

Microwave Heating Ceramics

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Alfred University
Undergraduate Seminar
December 12th, 2002

Outline

- About Ceralink
- Microwave Heating
- Microwave Research
- Commercial Firing with Microwaves
- Microwave Testing Center

About Ceralink

- Consulting
- Research and Development
- Linkages

Focus on materials related technologies:

- Breakthrough
- Ready to implement

About Ceralink

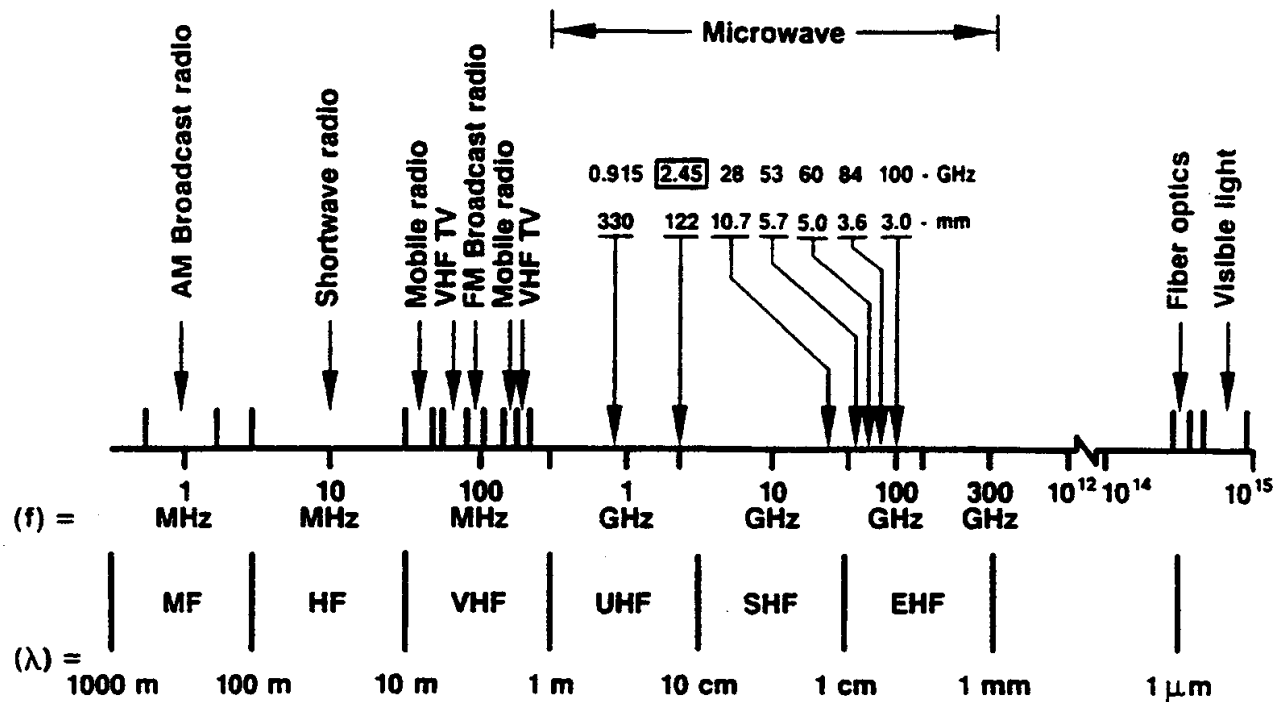


- 2 Full time
- 1 FT opening for engineer
- Part time student engineers
- Part time office help

Affiliate Member CACT Alfred University

- Equipment
- Faculty Expertise

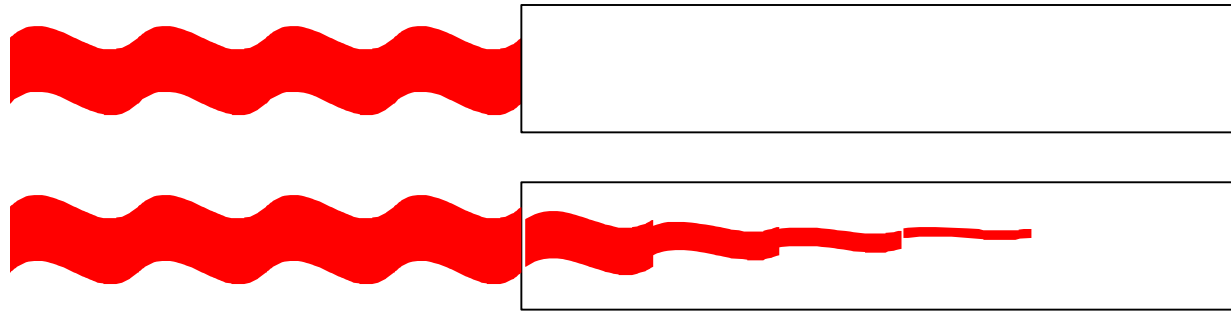
Electromagnetic Spectrum



ISM (GHz)

