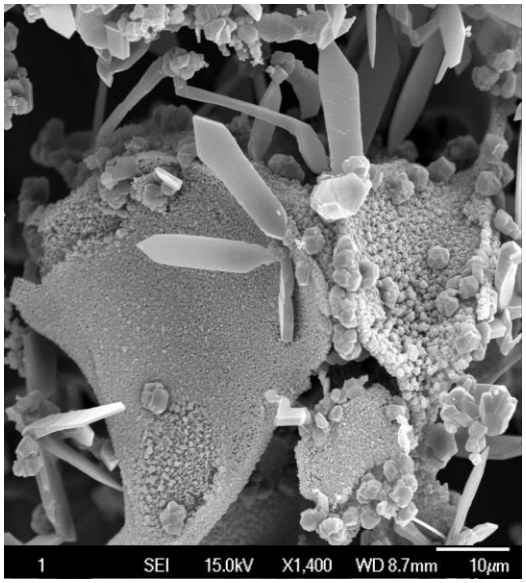
http://photos.oregonlive.com/photo-essay/2013/03/bennu_glass_in_kalama_produces.html

Glass (containers, building, optical or chemical parts)

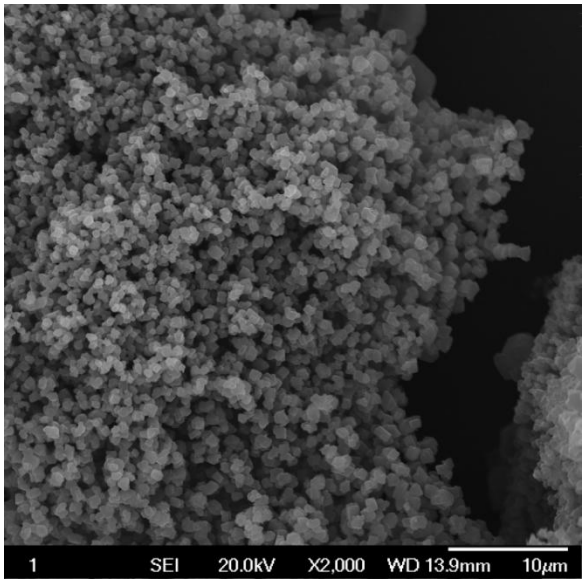
Microstructure of Ceramics

B_4C powder synthesized, SEM by Paniz Foroughi

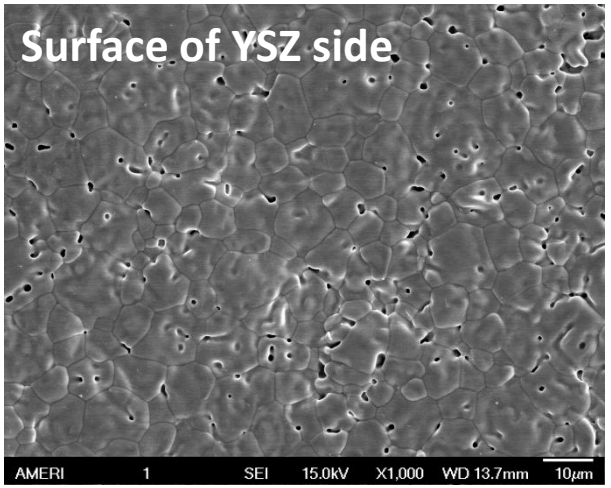
1450 °C/3 hour, tube furnace

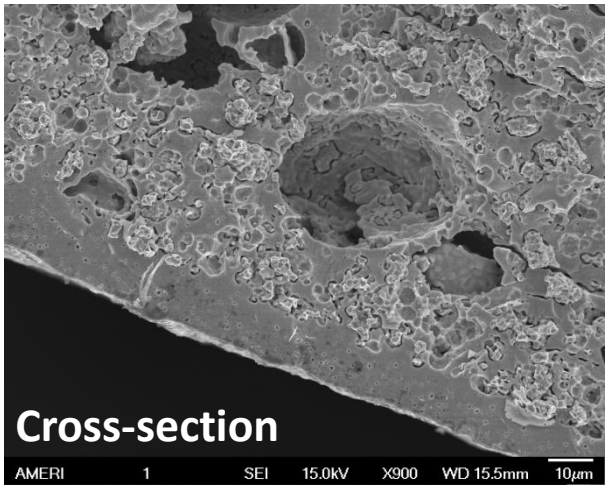


1750 °C/3 min, microtube reactor



NiO-YSZ/YSZ bilayer co-sintered
SEM by Shichen Sun





❑Microstructure

- **Grain** features: size, shape, distribution
- **Pore** features: size, shape, distribution
- **Other**: uniformity, impurity phases…

