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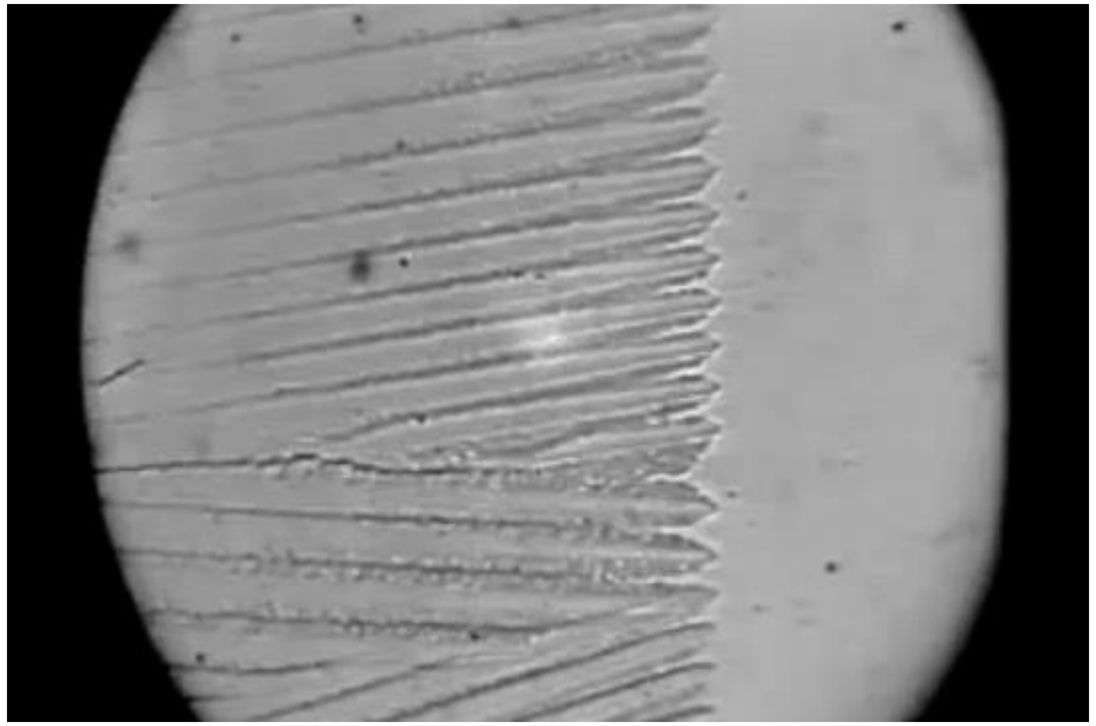
Adhesiveless Optical Bonding for Space Solar Cells

Dr. Bernie Carpenter
The Aerospace Corporation

- Advanced Technology and Concepts
- Space Innovation Directorate

Alternative Method for Joining Glass to Photovoltaic Cells

- Optical joining conducted at low temperature (~ 100C), with >200C remelt
- Heritage approach
  - *Bond established with silicone adhesive*
  - *Touch labor requirement*
- Inverted Metamorphic (IMM) solar cell
  - *Thin cells require new integration techniques*
  - *Support for next generation array technology*
    - Folded, rolled architectures
    - Modular, scalable power generation systems
- Compatibility with traditional solar cells
  - *Bonding applicable to both device formats*

