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SRTC Savannah River Technology Center

#81897, Millimeter-Wave Measurements of HL and LA Glass Melts

Paul P. Woskov, K. Hadidi, L. Bromberg
Massachusetts Institute of Technology
S. K. Sundaram
Pacific Northwest National Laboratory
Gene Daniel, Don Miller
Savannah River Technology Center

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Environmental Management Science Program

Objectives

Reduce Immobilization Costs and Risks

- Optimize melter process efficiency
- Improve chemistry/process control for long stability glass product
- Maximize waste loading in glass
- Reduce risk due to unpredictable melter anomalies
- Insure environmental compliance

Defense Waste Processing Facility

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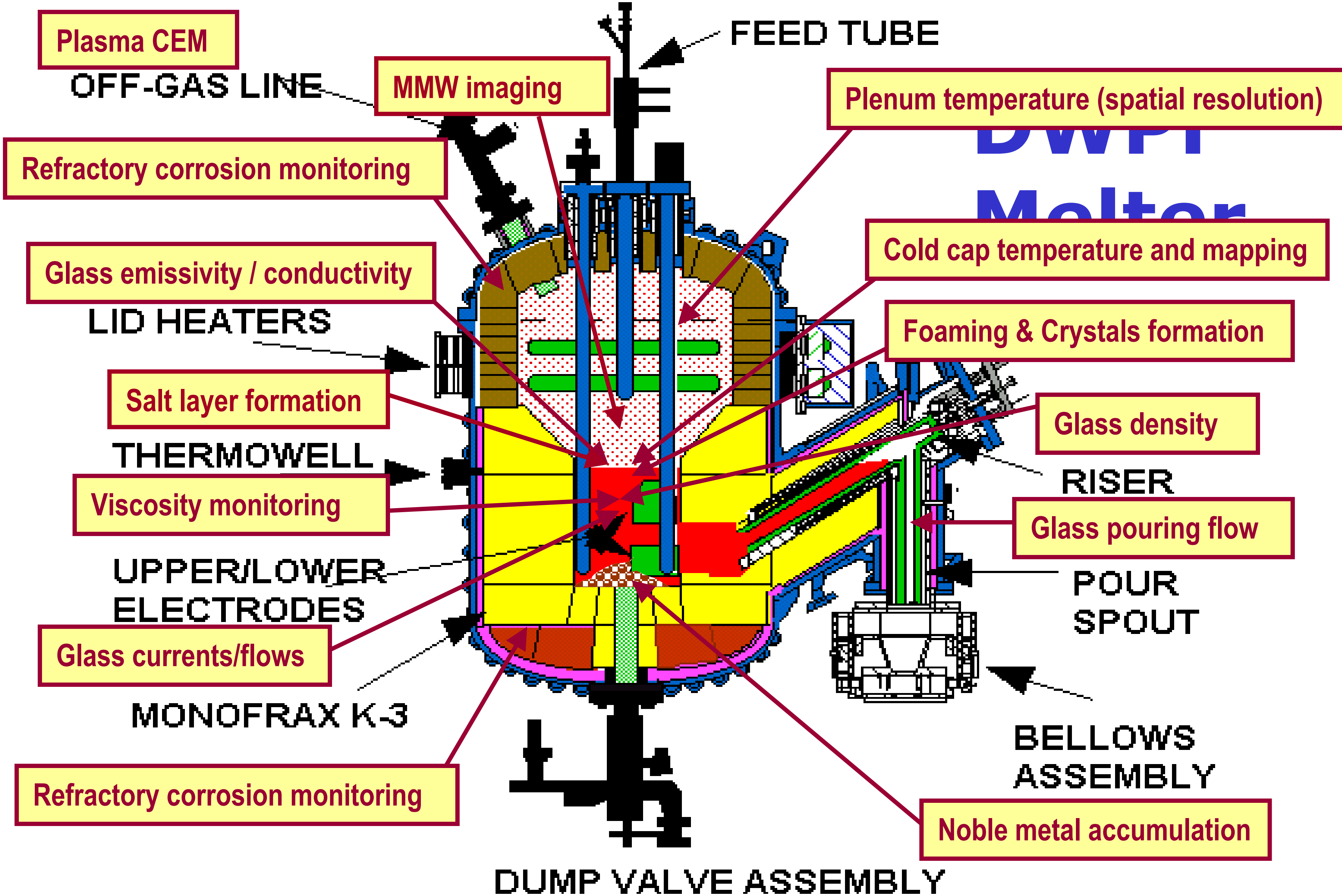
Current Operational Limits

- **Predictive Model Feed Forward Control**
  - ✓ Processing limited by prediction uncertainties
  - ✓ Requires conservative throughput and waste loading
- **Susceptible to Process Anomalies and Unknowns**
  - ✓ Foaming
  - ✓ Combustion gas build up
  - ✓ Noble metals accumulation
  - ✓ Pour spout problems