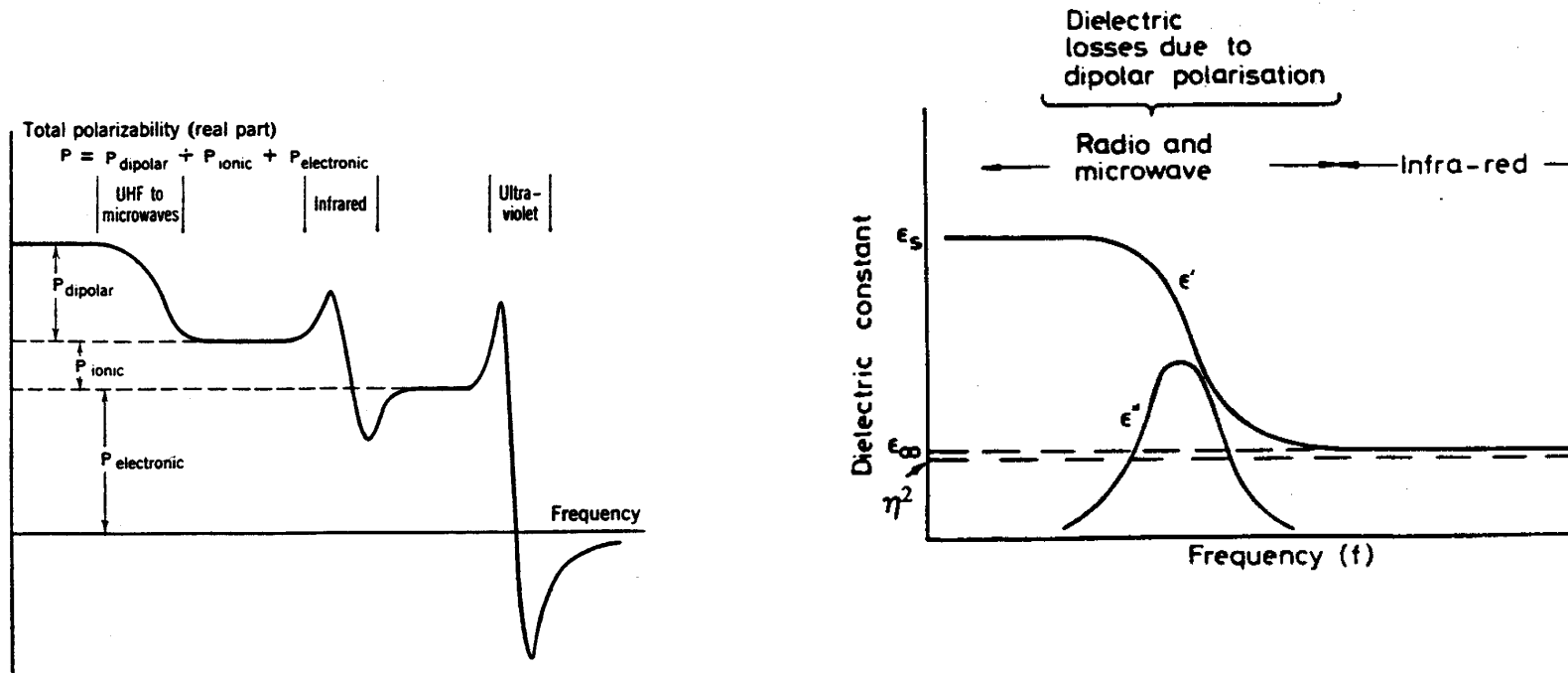
- | |
|--------|
| 0.915 |
| 2.45 |
| 5.80 |
| 24.124 |

Microwave Heating



Materials absorb microwave energy through relaxation mechanisms:
e.g. dipolar, ion jump, and ohmic losses