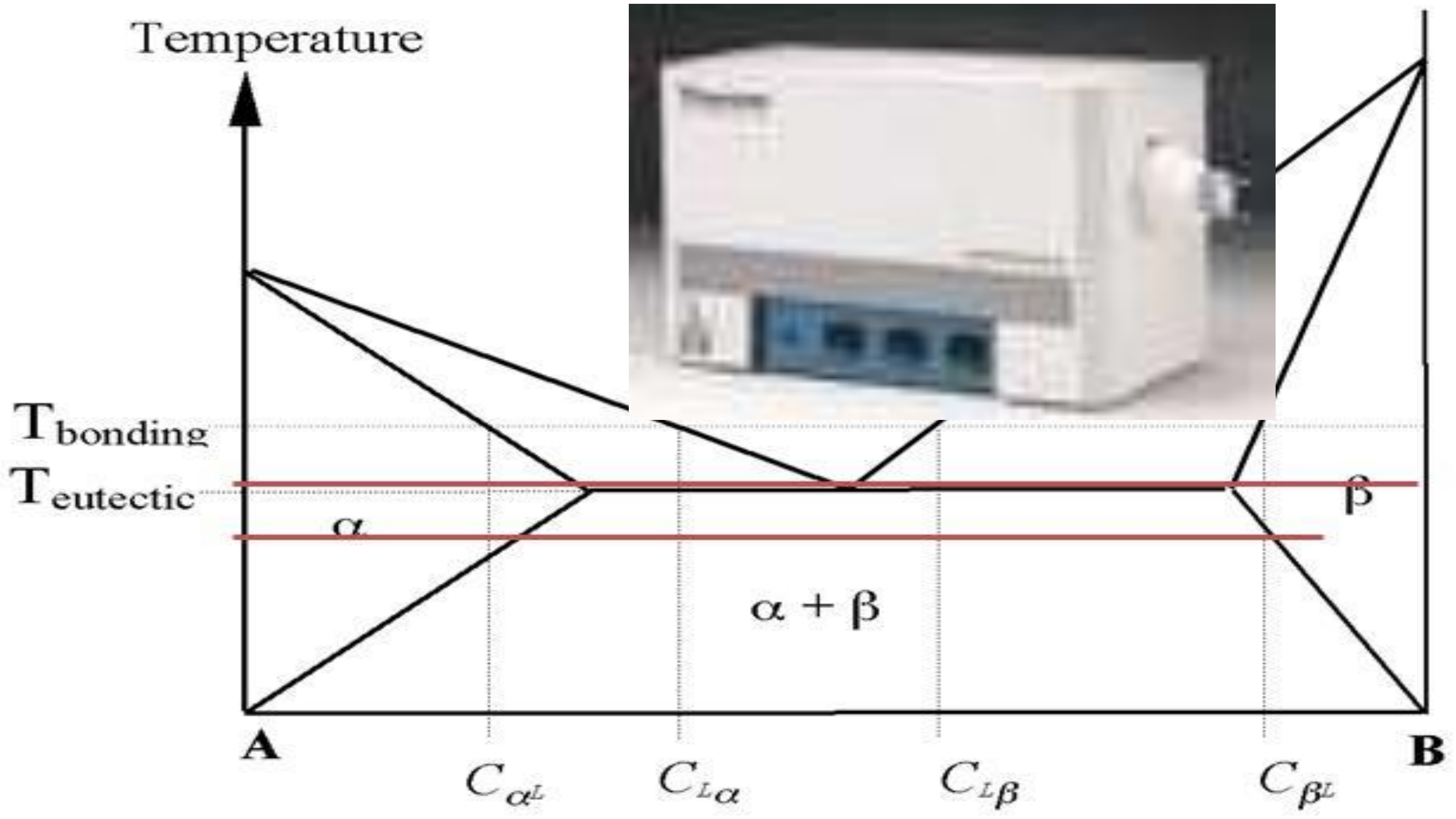


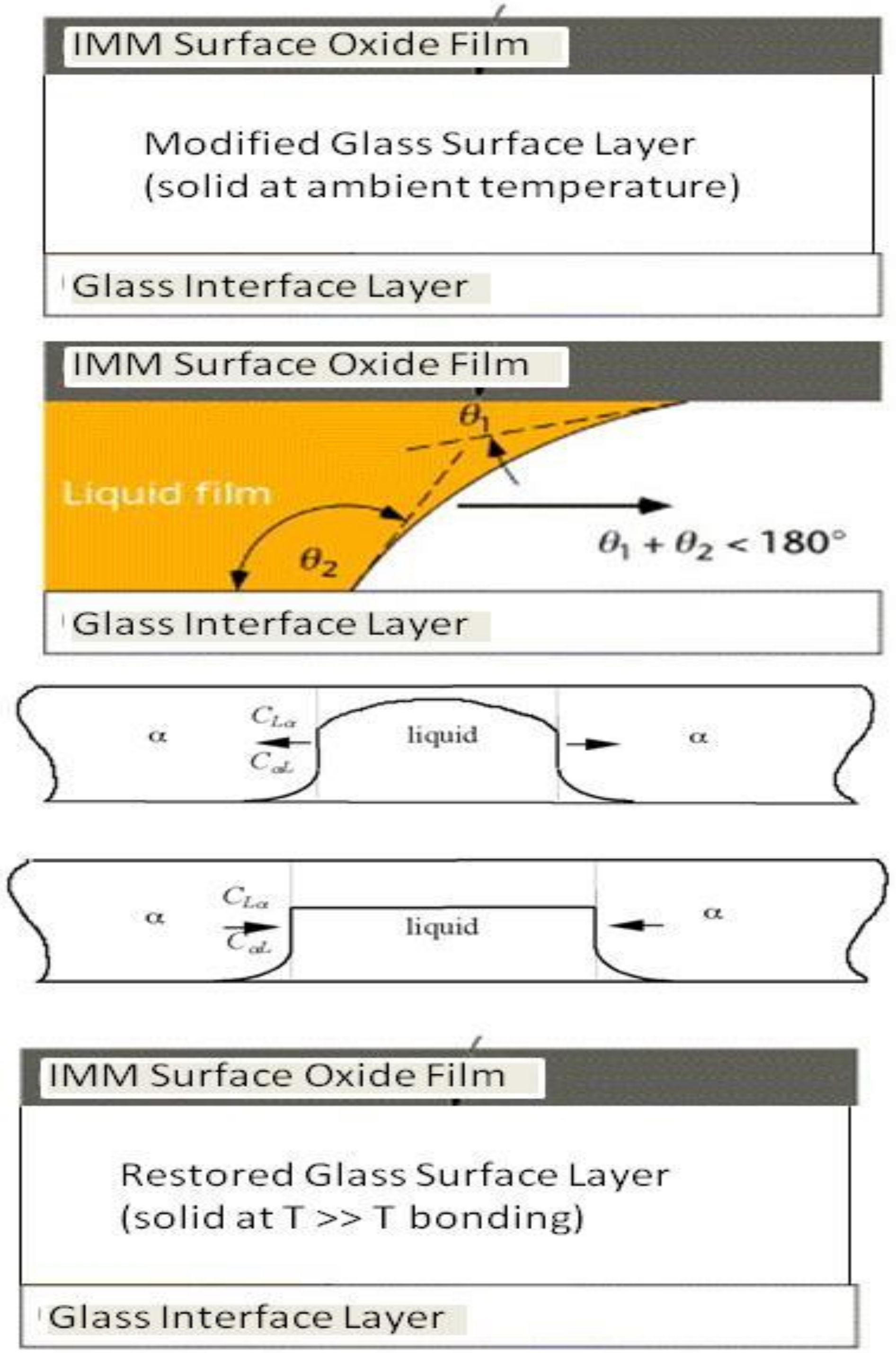
Research Overview

- Joining method and process variables
- Preliminary results
- Discuss future plans

Process Overview

Current Practice	Proposed Method
Cover glass	Cover glass
DC 93-500 adhesive (2 to 4 mils thick)	Spinel Bond Layer
MJ Cell	IMM Cell (1 to 2 mils thick)





Surfaces placed in contact and heated to bonding temp.

Liquid film forms and spreads across IMM surface under surface tension

Liquid forms according to phase diagram

Diffusion alters composition, forcing solidification at constant temp.

Diffusion continues with glass acting as a sink, completing bonding process

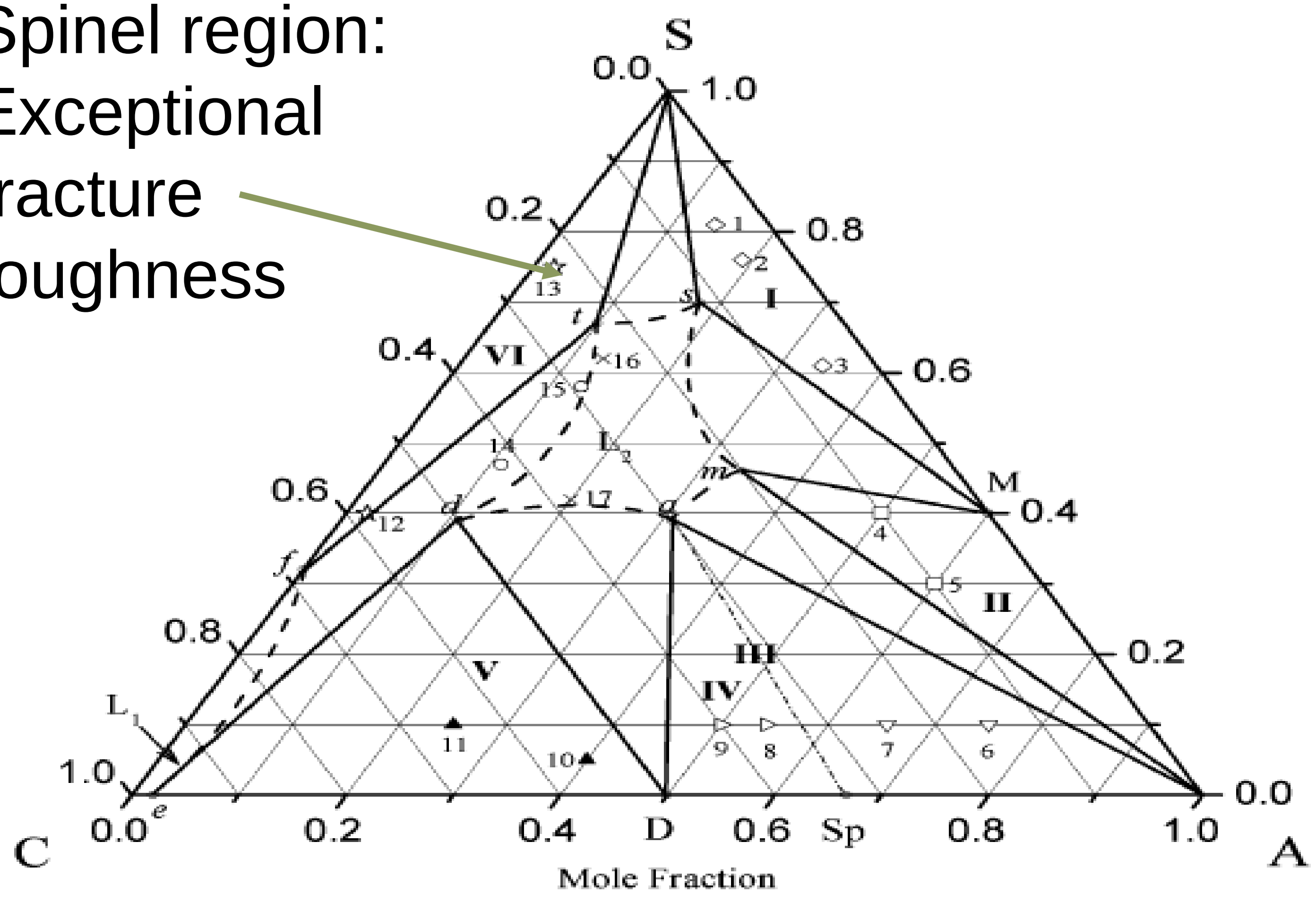
Isothermal conversion of liquid film to solid with spinel structure

Benefits

- Physical properties of bonding layer used to manage forces applied to IMM film
  - *Surface tension and wetting apply consistent forces*
- Stiffness matching and CTE mismatch mitigation
  - *Improved material similarity*
  - *Use of compositional gradient (high local concentration at onset of bonding approaches bulk composition towards end of bonding period)*
- High temperature exposure survivable
  - *Expect higher temperature joints than that which can be attainted with optical silicone*
  - *Diffusive sink removes low melting point signature*

