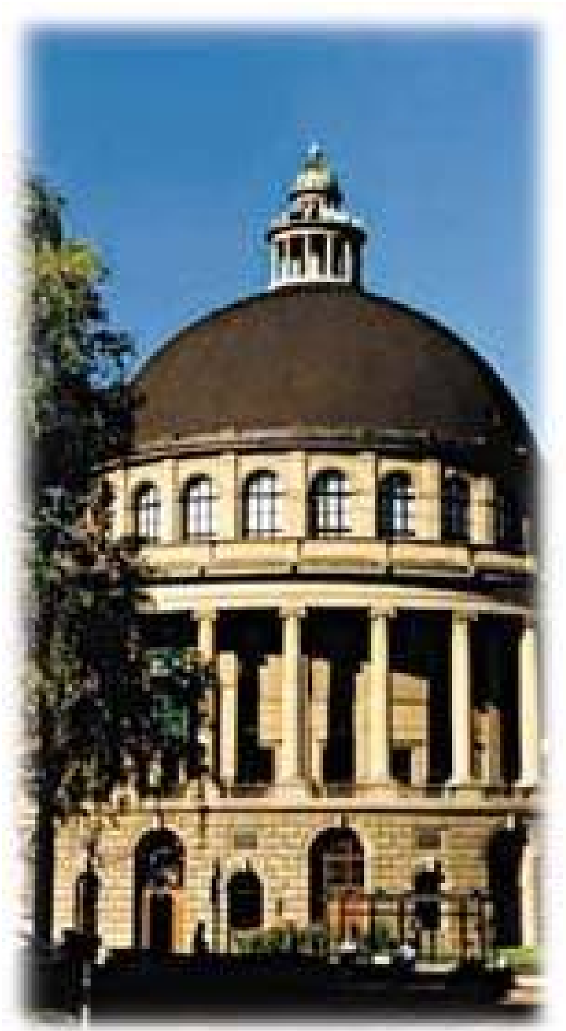

INTERNATIONAL MATERIALS FORUM 2005

FRONTIERS IN MATERIALS SCIENCE & TECHNOLOGY CONFERENCE

1. and 2. August 2005

Bayreuth, Germany

Innovations through new Ceramic Materials and Processes:

When Innovations meet Market Needs

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ETH Zurich
Materials Science
Inorganic Nonmetallic Materials
Wolfgang- Pauli Str. 10
Zurich
http://www.nonmet.mat.ethz.ch/

http://ceramics.ethz.ch

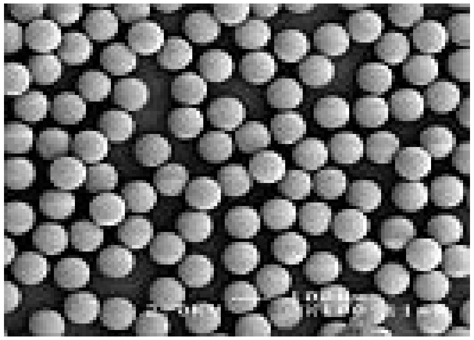
ETH Materials

Outline

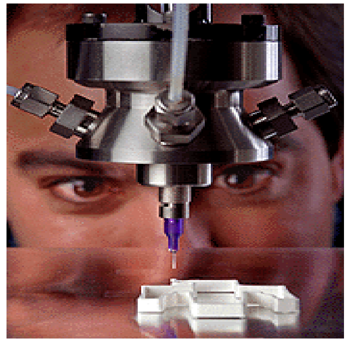
- Colloid chemistry
  - Manipulation of colloidal particles
  - Enzyme assisted coagulation of suspensions: Direct Coagulation Casting, DCC®
  - Ceramic foams and emulsions
  - Capillary filling: μ - sensor array
  - Chemical micro-reactor
- Processing properties of HTSC materials for fault current limiters
- Rapid prototyping of ceramics: Cercon®
- Summary

Why Colloidal Processing of Ceramics?

Shaping ceramics



Spray drying



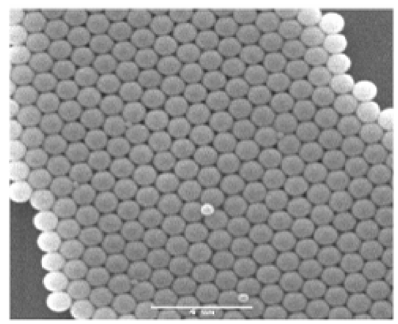
Robocasting
http://www.sandia.gov/LabNews/LN01-29-99/images/lens_pix.gif

Tape casting

Extrusion

Ferro - 'KeraJet'
http://www.xaar.co.uk/industrial.htm

Pressure slip casting
http://www.dorst.de/dorst_seite/index.html



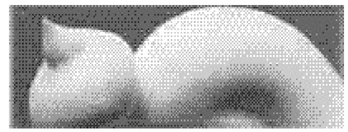
SiO_2; d_{50}=0.9 µm

Ceramic components for hip joint endoprostheses
http://www.ceramtec.de

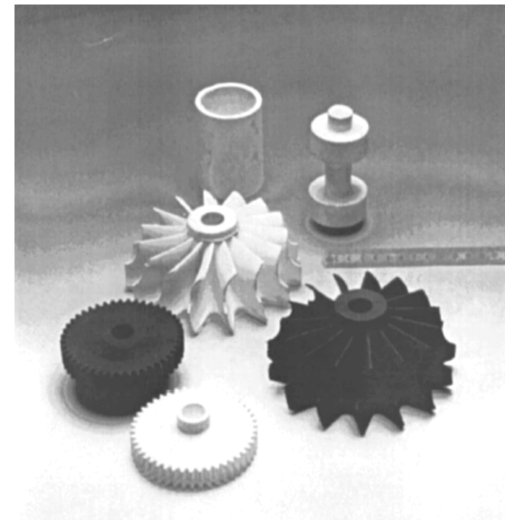
Concentrated Particle Gels

- *Food technology*

- *Cosmetics*

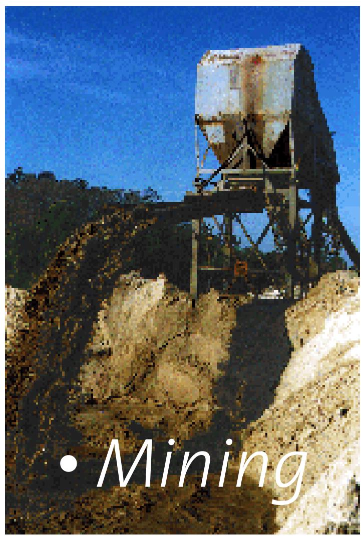


- *Ceramics*



- *Pharmaceutical*

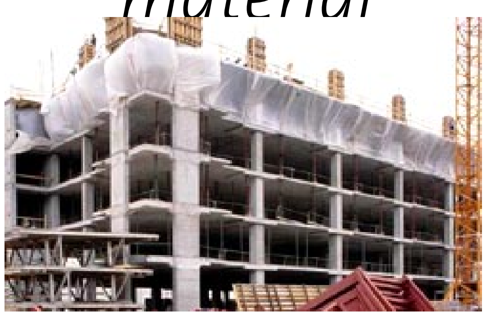
- *Paper*

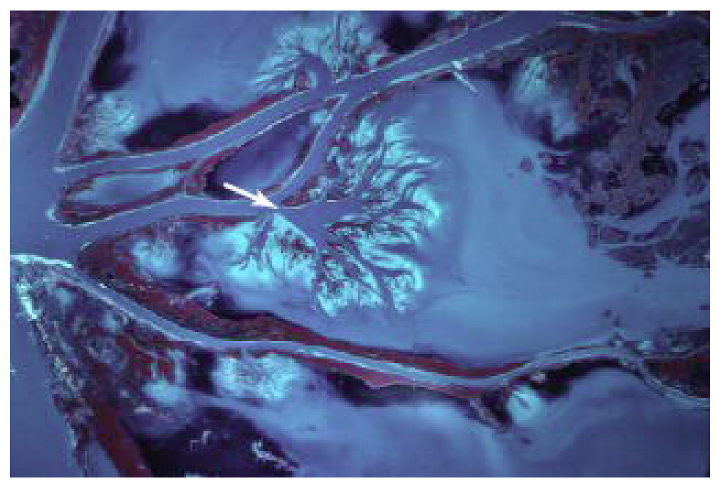


- *Mining*

- *Paint*

- *Building material*



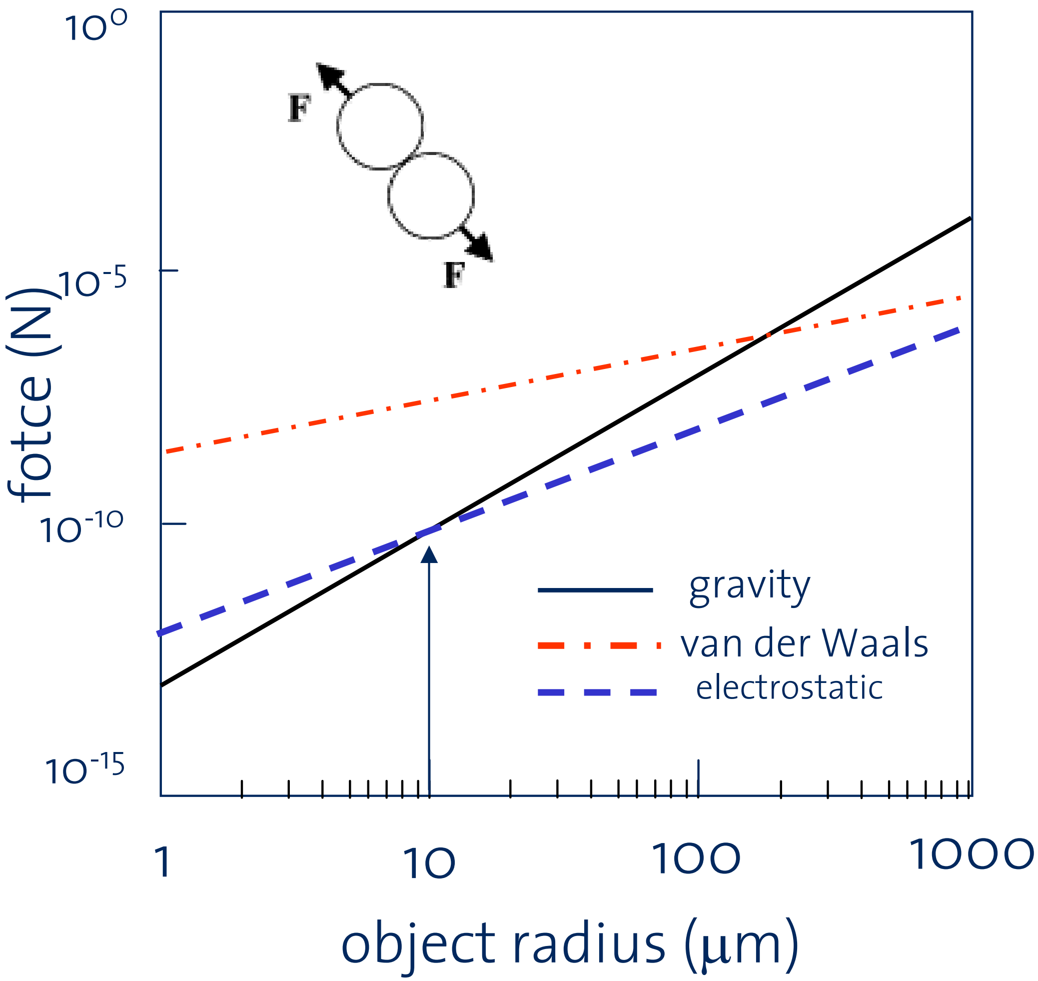


- *Earth Science*

http://ceramics.ethz.ch

ETH Materials

Small particles stick to each other and form agglomerates = large defects in the material.



gravitational potential:

$$V_g = \frac{G m_1 m_2}{r}$$

Van der Waals potential:

$$V_{\mathrm{vdW}} = -\frac{A}{6}\left(\frac{2}{s^2-4} + \frac{2}{s^2} + \ln\frac{s^2-4}{s^2}\right)$$

$$s = \frac{2a+h}{a}$$

electrostatic interaction:

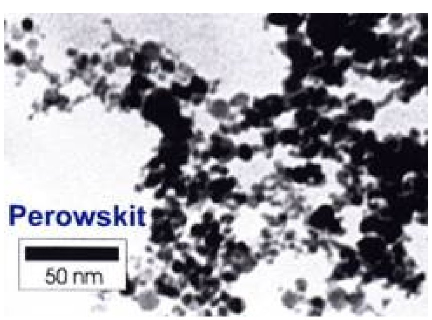
$$V_{\mathrm{elect}} = 2\pi\varepsilon_r\varepsilon_0 a \Psi_0^2 \ln[1+\exp(-\kappa h)]$$

κa is sufficiently large (>10)

$$V_{\mathrm{elect}} = 2\pi\varepsilon_r\varepsilon_0 a \Psi_0^2 \exp(-\kappa h)$$

$(\kappa a < 5)$

$$\kappa = \left(\frac{F^2 \sum_i N_i z_i^2}{\varepsilon_r\varepsilon_0 k T}\right)^{1/2}$$



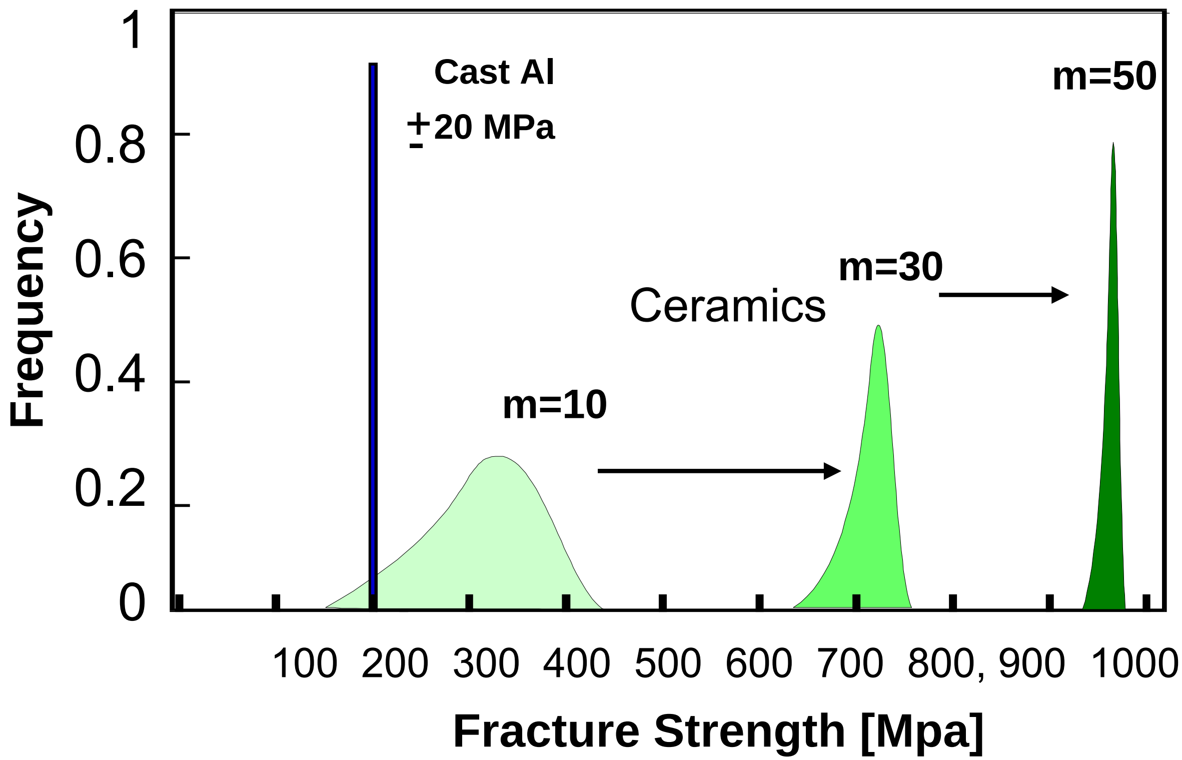
ETH Materials

http://ceramics.e

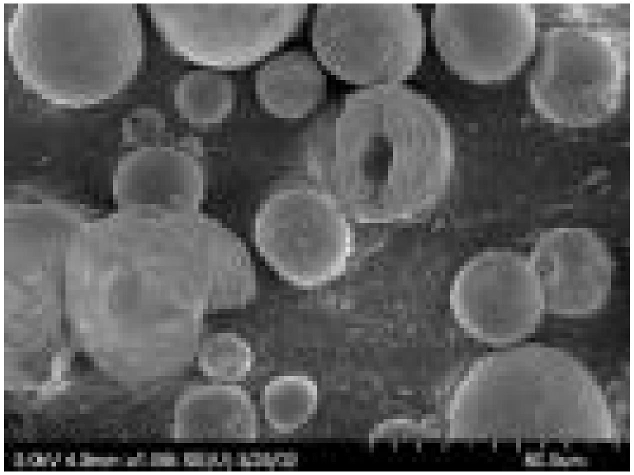
Why Colloidal Processing of Ceramics?

