Glass Processing

Lecture #15 Glass-ceramics: Nature, properties and processing

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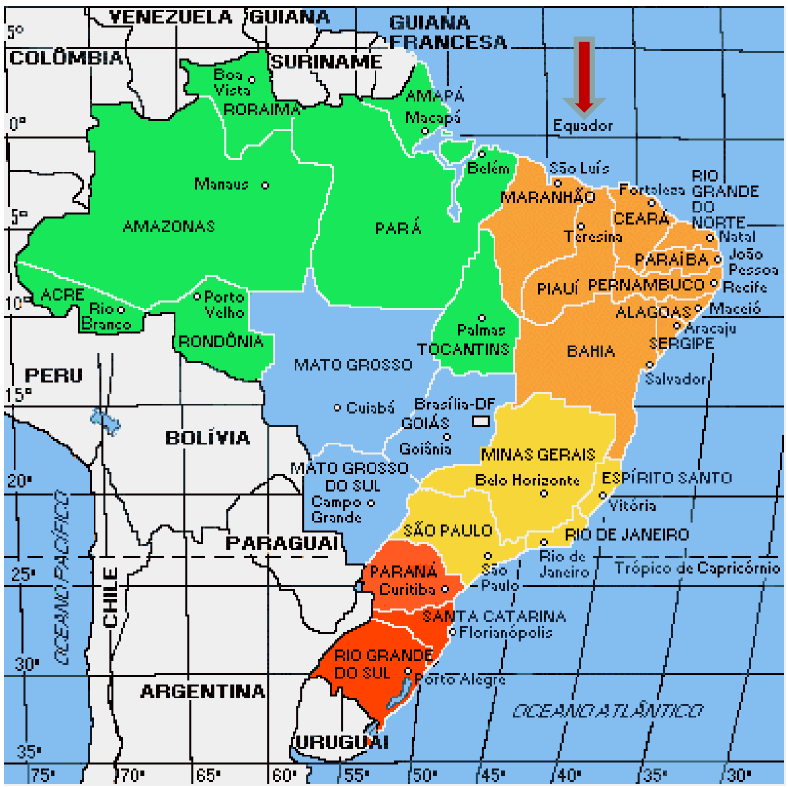
Spring 2015

Lectures available at:
www.lehigh.edu/imi

Sponsored by US National Science Foundation (DMR-0844014)

Center for **R**esearch **T**echnology and **E**ducation in **V**itreous Materials



Zanotto

ufscar

CeRTEV

The Vitreous State

August – Nov. 2015 (15 weeks = 30+30h)
LaMaV - Federal University of São Carlos

Instructor: EDZ

Glass – nature and properties
Glass structure
Relaxation - glass transition
Liquid-liquid phase separation
Crystal nucleation kinetics
Crystal growth kinetics
Overall crystallization

Sintering with concurrent crystallization
Glass forming ability - CCR
Glass stability against devitrification
Glass-ceramics

Nucleation, Growth and Crystallization in Glasses — Fundamentals and Applications

May 16-17, 2015 | 1:00 p.m. – 5:00 p.m.; 8:00 a.m. – Noon | 8h

Hilton Miami Downtown

Instructor: EDZ

Fundamentals:

-Crystal nucleation

-Crystal growth

-Overall crystallization

Applications:

-Sintering with concurrent crystallization

-Glass forming ability - CCR

-Glass stability against devitrification

-Glass-ceramics

Glass-ceramics: nature, applications and processing (2.5 h)

High T reactions, melting, homogeneization and fining = previous lectures!
Glass forming: previous lectures!

Glass-ceramics: definition, properties & applications

Thermal treatments – Sintering (of a glass powder compact) or
Controlled nucleation and growth in the glass interior

Micro and nano structure development

Concluding remmarks

IMI   

Zanotto

Reading assignments

E. D. Zanotto – *Am. Ceram. Soc. Bull.*, October 2010

Properties of inorganic glasses

Isotropic

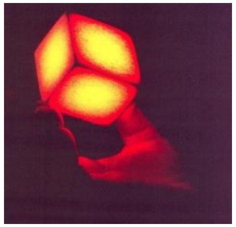
Transparent, opaque, colorless colored

Refractive index: 1.2 – 2.2

Electrical conductivity (T_{amb}): 10^{-6} - 10^{-18} $(\text{ohm.cm})^{-1}$

T_g: 150ºC - 1200ºC.