Dielectric Properties



Polarizability and Dielectric Properties as Function of Frequency

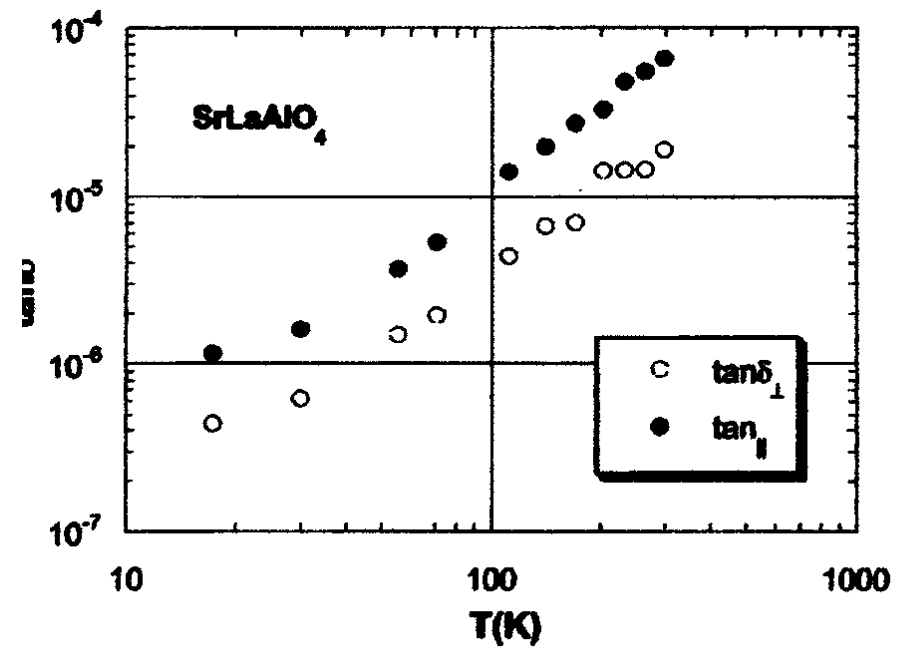
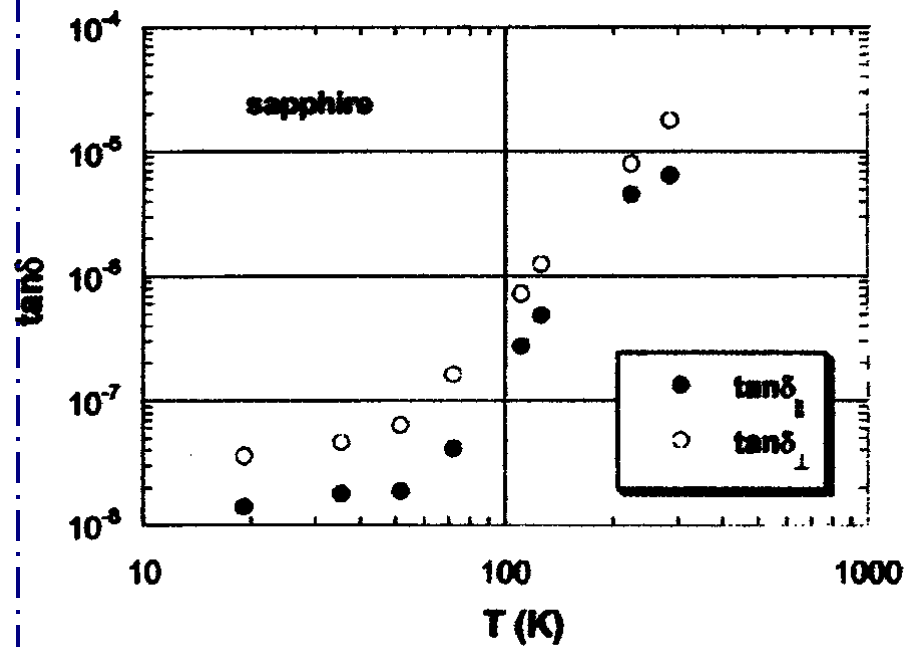
Dielectric Properties

$$\epsilon_r = \epsilon_r' - i \epsilon_r''$$

$$\text{Tan } \delta = \epsilon_r'' / \epsilon_r'$$

- Complex permittivity \rightarrow ability to absorb and store energy
- Permittivity (ϵ_r') \rightarrow penetration of microwaves
- Loss factor (ϵ_r'') \rightarrow store energy
- Loss tangent ($\text{Tan } \delta$) \rightarrow Convert absorbed energy to **HEAT**

Dielectric Loss increases with Temperature



Krupka et al., Meas. Sci. Technol. 10 (1999)

Microwave Heating

$$P = 2\pi f \epsilon_0 \epsilon_r'' E^2$$

P = volume energy density (W/m²)
f = frequency (Hz)
 ϵ_0 = permittivity of free space
 ϵ_r'' = dielectric loss factor
E = electric field strength (V/m)

Power Density → Heat

$$D = \frac{\lambda_0}{2\pi} \frac{\epsilon_r' 1/2}{\epsilon_r''}$$

D = penetration depth
 λ_0 = wavelength in vacuum
 ϵ_r' = permittivity
 ϵ_r'' = dielectric loss factor

Penetration Depth

Microwave Heating

Material	Temp C	Penetration depth (cm)
Water	25	1.5
Water	95	5.7
Ice	-12	1100
Wood	25	3-350
Hollow Glass	25	35
Porcelain	25	56
Epoxy resin	25	4100
Teflon	25	9200
Quartz glass	25	1600

Microwave Heating

Microwave:

- Volumetric heating → fast
- Inverse temperature profile
- Thermal runaway possible
- “Microwave effect”

Conventional:

- Surface heated by radiation
- Temperature gradient
- Slow

Factors to Consider in Microwave Firing

Susceptors

- Are they necessary
- Best material for the process

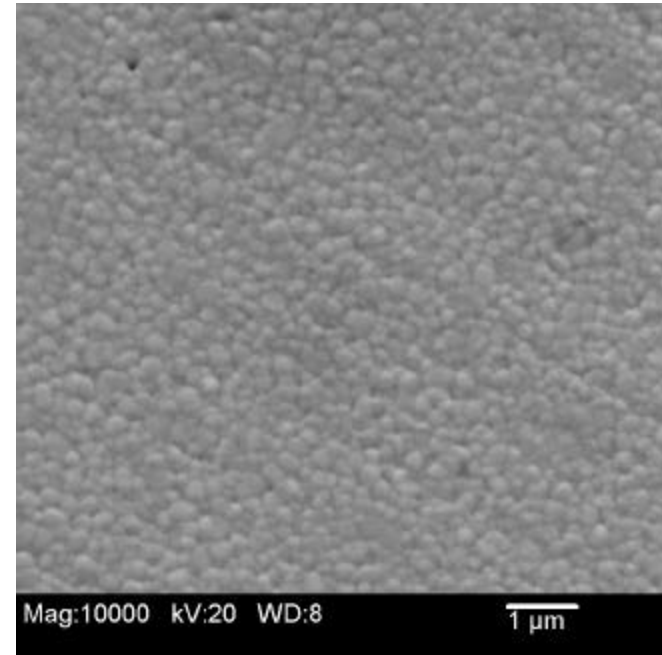
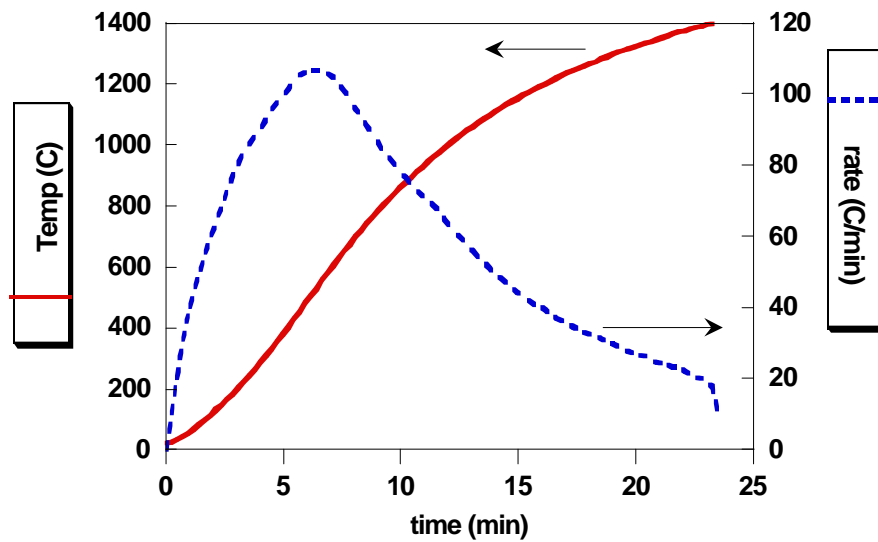
Relationship Susceptors and Product Load

- Competing for energy, temp product load takes over?
- Relative mass susceptor vs. load
- Effect of placement of susceptors