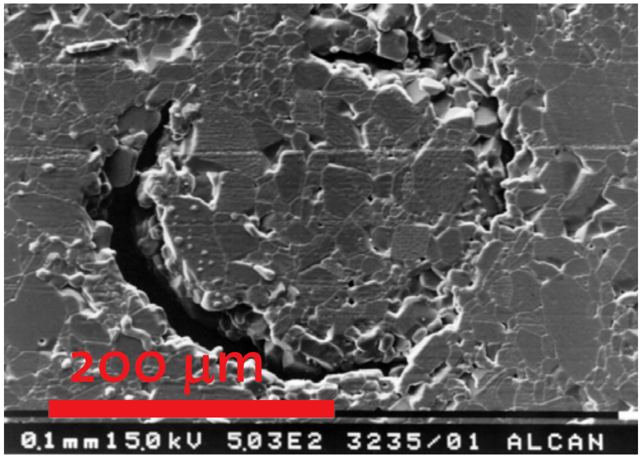
$$\sigma_c = \frac{K_c}{\gamma\sqrt{a}}$$

σ_C	stress at fracture
K_C	critical stress intensity factor
γ	surface energy
a	size of largest flaw in the part



m= Weibull paramter= a measure of the distribution width.





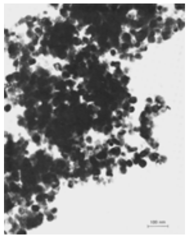
microstructural defect in sintered Al_2O_3

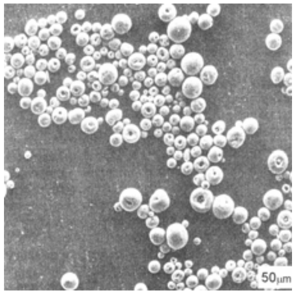
The load bearing capacity of ceramics is determined by the largest defect in the part.

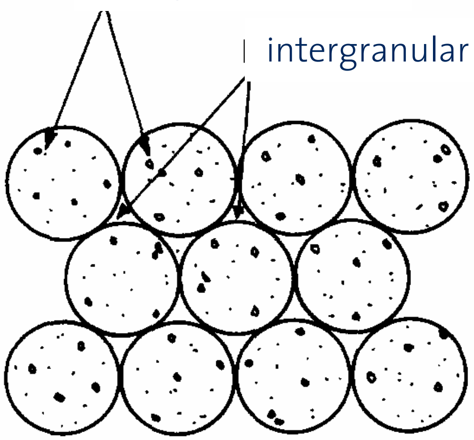
The largest flaw in a component can be from ~300µ to 0.1 µ.

→ Ceramics are unreliable!!

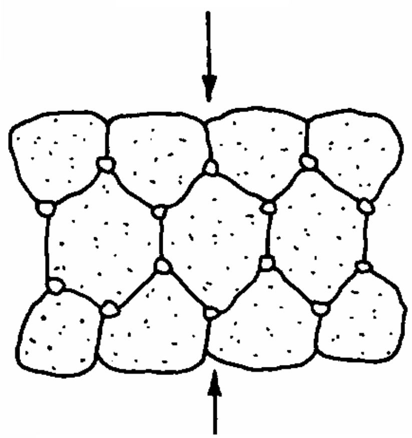
Classical Processing of Ceramics versus colloidal processing



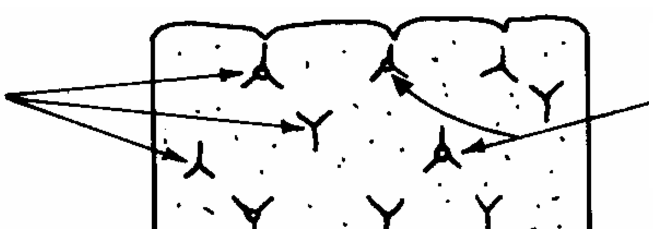




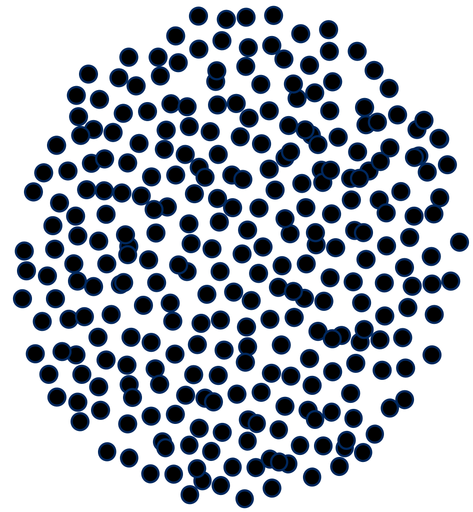
packed spherical granules

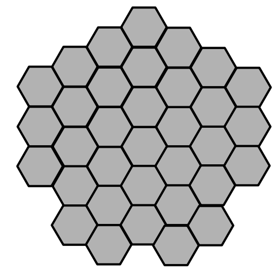


plastically deformed granules



pressed component





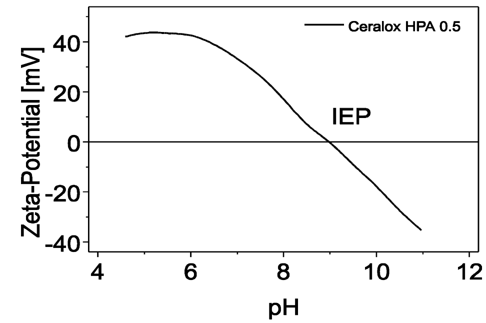
ETH Materials

Enzyme Catalysis of Ceramic Forming: Direct Coagulation Casting: DCC

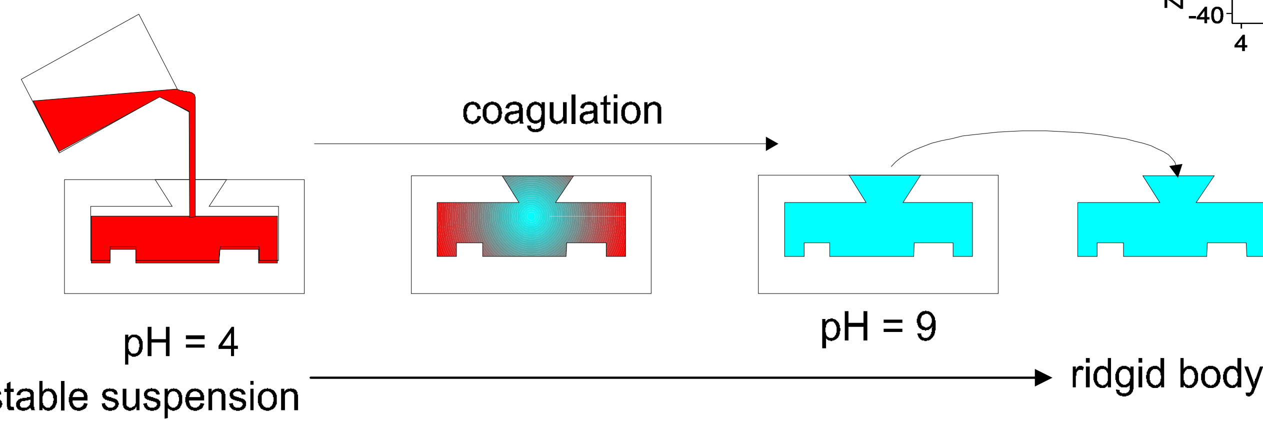
$$CO(NH_2)_2 + H_2O \xrightarrow{\text{urease}} NH_3 + CO(NH_2)OH$$

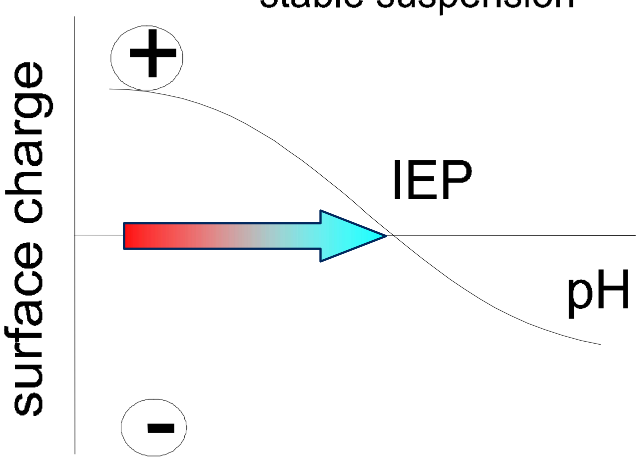
$$CO(NH_2)OH + H_2O \xrightarrow{\text{urease}} NH_4^+ + HCO_3^-$$

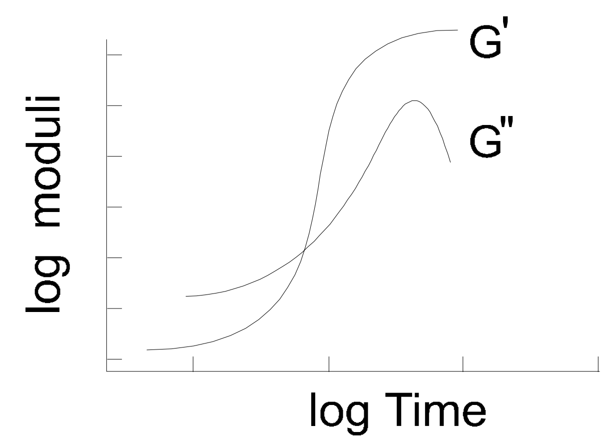
buffer pH=8.7



$Al_2O_3 + H_2O + CO(NH_2)_2$ + enzymes

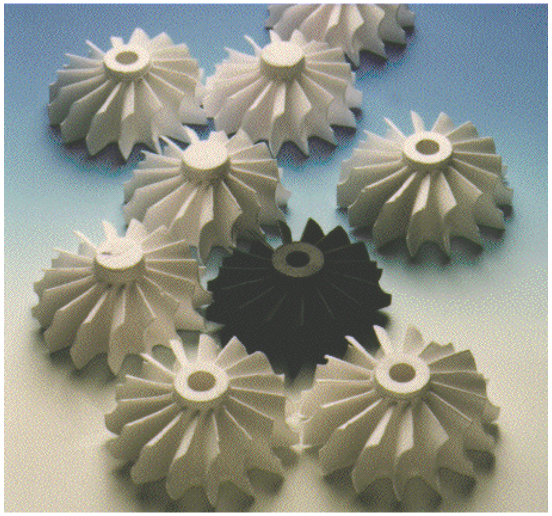


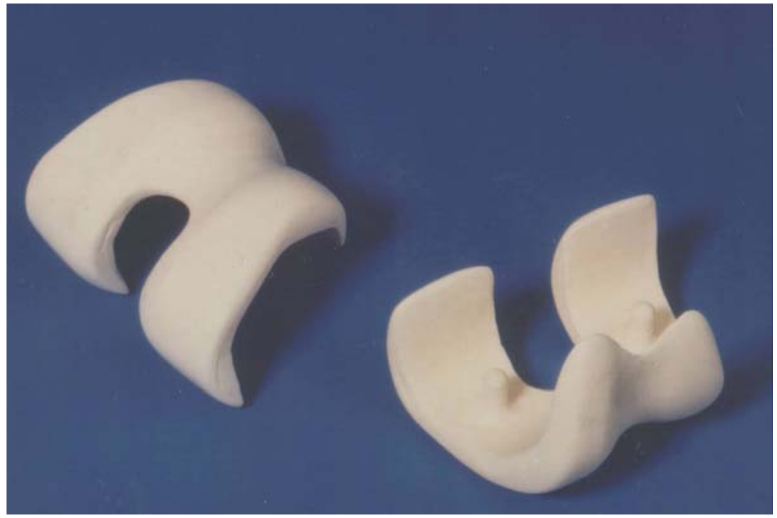


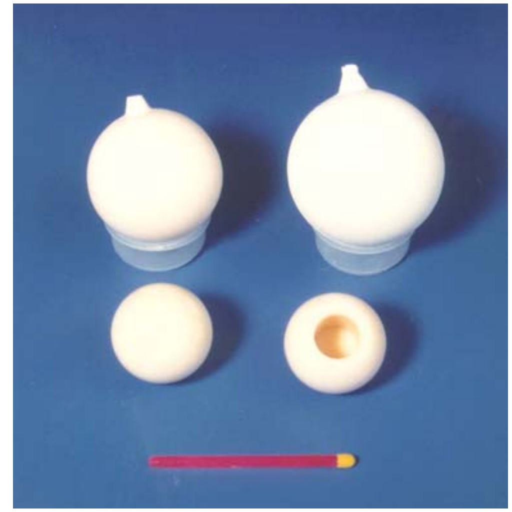


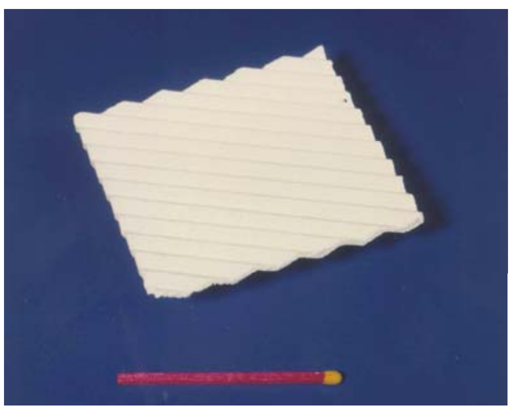
http://ceramics.ethz.ch

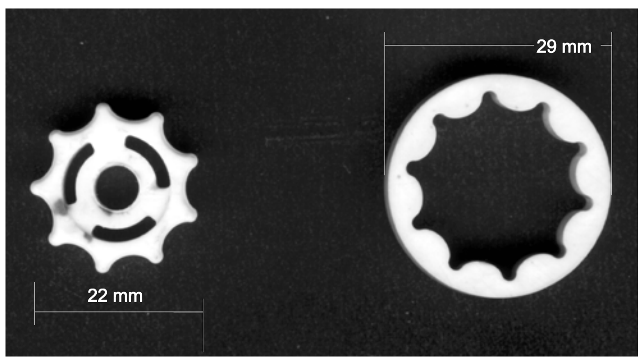
Complex shaped ceramic componets via DCC

