

CH5716

Processing of Materials

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Lecture MC1 – Introduction, Background
& Context of Ceramic Processing

Module Structure

16 Lecture Course

8 x Green Processing

8 x Synthesis & Thermal Processing (Firing & Sintering)

1 x practical Sessions*

2x Tutorials (one MC one JTSI)*

Introduction, Background & Context of Ceramic Processing

Bulk Ceramic Processing

Thin Film Processing

Thick Film Processing

Slurry Formation

Slurry Characterisation

Tape Casting

Screen Printing

Application of Processing to Device Design and Fabrication

(controlling microstructure)

Location : 10 am Thur & Fri: Seminar Room 3 Gateway
 Wks 7 & 8 Wed 9am Med Sci Build. Tutorial Rm 6

Assessment : 2hr Examination*

* UG only

Course Aims

- Develop an understanding of various aspects of materials processing and how these influence the final form of the material or device.
- Concentrate on ceramics processing for thick and thin film devices with a focus on the former

Today's Objectives

- Outline the history of the subject
- Put ceramic processing into a general context
- Review some examples of device architectures & microstructures from thick film processes

Course Scope

- It is not a magic wand which will solve all your process woes
- Nor an exhaustive Treatise on Materials Processing
 - The whole subject covers a massive area
 - We can only scratch the surface
 - Focus on 1-2 pertinent techniques
- Why Ceramic & Thick Film processing?
 - Being used in many cutting edge technologies and applications
 - Electronics, Energy, High Temp Materials & Coatings, Medical
 - Not well covered in text books

To process ceramics well, you need to *understand the process fundamentals*, try to *maintain best practice* as much as possible and *make well considered adjustments* to the system to get the best results.

- We aim to provide a background and foundation of the processes
 - Give you a basic vocabulary to understand other practitioners and guides
- You will need to build further knowledge on to this
 - Ceramics processing is a skill
 - Requires training and practice to master

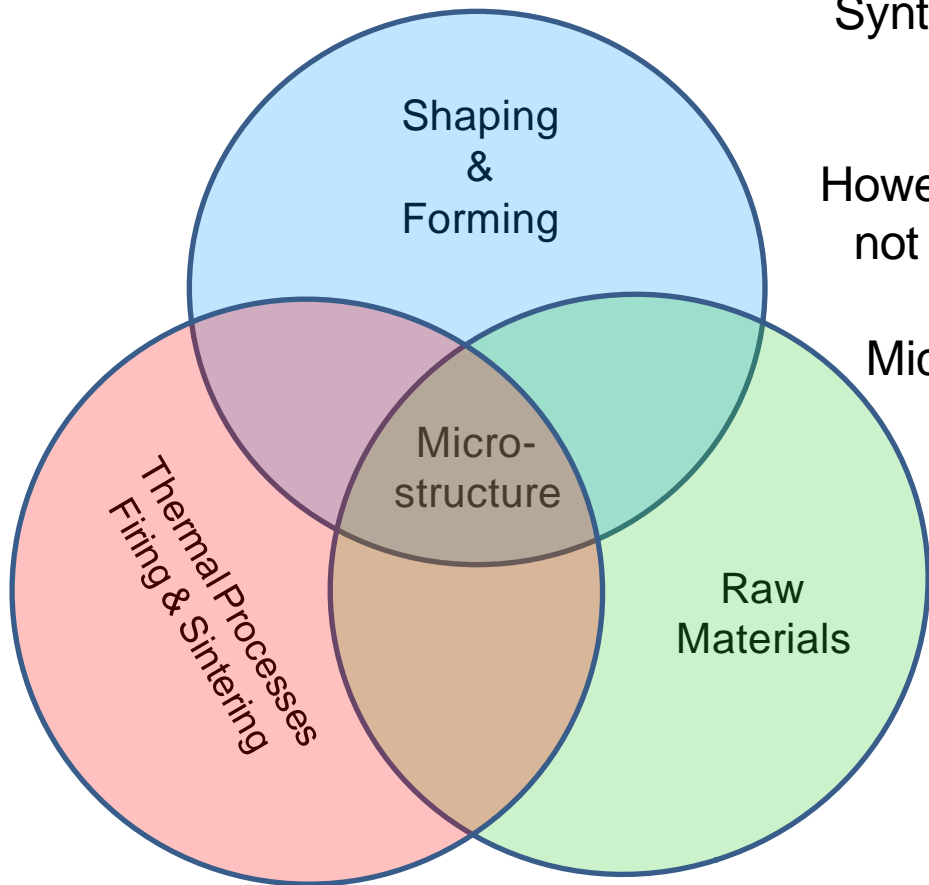
Why Bother with Processing?