Constituent Selection and Melting Point Suppression

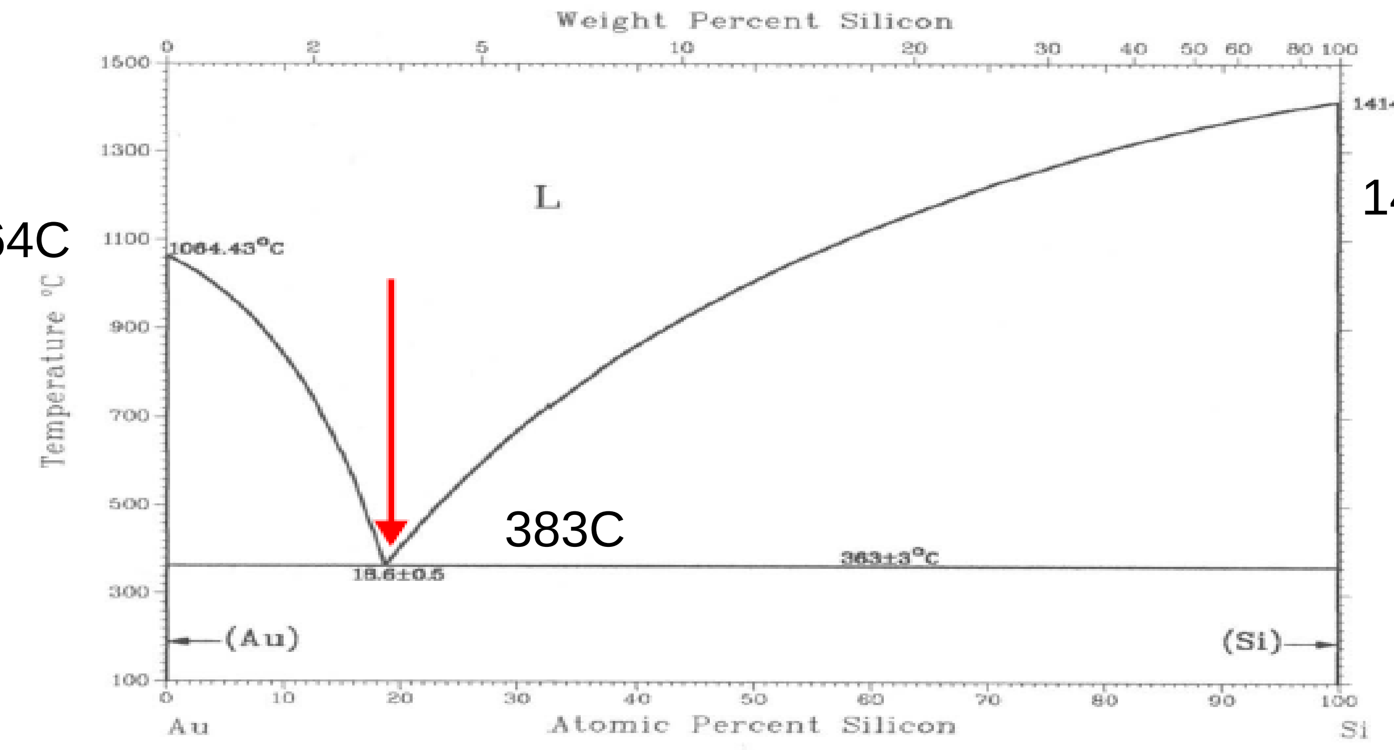
Spinel region:
Exceptional fracture toughness