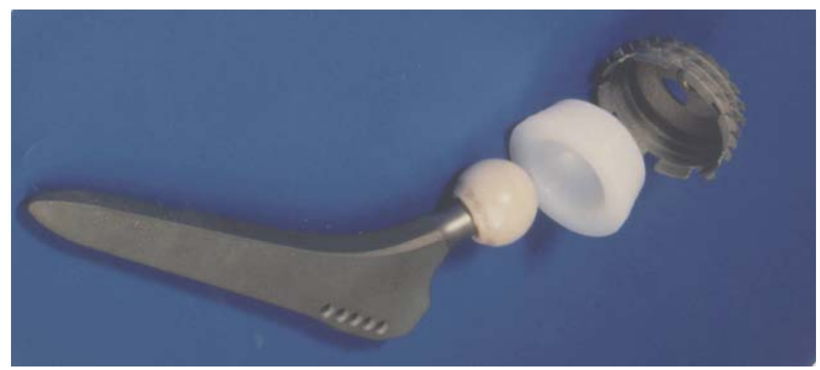










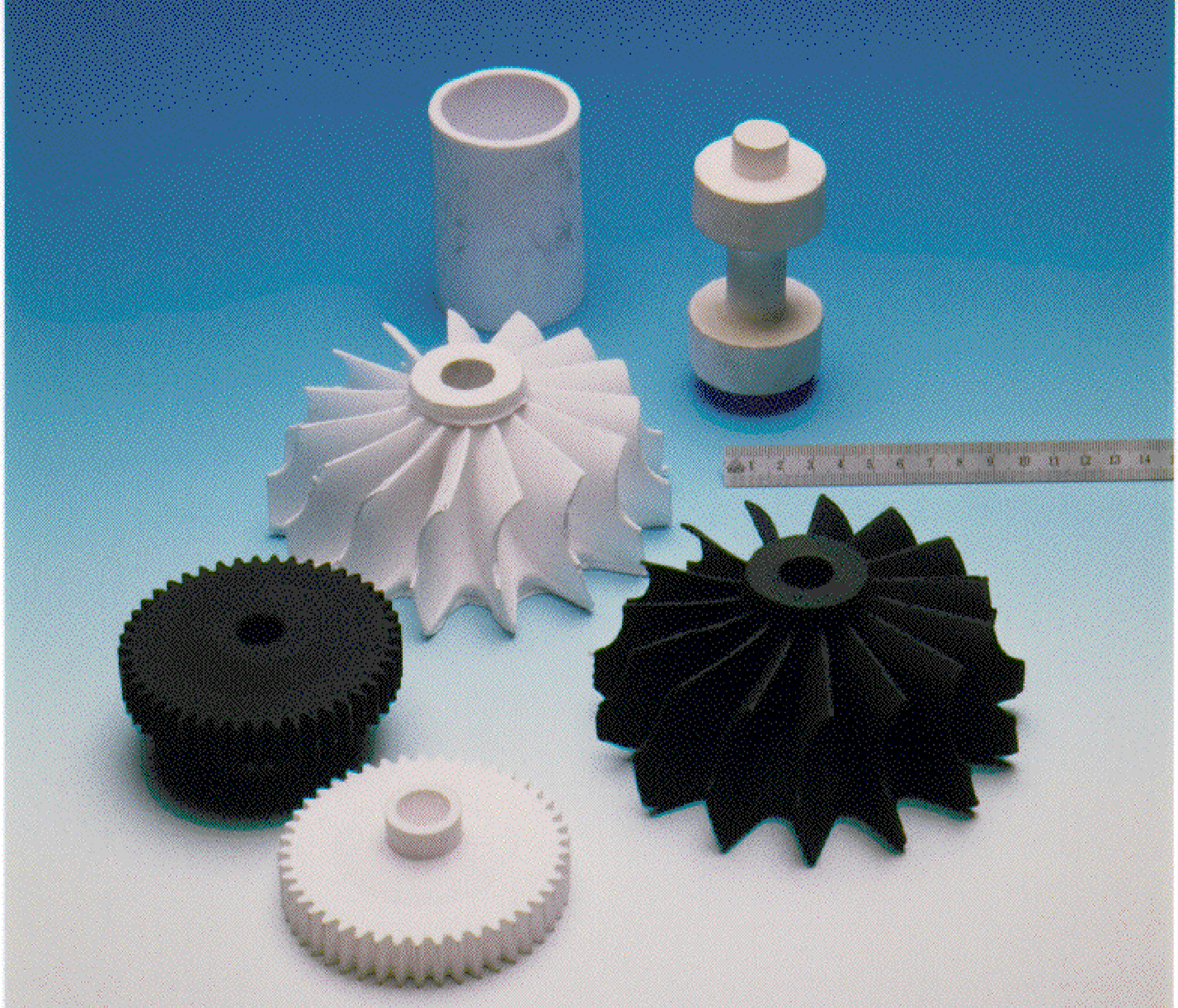


ETH Materials

http://ceramics.ethz.ch

CeramTec

Si_3N_4, SiC and Al_2O_3 Components

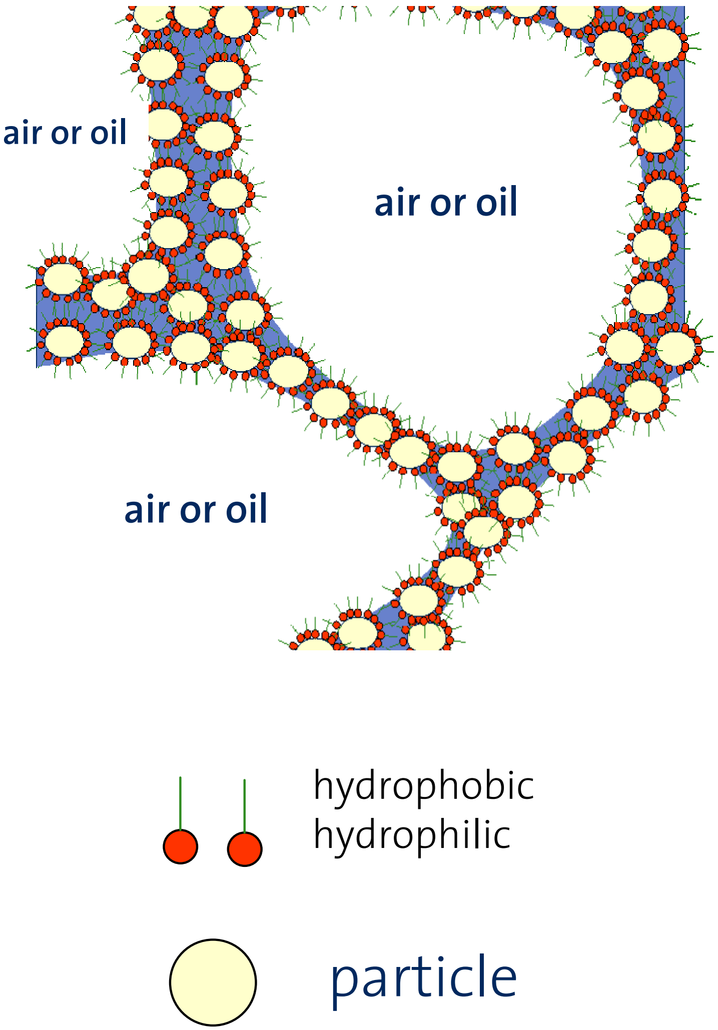


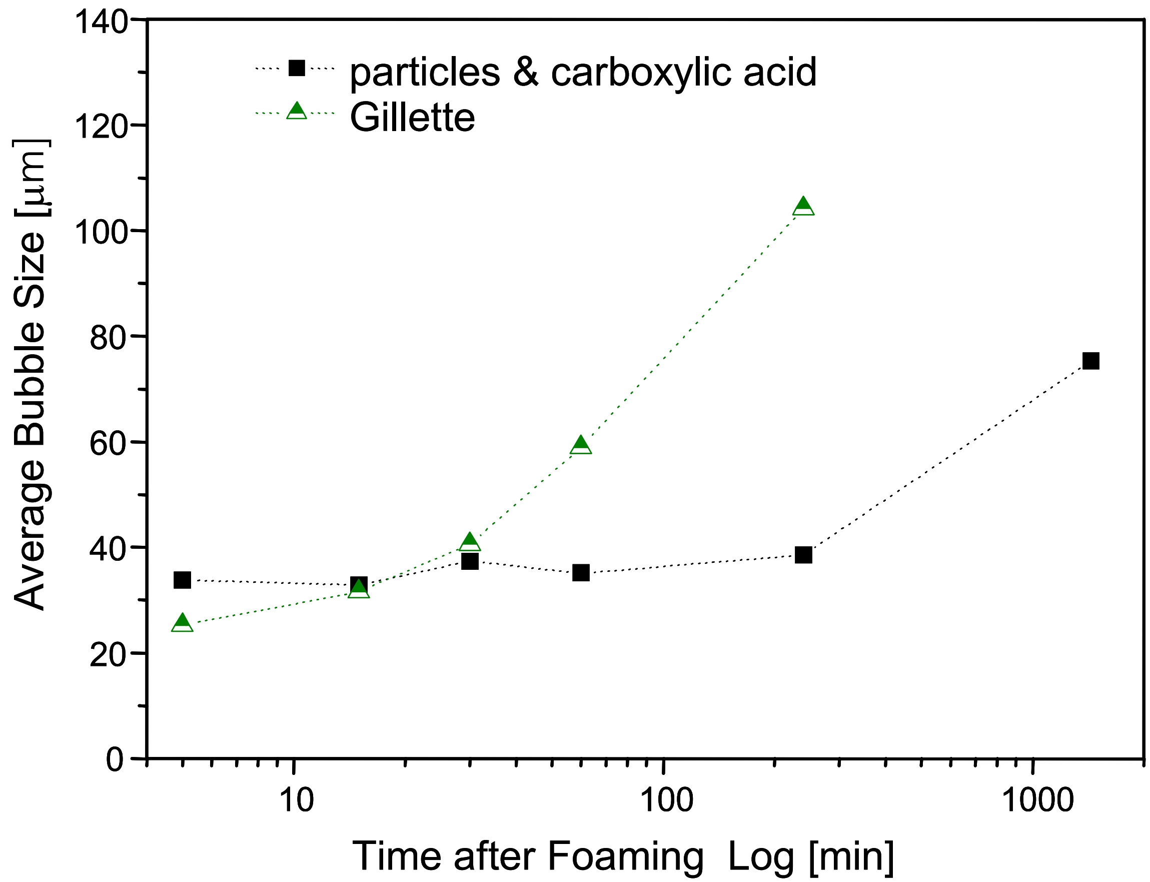
ETH Material

ETH Swiss Federal Institute of Technology Zurich

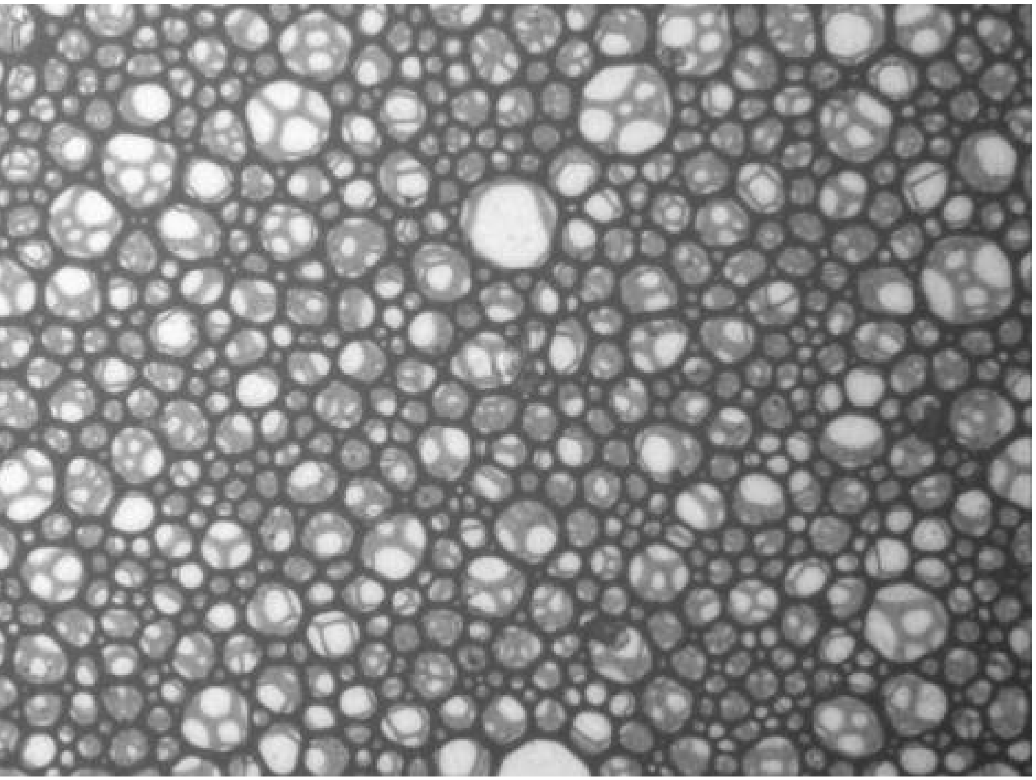
H_2O foam lamella stabilized by surface modified particles

Gonzenbach, U.; Gauckler, L. J. to be published



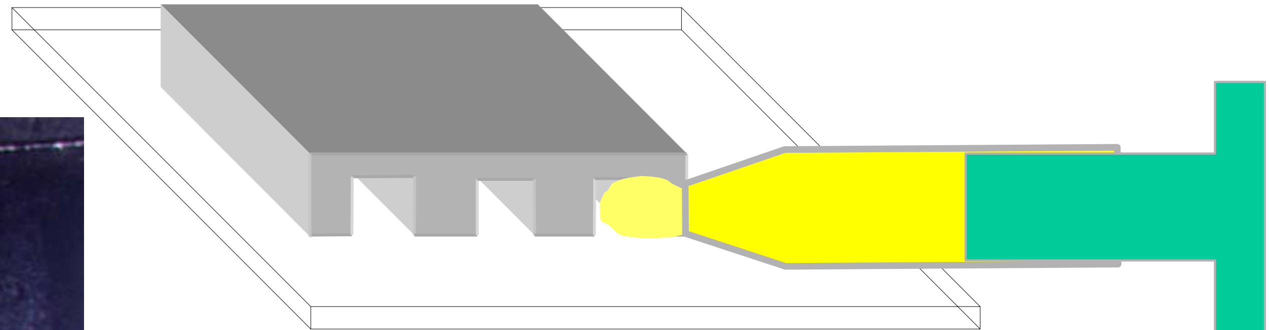


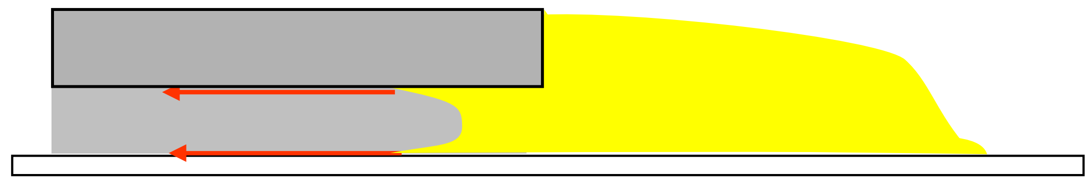
Foams & emulsions, ceramics



Gonzenbach, U., Gauckler, L.J. to be published

Micromolding in Capillaries (MIMIC)





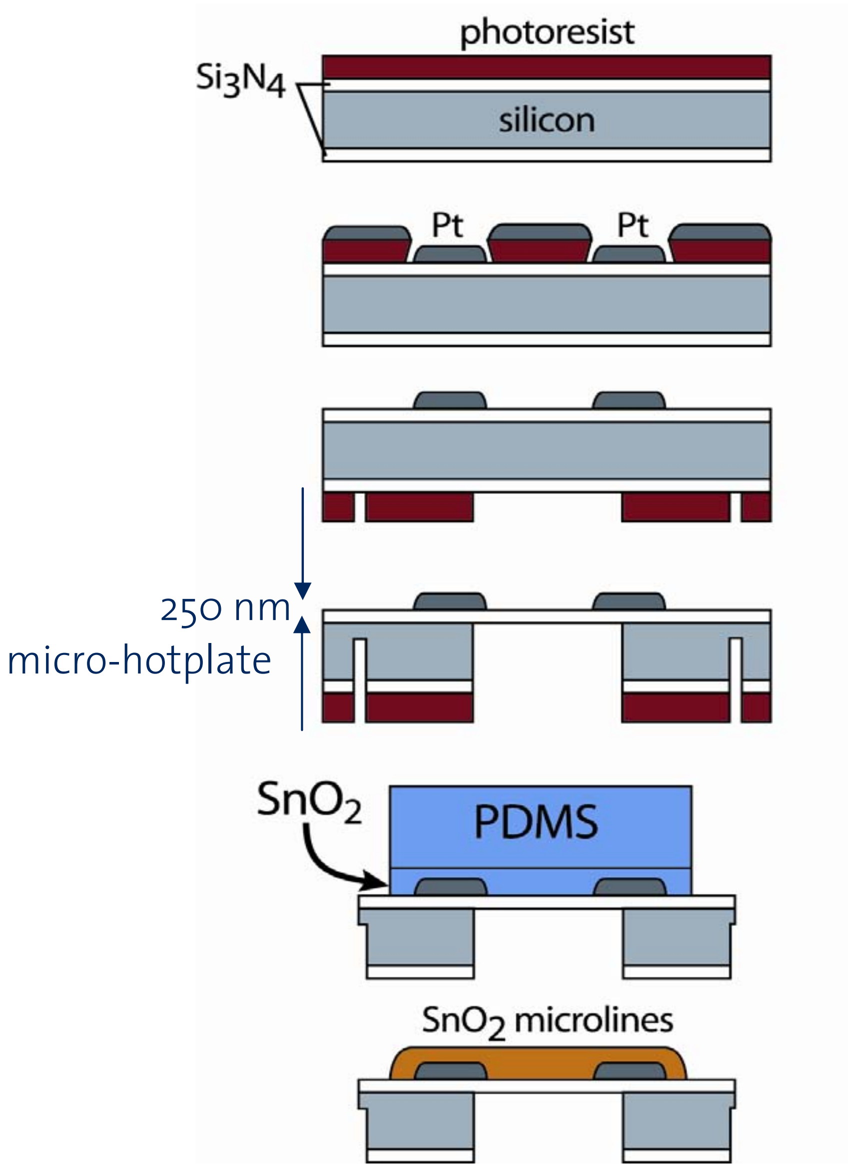
Capillary forces draw aqueous suspensions into microchannels.