Solution

- Develop Advanced On-Line Monitoring

A Vision of On-Line Diagnostics for Melters



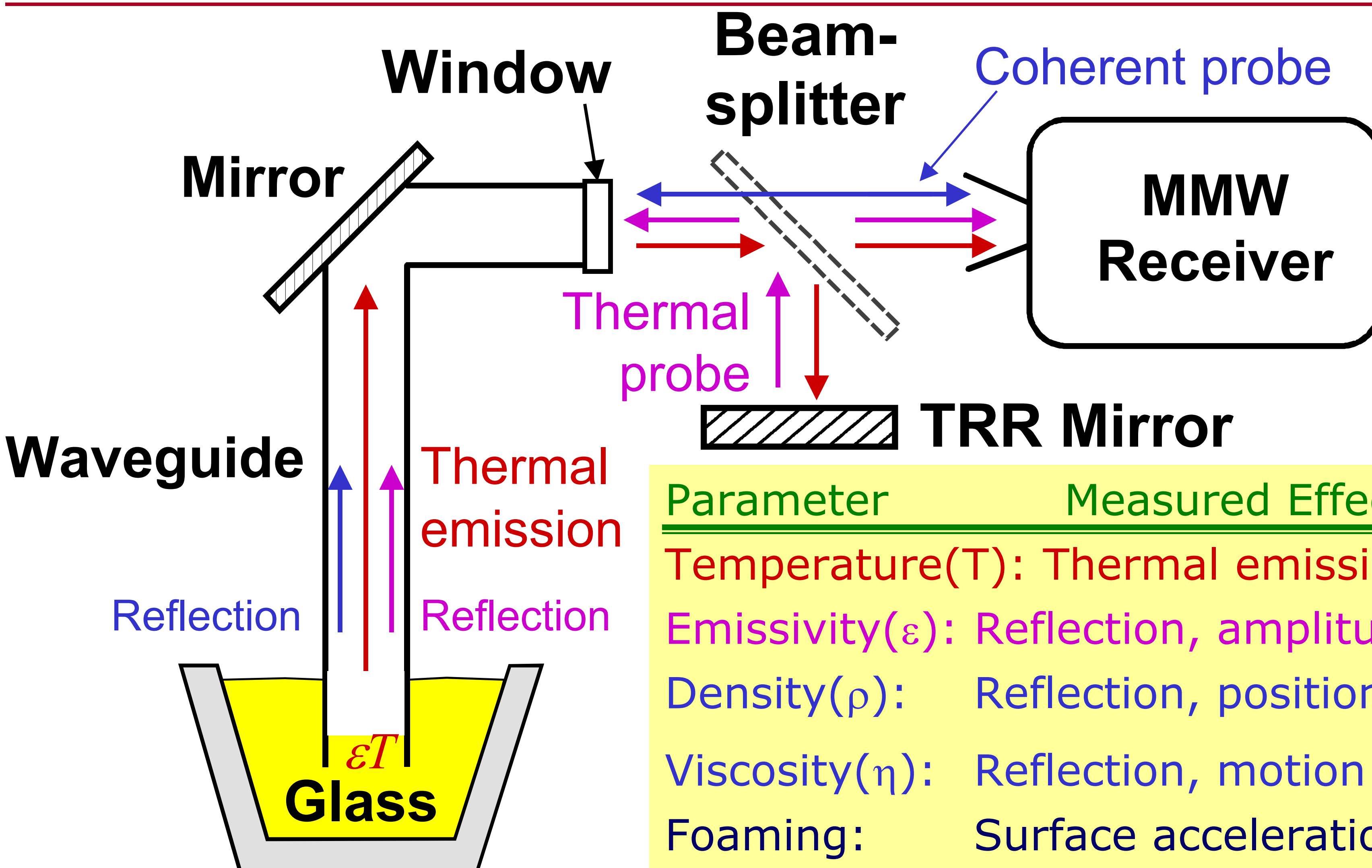
Millimeter-Wave Technology

10-0.3 mm (30-1000 GHz)

Advantages for Melters

- Wavelengths are long enough to penetrate optical/infrared obscure viewing paths through dust, smoke, and debris
- Wavelengths are short enough for spatially resolved point measurements and profiles
- Robust refractory material melter interface and remote electronics

MMW Sensor Approach



Parameter	Measured Effect
Temperature(T):	Thermal emission
Emissivity(ε):	Reflection, amplitude
Density(ρ):	Reflection, position
Viscosity(η):	Reflection, motion
Foaming:	Surface acceleration/ emissivity

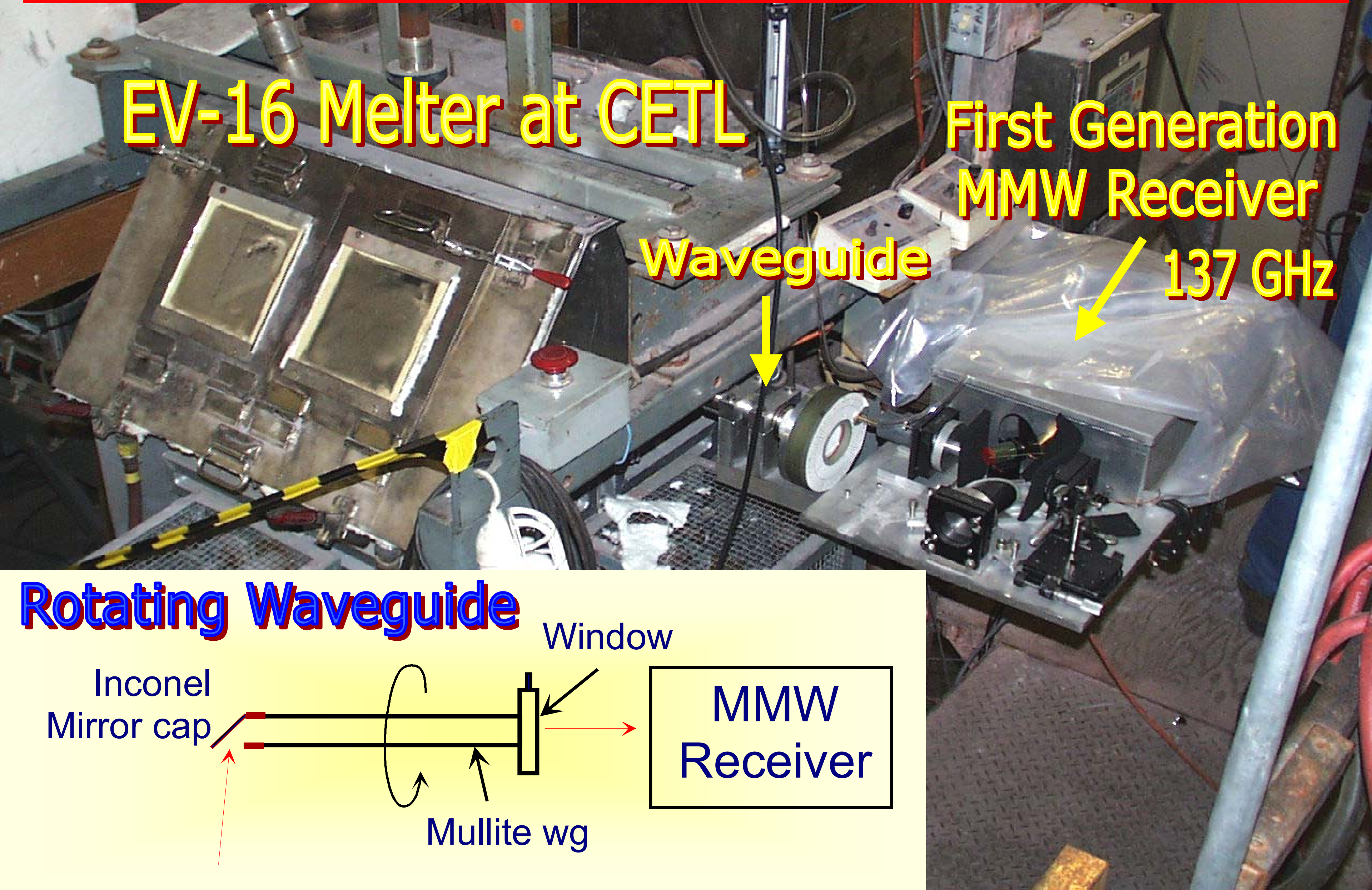
$r = 1 - \varepsilon$

Accomplishments

- Efficient high temperature MMW waveguides demonstrated for melter interface to > 1500 °C
- Cold cap monitoring field test demonstrating MMW engineering reliability and 2-D temperature profiles
- Innovative MMW viscosity monitoring technology developed (R&D 100 Award)