Main focus of ceramics courses
is often solid state chemistry

Synthesis & characterisation of new materials
often focus of ceramics research

However performance of any material function
not only composition but also Microstructure

Microstructure determined in large part by
Processing



A Little History

Ceramics the oldest of any materials technology
Use of stone tools goes back around 2 million years

Oldest “fired” clays have been dated ~25,000 years
Baked clay figurines – Dolni Vestonice, Czech Republic

Evidence of pottery production appears ~10,000 yrs ago
Mainly bonfire and pit firing

First time humans have manipulated chemical structure of a material for function

Proper kilns appear certainly by 2000BC possibly earlier

As these are refined temperatures increase and glasses begin to appear.

Slow development continues over the next 1500 years both in Mediterranean, Middle East & China

This became the basis of traditional ceramics as a craft based institution which continued for many centuries

Industrial Revolution

- 18th Century marked a turning point in ceramics manufacturing
 - At the beginning craft based organisation
 - By the end, one of the first large scale manufacturing industries & a significant factor in the industrial revolution
- Several sites developed in parallel
 - Vincennes – France
 - Meissen – Germany
 - Staffordshire – England
- Spurred by several factors
 - Improved scientific understanding – emergence of chemistry
 - Improved transportation – opened up wider and larger markets
- Attracted several entrepreneurs and engineers
- In particular Josiah Wedgwood (Stoke-on-Trent)
 - Development of factory systems
 - Subdivision of the process in separate steps
 - Understanding importance of systematic approach to process control
- Beginnings of modern process engineering