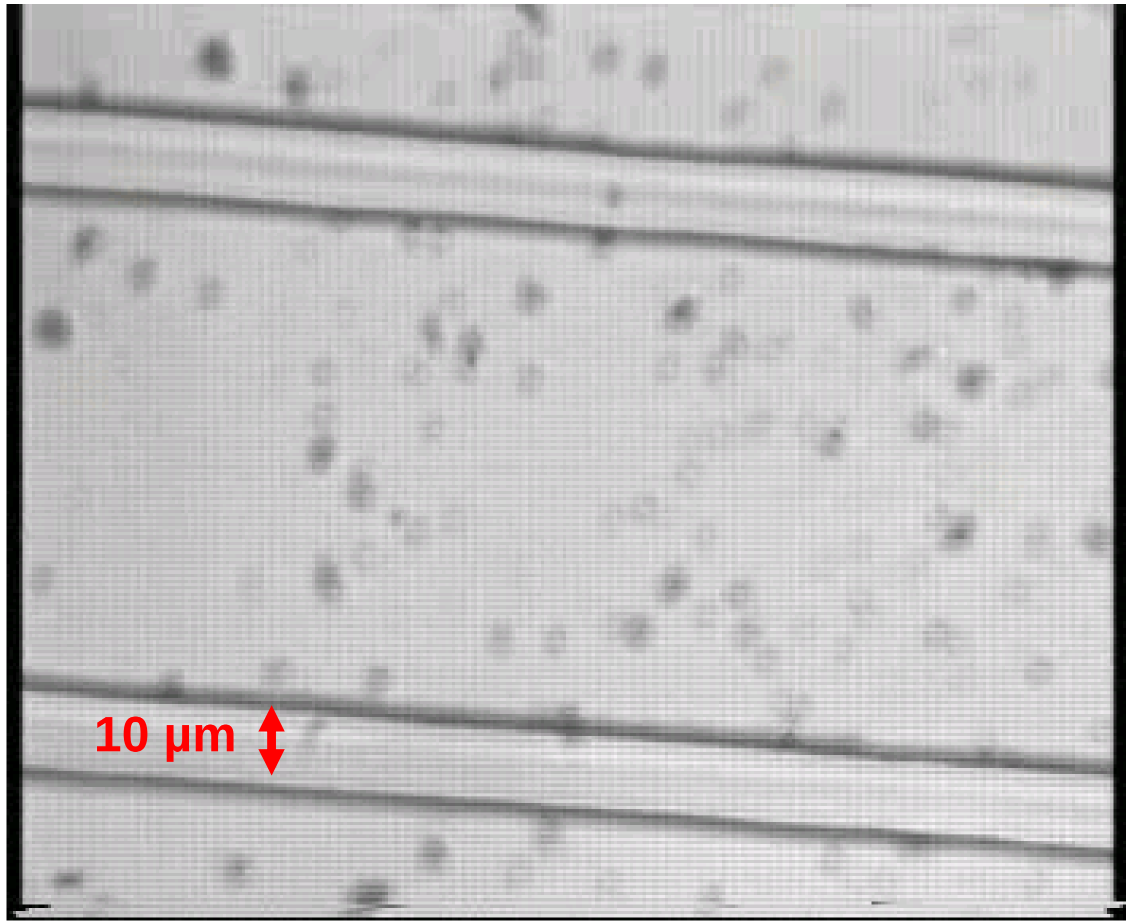
The PDMS (poly-dimethylsiloxane) stamp is oxygen plasma-treated to make its surface hydrophilic.

Y. Xia, G. M. Whitesides, *Angew. Chem. Int. Ed.* **1998**, *37*, 550-575

SnO2 sensor lines made by MIMIC: Directly observed

Heule, Vuillemin, Gauckler, Adv. Mater.15, 1237-1245; 2003,





33%vol suspension

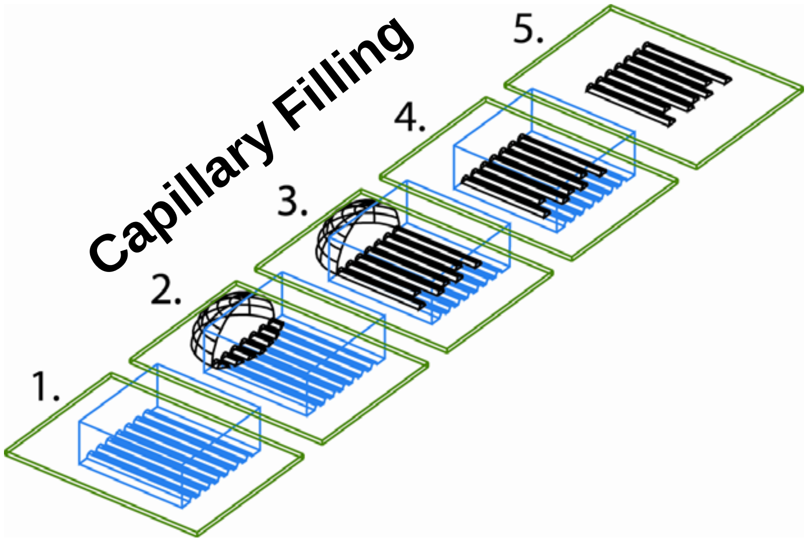
6 g water, 21 g SnO_2

tuned by colloidal chem.

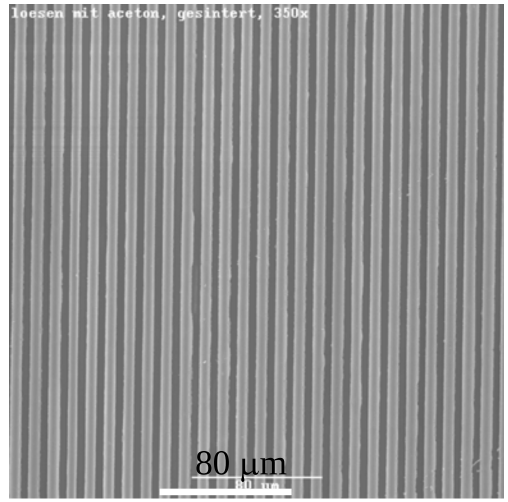
channel width 10 µm.

Micro-Ceramic Sensor Array

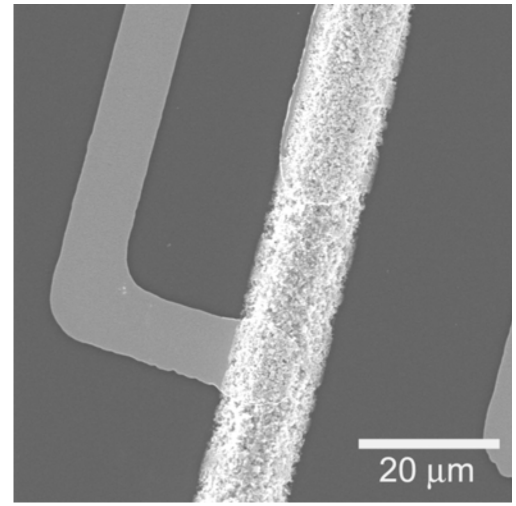
M. Heule and L. J. Gauckler, Adv. Mater., 13 [23] 1790–3, (2001).

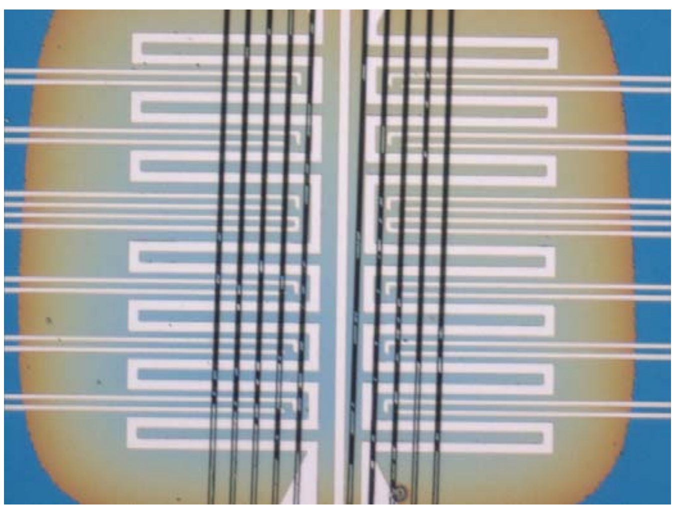


ceramic lines on Si



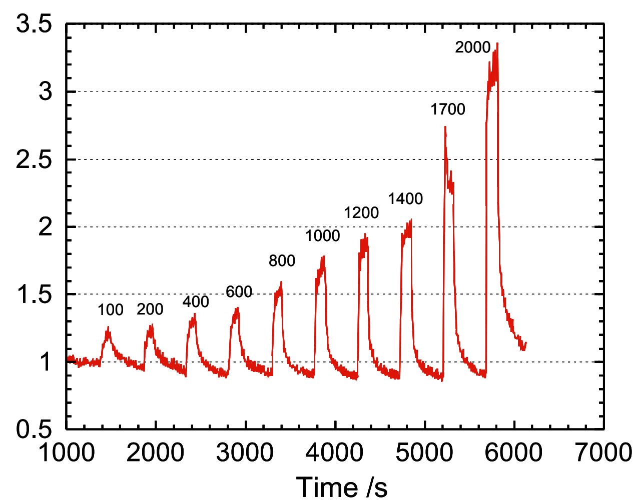
SnO_2 lines on Si
with Pt microcontacts





sensor array on micro-hotplate

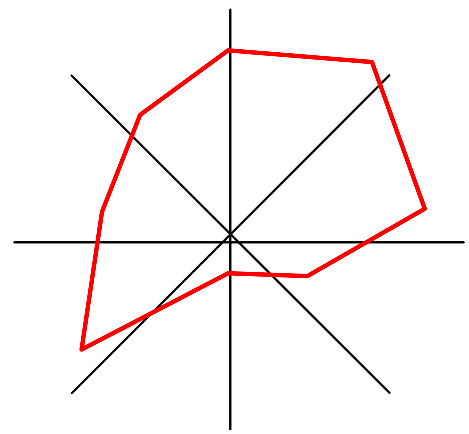
Dilution series from 100 to 2000 ppm H_2.



signal from one SnO_2 sensor

http://ceramics.ethz.ch

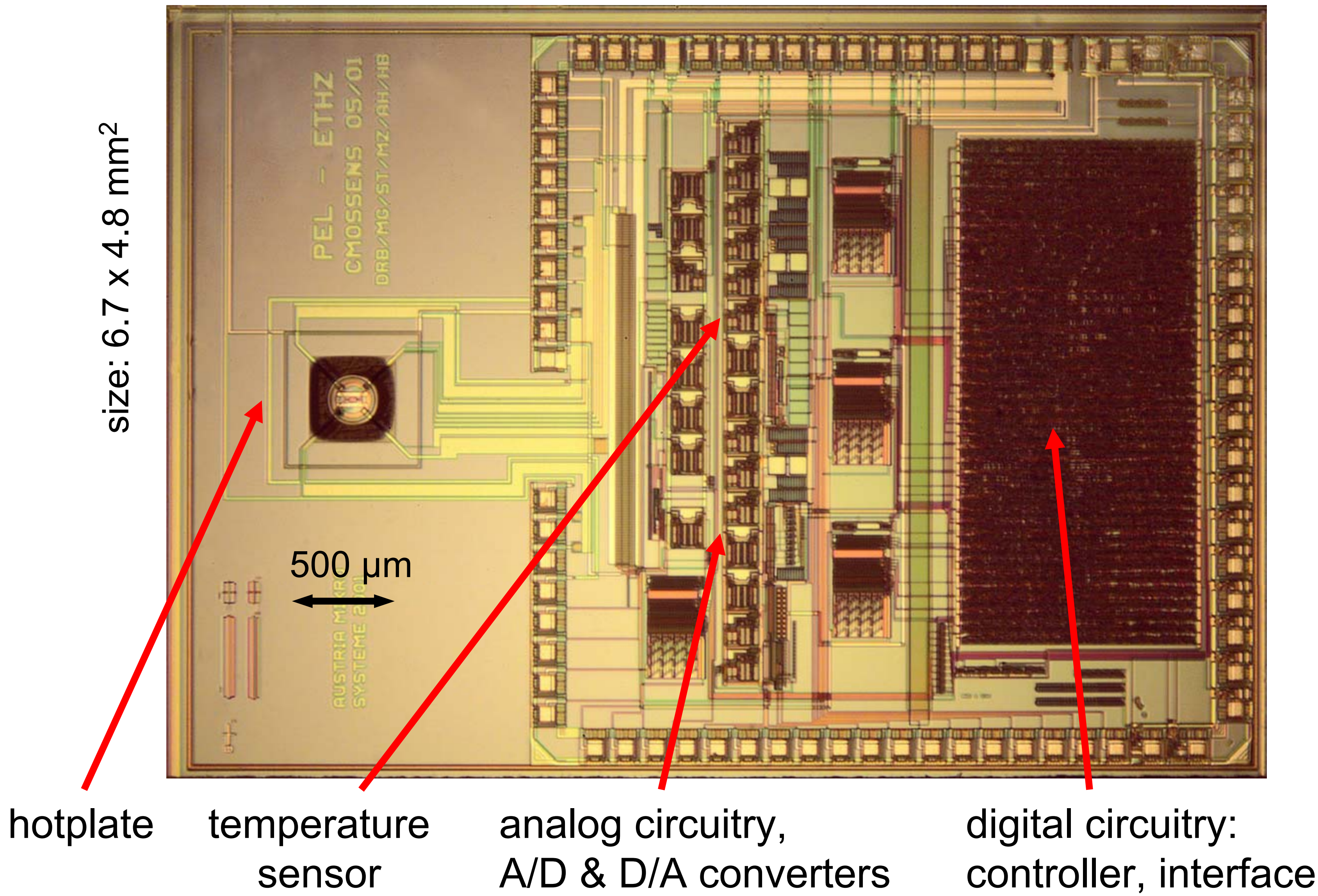
odor pattern



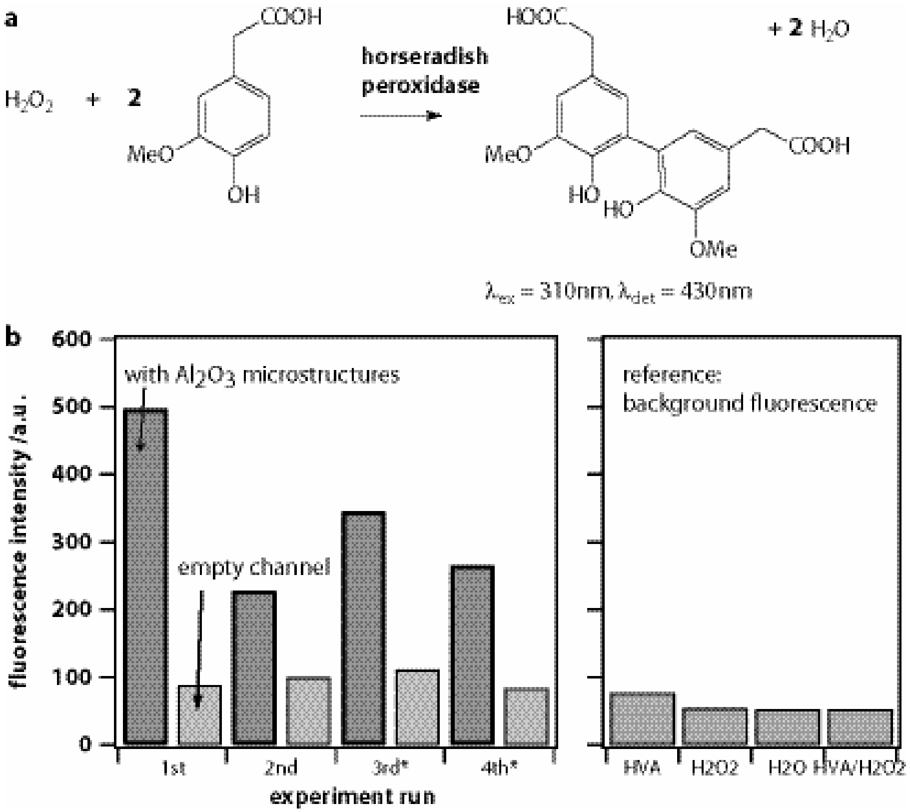
H_2, CO, NO_2, SO_2,
Alkanes, Ethanol...