- Thermal return reflection (TRR) method developed for real-time emissivity/temperature measurements
- Second generation more compact MMW receiver designed and fabricated for melter applications
- Initial MMW foaming signature documented

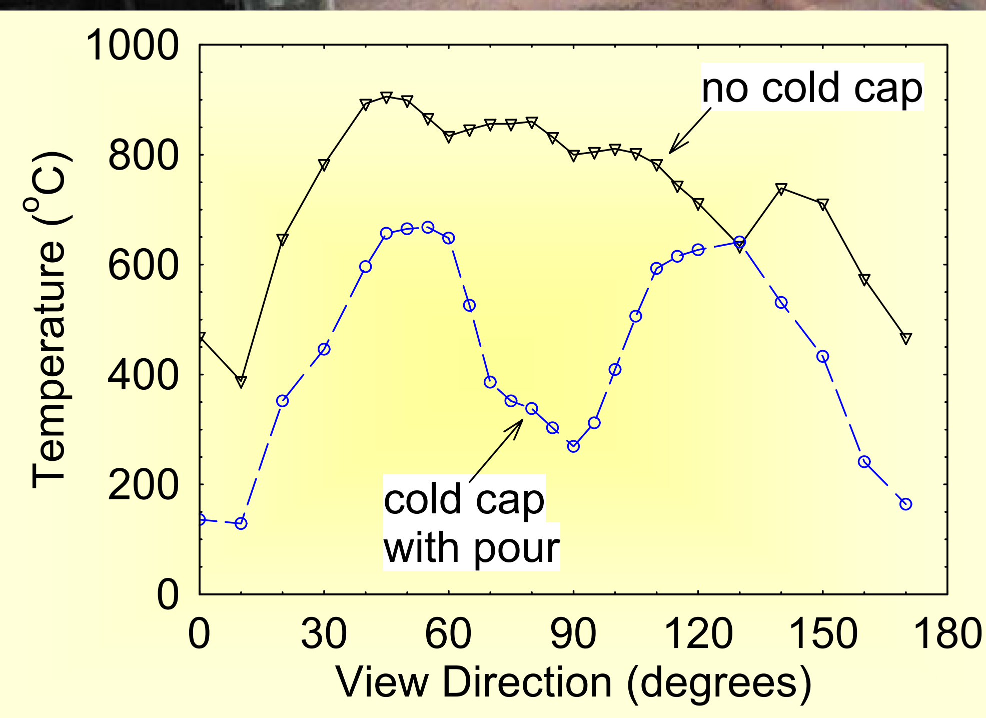
Cold Cap Monitoring Field Test



Cold Cap Monitoring Field Test

Cold-cap temperature profiles indicative of melter process

- Electrode heating gradients observed
- First observations of large temperature gradients during glass pour



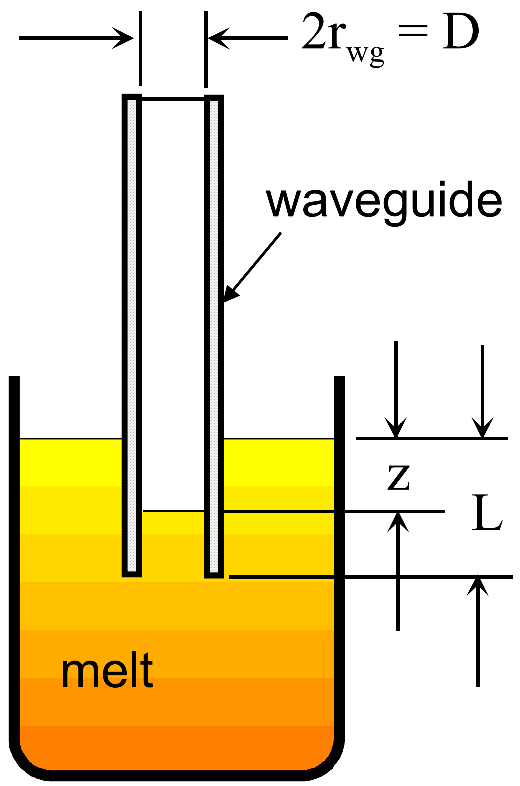
- MMW temperature monitoring reliablity demonstrated 24/7

Viscometer Analytical Model

- Reynold's number very small for measurements of interest

$$R = \frac{\rho \bar{v} D}{\eta} < 1$$

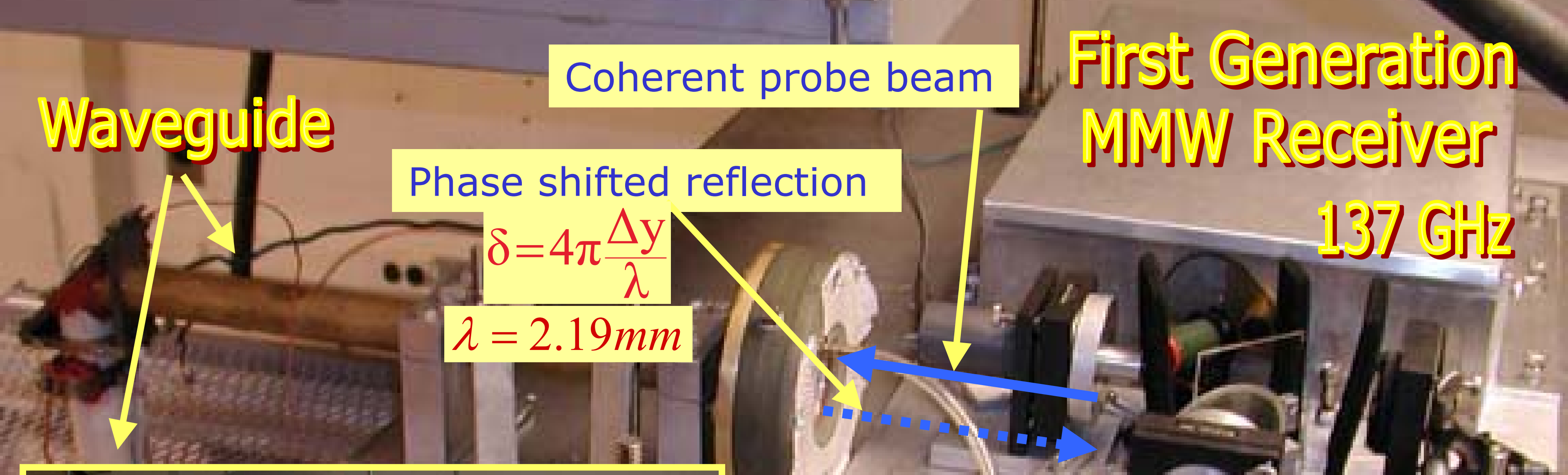
- Simplified Navier-Stokes equation applies
  - Incompressible, laminar flow
  - Valid for small displacements < 1 mm