Ceramic Processing

- **Processing of ceramic materials into useful form/part**
- **Primary approach: solid powders (mostly) into a ceramic body/part**
- **Alternatives**
  - Liquid processing
    - Single crystal growth (from high-purity melt)
    - Melt casting (typically for glass processing)
  - Liquid precursor processing
    - Sol-gel
    - Polymer pyrolysis (via pre-ceramic polymers)
  - Gas precursor processing
    - Chemical vapor deposition (CVD)
    - Other (e.g., ALD)
  - Others
    - Solid transfer: sputtering, physical vapor deposition (PVD), pulsed laser deposition (PLD);
    - Reaction bonding/Directed metal oxidation

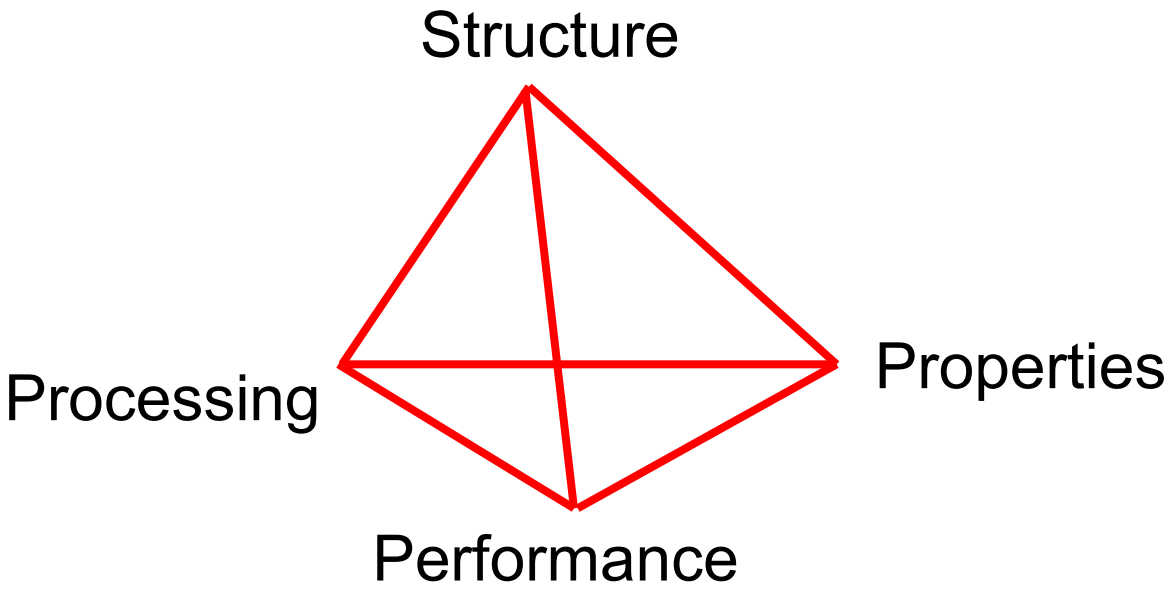
http://photos.oregonlive.com/photo-essay/2013/03/bennu_glass_in_kalama_produces.html

http://www.canaanpack.com/colloidal-silicasilica-sol/

https://www.mtixtl.com/Compact4CVDFurnace-OTF-1200X-4-NW-UL.aspx

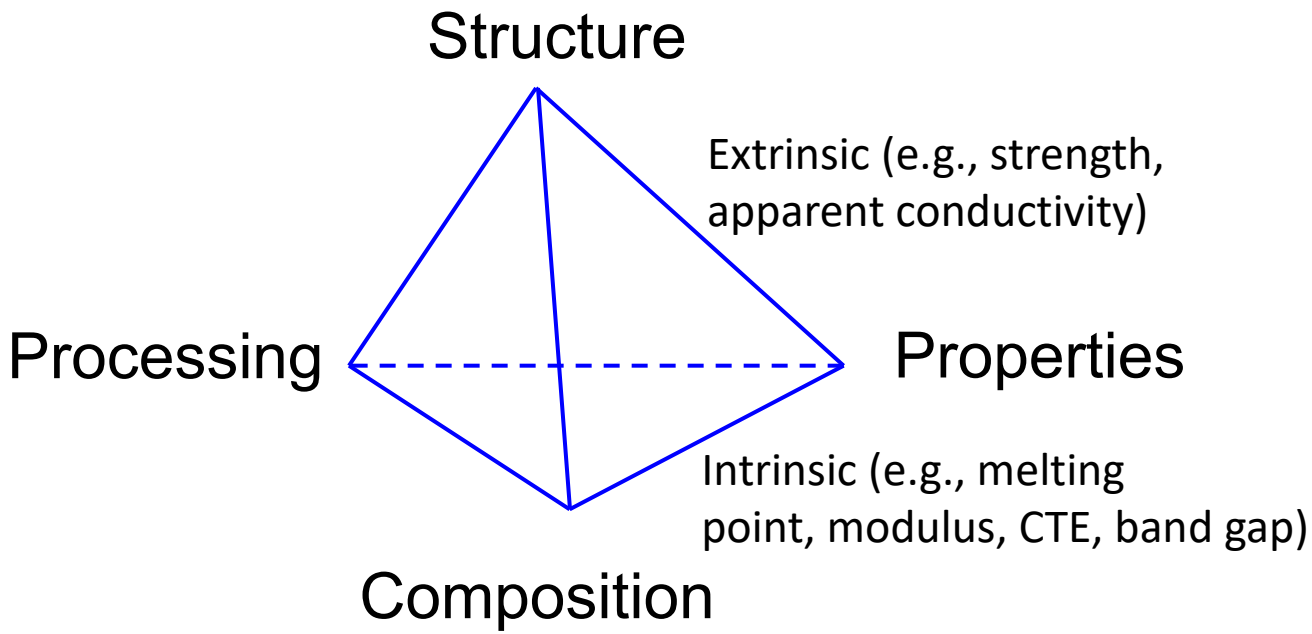
Conventional "Materials Tetrahedron"