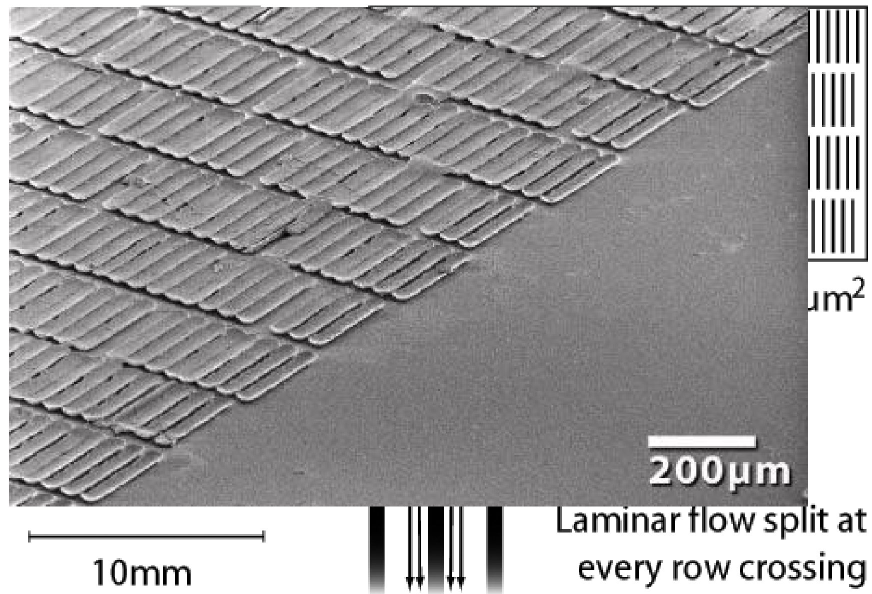
ETH Materials

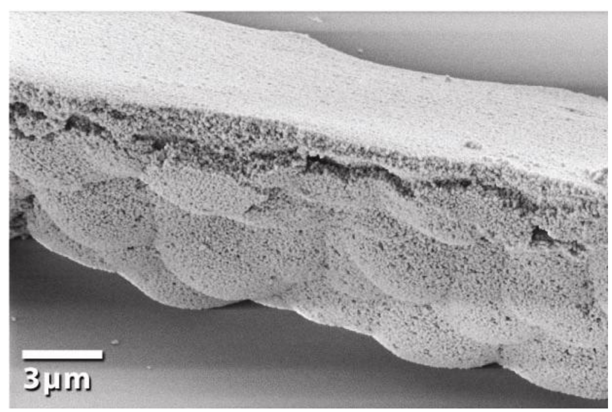
Analog/Digital Microhotplate System

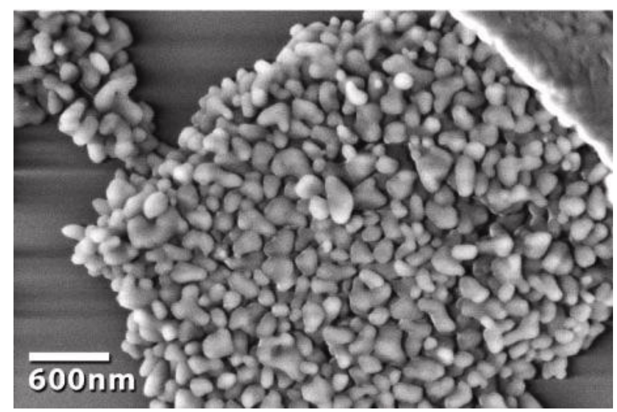


Chemical micro - reactor









M. Heule, K. Rezwan, L. Cavalli, L. J. Gauckler,
Adv. Mat. 15 (14), 1191-1194, 2003

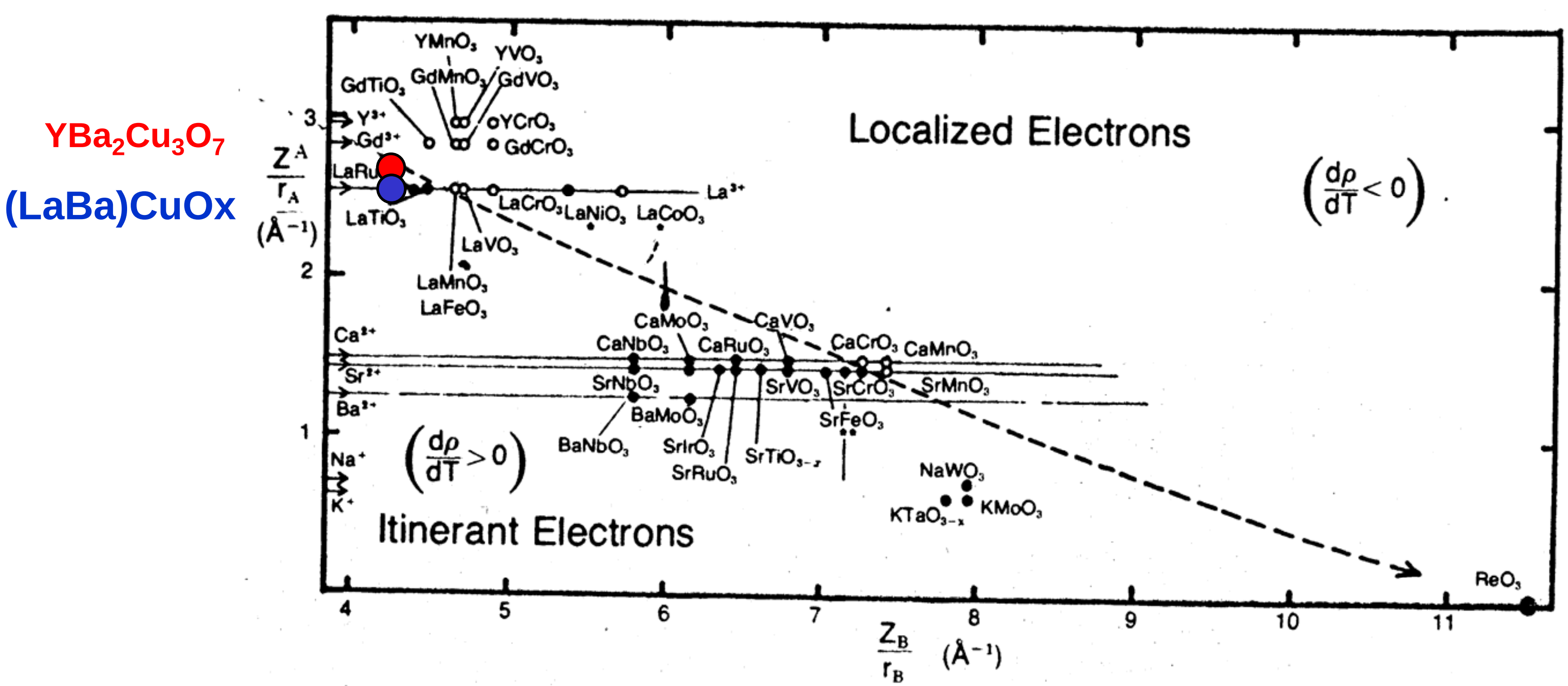
ETH Materials

http://ceramics.ethz.ch

HTSC materials for fault current limiters

Perovskite ABO_3

K. Kamata, **T. Nakamura** and T. Sata, Bull. Tokyo Inst. Tech. 120, 73-79 **(1974)**



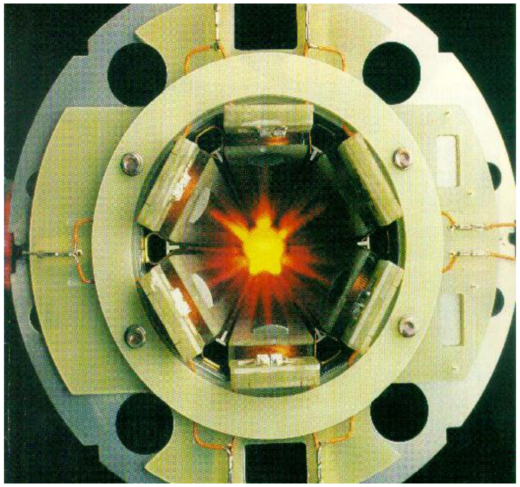
R. Roy: J. Am. Ceram. Soc. 60, 7-8, **1977**, 350-363

.....Very little cut-and-try is now needed by the molecular engineer **designing a new perovskite catalyst or superconductor** or one most likely to undergo a metal-insulator transition. (Obviously, these would sit on the borderline in the SFM.) ....

A. Müller & G. Bednorz: G. Bednorz and K. A. Müller, Z. Phys. B: Condens. Matter **64**, 189,1986

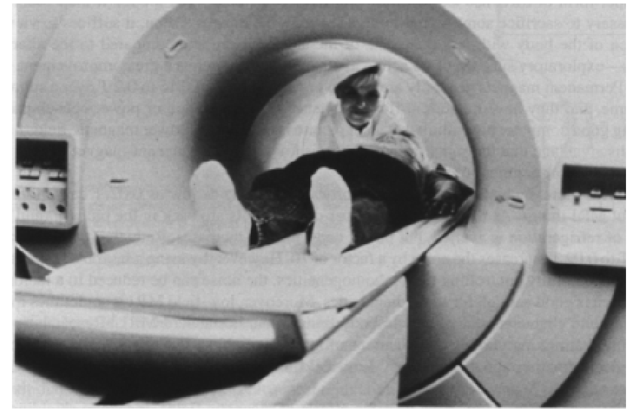
Discovery of superconductivity in 1986 in La-Ba-Cu-O

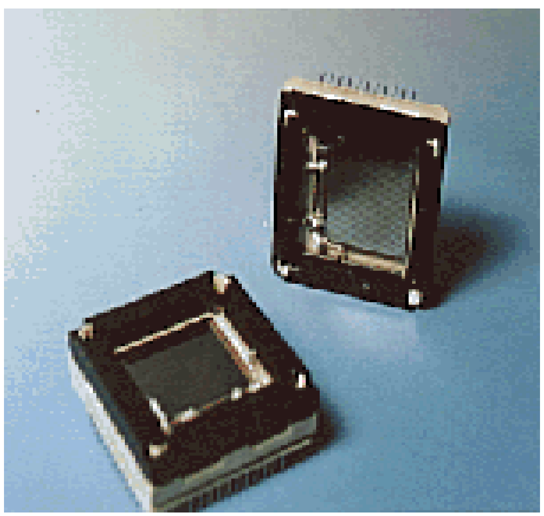
HTSC materials & potential applications



Research:
Accelerator
Resonator

Medicine:
MRI



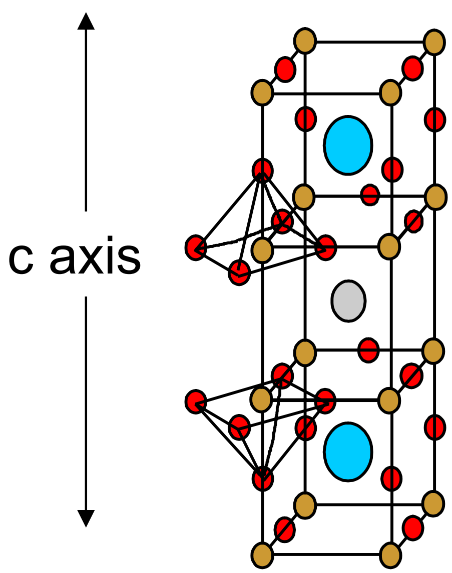


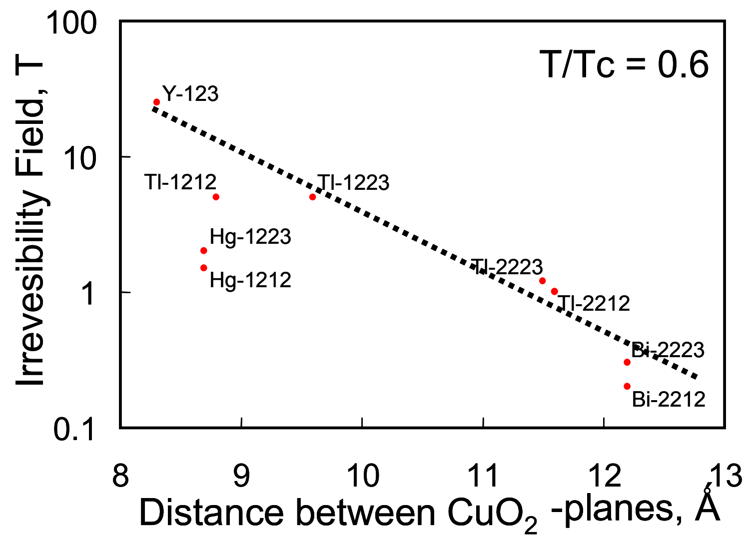
Electronics:
Microwave filters

Transportation:
Maglev

Pinning & weak links

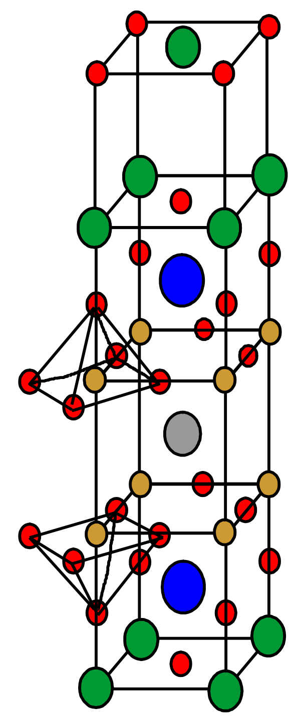
good pinning
(Y-123)
but weak links
no transport current
$YBa_2Cu_3O_7$

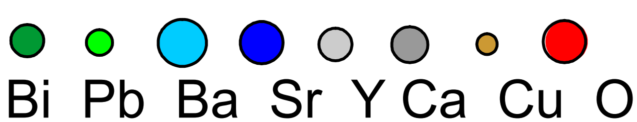




no weak links
(Bi-2212)
but low irreversibility field
and highly anisotropic
properties