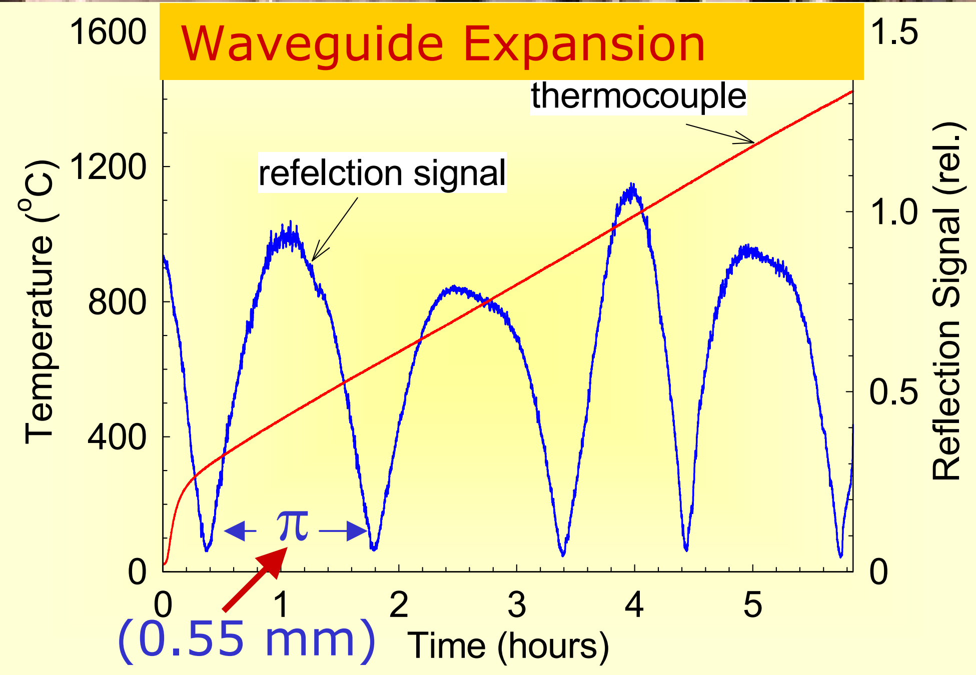


$$\frac{d}{dt}(L-z)v = -gz - A(L-z)v$$

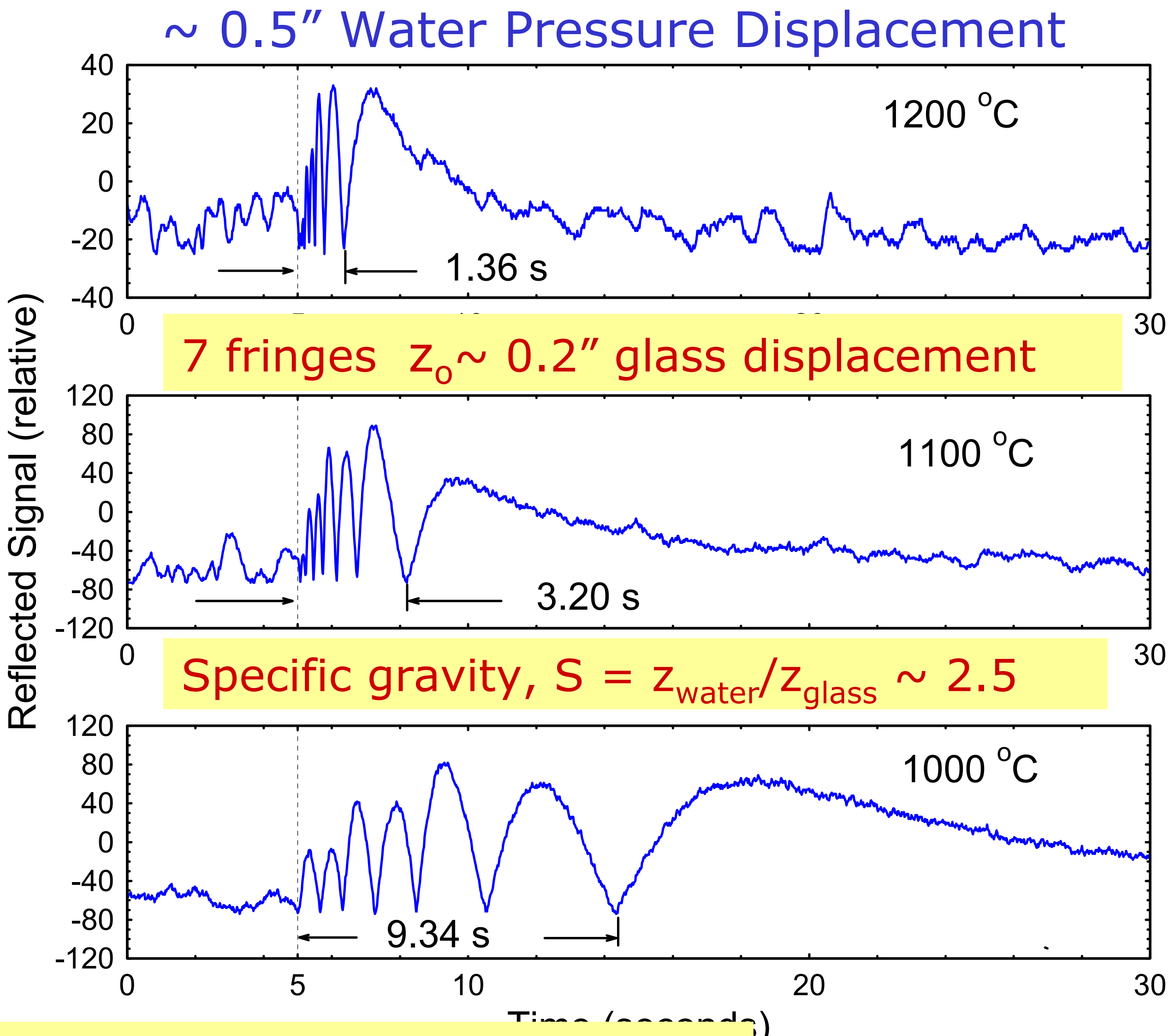
$$A = \frac{2\eta}{\rho r_{wg}}$$

Laboratory Glass Flow Measurements





Hanford #7 Glass Flow



From Corning Laboratory

339 Poise (0.1kg/m s)

