EMA5646
Ceramic Processing
1 Introduction

FIU FLORIDA INTERNATIONAL UNIVERSITY

Course Information & Policy

❑Zhe Cheng

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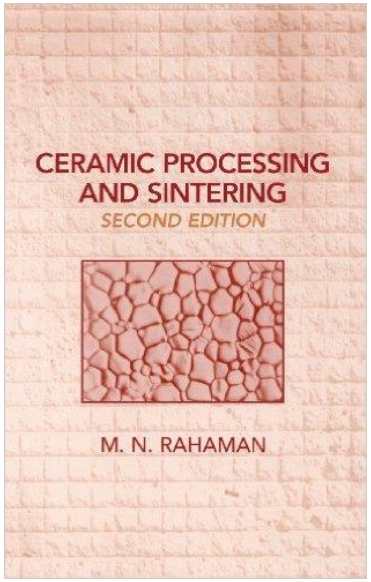
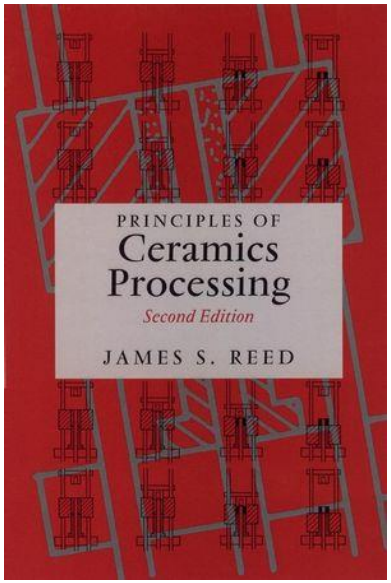
- Class: EC1110, M W F 10-10:50
- Office hour: EC3172, W, F 11-13

❑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





Course Policy

❑Policy

- Attendance required
- 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 (http://drc.fiu.edu/) 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 FIU policy

Exams & Grading

- **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+: 64-66.9; D: 60-63.9; D-: 57.0-59.9;
  - F: <57

Course Objective & Outcome

❑Objectives

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

❑Related MME 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 is 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)

http://image.dhgate.com/albu_503998390_00/1.0x0.jpg

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

Advanced Ceramics - Structural Ceramics

Function	Property & Application	Examples
Mechanical	High hardness and modulus for cutting/grinding/polishing/armor…	c-BN, B_4C, SiC, Si_3N_4, WC…
	Low hardness for lubrication, fillers	Talc, MoS_2, graphite (?)…
	Low toughness (Brittle)	Glass, Most ceramics…
	High toughness ("Tougher")	MAX phase (Ti_3SiC_2), Si_3N_4, toughened ZrO_2
Thermal	Low thermal conductivity (Thermal barrier/insulation material)	Al_2O_3, SiO_2…
	High thermal conductivity (Heat sink)	AlN; diamond (?)
	High melting point (Refractories)	Al_2O_3, SiO_2, SiC, ZrB_2, HfC…
	Low melting point	Glass; Salts…

Advanced Ceramics - Functional Ceramics(1)

Function	Property & Application	Examples
Electrical	Superconductor	$YBa_2Cu_4O_{7-x}$, MgB_2…
	Metallic conductor	TiC, ZrB_2, $SrVO_3$, Ti_3SiC_2…
	Semiconductor	GaAs, $CuIn_{1-x}Ga_xSe_2$ (CIGS), CdTe, ZnO…
	Insulator	Al_2O_3, SiO_2, MgO…
	Piezoelectric/Ferroelectric (capacitor; actuators)	$BaTiO_3$, $PbTiO_3$…
	Electronic conductor	$SrVO_3$, RuO_2…
	Ionic conductor (sensors; fuel cells)	Y_2O_3-stabilized ZrO_2, AgI…
	Mixed conductor (electrodes; catalysts)	$La_{0.5}Sr_{0.5}Co_{0.2}Fe_{0.8}O_3$; $Ce_{1-x}Gd_xO_{2-\delta}$…

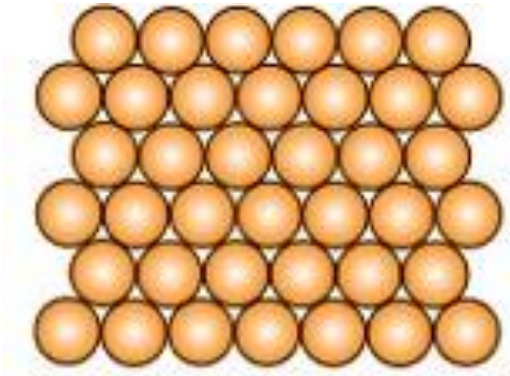
Advanced Ceramics - Functional Ceramics (2)