- Basic aspects of materials engineering & their inter-relationships



Alternative "Materials Tetrahedron" (2)

- **Alternative version**



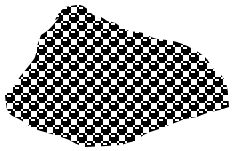
Overview of Ceramic Processing from Powder

❑ **Ceramic powder(s) → dense, bonded polycrystalline ceramic parts**

Powder processing
(milling and/or other treatments)

Mixing and green body formation
(e.g., dry pressing or slip casting)

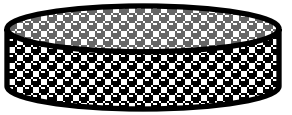
Ceramic powders



http://www.unitednuclear.com/extract.htm

http://www.ebay.co.uk/itm/20mm-Diameter-ID-Pellet-Press-Steel-Dry-Pressing-Die-Set-Mold-/200438956668

Green body



Sintered ceramic body

- **Control of microstructures via processing is critical**
- **Microstructural defects in green body will NOT be healed by firing/sintering**

Firing/Sintering

Topics & Planned Schedule

1. Introduction (week 1)
2. Powder synthesis and processing (week 2-3)
3. Ceramics (powder) characterization (week 4-6)
4. Additives in ceramic processing (week 7)
5. Colloidal processing (week 8-10)
6. Other green body formation including (week 11-12)
7. Heat treatment for ceramics (week 13-14)
8. Post firing processing and other ceramic/glass processing (if time allows)

Mini Research Proposal - Graduates Only

Identify a particular ceramic material, or a ceramic-based composite, or ceramic-based simple device of your (research) interest, do some research, and write a **mini research proposal** about that material/device with particular focus on:

1. Why the material/device is of interest and important
2. How is it typically processed including common features and variations
3. What are the unanswered questions or remaining challenges concerning its processing
4. What are your hypothesized solution and experimental plan to prove/disprove your solution
5. Literature search results (if any) or theoretical analysis to show your plan/solution is promising

- **1 page (excluding references), single space, Times New Roman 10-point font size**
- **50 points towards overall grade**
  - 1st draft (5 points), 2nd draft (10 points), final version (25 points)
  - Review feedbacks to "mini research proposal" by peer students (5 points)
  - Response/rebuttal to peer review feedbacks (5 points)

Mini Term Paper – Undergraduates Only

Identify a particular ceramic material, or a ceramic-based composite, or a ceramic-based device of your interest, do some research/literature review, and write a **half-page (≤250 words)** mini-term paper about that material/device with particular focus on:

1. Why that material/composite/device is of particular interest to you,
2. How it is typically processed including common features and important processing parameters,
3. What is one unanswered question and/or remaining challenges concerning its processing that interest you or need to be resolved

- **Format: half page (up to 250 words, excluding references), single space, Times New Roman 10 point font**
- **Topic must be approved by Dr. Cheng before writing/submission.**

NO Plagiarism

- **NO plagiarism in any form**
- **Common forms of plagiarism**
  - Use without citation
    - Verbatim, i.e., word-for-word
    - Paraphrase
      - "Kate has a cute little cat" →
      - "The girl owns a lovely kitten"

    } **Plagiarism if no proper citation!**

  - Excessive use - NO matter citation or not
    - Entire paper
    - Paragraphs
    - Large sections - multiple sentences)
- **Additional resources**