868 Poise

3,014 Poise

Glass density and flow velocity both determined simultaneously

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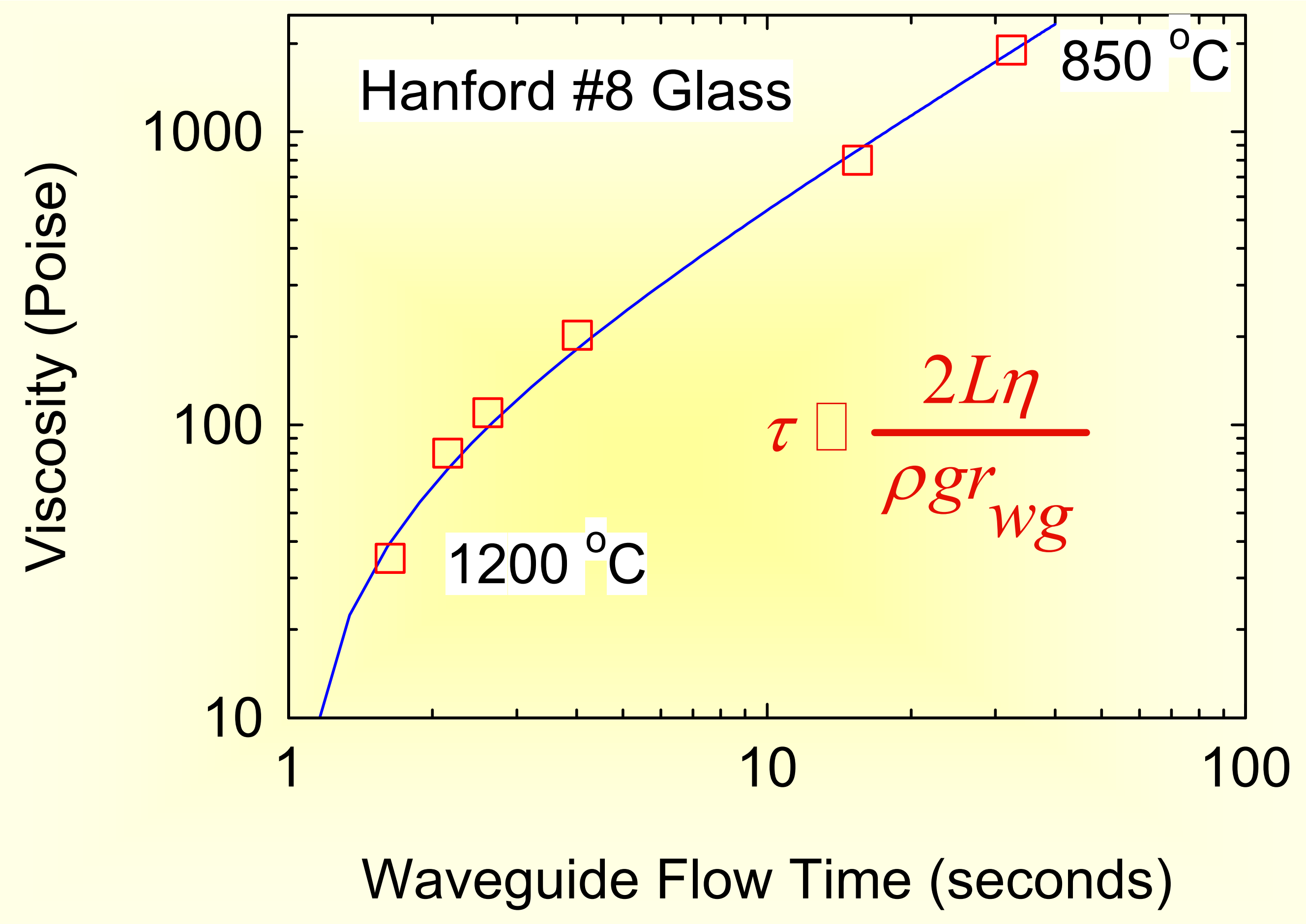
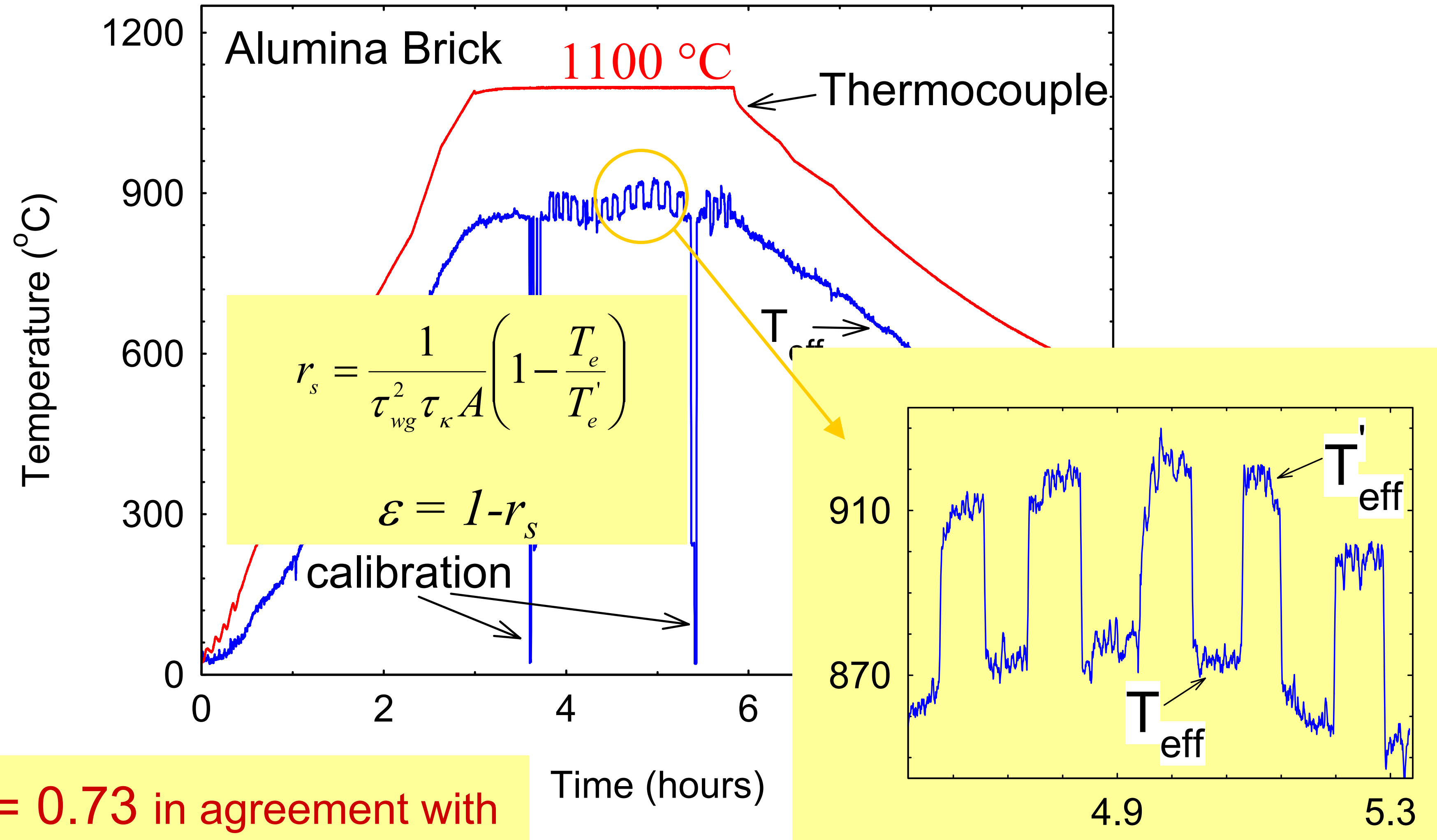
Observations Consistent with Model