Josiah Wedgwood
1730-1795

Technical Ceramics

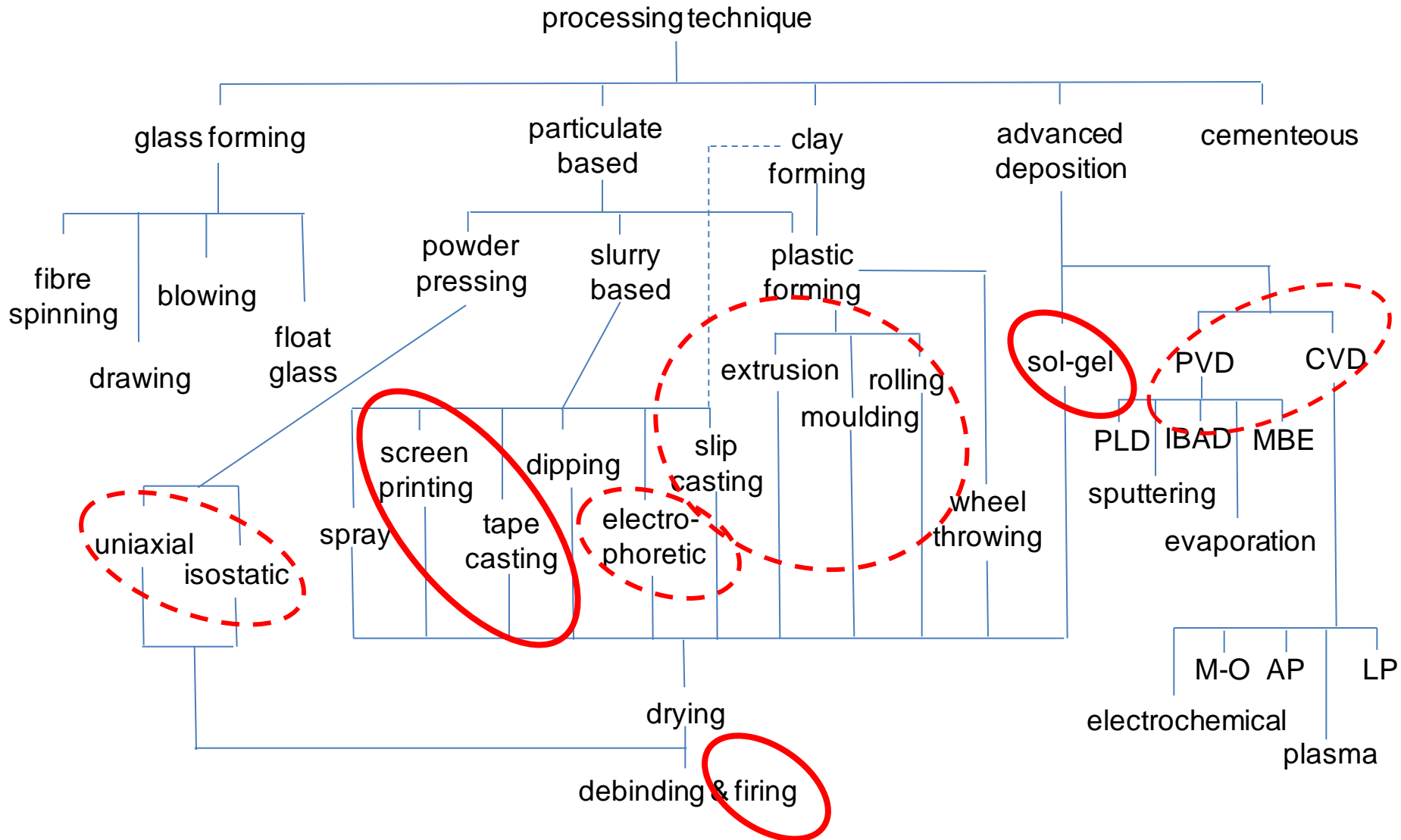
- For most of its history ceramics processing very much an empirical endeavour
 - Processes occurring during ceramics manufacture complex and not well understood
- A lot rested on experience of the practitioner – *The Dark Arts*
- As 20th Century progressed large improvements in analytical capability occurred
 - XRD, SEM, TEM – chemical, structural, imaging data
 - DTA, TGA, DSC, PSA, Dilatometry SSA, important analysis of process changes
- Allowed quantification of changes taking place during process steps
- Spurred developments in ceramic science and process developments
 - Improved synthesis leading to high purity, engineered stoichiometries
 - New boom in technically exact ceramic materials
 - Engineering of specific defects in structure or composition for functionality
- Still a relatively new branch of the subject - but has many applications
 - Electronics
 - Energy
 - Biotech
 - Many more

Research continues while great progress has been made in understanding ceramics there is much that is still not clear – The empirical nature of process continues to be a strong influence in process development

Some Technical Ceramic Applications

<i>Property</i>	<i>Example</i>	<i>Application</i>
Electrical	Bi ₂ Ru ₂ O ₇ Doped ZrO ₂ Indium tin oxide (ITO) SiC YBaCuO ₇	Conductive component in thick-film resistors Electrolyte in solid-oxide fuel cells Transparent electrode Furnace elements for resistive heating Superconducting quantum interference devices (SQUIDs)
	SnO ₂	Electrodes for electric glass melting furnaces
Dielectric	α-Al ₂ O ₃ PbZr _{0.5} Ti _{0.5} O ₃ (PZT) SiO ₂ (Ba,Sr)TiO ₃ Lead magnesium niobate (PMN)	Spark plug insulator Micropumps Furnace bricks Dynamic random access memories (DRAMs) Chip capacitors
	Magnetic	γ-Fe ₂ O ₃ Mn _{0.4} Zn _{0.6} Fe ₂ O ₄ BaFe ₁₂ O ₁₉ Y _{2.66} Gd _{0.34} Fe _{4.22} Al _{0.68} Mn _{0.09} O ₁₂
Optical		Doped SiO ₂ α-Al ₂ O ₃ Doped ZrSiO ₄ Doped (Zn,Cd)S Pb _{1-x} La _x (Zr ₂ Ti _{1-z}) _{1-x/4} O ₃ (PLZT) Nd doped Y ₃ Al ₅ O ₁₂
	Mechanical	TiN SiC Diamond Si ₃ N ₄ Al ₂ O ₃
Thermal		SiO ₂ Al ₂ O ₃ and AlN Lithium-aluminosilicate glass ceramics Pyrex glass