Isothermal Phase Diagram for M Oxide—Silica—Alumina compounds

T melt spinel region ~ 1150C is higher than maximum cell survival temperature

1064C

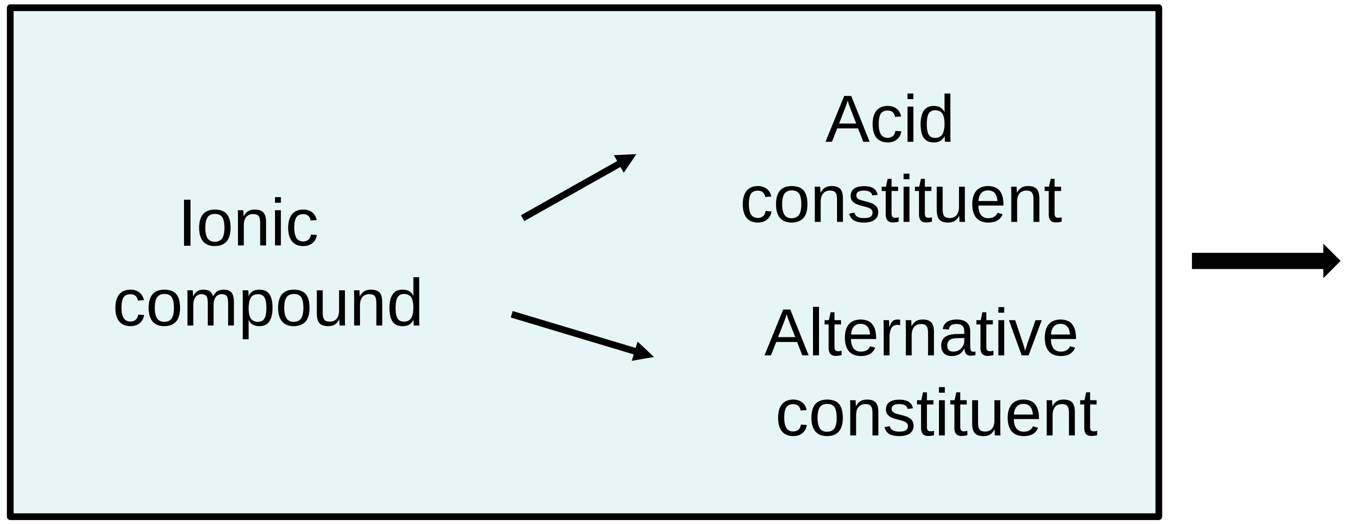


1414C

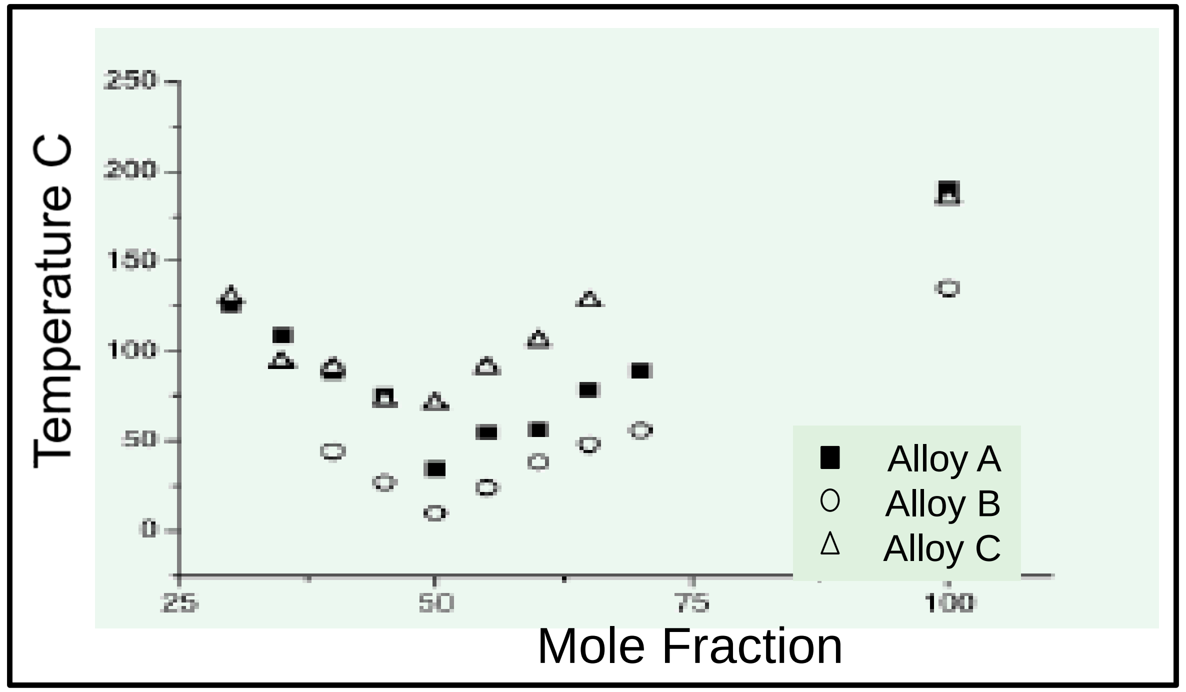
383C

Si-Au example of simple eutectic

Eutectic Chemistry and Solubility

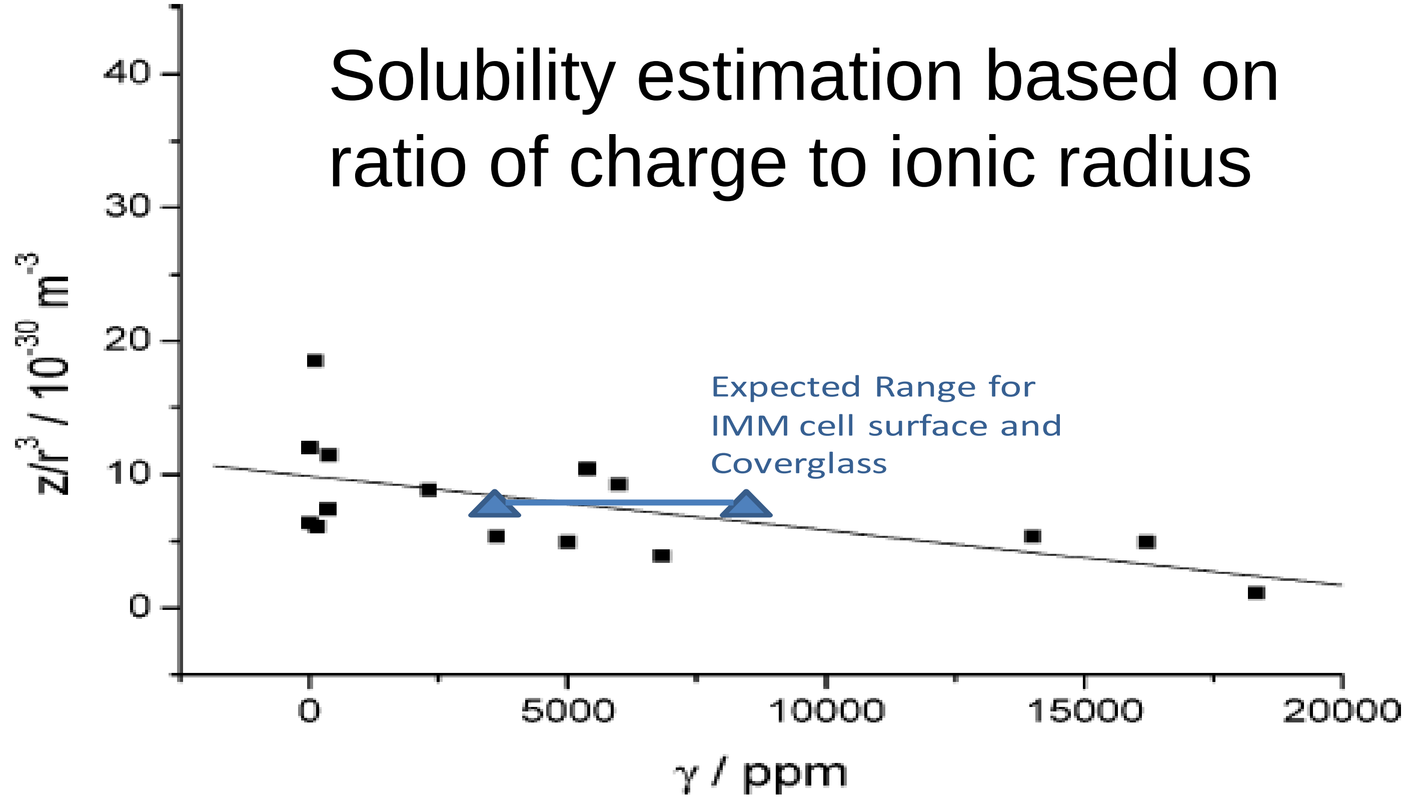


Melting point suppression (0.17 Tmelt)



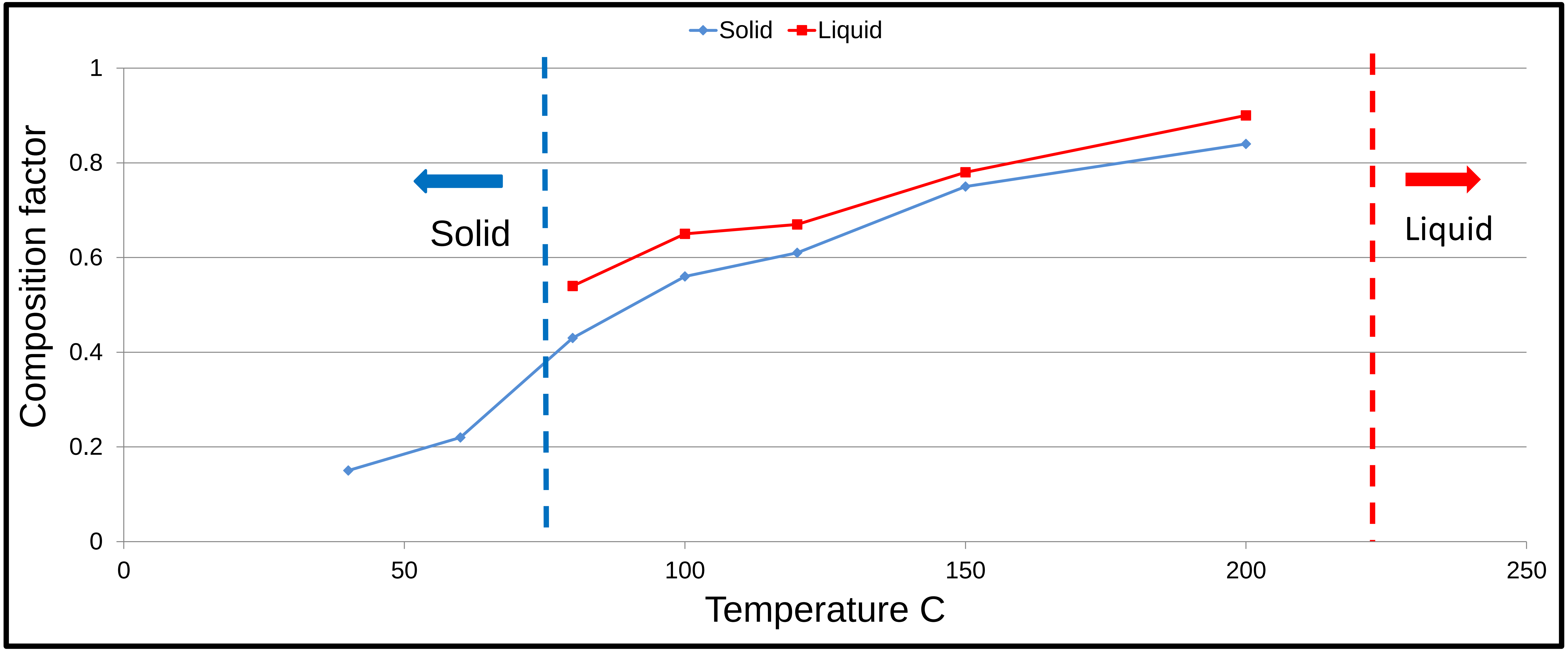
Original 1150C eutectic reduced to about 100C

Oxide	Acid Constituent (50C)	Alternative Constituent (50C)	Alternative Constituent (70C)
AxO	4	0.5	
BxO	3626	13.6	
CyO	14008	4.8	234
CyOz	18337	219	22888
DxOz	16217	1894	90019



Preliminary Results

Determination of Liquid Solid Transition (Short Term)

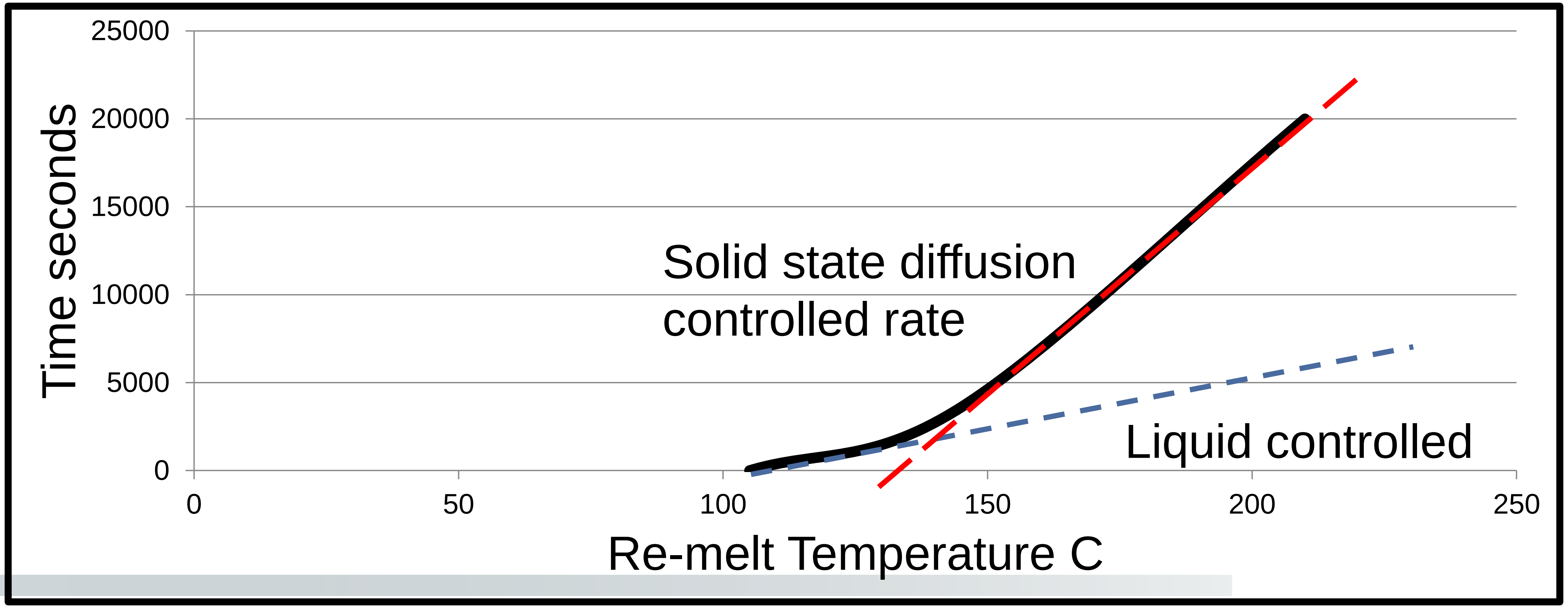


Composition Factor = mole fraction (CC/AC) * η (η = 1 for no solubility interaction)