- Waveguide flow time linear with viscosity over large dynamic range 20 to 2000 Poise



Thermal Return Reflection (TRR)

Emissivity and Temperature Measurement



$$r_s = \frac{1}{\tau_{wg}^2 \tau_\kappa A}\left(1 - \frac{T_e}{T_e'}\right)$$

$$\varepsilon = 1 - r_s$$

$\varepsilon = 0.73$ in agreement with published value for alumina at 137 GHz

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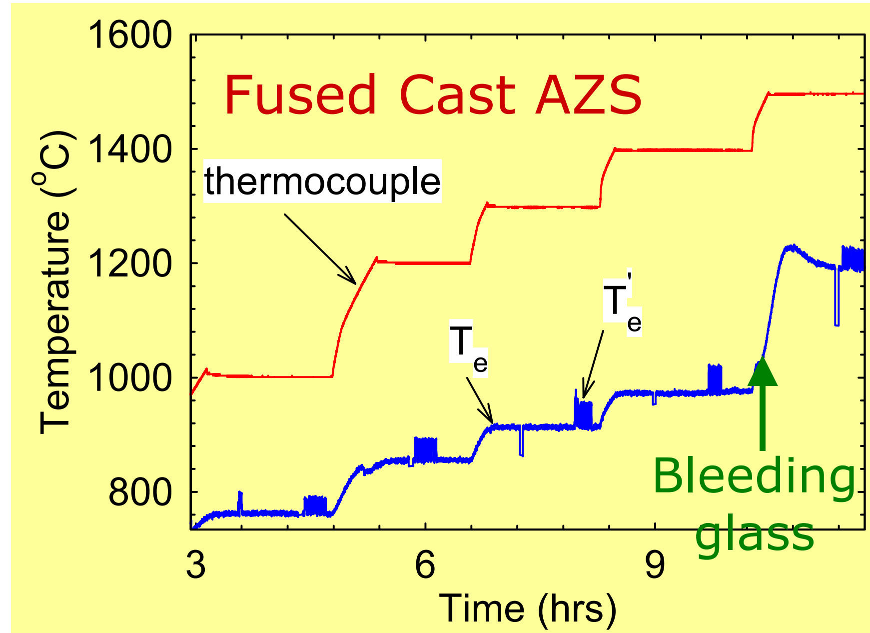
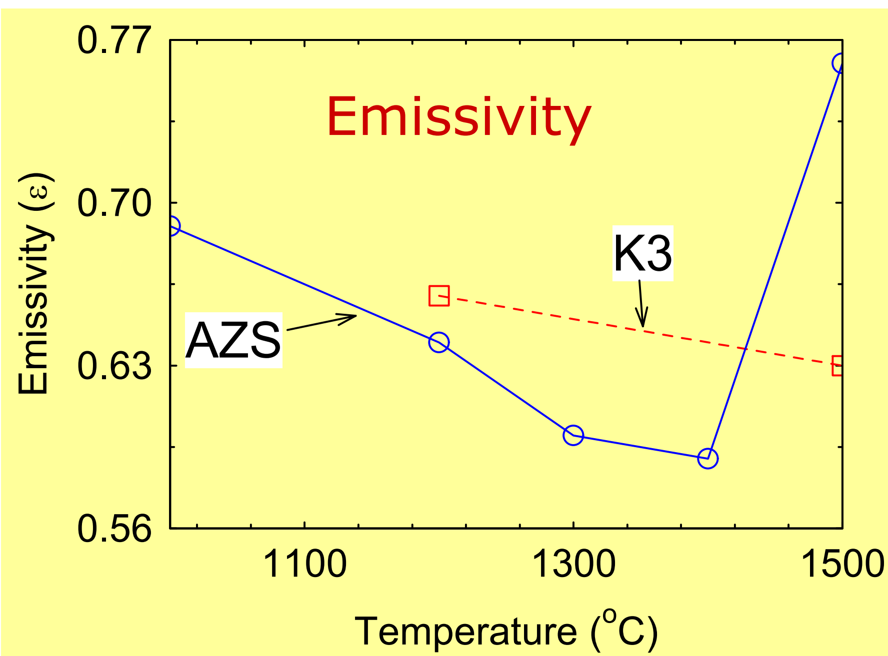
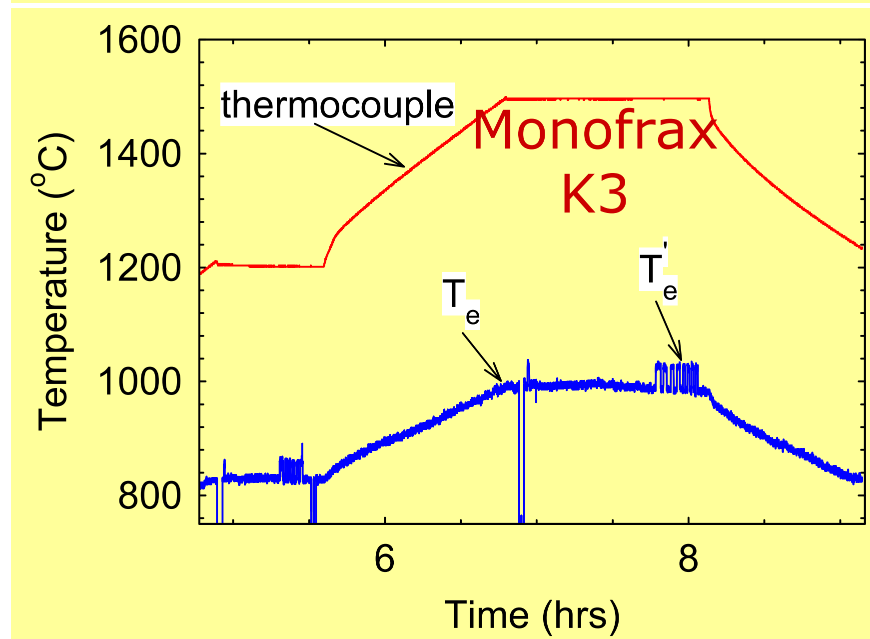
Thermal Analysis of Materials