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), glass…
	Black	RuO_2
	Colored	Doped Al_2O_3, Cr_2O_3, NiO…
	Isotropic	Glass
	Anisotropic	Single crystal

Atomic-Scale Structure of Ceramics

- **Atomic-scale structure**

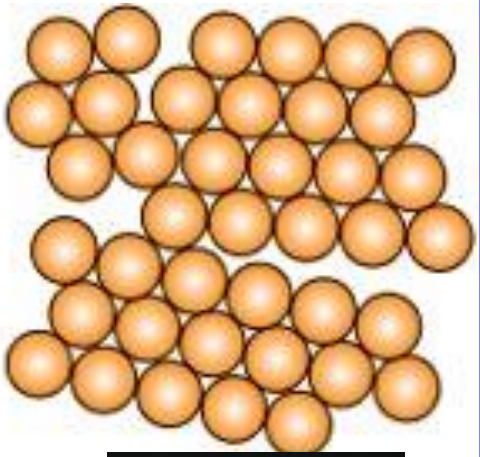
(Single) Crystalline



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

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

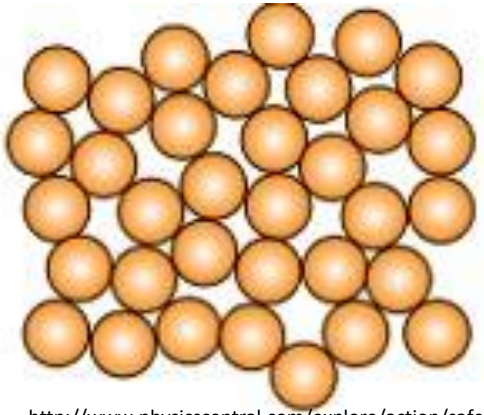
Polycrystalline



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

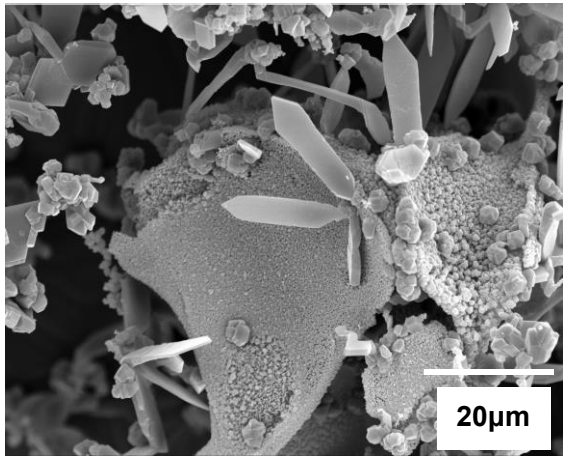
Glass

Microstructure of Ceramics

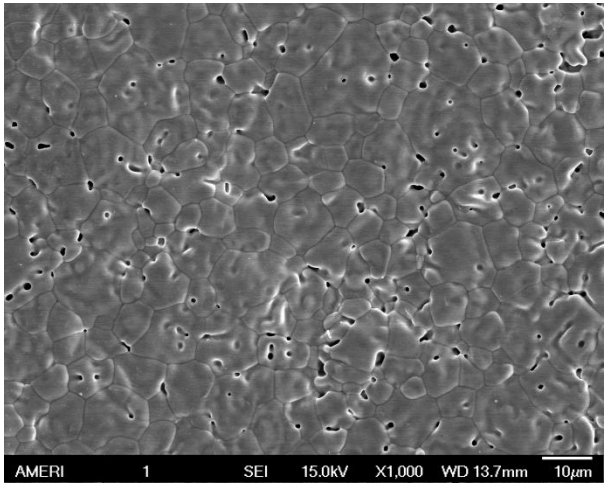
❑Microstructure

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

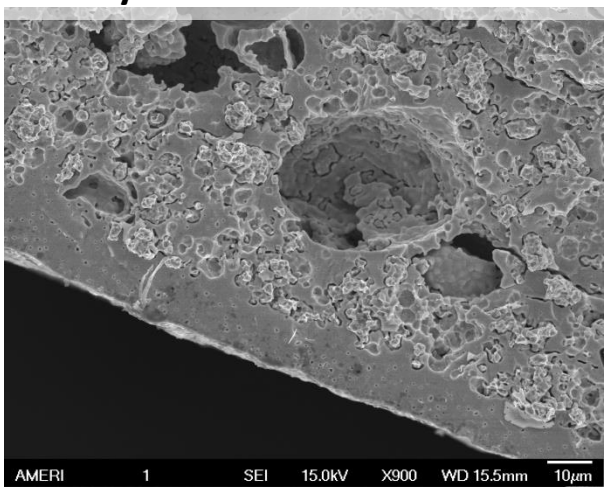
B_4C synthesized
SEM by Paniz Foroughi