Low thermal conductivity: $k \leq 1$ W/m.K



Hardness: 3 -15GPa

Resistant to acids to soluble in H_2O

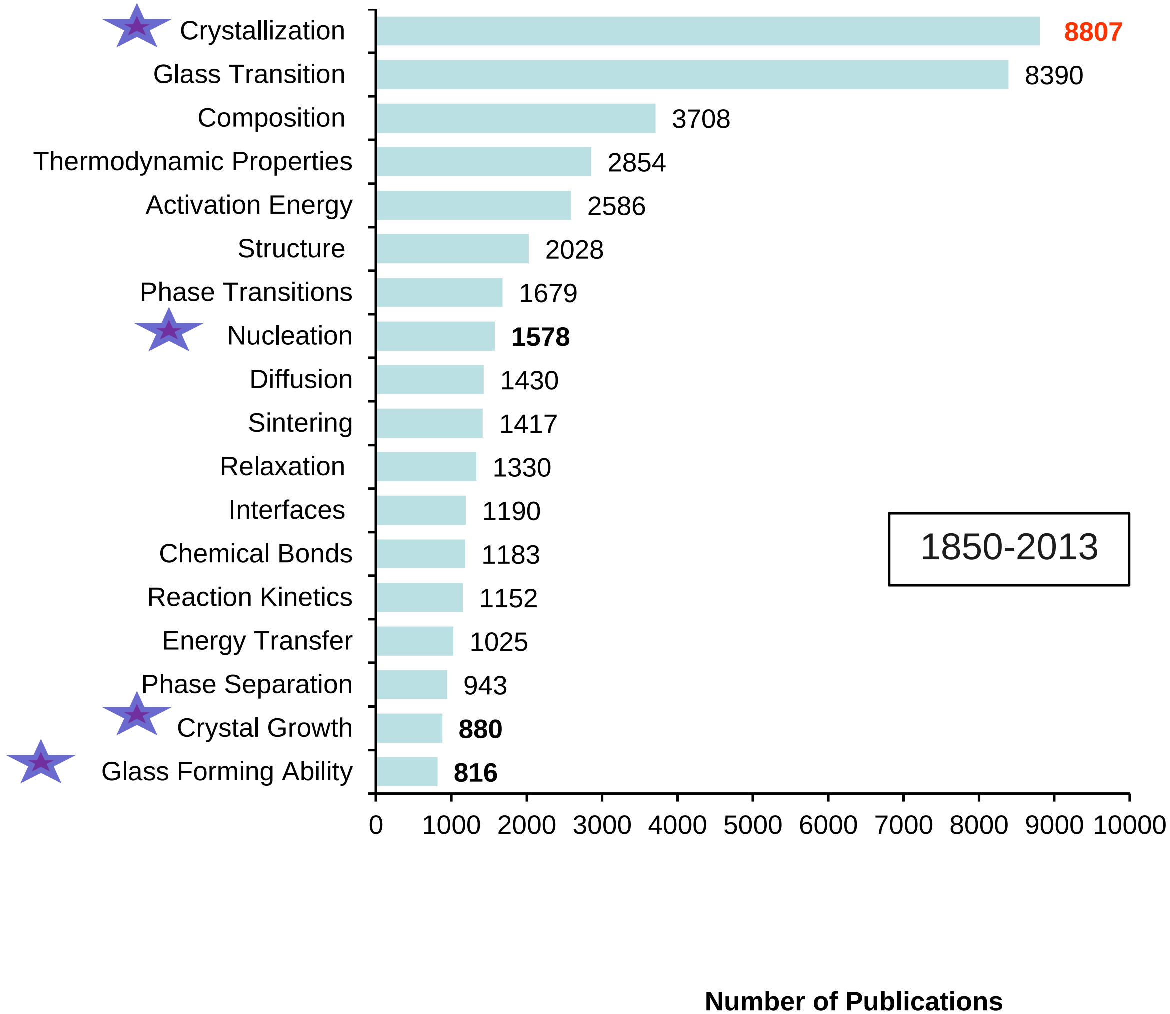
Fragile: K_{IC} < 1 MPa.$m^{1/2}$

Conchoidal fracture ...

Metastable!

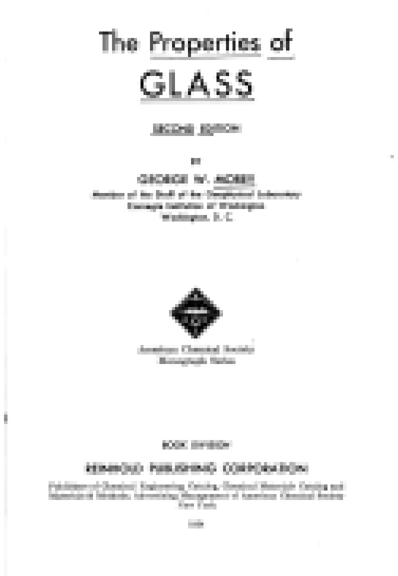
Tend to devitrify on slow cooling or heating

Most frequent keywords in the history of glass research



J.C. Mauro & E. D. Zanotto - "200 years of glass research..."
IJAGS, 2014

"Devitrification is the chief factor which limits the composition range of practical glasses, it is an ever-present danger in all glass manufacture and working, and takes place promptly with any error in composition or technique"