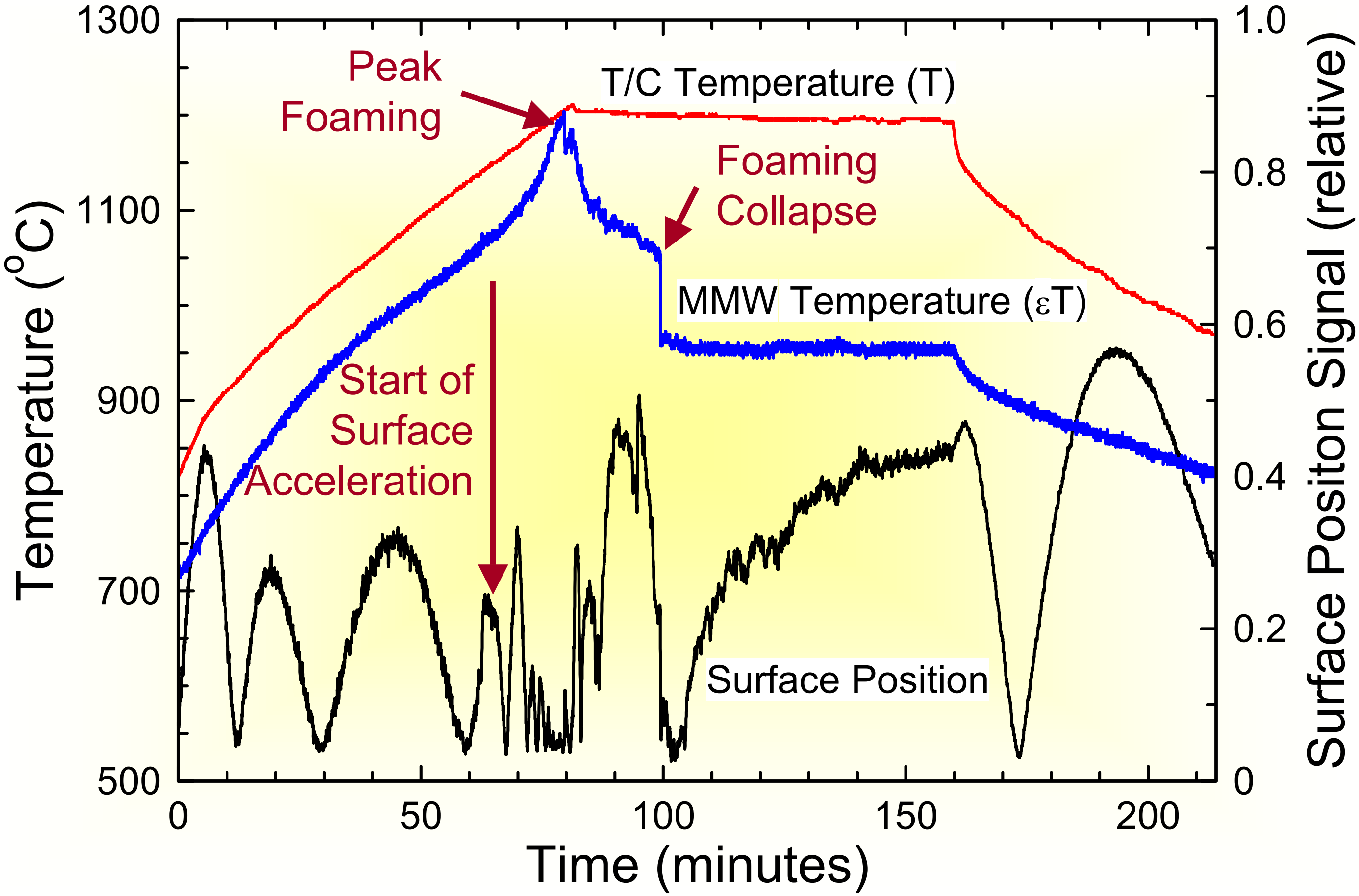
- Molten glass corrosion resistant materials studied
- Alumina-Zirconia-Silica (AZS) has unstable MMW properties
- Monofrax K3 more stable at MMW wavelengths







High Foaming Glass Measurements



MMW Foam Signature

1. Surface accelerates
2. Emissivity goes to one
3. First gradual then sudden collapse of emissivity

- MMW Monitoring could give a 20 to 30 minute warning of a sudden foaming event gas release