Preliminary Re-melt Temperature Behavior

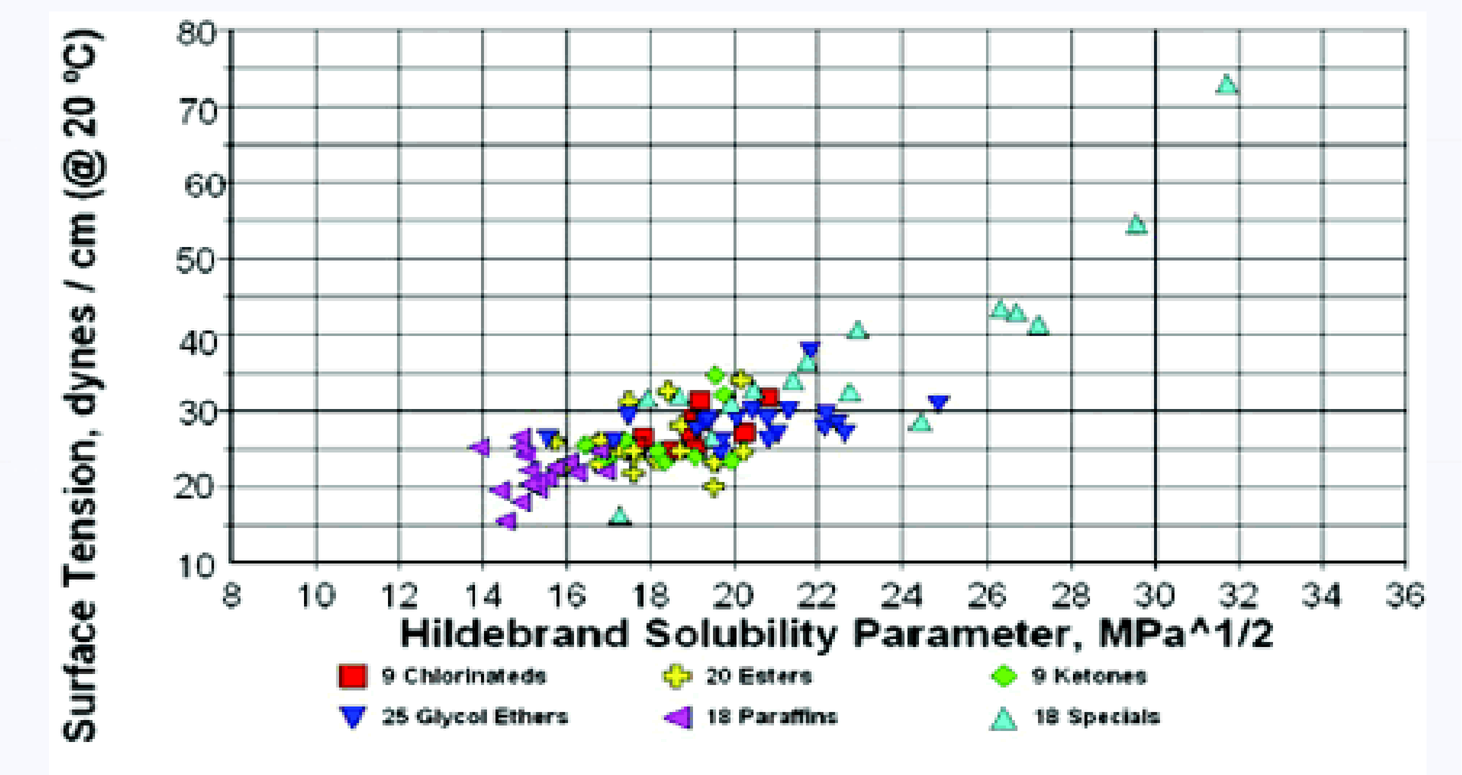
- Not the same as liquid-solid transition; Result of iso-thermal transport processes
- Behavior for composition factor 0.65
- Change in slope indicates mechanism change typical of liquid to solid state diffusion
- Apply Ficks law (planar boundary conditions, activation energy, diffusion constants)

Governing Equations : C = C” efrc (x/{2sqrt(Dt)}) and D = D” exp (-Q/RT)

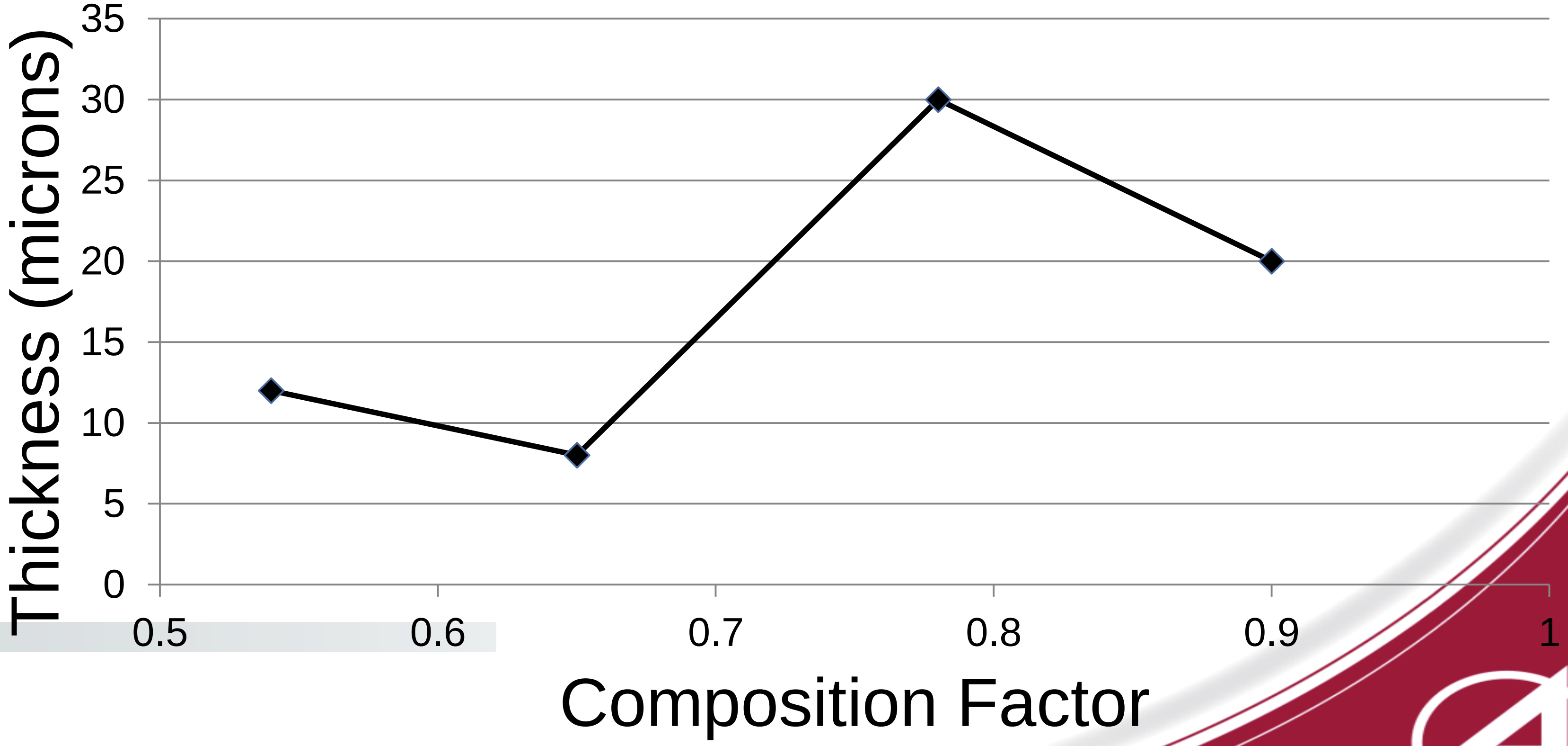


Surface Tension and Thickness

- Generate very thin interfaces
  - *Planer transport phenomena easier to analyze and model*
  - *Small diffusion distances reduce overall thermal budget*
  - *Mechanical benefit*
  - *Some array architectures require precise, repeatable control of thickness*
- Optical behavior
  - *Influence of bond layer thickness on transmission and cutoff wavelength*
- Thickness after 10 hours as a function of composition factor