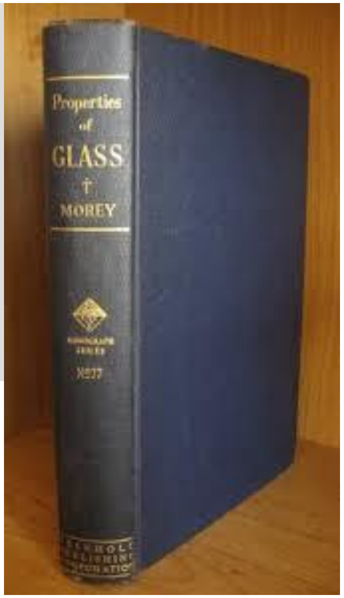

The Properties of
GLASS
SECOND EDITION
by
GEORGE W. MOREY
REINHOLD PUBLISHING CORPORATION

G. W. Morey

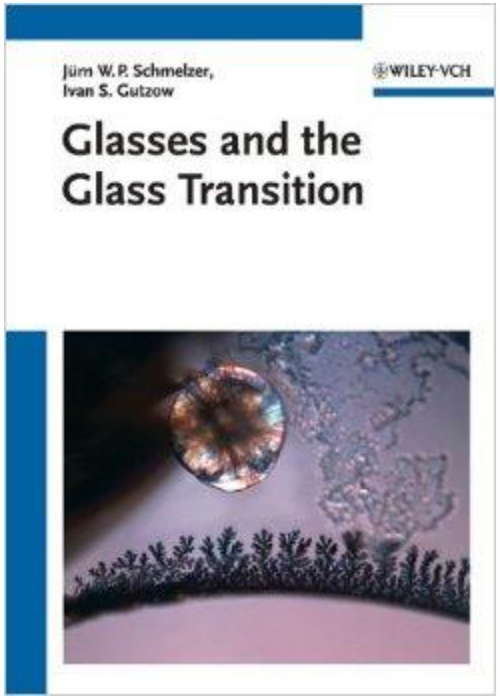
The Properties of Glass

Reinhold Pub, NY

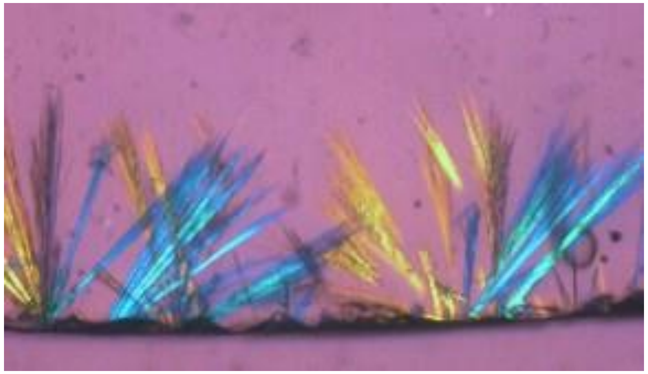
1938 & 1954



Heterogeneous (surface) nucleation on silicate glasses



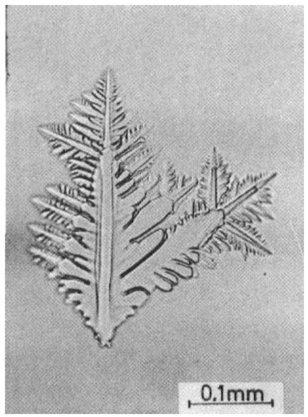
LS + CS

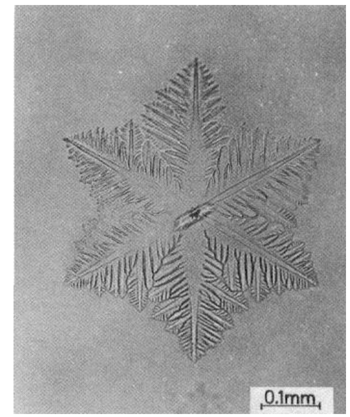


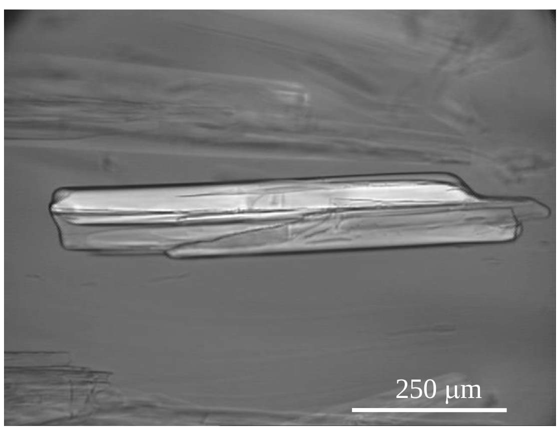
Devitrite

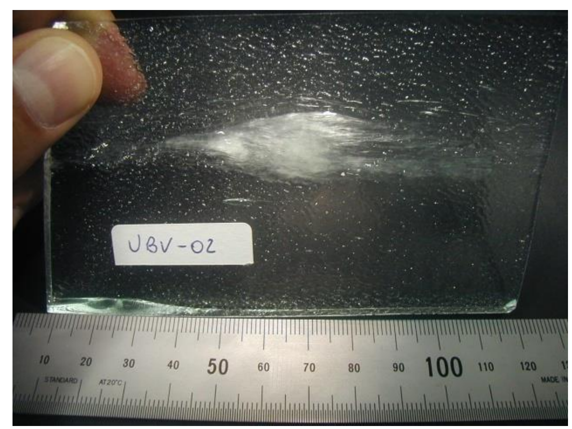
R.Muller, V. Fokin, E.D. Zanotto- *J. Non-Crystalline Solids* (2001)

Defect: devitrification









Sildes from E.B. Ferreira

The discovery of GC

Natural glass-ceramics, such as some types of obsidian "always" existed.

René F. Réaumur – 1739 "porcelain" experiments…

In 1953, Stanley D. Stookey, then a young researcher at Corning Glass Works, USA, made a serendipitous discovery when a furnace containing a piece of a lithium silicate glass with precipitated silver particles (meant to form a permanent photographic image) accidentally overheated to about 900°C, instead of 600°C…

Volfram Hoeland and George Beall mention in their book that: "*knowledge of the literature, good observation skills, and deductive reasoning were clearly evident in allowing the chance events to bear fruit*".

Crystallization symposium, Stone Mountain (2006)

TC 7 members and guests

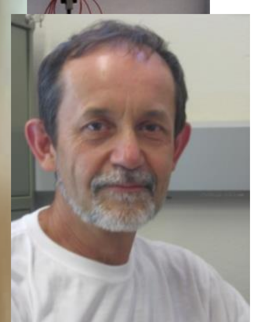
S.D. Stookey

Zanotto

Photo by Mark Davis

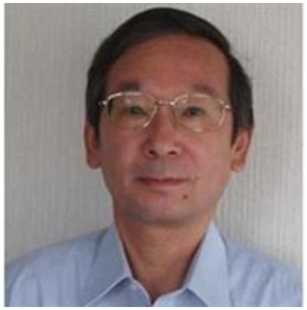
ICG TC-7


Glas-Keramik-Komposite:
Low-Temperature Co-Firing (incl. Leiterbahnen)
SIEMENS




MONDAY
TUESDAY
WEDNESDAY

TC 7
The next symp in the series



Crystallization 2015

11th International Symposium on Crystallization in Glasses and Liquids

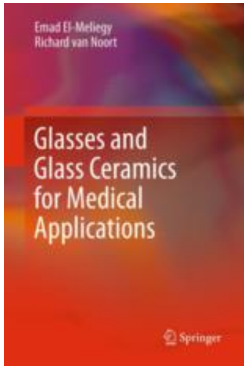
October 11-14, Nagaoka, Japan

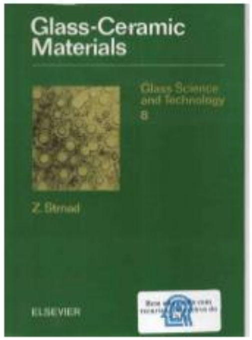
http://crystallization-2015.jp/

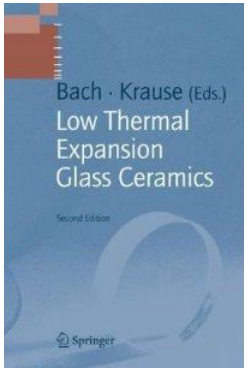
References

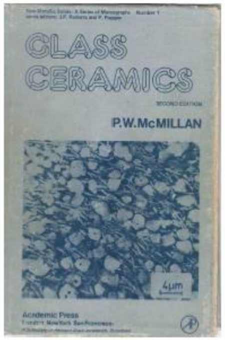
From glass to crystal: nucleation, growth and phase separation, from research to applications - D. Neuville et al. (2015)

Nano-Glass Ceramics: Processing, Properties and Applications. Marghussian, V., 1st Edition, Elsevier, 2015.









+ review articles by:

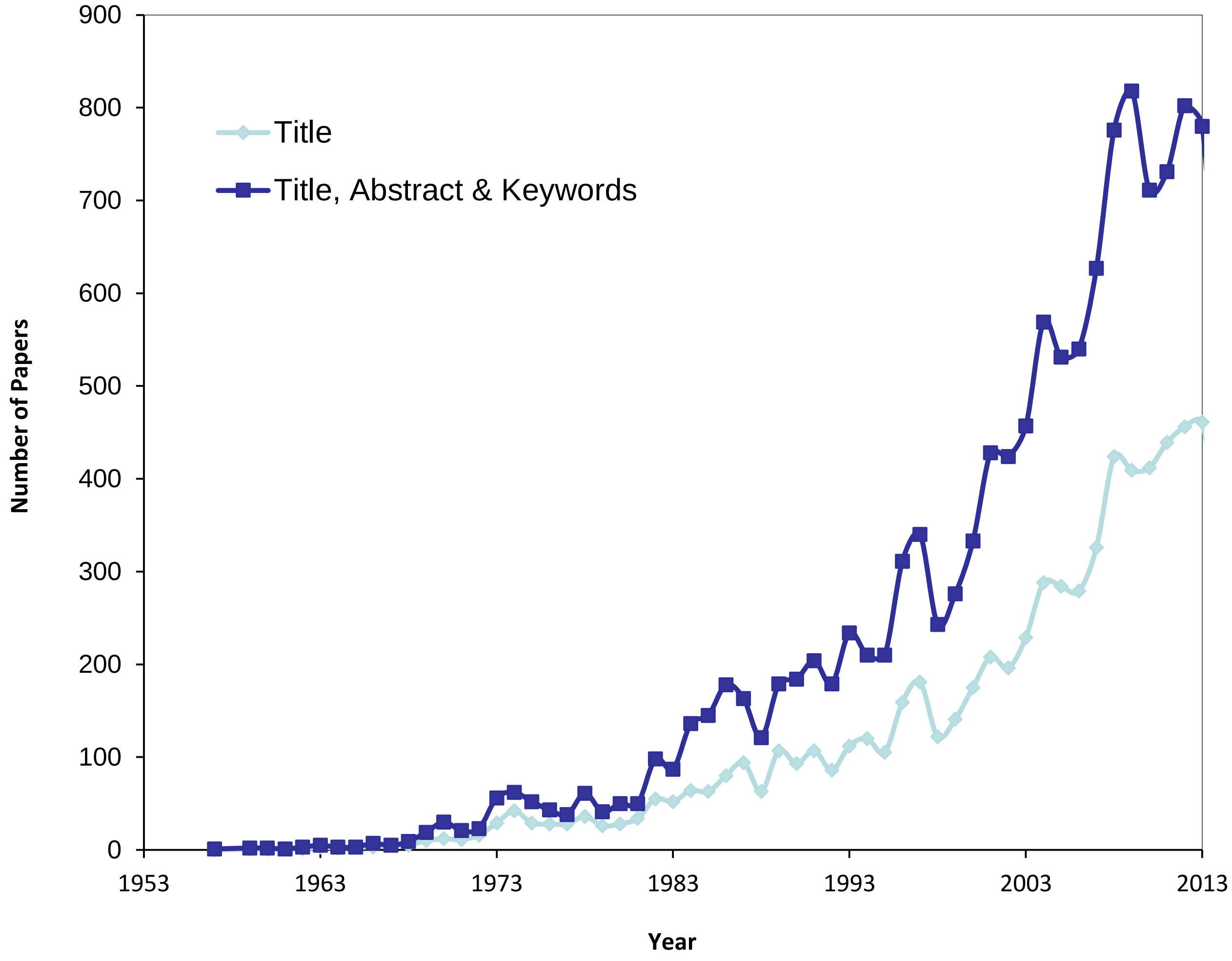
Beall & Pinckney, Hoeland, Pannhorst, James, Davis, Zanotto, Dymshits…

Statistics /scientific papers *July 2014 search*

- Scopus database with the keywords (glass-ceramic*) OR (“glass ceramic*) in the title or abstract or keywords in all types of docs: ~13,000 articles

  or ~7,000 using only article titles

GC: papers / year



Am. Cer. Soc. Bull. May 2015

A Statistical Overview of Glass-Ceramic Science and Technology

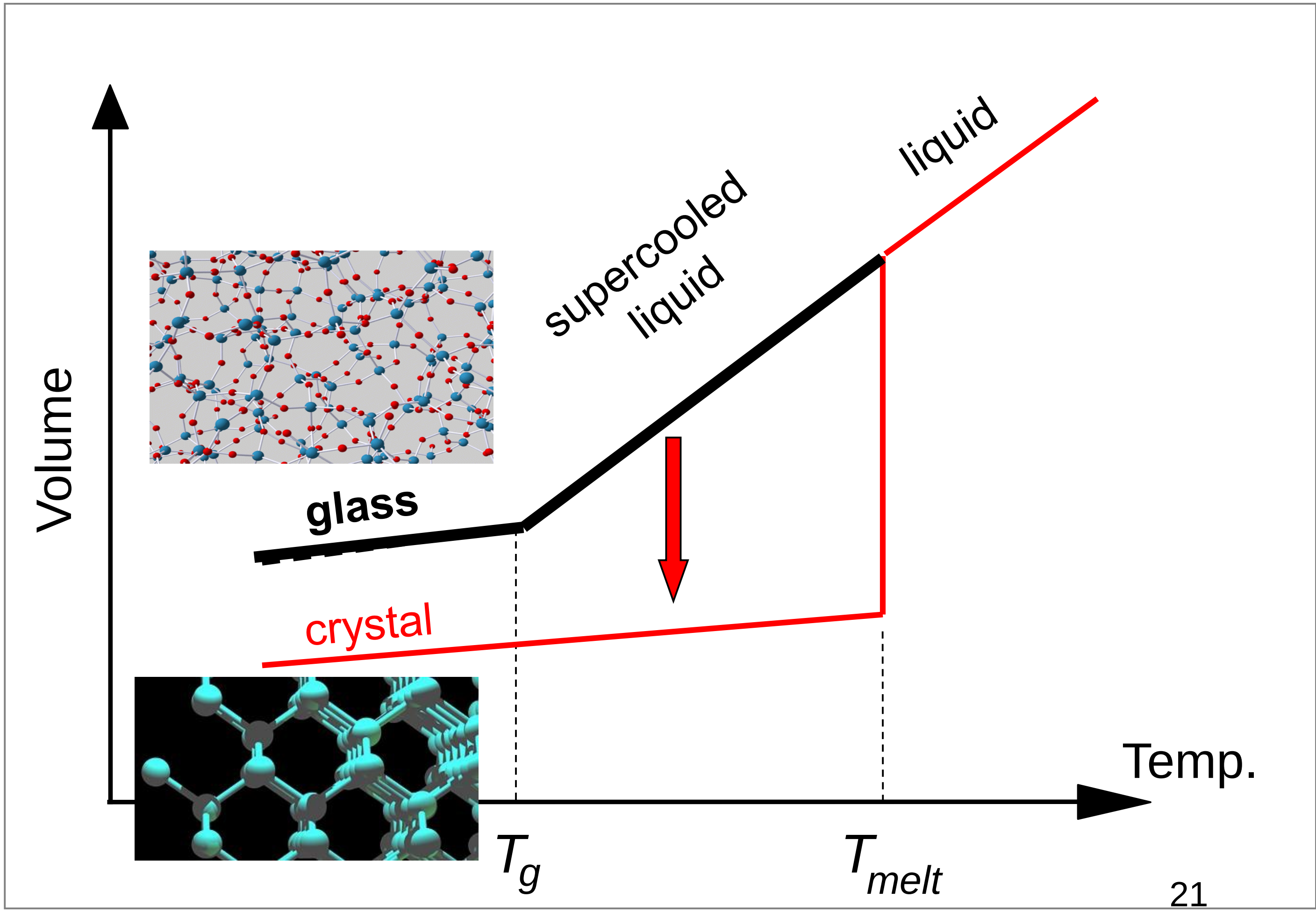
Maziar Montazerian, Shiv P. Singh, Edgar D. Zanotto