NiO-YSZ/YSZ bilayer co-sintered
Surface of YSZ side
SEM by Shichen Sun



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

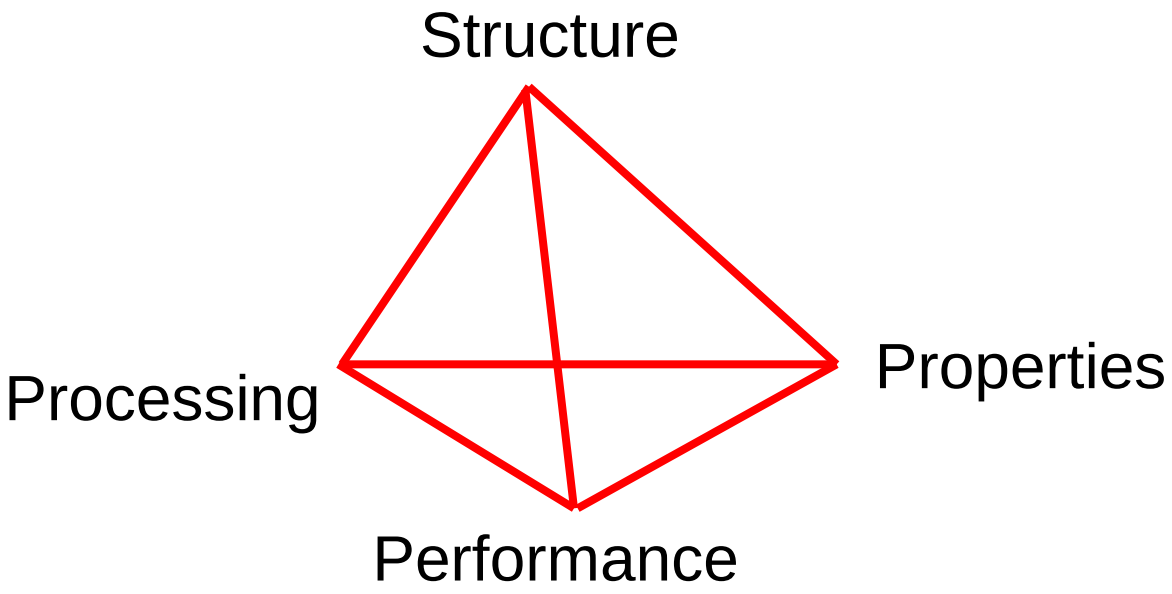


Ceramic Processing

- **Process or manufacturing of ceramic materials into useful form/body**
- **Primary approach**
  - Solid powder processing
- **Alternative approaches**
  - Liquid processing
    - Single crystal growth
    - Melt casting (typically for glass processing)
  - Liquid precursor processing
    - Sol-gel
    - Polymer pyrolysis (via pre-ceramic polymers)
  - Gas precursor processing
    - Chemical vapor deposition (CVD, various form)
    - Other (e.g., ALD)
  - Others
    - Solid transfer: sputtering, physical vapor deposition (PVD), pulsed laser deposition (PLD);
    - Reaction bonding/Directed metal oxidation
    - …