Relationship Total Load and Container Volume

- Avoid inverse temperature profile
- Minimize volume to improve heating rate

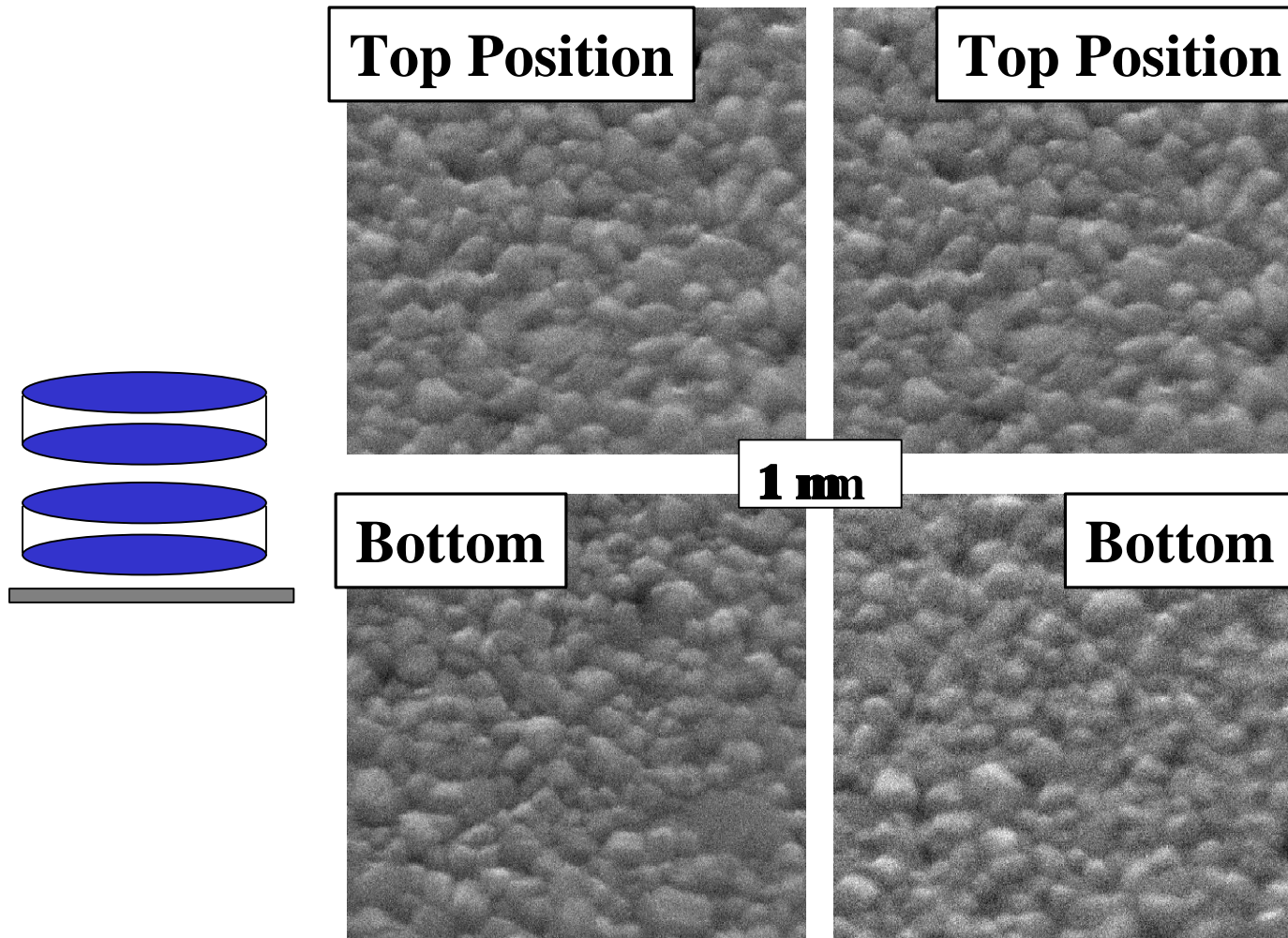
Microwave Research



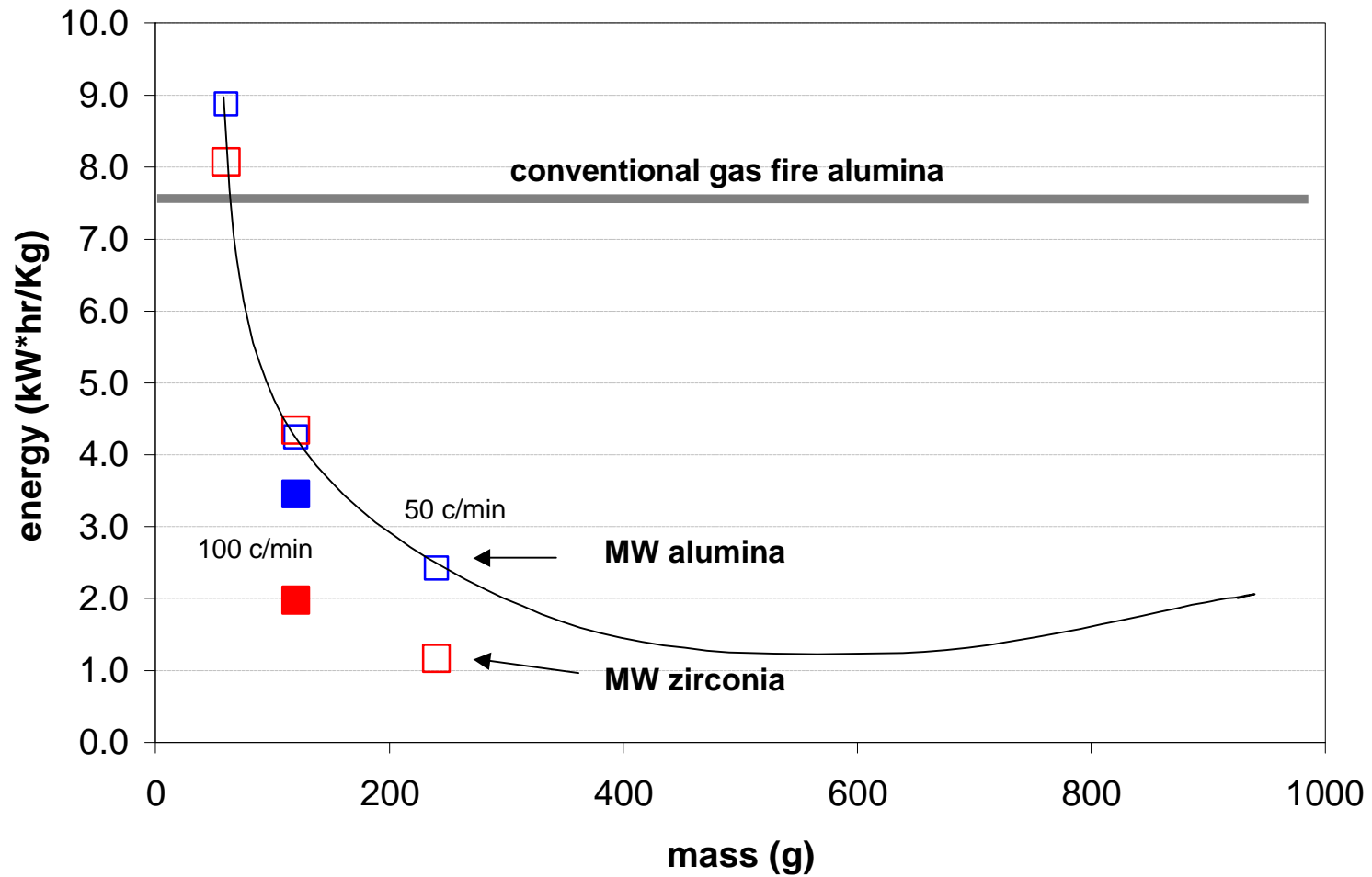
Zirconia Tosoh

ThermWAVE Firing Profile

Microwave Sintering Zirconia



Energy Consumption

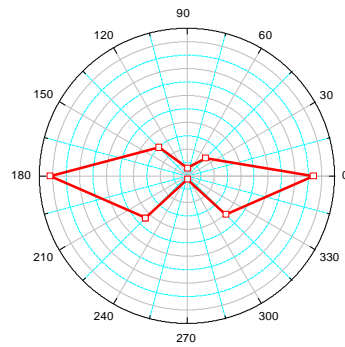
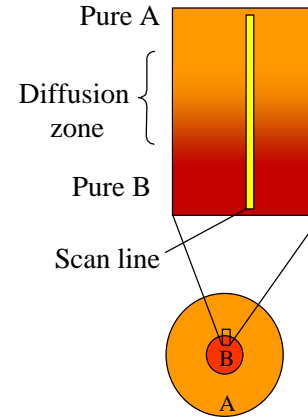
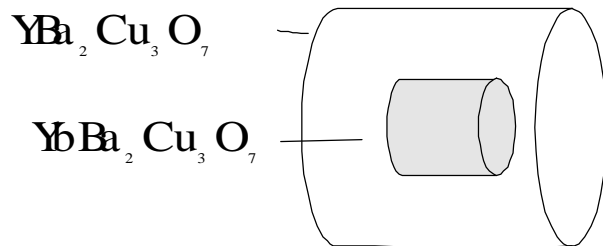


“Microwave Effect”

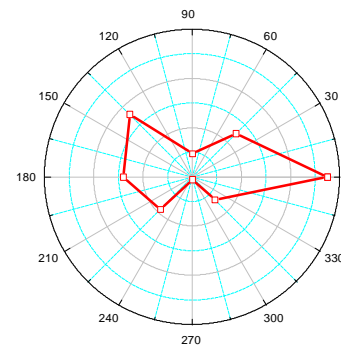
Temperature measurement problems
comparing MW and conventional
but still appears to be a real “microwave effect”

- Decreased sintering temperatures
- Different porosity characteristics
- Densification with minimal grain growth
- Unexpected exaggerated grain growth

Microwave Enhanced Diffusion



$\text{Yb} / \text{YBa}_2\text{Cu}_3\text{O}_7$
5 days, *Ca.* 600°C



$\text{Yb} / \text{YBa}_2\text{Cu}_3\text{O}_7$,
3 days, *Ca.* 700°C

Whittaker and Cronin, to be published

“Microwave Effect”

Accelerated Diffusion: Non-Thermal Effects

- Mobility
- Driving force

John Booske, K.E Ribokov and S.E. Seminov

ponderomotive force- microwave excited ionic currents locally rectified (at interface) give additional driving force for mass transport