Bi-2212



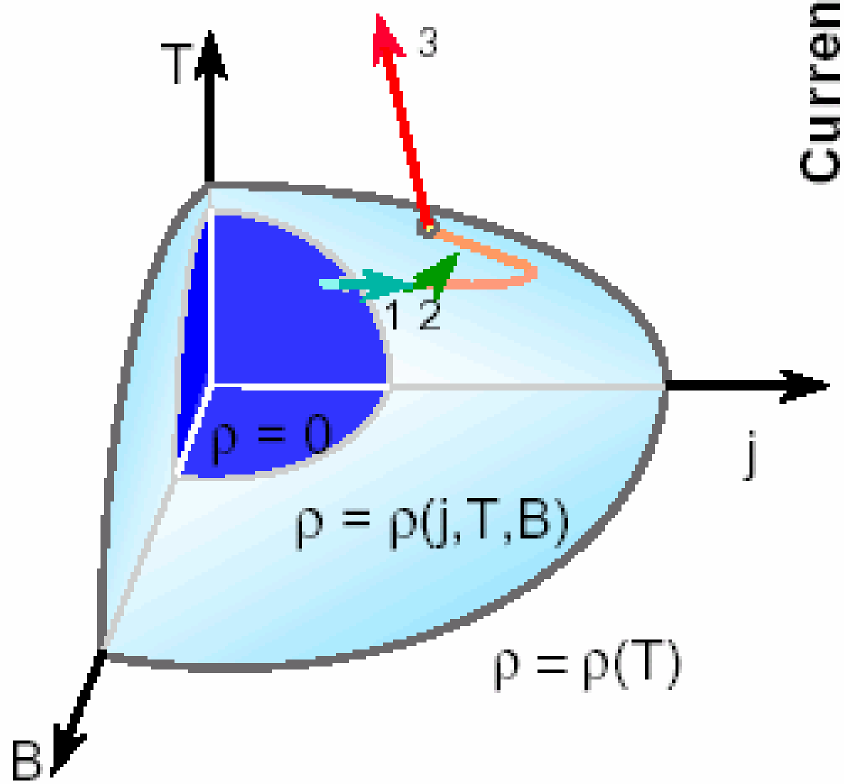


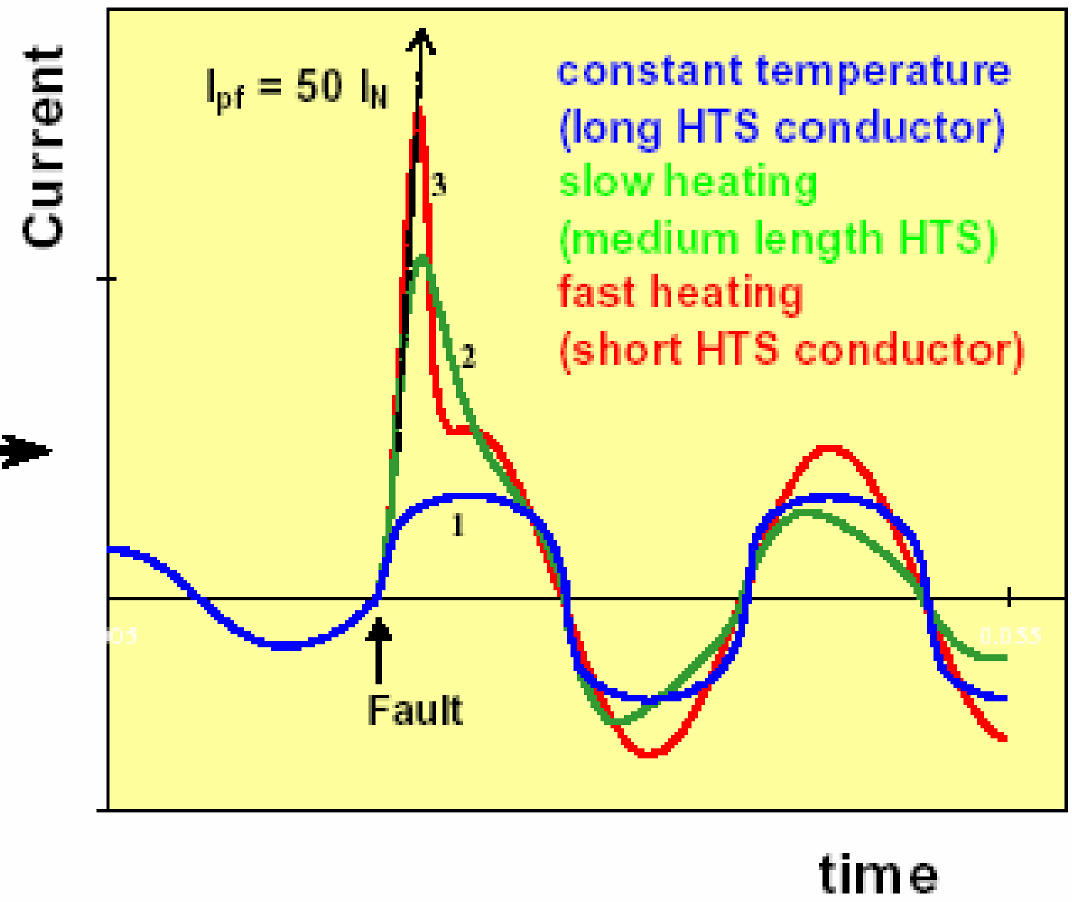
D. Schneider, Dissertation, ETH-Zurich

ETH Materials

http://ceramics.ethz.ch

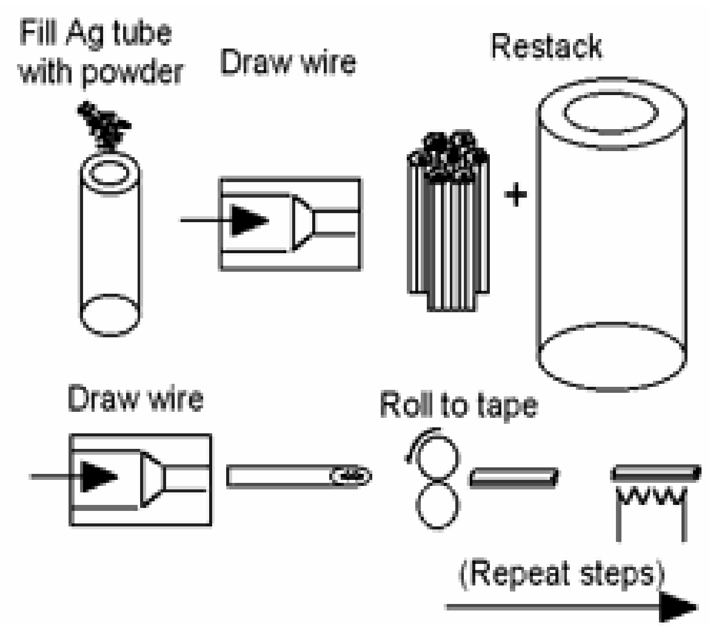
Principles of Fault Current Limiters



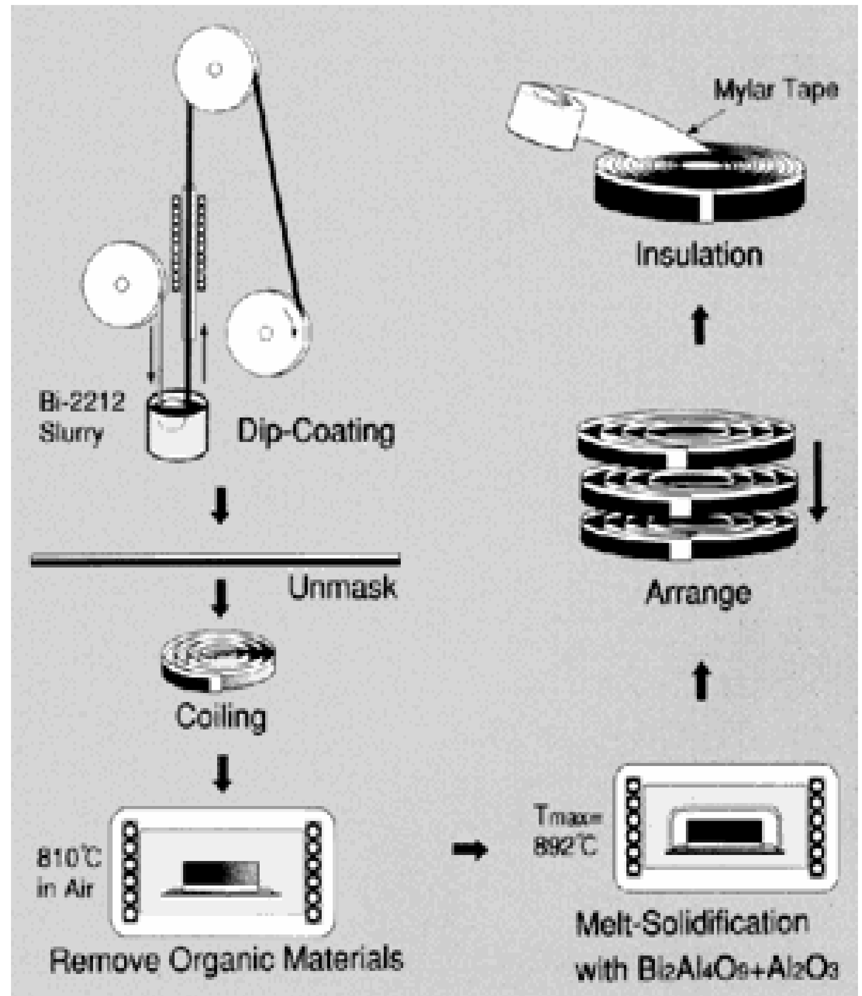


HTC Device Fabrication Technologies

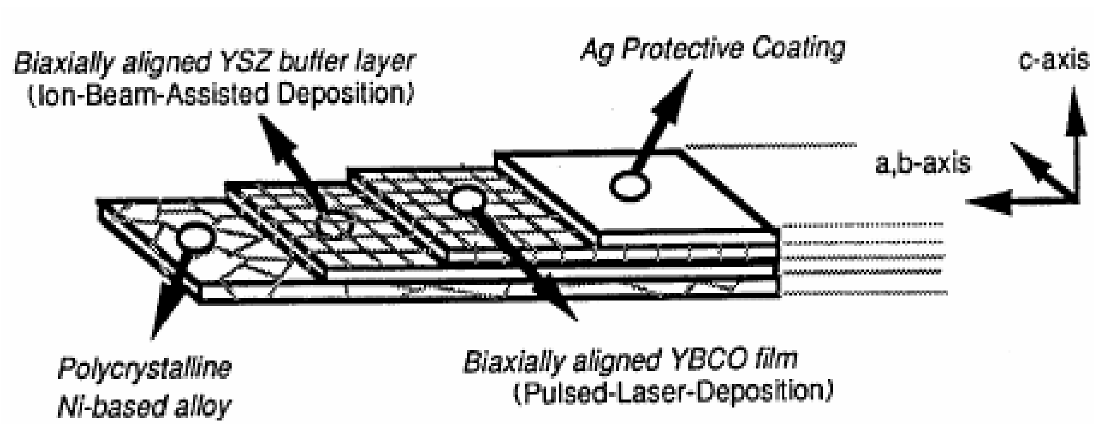
for Bi-2223: powder in tube, draw & redraw &annealing



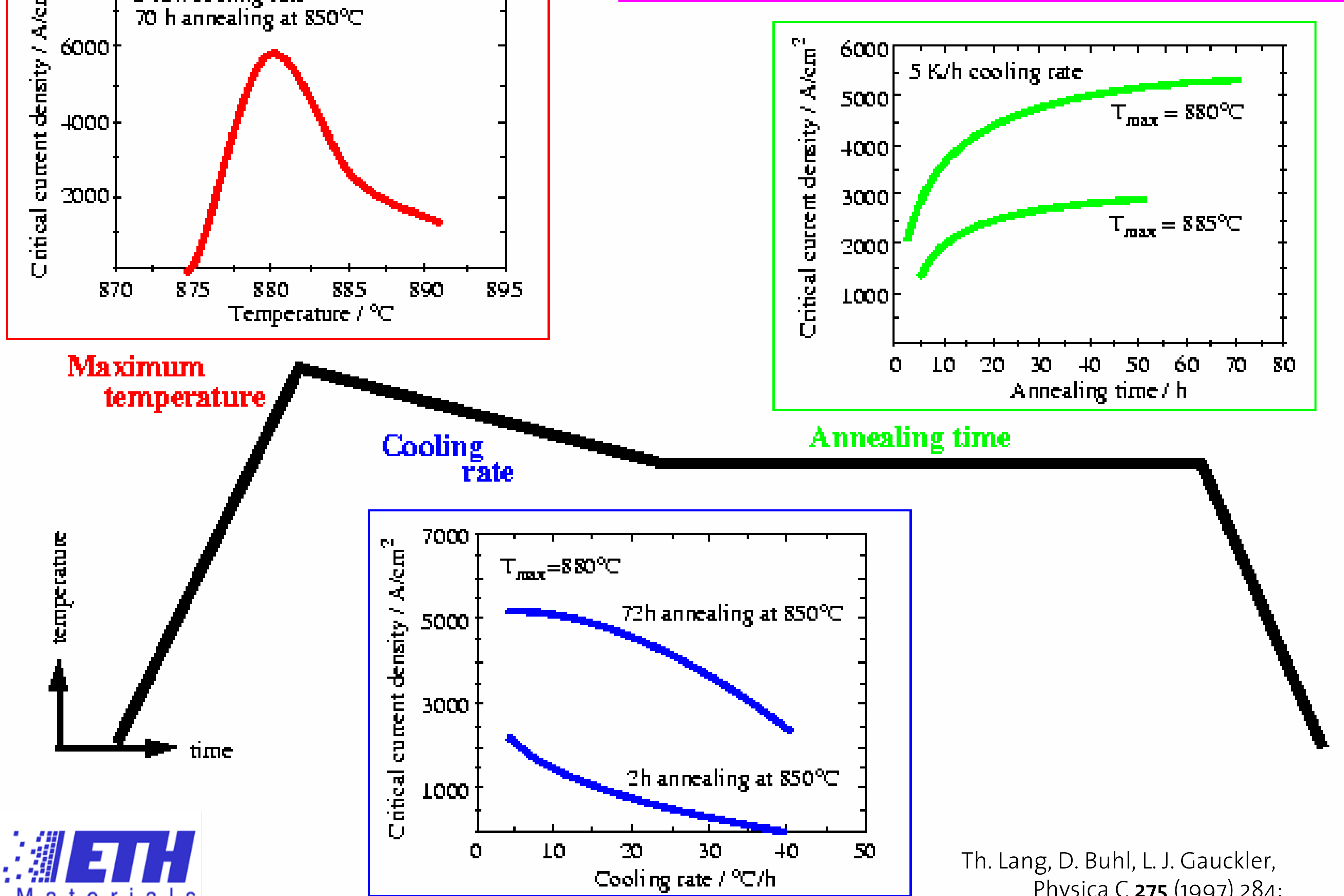
for Bi-2212: melt processing



for YBCO: gas phase process



PROCESSING



Th. Lang, D. Buhl, L. J. Gauckler, Physica C **275** (1997) 284;

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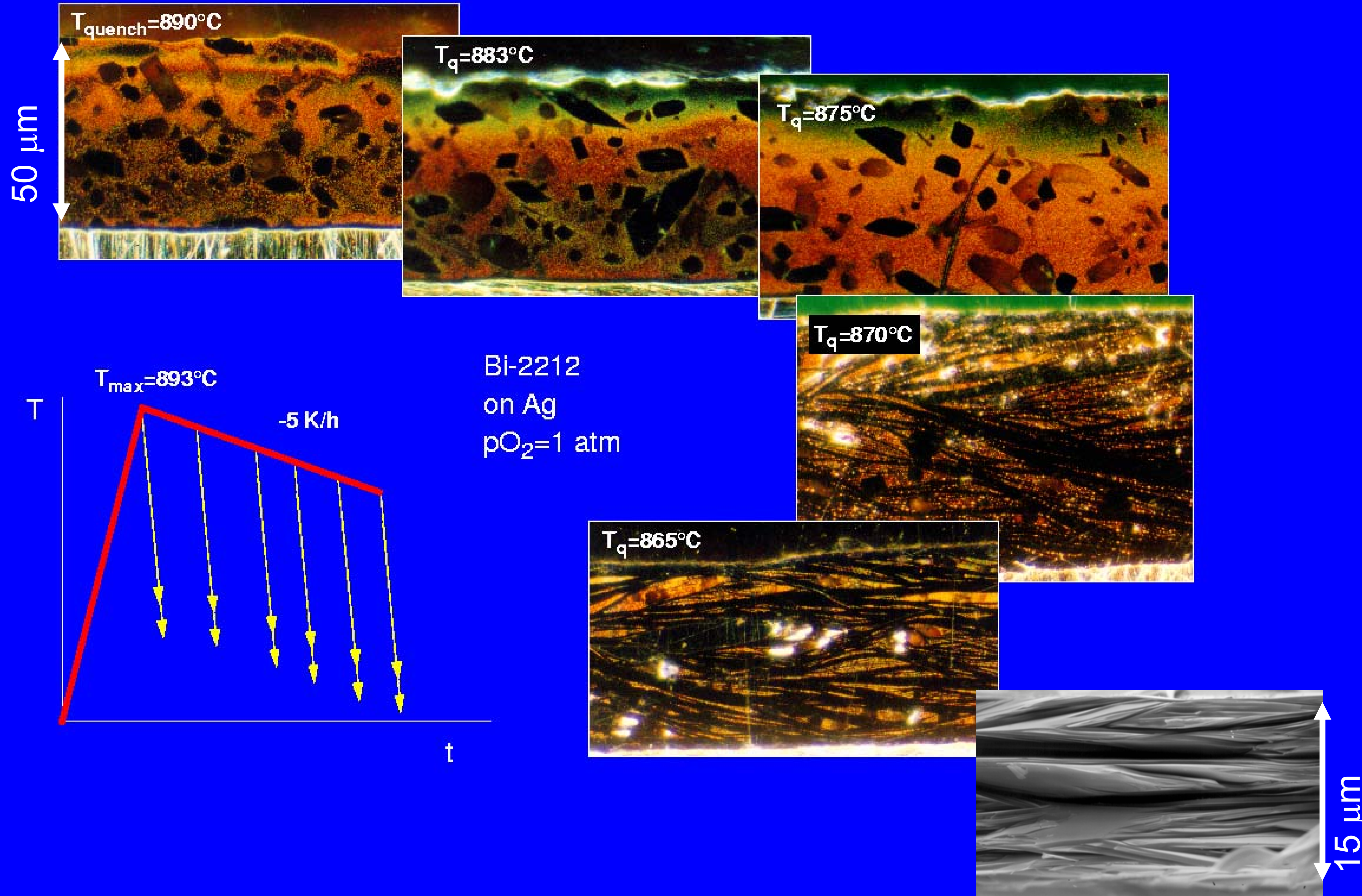
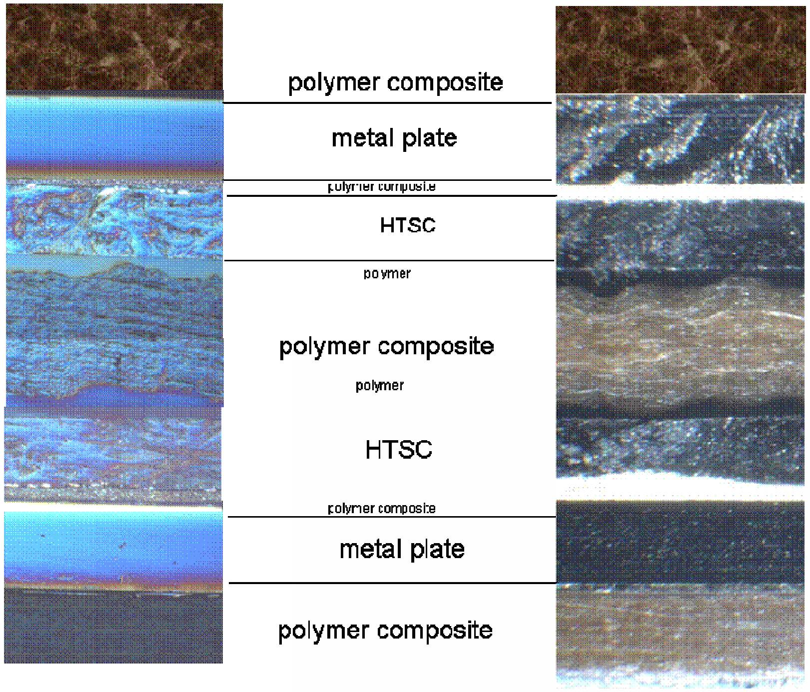
Bi-2212 Phase Formation