Objectives

Critically comment on a number of exciting new types of GC that are being currently developed;

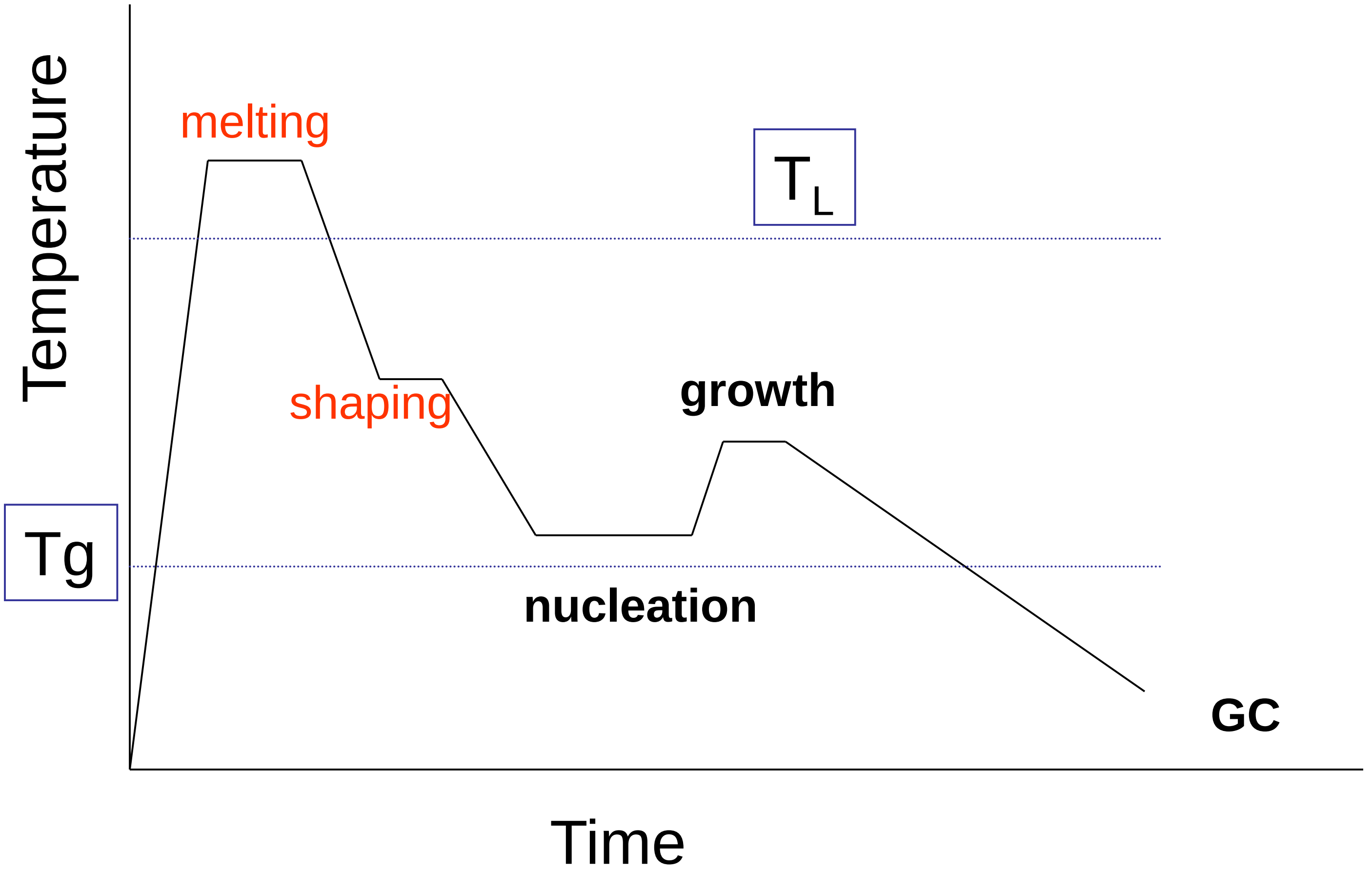
Discuss some critical issues regarding GC processing

Glasses and Glass-ceramics



Zanotto

Production steps



Glass-ceramics (GC) =
glass ceramics, vitrocerams, pyrocerams, vitrocerâmicos, vitroceramiques or sittals

GC always contain a residual glassy phase and one or more embedded crystalline phases – with widely varying crystallinity between 0.5% and 99.5%, most frequently 30-70%.

Advantages of CGs:

- can be mass produced by any glass forming technique
- it is possible to design the material's nano or microstructure
- most have zero or very low porosity,
- It is possible to combine desired properties

Microstructural Design

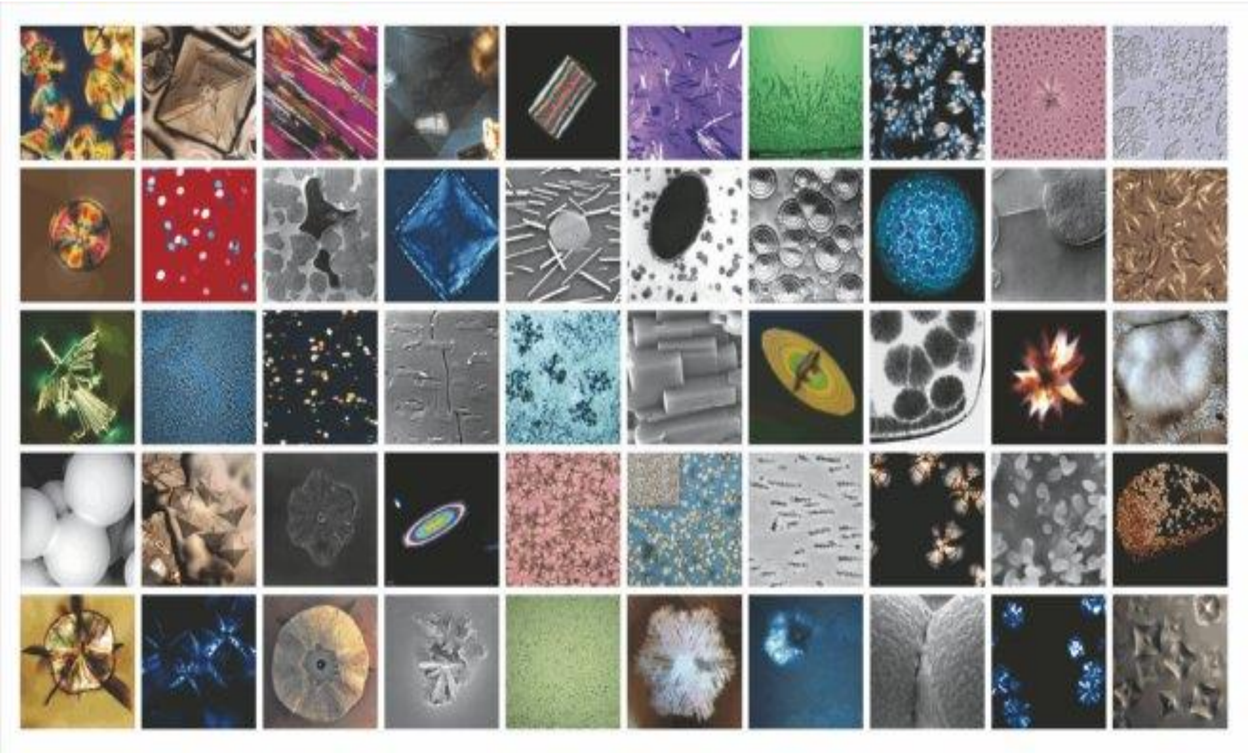
grain size distribution & shape, texture, porosity, %crystallinity, type and # crystal phases…