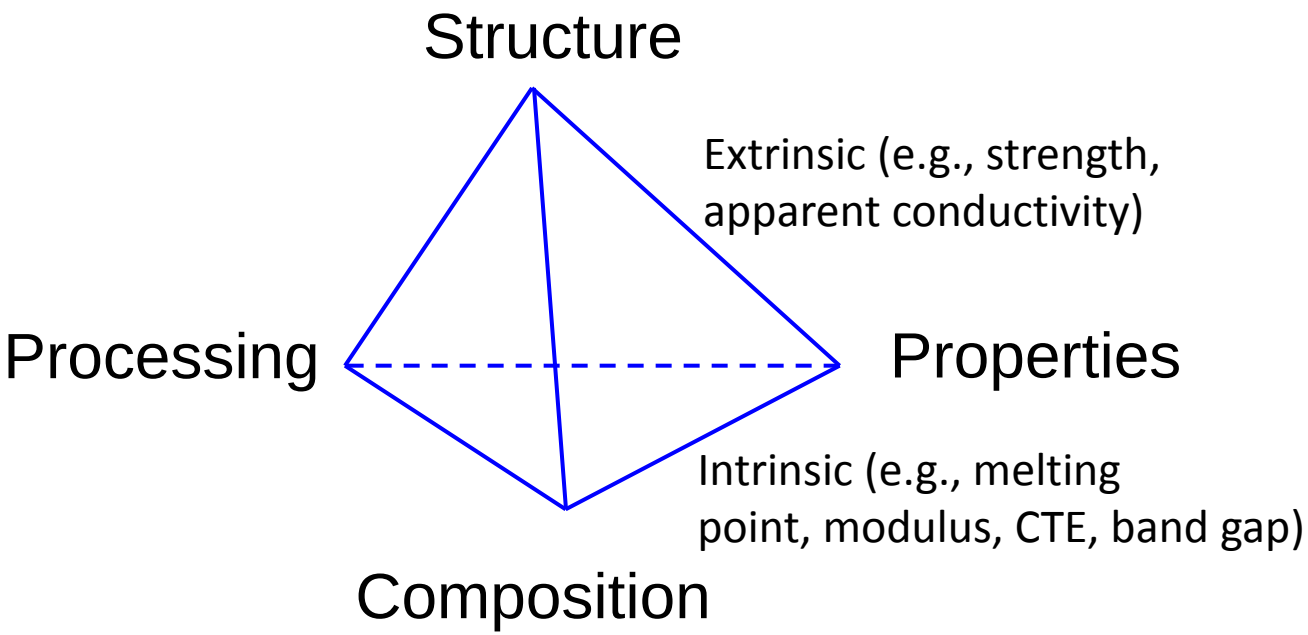
Conventional "Materials Tetrahedron"

- Basic aspects of materials engineering & their inter-relationships



Alternative "Materials Tetrahedron" (2)

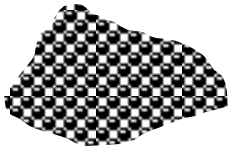
- **Alternative version**



Overview of Ceramic Processing via Powder

- **Processing of solid ceramic powders into relatively dense, bonded polycrystalline ceramic products via heat treatment**

Ceramic powders



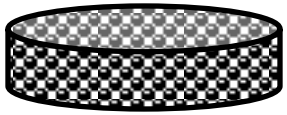
Powder processing
(milling and/or other treatments)

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

Mixing and consolidation
(e.g., dry pressing)

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

Green body



Sintered ceramic body

Firing

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

Topics & Planned Schedule

- ❑Particle synthesis, processing, and characterization (week ~1-3)
- ❑Additives in ceramic processing (week ~4)
- ❑Green body formation (week ~5-6)
- ❑Heat treatment for ceramics (week ~7-10)
- ❑Post firing processing (week ~11)
- ❑Processing of glass (week ~12-13)
- ❑Other ceramic processing (week ~14-15)

Term Paper

- **Description**

  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: i) why that material/device is of interest to you, ii) how it is typically processed from powder into useful form including common features and variations, iii) what are the unanswered questions and/or remaining challenges concerning its processing, and iv) what are your hypothesized solution and detailed experimental plan to prove/disprove your solution; v) preliminary results you have collected/literature search results to show your plan/solution is feasible

- **3 page (excluding references), single space, 10-12 point font size,**
- **50 points towards overall grade**
  - 1st draft due Oct 7, 2015 (5 points)
  - 2nd draft due Nov 4, 2015 (10 points)
  - Final version due Dec 4, 2015 (20 points)
  - Review feedbacks to “mini research proposal” by peer students (10 points)
  - Response/rebuttal to peer review feedbacks (5 points)

NO Plagiarism

- **NO plagiarism in any form**
- **Common form of plagiarism**
  - Use without citation
    - Word for word
    - Paraphrase
  - Excessive use (no matter citation or not)
- **Additional resources**
  - FIU

http://education.fiu.edu/plagiarism/index.htm
http://libguides.fiu.edu/plagiarism