Ceramic Processing



Requirements for Mass Manufacture

Any potential manufacturing route must be capable of *high volume, affordable* production with a *high performance*.

Production techniques must therefore

- **Scalable**
- **Minimise costs**
 - Capital
 - Running
 - Infrastructure
- **Reproducible, Reliable, High Quality**
- **Minimise environmental impact**
- **Exhibit scope for process improvement /development**

Linking Research to Industry

- Always understand the industrial need and how it changes
 - Technology Integration is a key requirement
 - Fit to existing or planned plant growth
- Revolutionary or expensive process needs to justify investment and costs
 - New rather than displacement technology
 - Offer significant operational advantage
 - A Game Changer

e.g. development of ICs and semiconductors offered brand new applications

Fuel cells although offering many advantages must fight to displace existing energy conversion technologies

How does your work fit to the industrial picture?

Effective Process Development

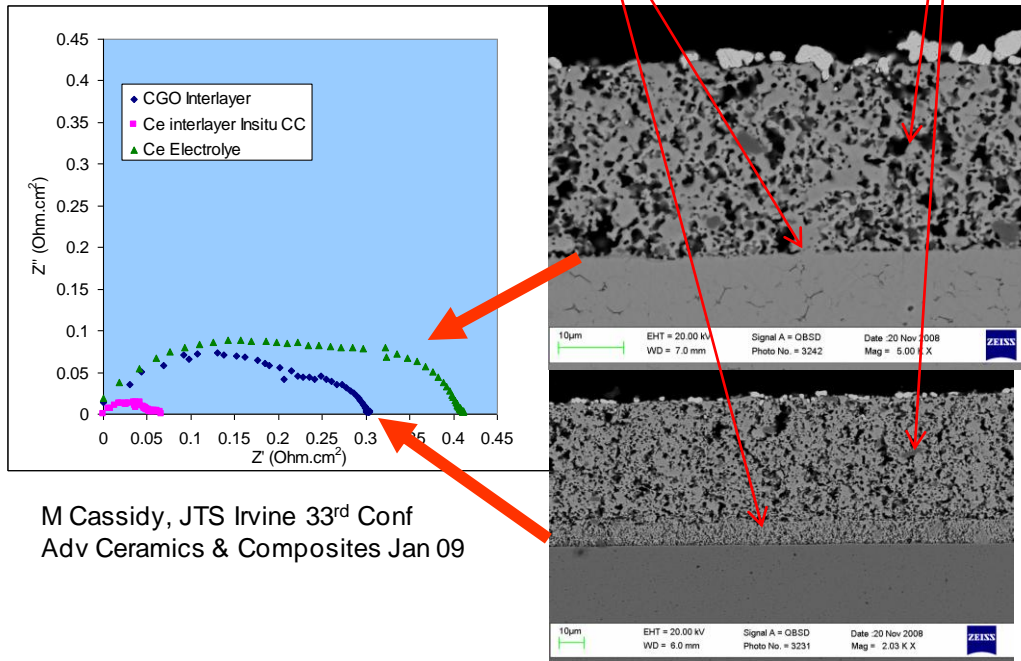
- Process development can be tricky
- Do not underestimate the time it may take
- Begin to think about it sooner rather than later in your research
 - Where does it fit in a project
 - How much effort will you need to spend on this