Alfred University Research

Undergraduate Projects

Shawn Allan- Microwave Burnout and Sinter Epoxy Alumina, ZTA

PJ Campbell- Microwave Hot Press

Carlos Cheng- Microwave Sinter Alumina Microgears

Morgana Fall- Microwave Sintered Alumina, Zirconia, ZTA

Karl Gnann- Microwave Sintered Ferrites

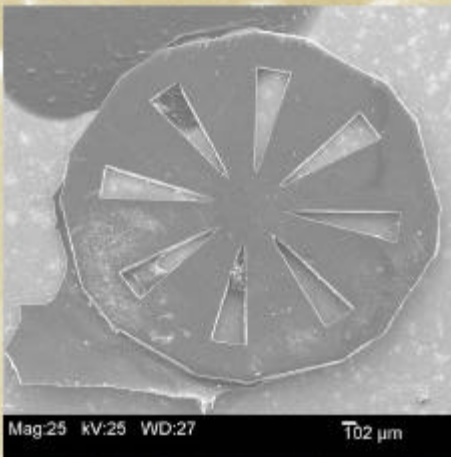
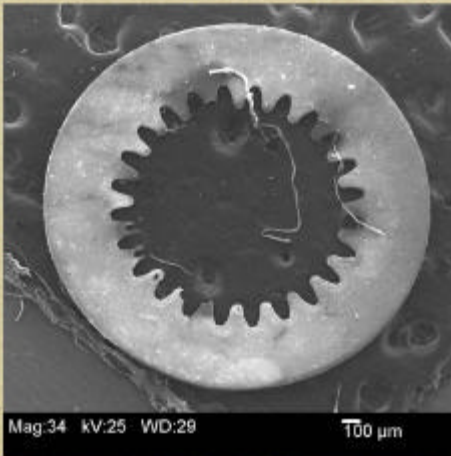
Jeff Kohlhas- Comparative Microwave Heating

Graduate Projects

Ozan Ugurlu- Microwave Sintered Rapid Prototype Ceramics

Sreekkumar Chockalingam- Microwave Sintered Silicon Nitride

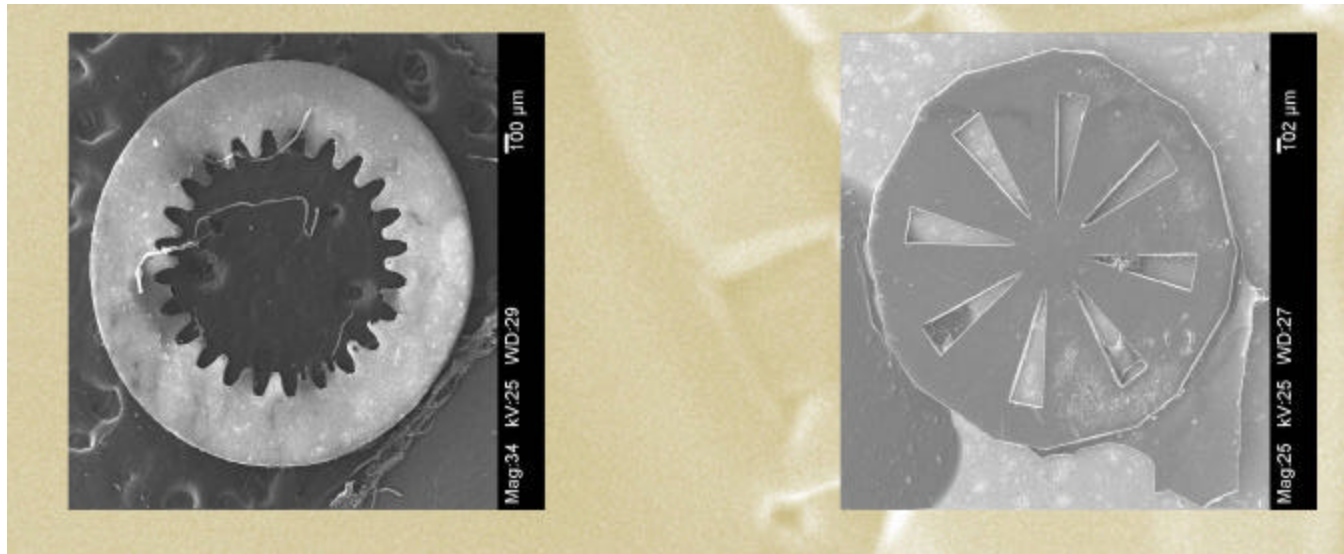
Ram Mohan V.C.- Microwave Sintered Dental Ceramics