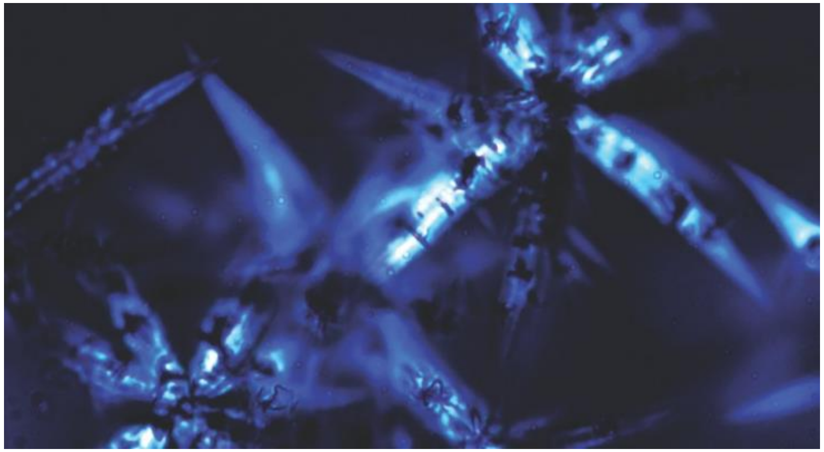
GLASS-CERAMICS

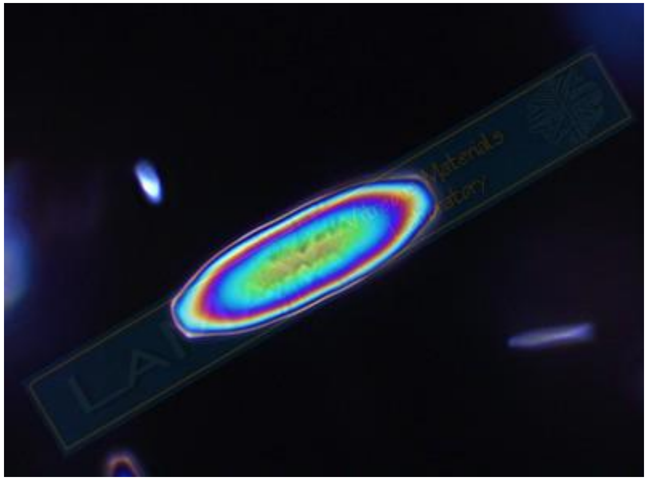
↓

Combination of properties

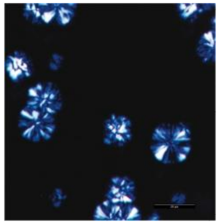
- high thermal and chemical stability
- harder and tougher than glasses
- controllable electrical properties
- optical transparency
- bioactivity
- controllable TEC

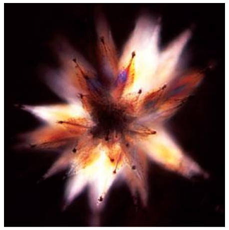






Designed micro and nanostrucures lead to...





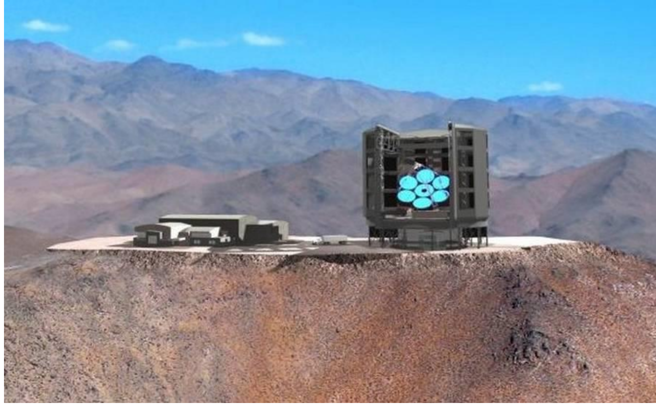
glass-ceramic products

Donald Stookey
(2000)

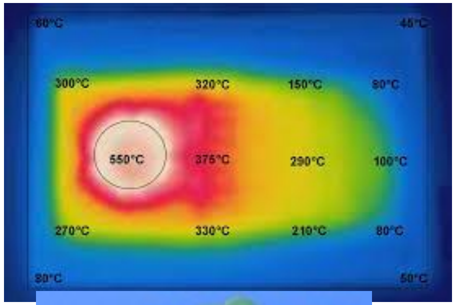
HD Substrate

Cooktop

Otawa Dental Lab.