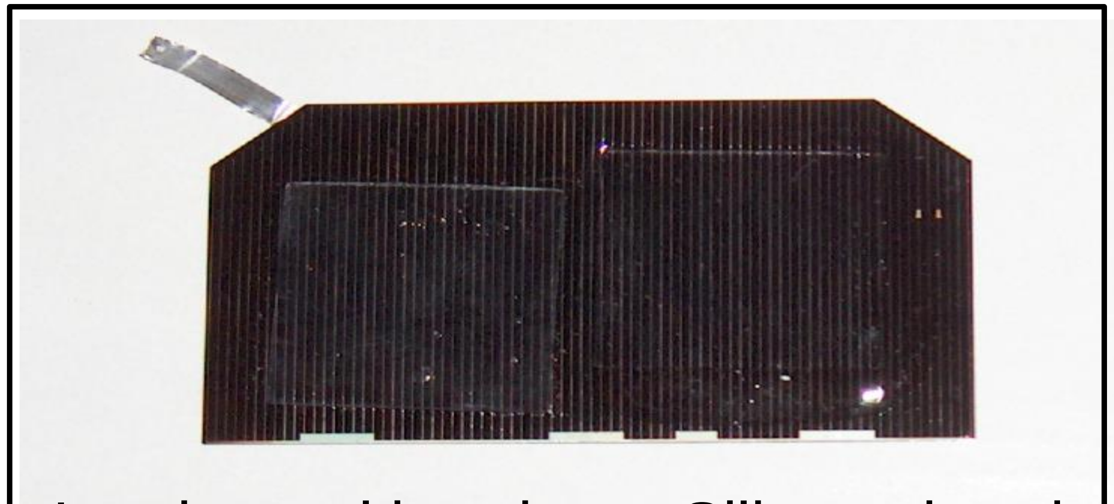


Relationship between solubility surface tension

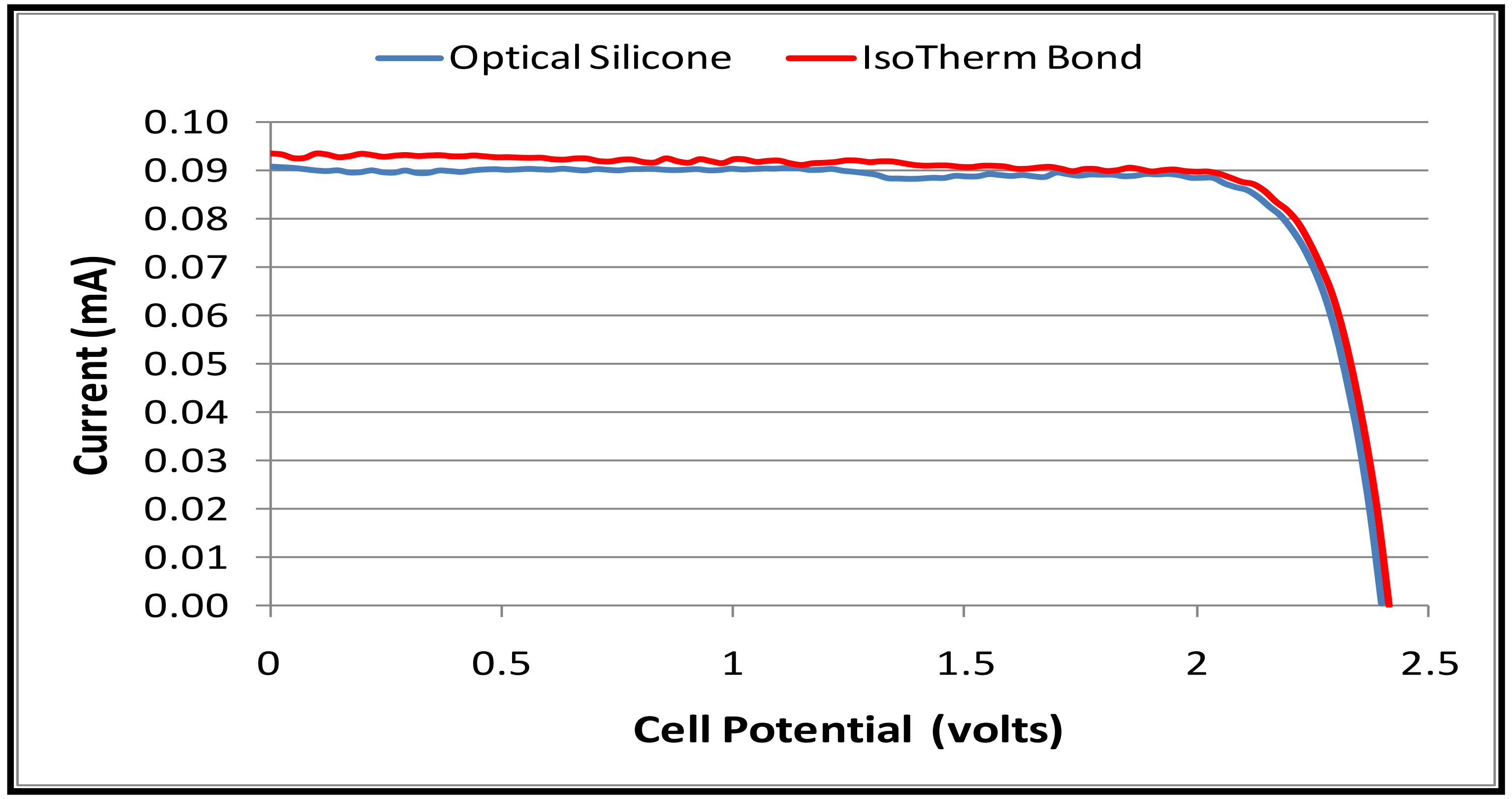


 Hildebrand, J. , *"The Solubility of Electrolytes", Interscience, NY,* 1950

Electric Properties



Bonding demonstration article on traditional multi-junction solar cell



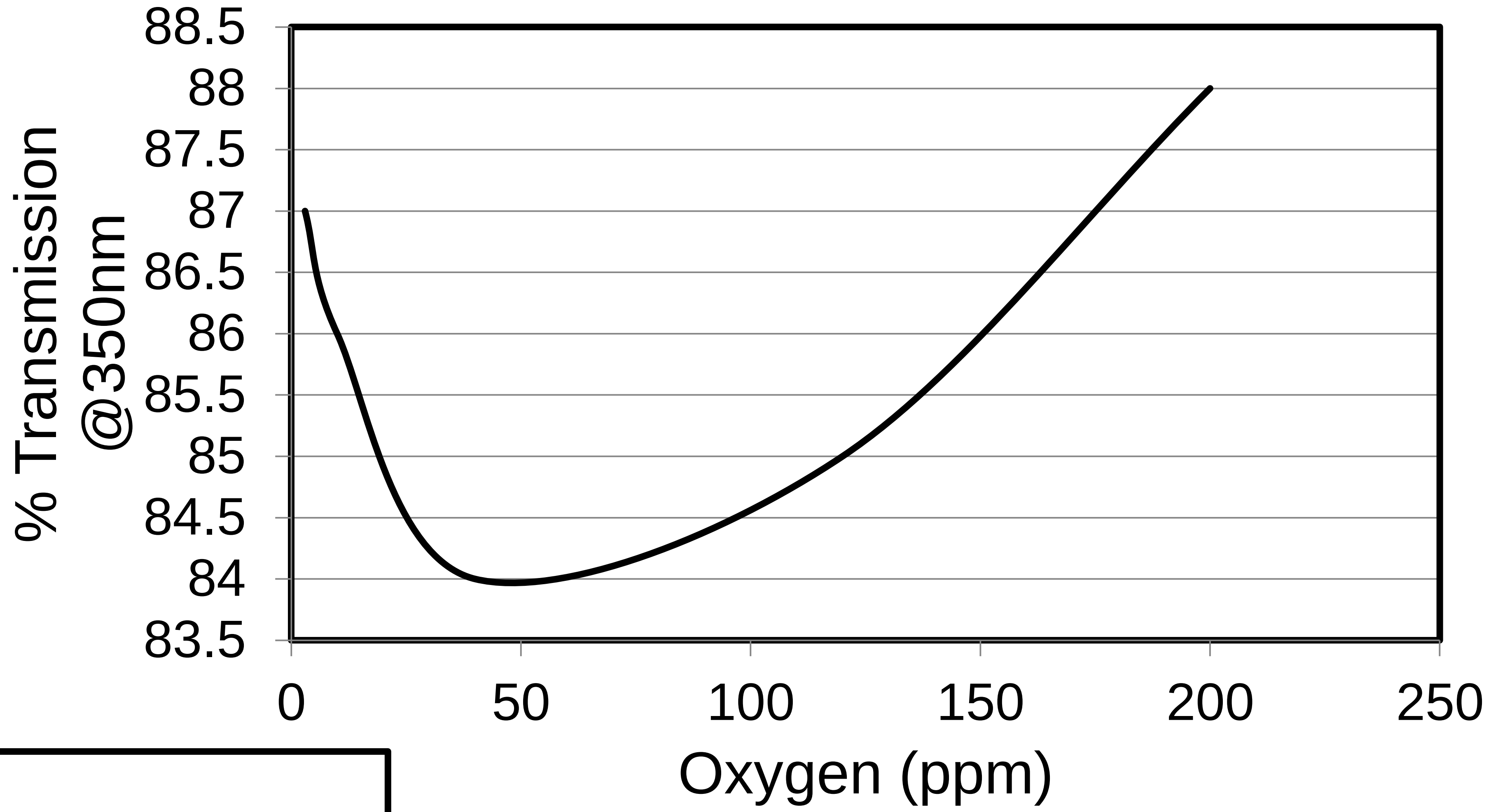
Comparison in electric behavior for multi-junction coupons