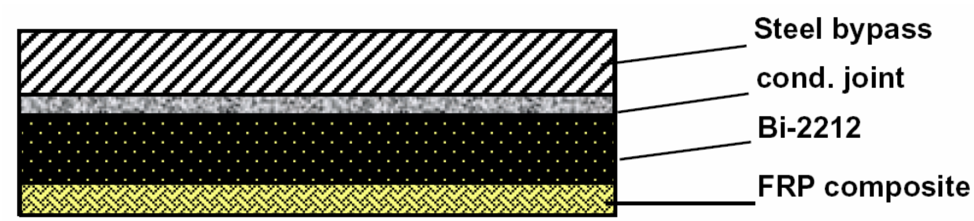


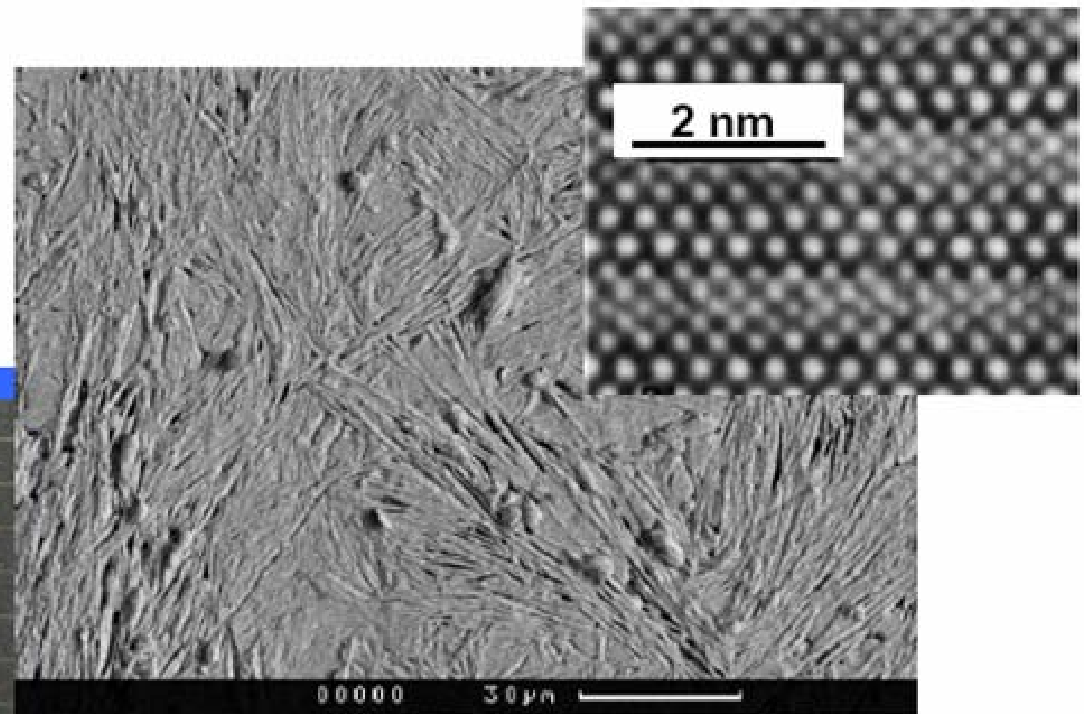
fully processed (SEM)

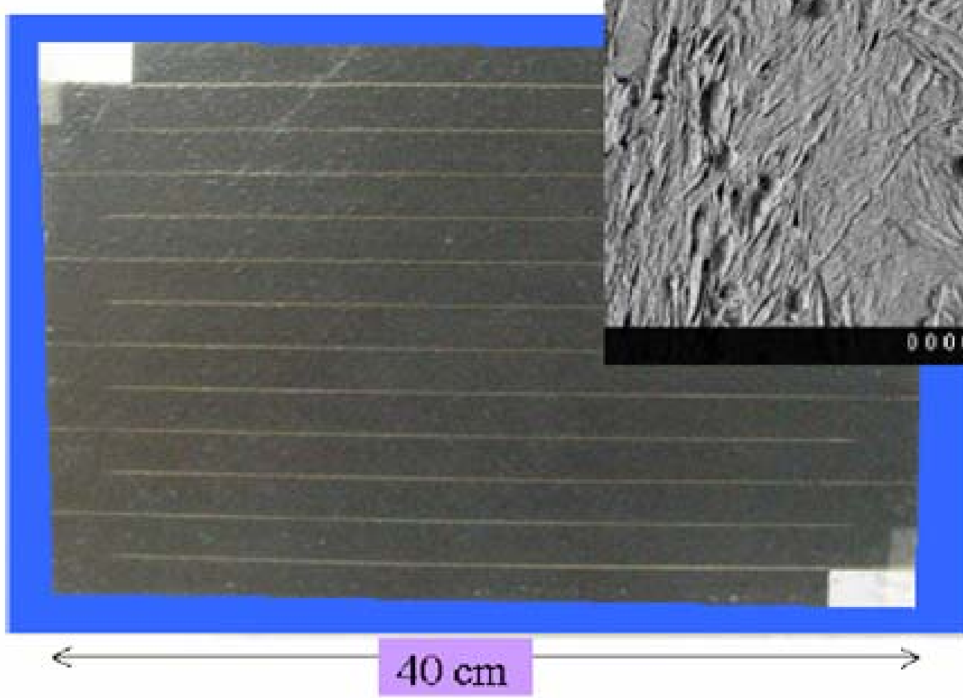
D. Buhl, T. Lang, L. J. Gauckler, Supercond. Sci. Technol. 10 (1997) 32

SCFCL composite based on Bi 2212







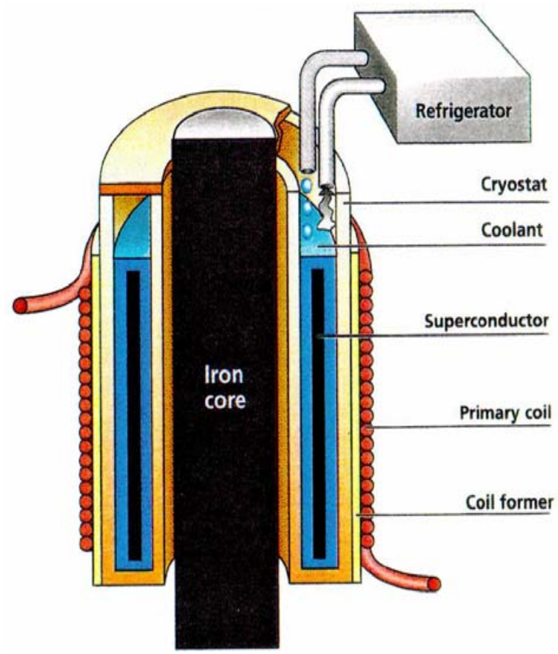


Fault Current Limiters (FLC)

1998

inductive FLC

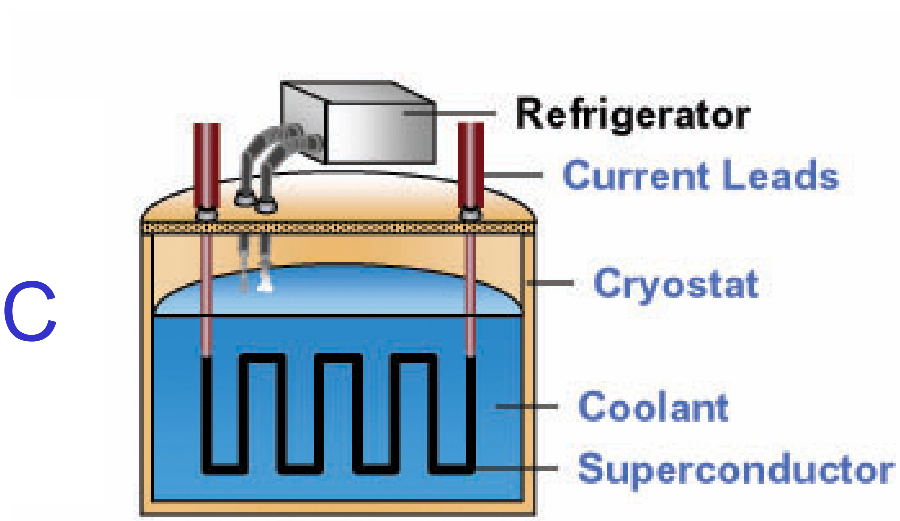
1.2 MW

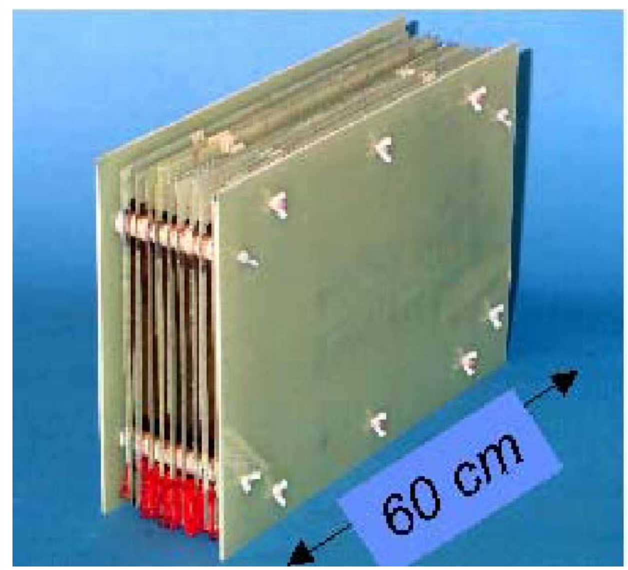


2004

resistive FLC

20 MW





http://ceramics.ethz.ch

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SCFCL Project in ABB

1986 Discovery of HTS

1989 Start of project

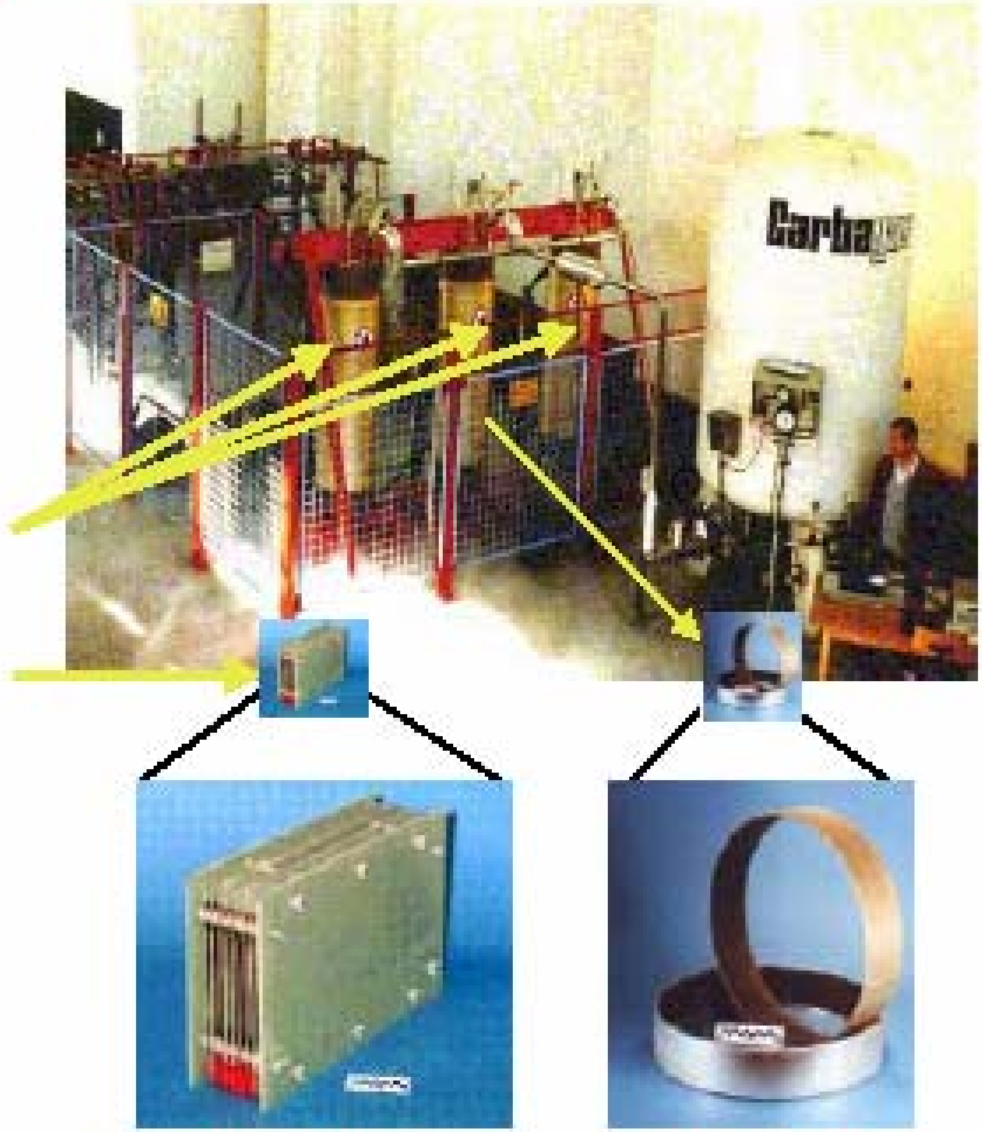
1993 0.1 MVA "inductive" model (wr)

1996 1.2 MVA "inductive" model (wr)

1998 1.6 MVA "resistive" model (wr)

2001 6.4 MVA "resistive" model (wr)

2003 20 MVA Pilot at customer site



1.6 MVA

0.02 MVA

ABB Corporate Research

CHCRC.V4 MkC 06.09.01

ABB

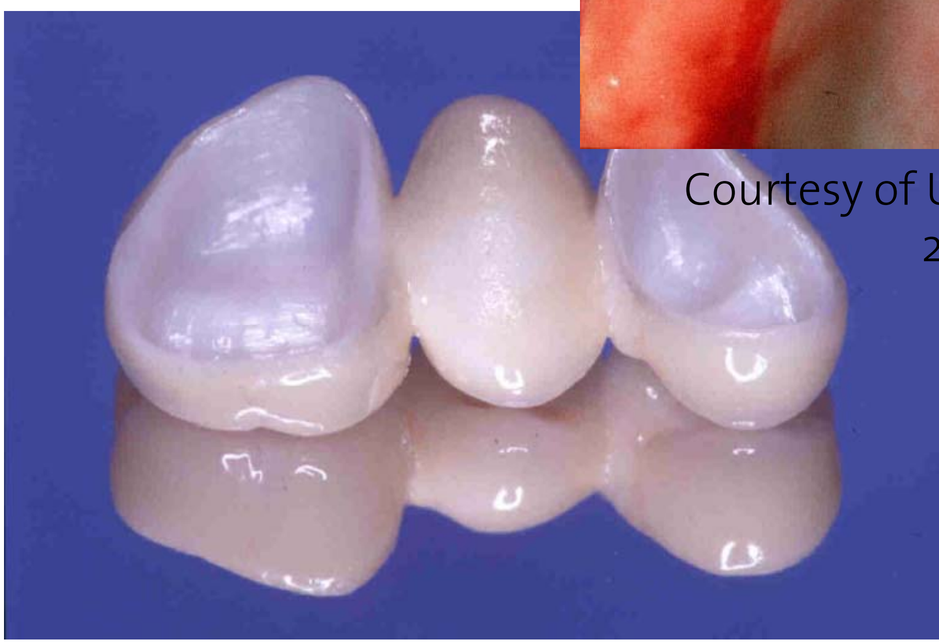
Rapid Prototyping of Ceramic Components

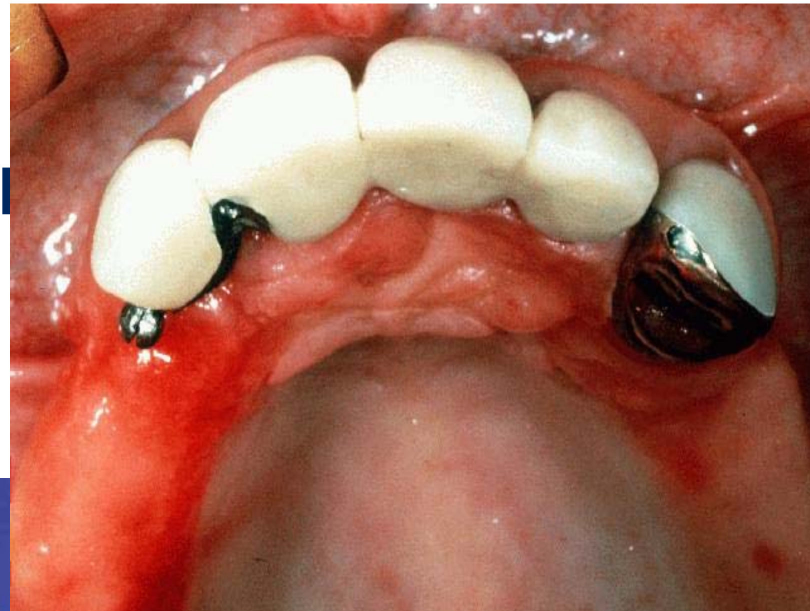
Etruscan bridge

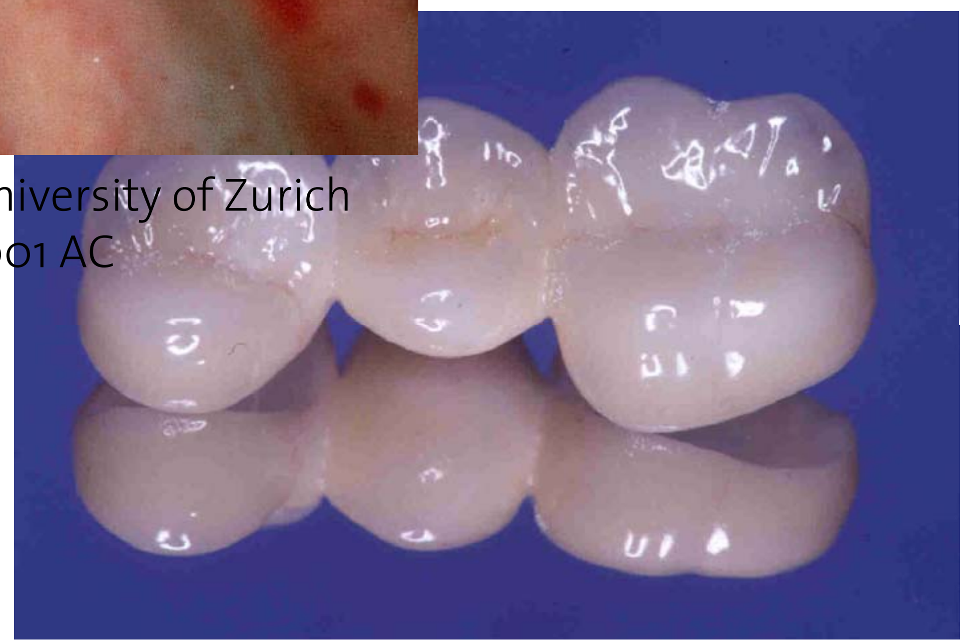
(200 BC)

(600 BC)

All ce ore.....