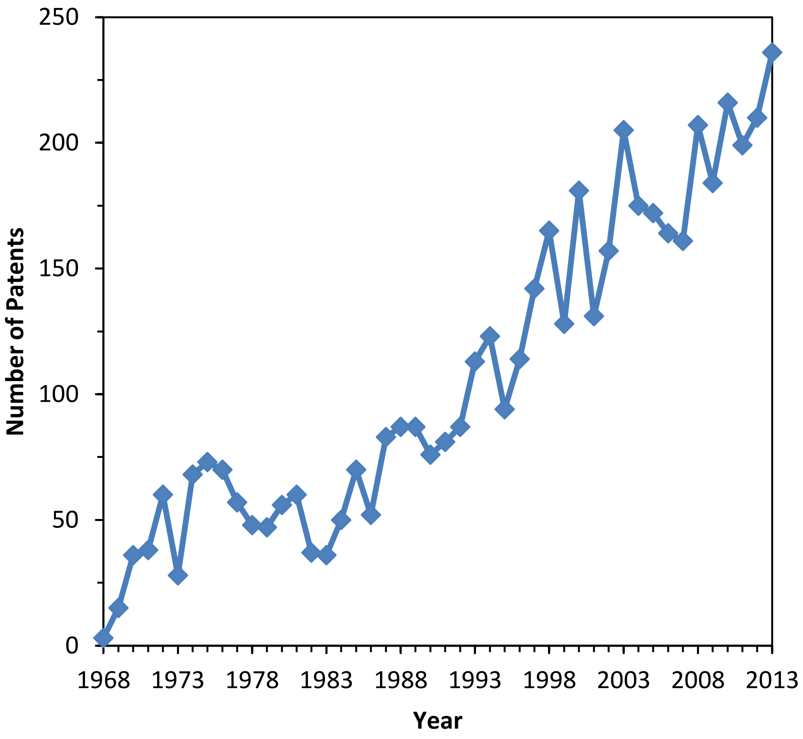


GLASS Ceramics



<rms> 1nm

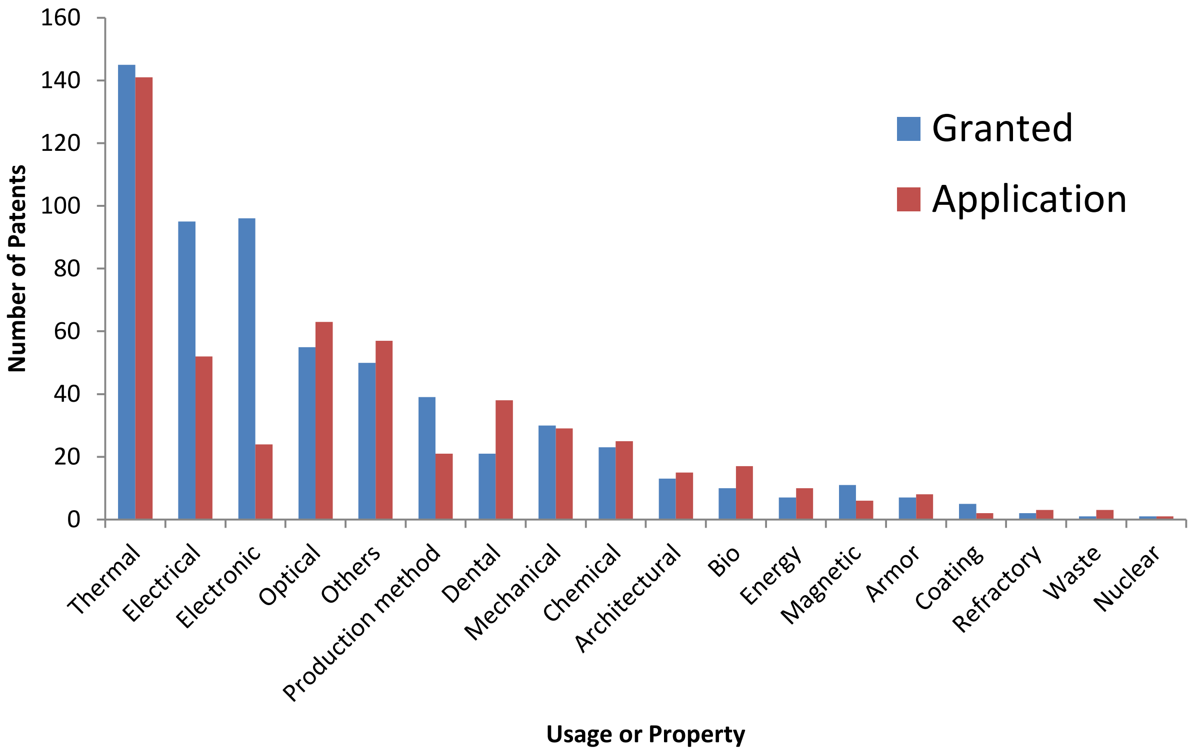
Patents granted per year extracted from the DWPI by searching for “glass-ceramic*” OR “glass ceramic*” keywords in the patent title.



Derwent Innovation Index search
~5,000 granted patents on GCs

Am. Cer. Soc. Bull., May 2015
Statistical Overview of Glass-Ceramic Science and Technology
Maziar Montazerian, Shiv P. Singh, Edgar D. Zanotto

Number of granted patents and patent applications extracted manually from the FPO website using the keywords “glass ceramic” or “glass-ceramic” in the patent title. Jan 2001 - July 2014
Per intended application



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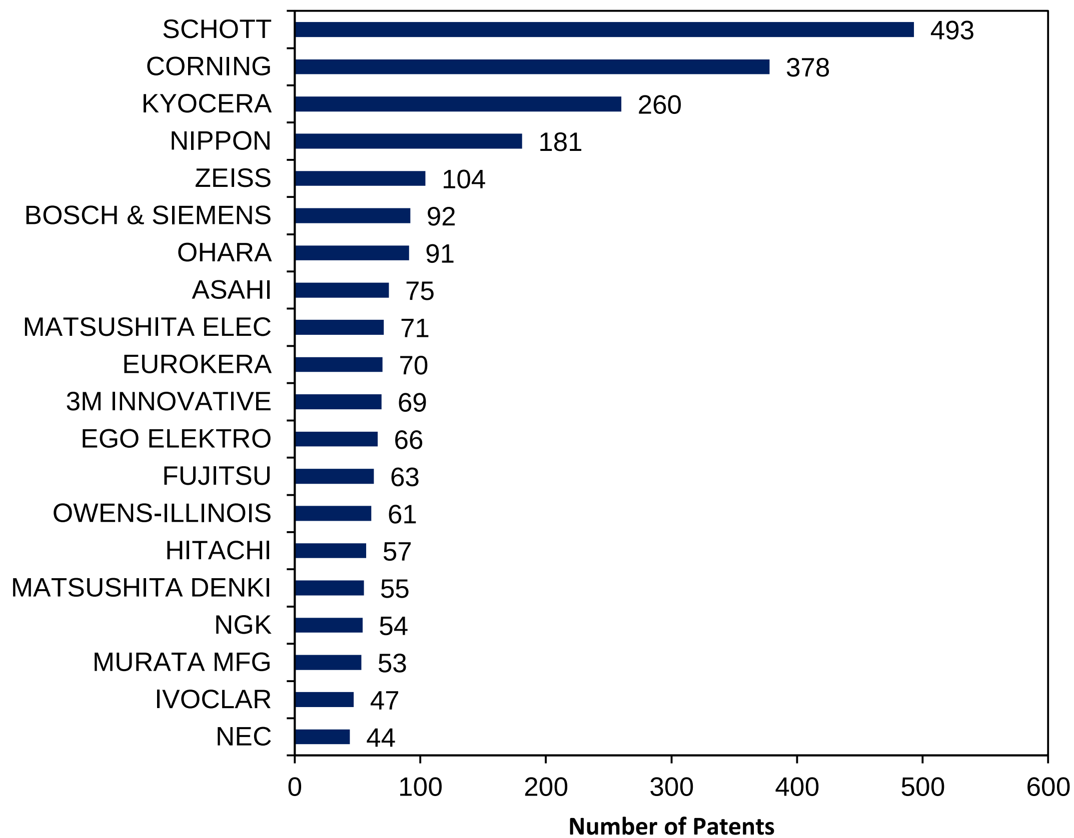
Twenty most prolific companies with largest number of glass-ceramic patents granted from 1968 to 2014. "Glass-ceramic*" or "glass ceramic*" keywords were searched in the patent title. Source: DWPI