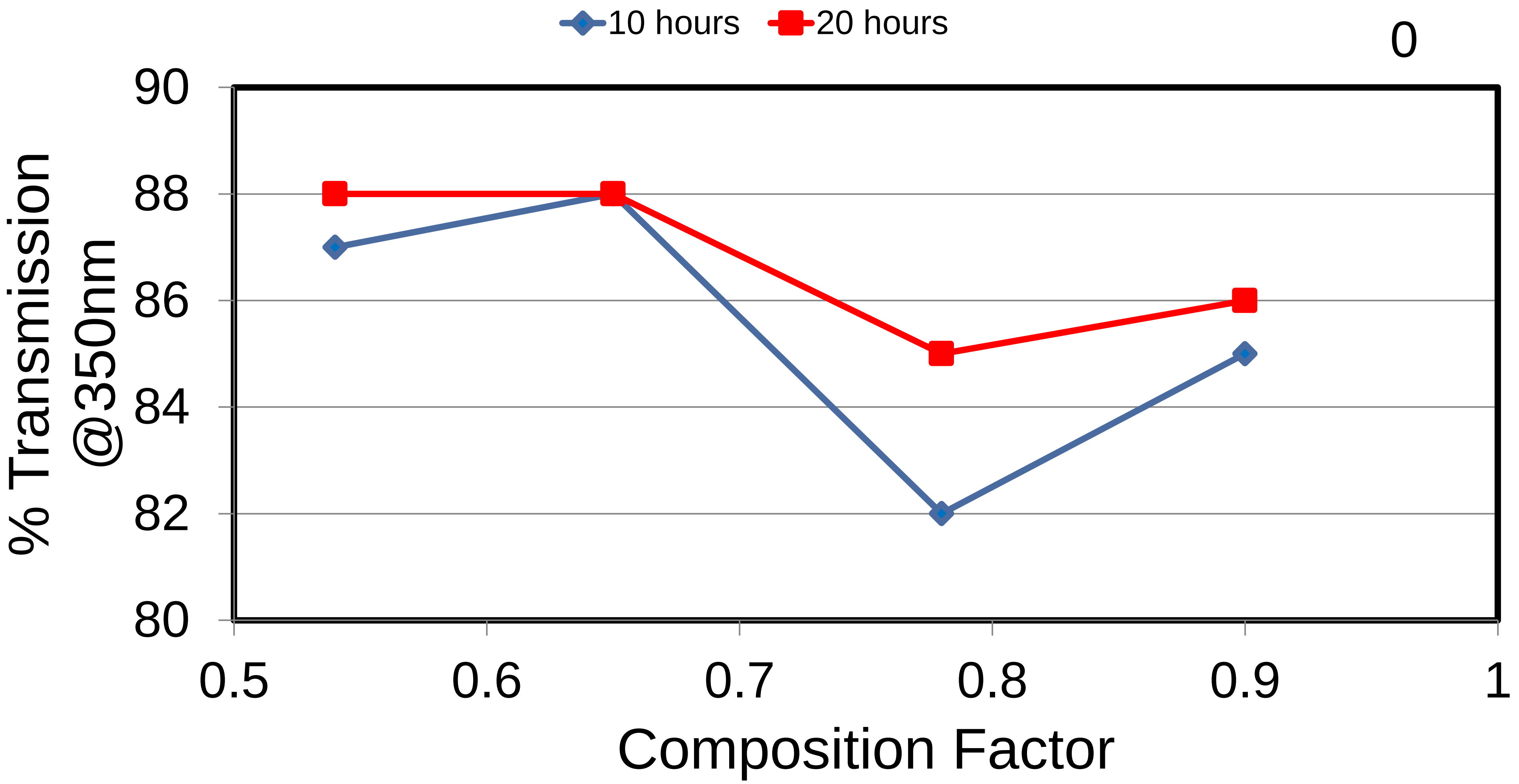
Fractional change in Voc and Isc for iso bonded cells relative to 28% reference comprised of same coverglass and optical silicone bond

Sample ID	05210	06410	06510	07910	09010	06520
Voc (%)	-0.15	-0.5	0.21	0.05	-0.02	0.09
Isc (%)	-0.5	-2.8	-0.8	-0.6	-1.8	-1.1

Optical Properties

- % Transmission as a function of bonding environment (as solidified time = 0 hrs)
- Change in % transmission with composition and time. Temperature held at T_{liquid}.

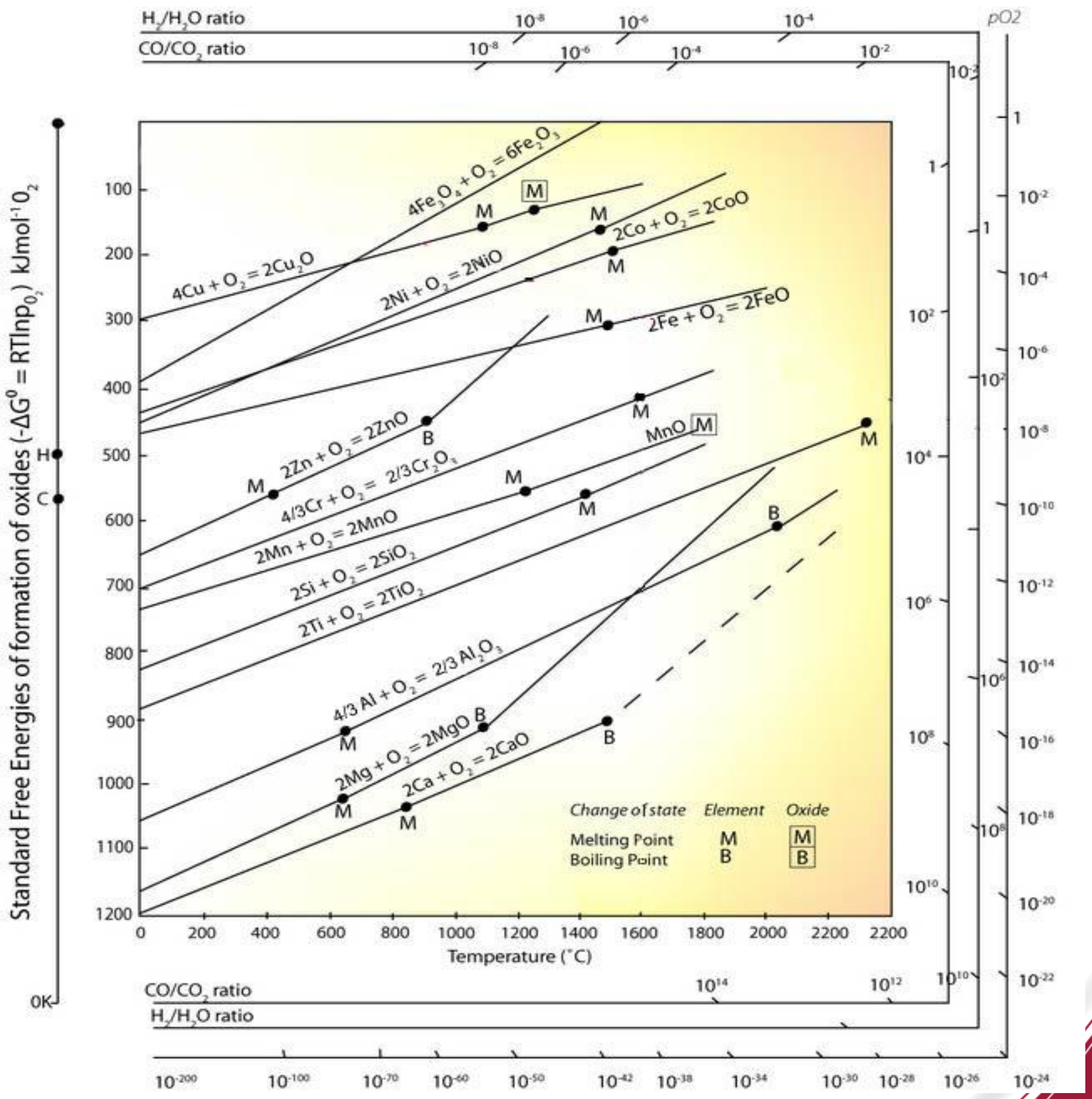




Oxide Stability

- Bond with photovoltaic cell surface but prevent dissolution
  - *Solubility*
    - Considered layered oxides although other combinations are possible
    - Certain oxides have low solubility in the solvent and demonstrate stability
      - *TiO2 is insoluble in eutectic solvent, Al2O3 likely similar with benefit of lower Gibbs free energy*
  - *Ellingham chart*
    - Thermodynamic indication of difficulty in dissociating various oxides
    - Provision for altering stability depending on atmospheric composition as well as temperature
- Atmospheric synthesis under consideration