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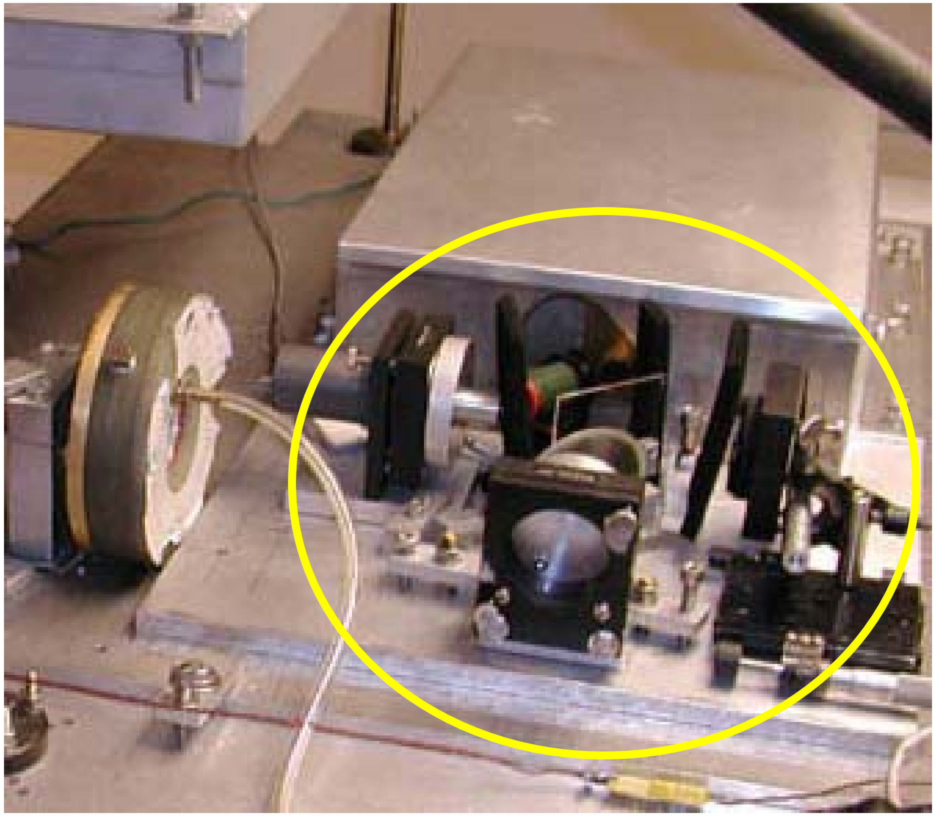
Glass Compositions

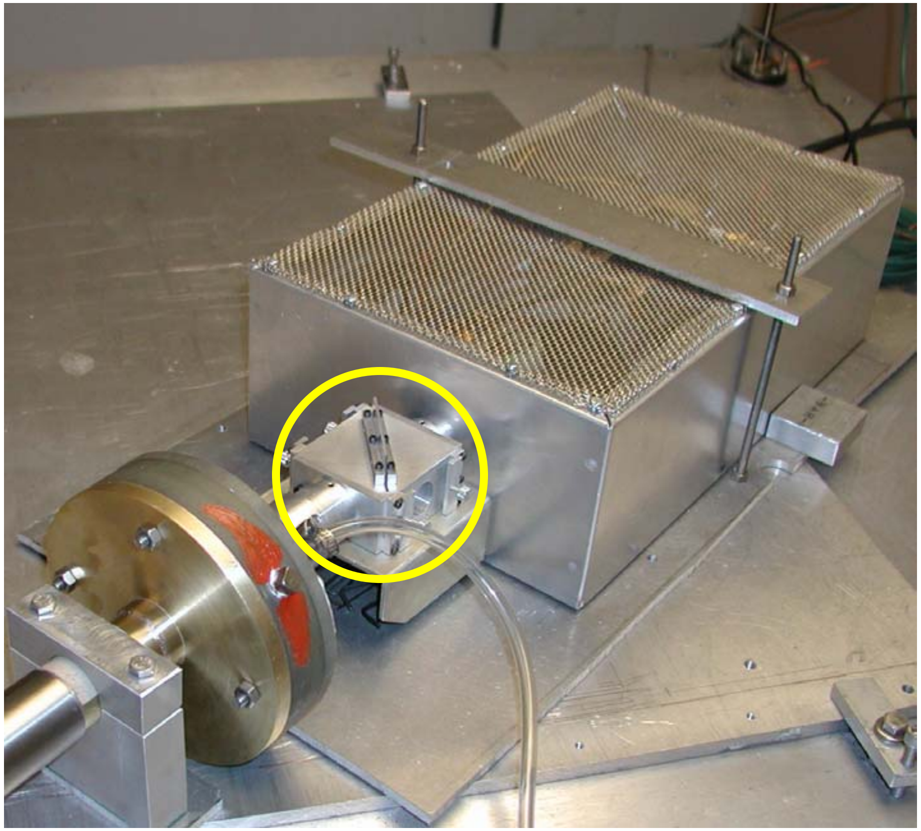
Oxide	HLW # 7 (Viscosity)	MS-7 (High Foaming)
Al_2O_3	6.02	8.00
B_2O_3	7.03	7.00
CaO	1.17	---
Cr_2O_3	---	0.30
Fe_2O_3	14.56	11.50
Li_2O	3.01	4.54
MgO	0.19	0.60
MnO	---	0.50
Na_2O	14.92	15.30
NiO	---	0.95
SiO_2	45.14	45.31
ZrO_2	3.01	6.00
Others	4.95	---
Total	100.00	100.00

MMW Hardware Advances

First Generation



Second Generation



The front end optics have been reduced to a small quasi-optical waveguide block.

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Planned Research

- Obtain more glass MMW viscosity data and tie to theoretical interpretation for stand alone monitoring from first principles
- Carry out viscosity monitoring field test to demonstrate engineering robustness
- Obtain more foaming glass MMW data to better establish this new monitoring capability
- Research advanced parameter measurement capability
  - ✓ Non-contact thermal analysis, liquidus, redox, gas temperature, salt layer, surface tension
- Continue MMW hardware refinement

Further Reading

"Millimeter-Wave Monitoring of Nuclear Waste Glass Melts – An Overview", *P. P. Woskov, J. S. Machuzak, P. Thomas, S. K. Sundaram, and W. E. Daniels, Jr.,* in Environmental Issues and Waste Management Technologies VII (*Ceramic Transactions, Volume 132*) pp. 189-201.

"Cold Cap Monitoring using Millimeter Wave Technology", *S. K. Sundaram, P.P. Woskov, J.S. Machuzak, and W.E. Daniel, Jr.,* in Environmental Issues and Waste Management Technologies VII, Editors: G. L. Smith, S. K. Sundaram, and D. R. Spearing (Ceramic Transactions, Volume 132) pp. 203-213, 2002.

"Thermal return reflection method for resolving emissivity and temperature in radiometric measurements", *P. P. Woskov and S. K. Sundaram,* J. Appl. Physics, December, 2002.