Am. Cer. Soc. Bull., May 2015

Statistical Overview of Glass-Ceramic Science and Technology

Maziar Montazerian, Shiv P. Singh, Edgar D. Zanotto

Company	Products	Crystal type	Applications
SCHOTT, Germany	Foturan®	Lithium-silicate	Photosensitive and etched patterned materials
	Zerodur®	β-quartz ss	Telescope mirrors
	Ceran® / Robax®	β-quartz ss	Cookware, stovetops, cooktop and oven doors
	Nextrema®	Lithium Aluminosilicate	Fireproof windows and doors
Corning, USA	Pyroceram®	β-Spodumene ss	Cookware
	Fotoform® / Fotoceram®	Lithium silicate	Photosensitive and etched patterned materials
	Cercor®	β-Spodumene ss	Gas turbines and heat exchanger
	Centura®	Barium silicate	Microwave tableware
	Vision®	β-quartz ss	Cookware and cooktop
	9606®	Cordierite	Radomes
	MACOR®	Mica	Machinable glass-ceramic
	9664®	Spinel-enstatite	Magnetic memory disk substrate
	DICOR®	Mica	Dental restoration
Nippon Electric Glass, Japan	ML-05™	Lithium disilicate	Magnetic memory disk substrate
	Neoparies®	β-wollastonite	Architectural glass-ceramic
	Firelite™	β-quartz ss	Architectural fire-resistant windows
	Neoceram™ N-11	β-Spodumene ss	Cooktop and kitchenware
	Narumi®	β-quartz ss	Low thermal expansion GC
	Neoceram™ N-0	β-quartz ss	Color filter substrates for LCD panels

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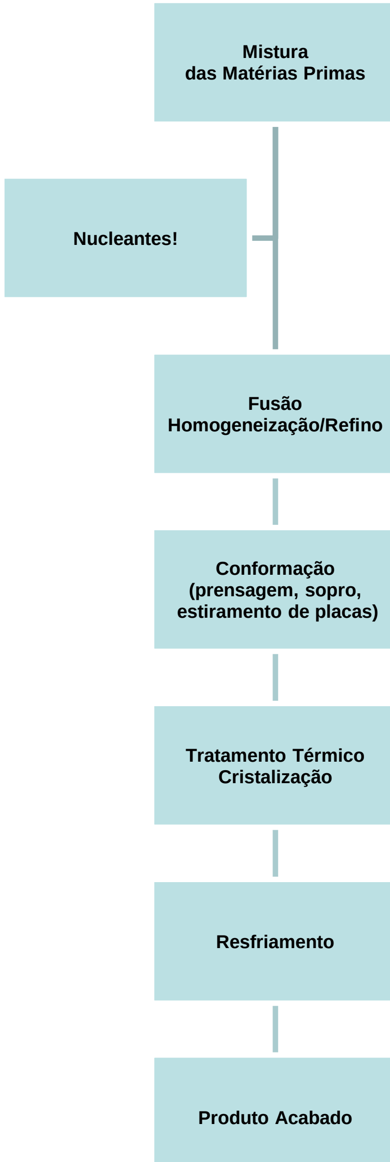
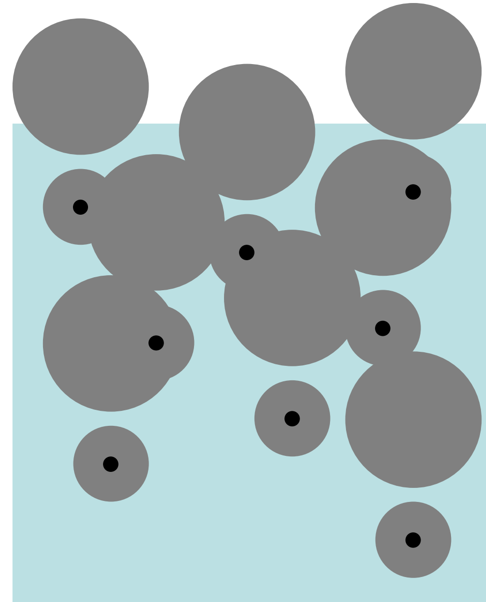
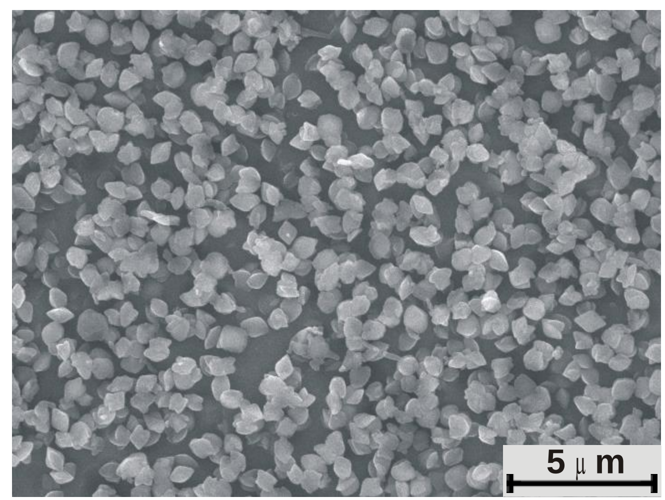
Fabricação – via cristalização volumétrica







Fabricação – via sinterização

From E.B. Ferreira - 34

- Mistura das Matérias Primas
- Fusão Homogeneização/Refino
- Fritagem/Granulação
- Cominuição
- Ajuste Granulométrico
- Mistura + Aditivos
- Conformação do Pó
- Tratamento Térmico Sinterização/Cristalização
  - Retífica e Polimento
    - Produto Acabado Polido
  - Produto Acabado