- Think about both the science and the technology of your processing
 - Understand the background of what you are doing
 - Base any changes on sound judgement of these
- Develop learning from things that do not work – understand why
 - Valuable when writing up and defending your thesis
- Try to avoid a “Home Run” mentality
 - There can be a lot of pressure for fast results
 - Especially in Industrial setting

Engineered Microstructures by Processing

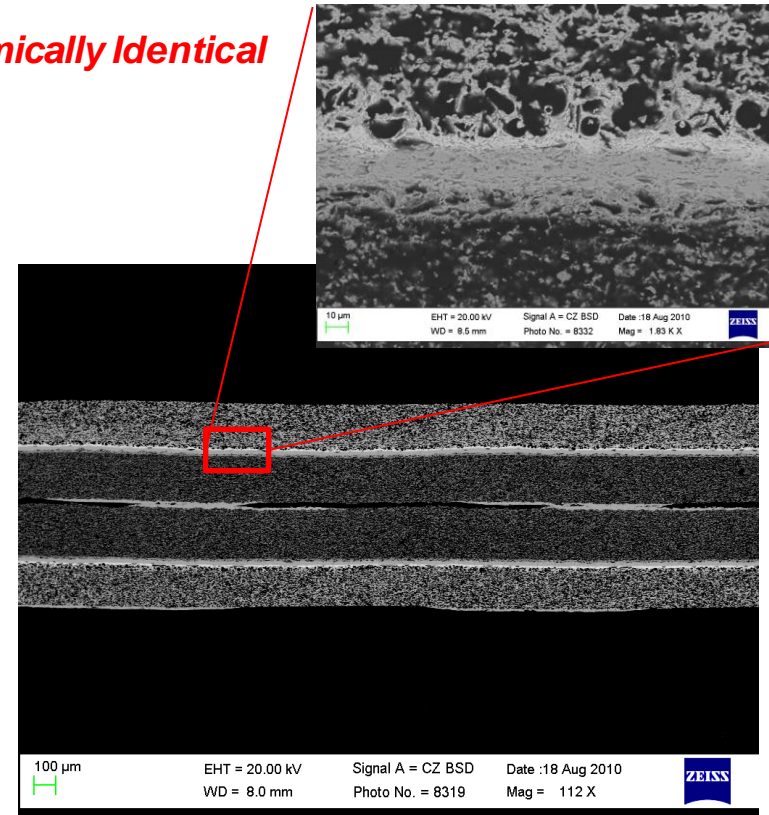
*Only difference in the interface
Is the porosity layer in lower micrograph
Chemically they are the same*