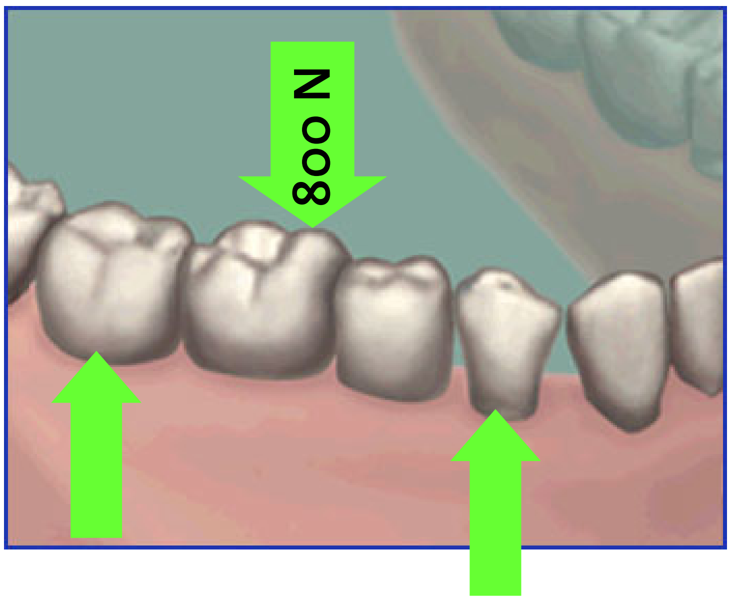






Courtesy of University of Zurich
2001 AC

Maxiumum load on a bridge during mastication



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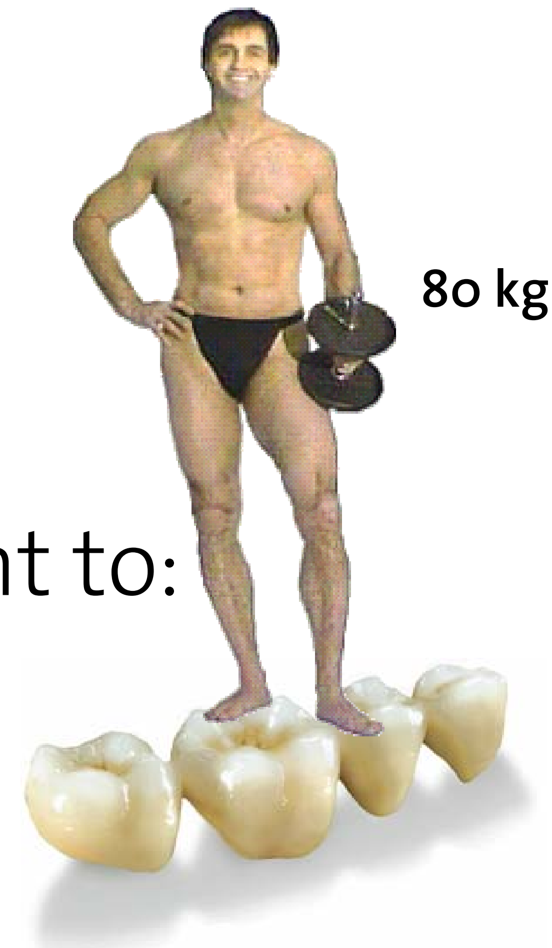
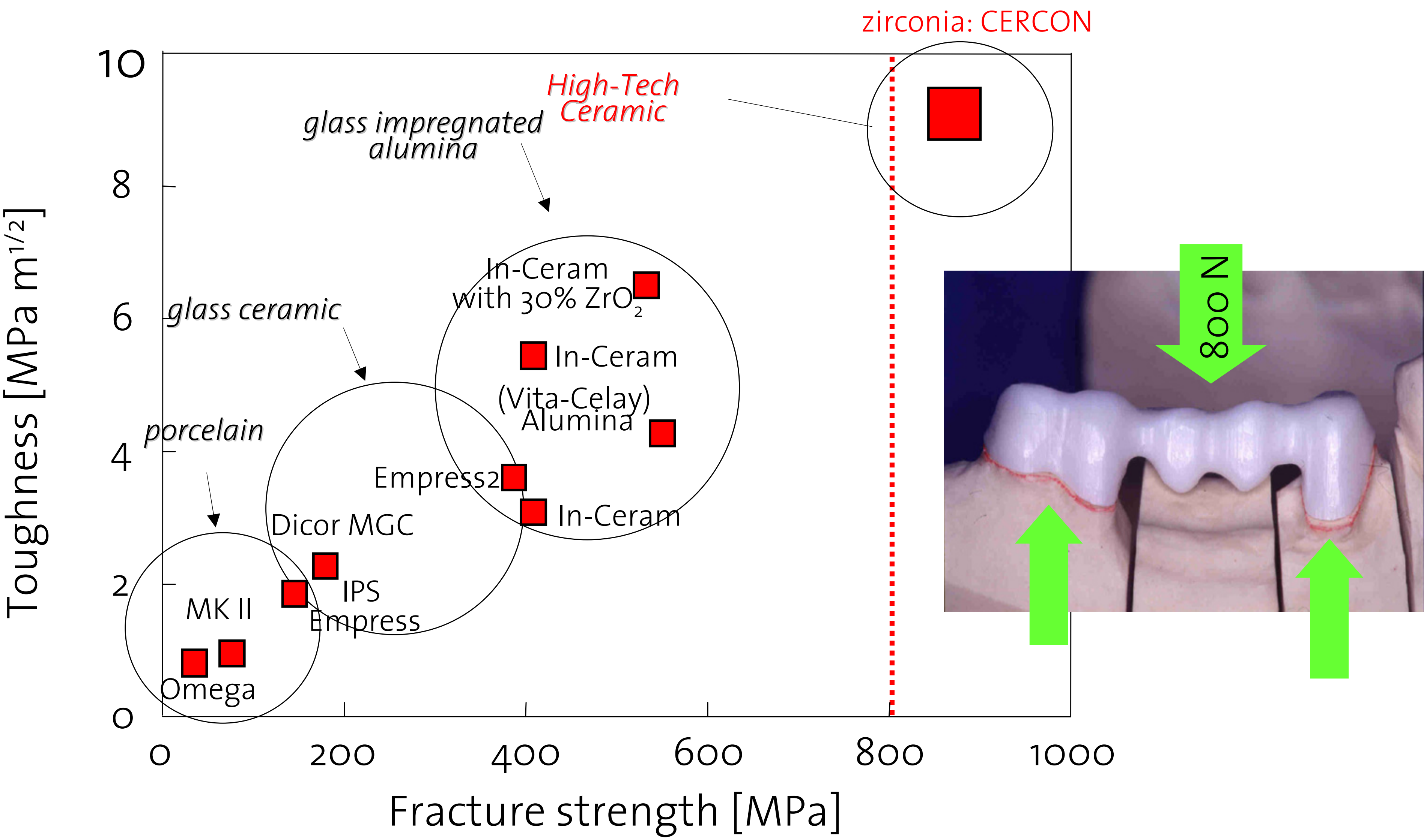


Ceramic materials in dentistry



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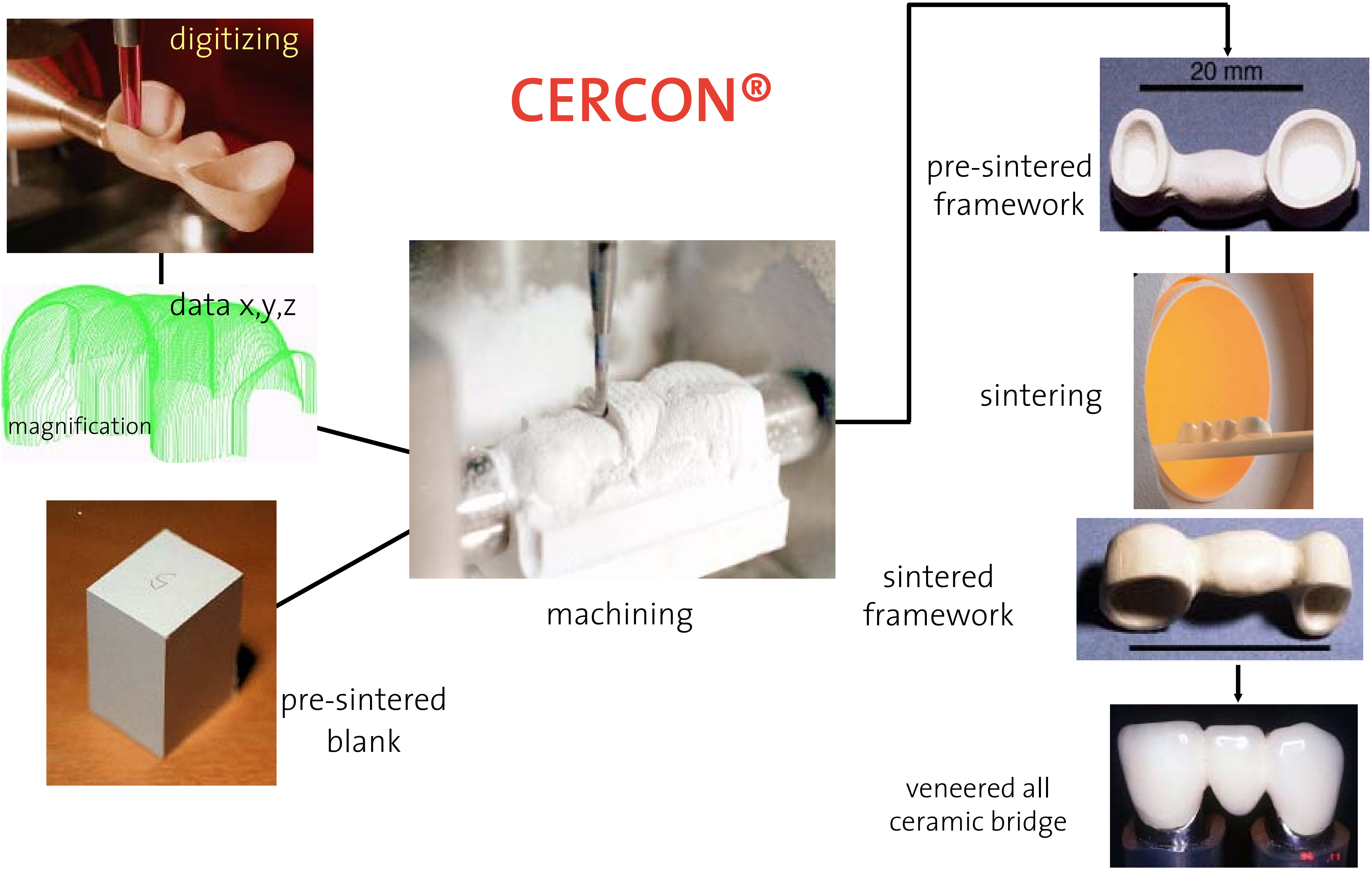
ETH Zürich aproach: CERCON®



http://ceramics.ethz.ch

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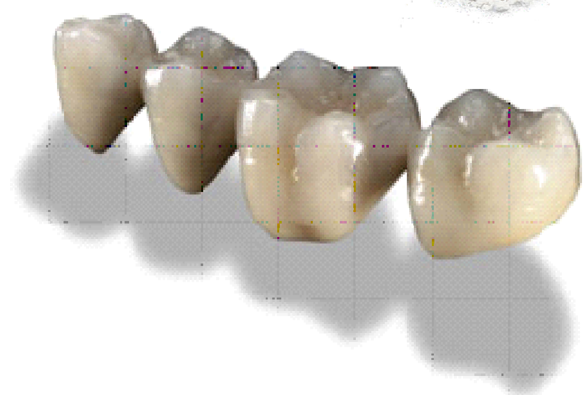
cercon®

smart ceramics

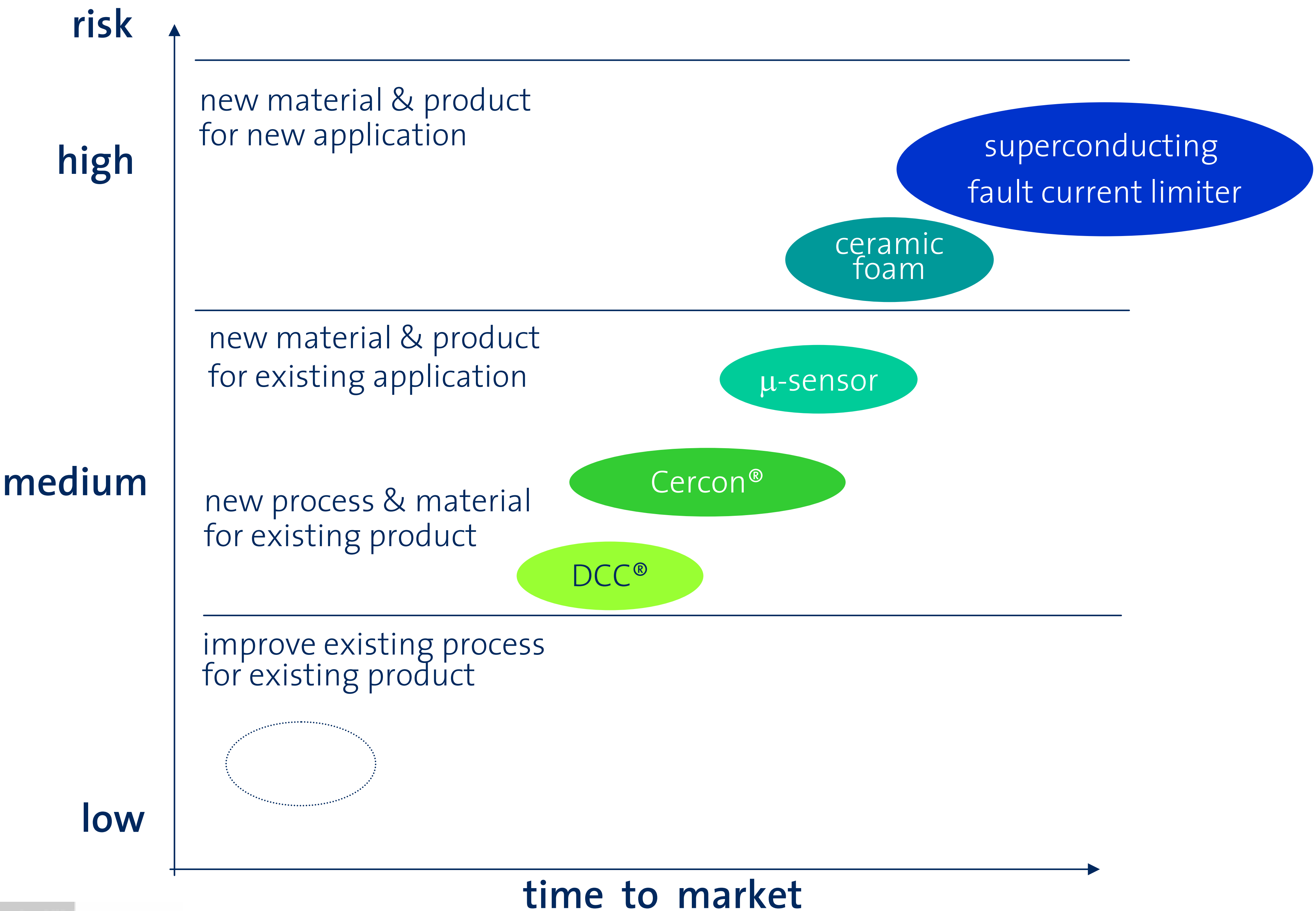
cercon brain



Clinical trails at UNI Zürich since 1998

(Courtesy of University of Zurich)

Innovations through New Ceramic Materials and Processing



ETH Materials

Thanks is due to:

for fuding:
KTI (CH)
NSF (CH)
ABB

for collaborations with:

MPI-Stuttgart
Technion Haifa
U. Penn.
U. Mich.
MIT Boston

ABB (CH)
Ceramtec (D)
Sensirion (CH)
Degudent (D)
Dentsply (USA)
CIBA (CH)
Novartis (CH)
Metoxit (CH)
Treibacher (A)

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