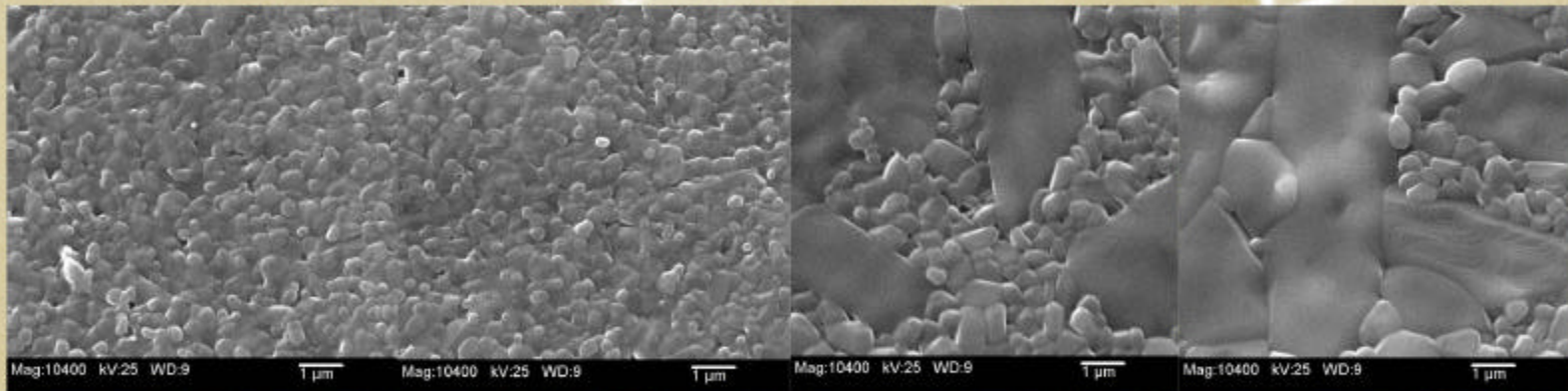
MicroThings

Carlos Cheng, Shawn Allan
Alfred University

Alf Morales
Sandia National Lab



Micropart SEM Images

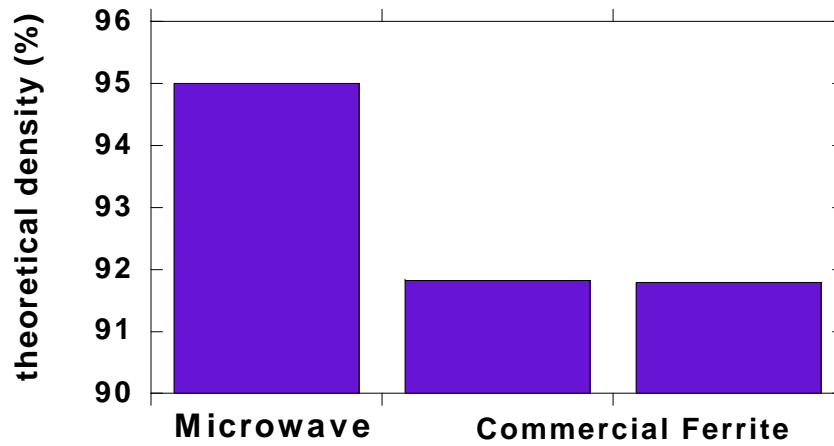
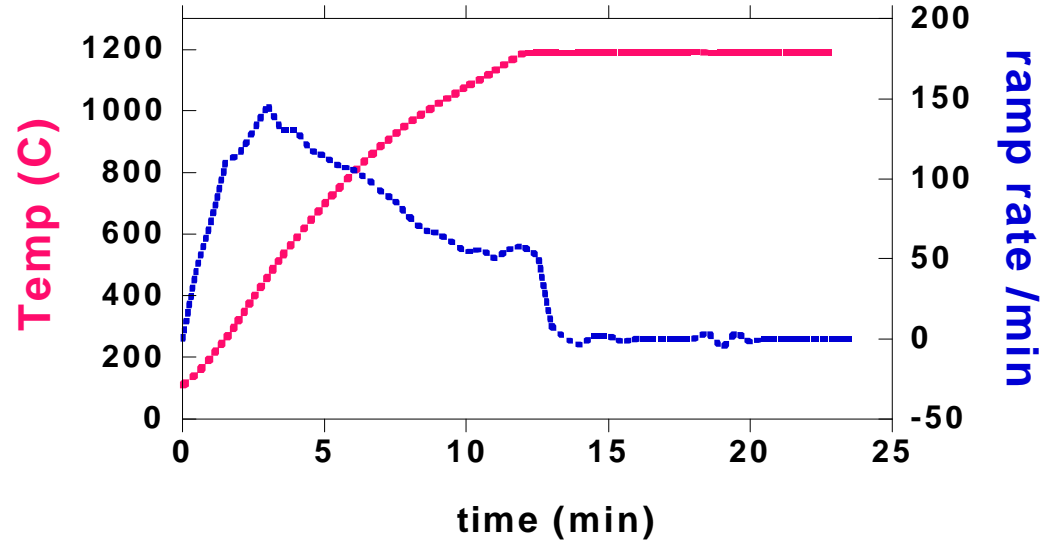


gear 7 (center, edge)

sand-dollar 7 (center, edge)

Karl Gnann

Microwave Sintered Ferrites



Industrial Microwave Firing

Valenite: WC/Co Cutting Tools
Stoke Type Continual Batch

Indexable: Silicon Nitride Cutting Tools
Batch Technology (licensed)

Microwave Testing Center

- **Snap shot view**
 - Quick, inexpensive feasibility study, control parameters
 - Analytical options: microstructure, phases, mech/electrical props, etc.
- **Development work**
 - All levels of product and process development
- **Microwave Resource Center**
 - Showcase MW equipment
 - Specialized, up to date MW library

Conclusions

Microwaves can be effective:

- Drying
- Binder Burnout
- Calcination
- Sintering Ceramics and Metals
- Melting glass
- Joining
- rapid R&D

Microwaves are still finding their place

Acknowledgements

Dr. Vasantha Amarakoon

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Dr. Licio Pennisi

Dr. Herbert Giesche

Ms. Morgana Fall

NYSERDA