Cathodes Chemically Identical



M Cassidy, JTS Irvine 33rd Conf
Adv Ceramics & Composites Jan 09

*Microstructure of Interface
influencing performance*

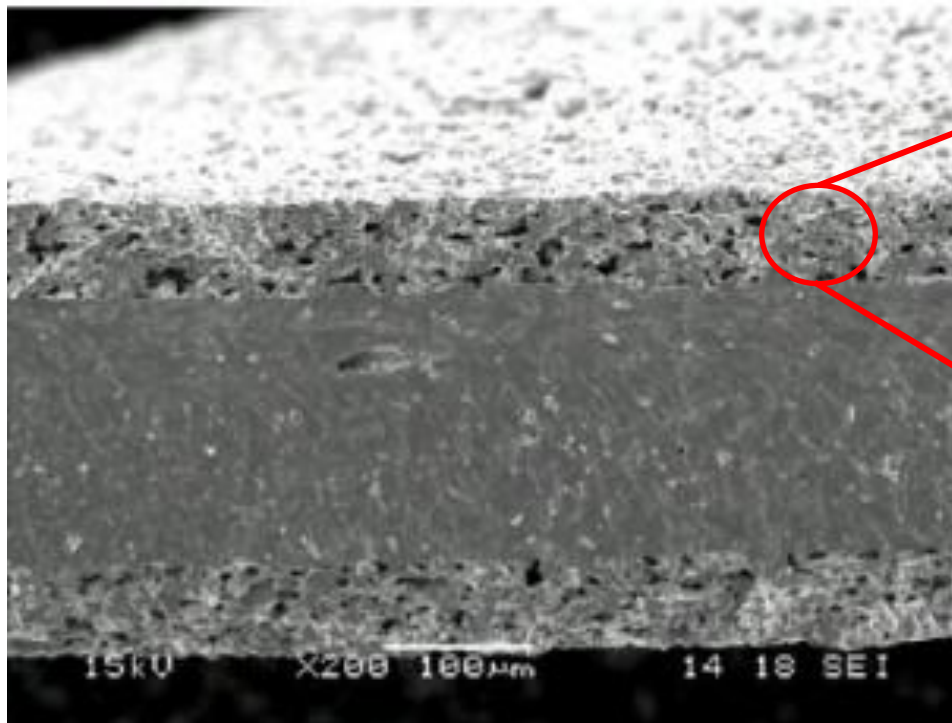


Complex Geometries

Multilayer device by multiple
Tape Casting & Screen Printing.
Also inclusion of channels by
use of fugitive inks.

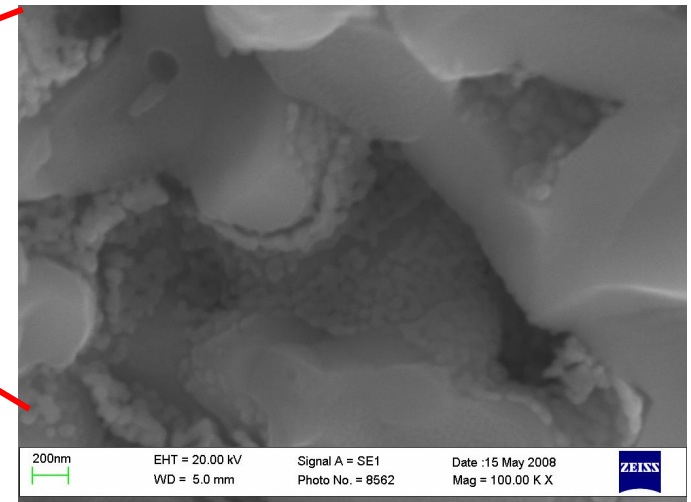
Microstructural control through processing over several length scales

Tape Casting dense & porous zirconia in single structure



Materials co-fired in single step
Different microstructures achieved
control of unfired “green” properties

Infiltration and heat treatment
of catalytic materials



Allows development of
insitu formed catalytic
structures on nanometric
scale

Industrial Tape Casting & Screen Printing



Courtesy Versa Power , Calgary

Reference Materials

Main Texts Used in the Preparation of Lectures

C.B. Carter. M.G. Norton, ***Ceramic Materials Science and Engineering*** Springer Science 2007
- Good general ceramics text, covers many aspects of processing not often found in other works, accessible style and presentation. Reasonably modern.

R.E. Mistler, E.R. Twinaime, ***Tape Casting – Theory and practice***. American Ceramic Society, 2000
- Specialist text on tape casting written by two well respected practitioners. Good practical advice. Much can be transferred to other thick film processes such as printing

Other General Good Sources of Info

W.D. Kingery et.al.. ***Introduction to Ceramics***, Wiley, 1976 (2nd Edition)
- The ceramics bible, major text in the field. Good source of background an many aspects of ceramic science.

W.D. Callister Jr., ***Materials Science and Engineering an Introduction***, Wiley, 1991 (2nd Edition)
- Good general materials texts, mostly metals, but some useful ceramics engineering and technology chapters.

American Ceramics Society (www.ceram.org)- Many specialist texts (through Wiley)
Journal of the American Ceramics Society
International Journal of Applied Ceramic Technology

Wiley – 2 Journals –

Advanced Materials

Advanced Functional Materials

Science Direct (Elsevier) Number of process related Journals

Journal of the European Ceramic Society