Increasing Stability

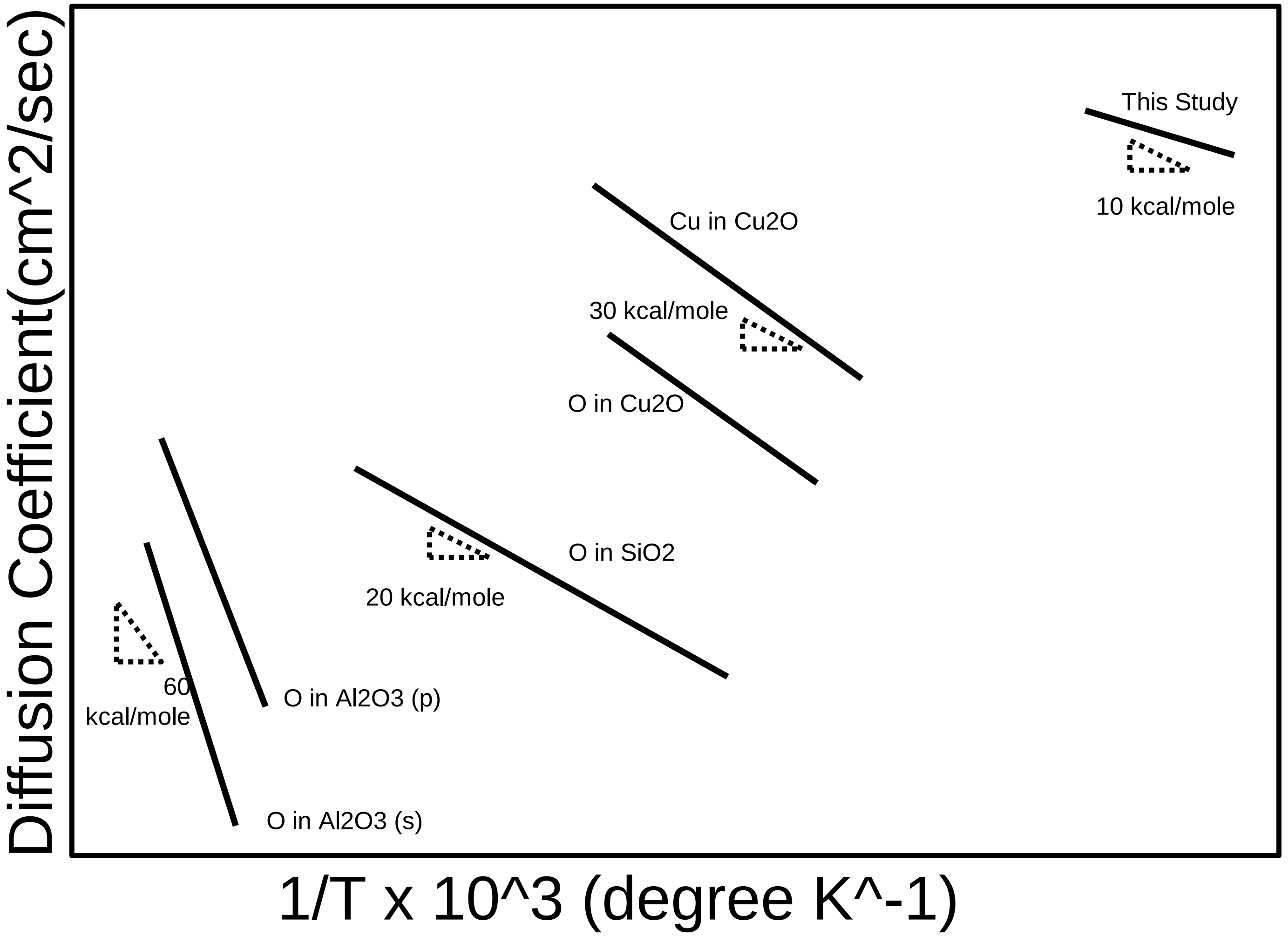


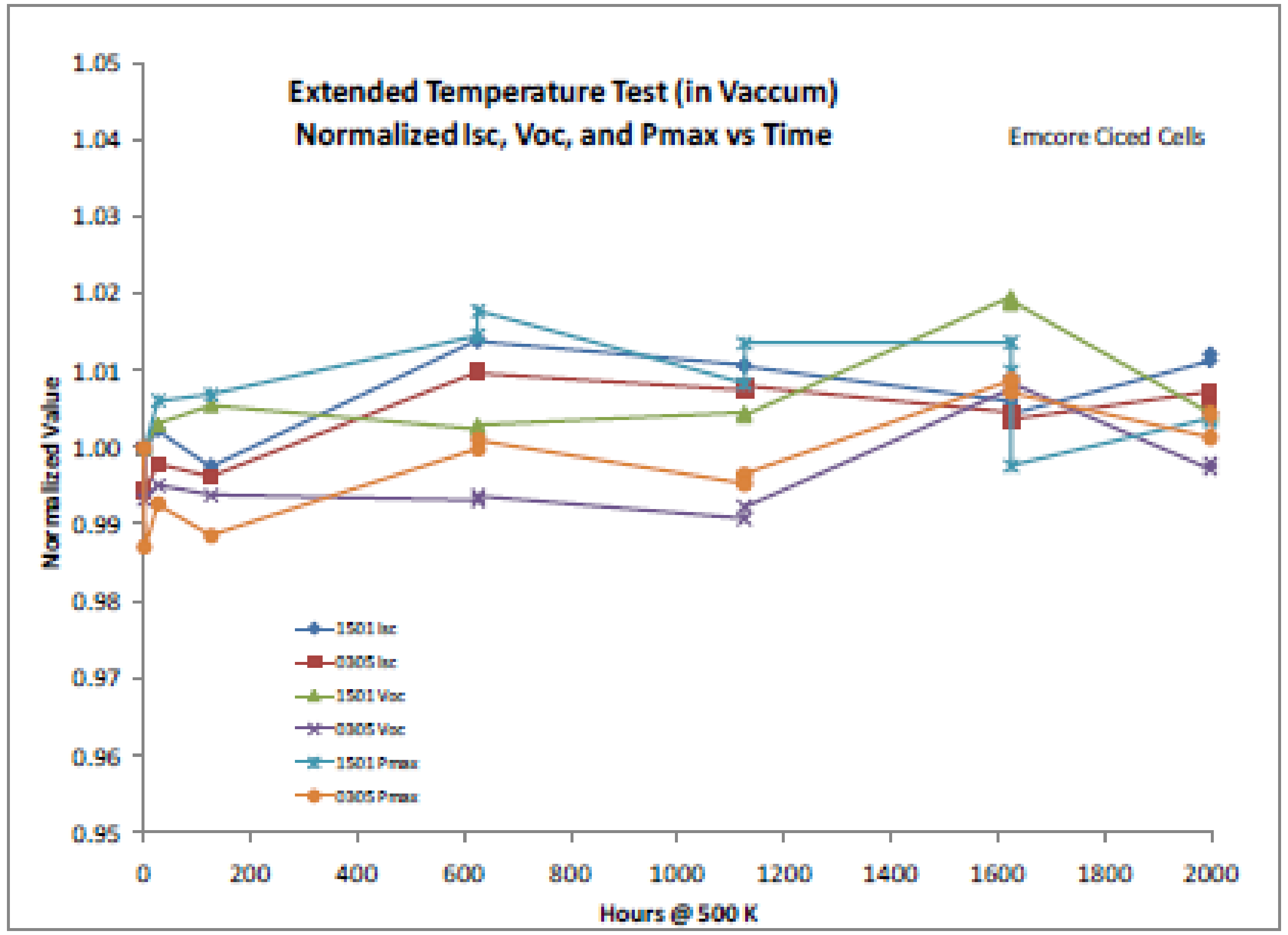
Ellingham Diagram

Ellingham, H, *J. Soc. Chem. Ind. (London)* **63**: 125, 1944

Future Plans

Solid State Transport Mechanism

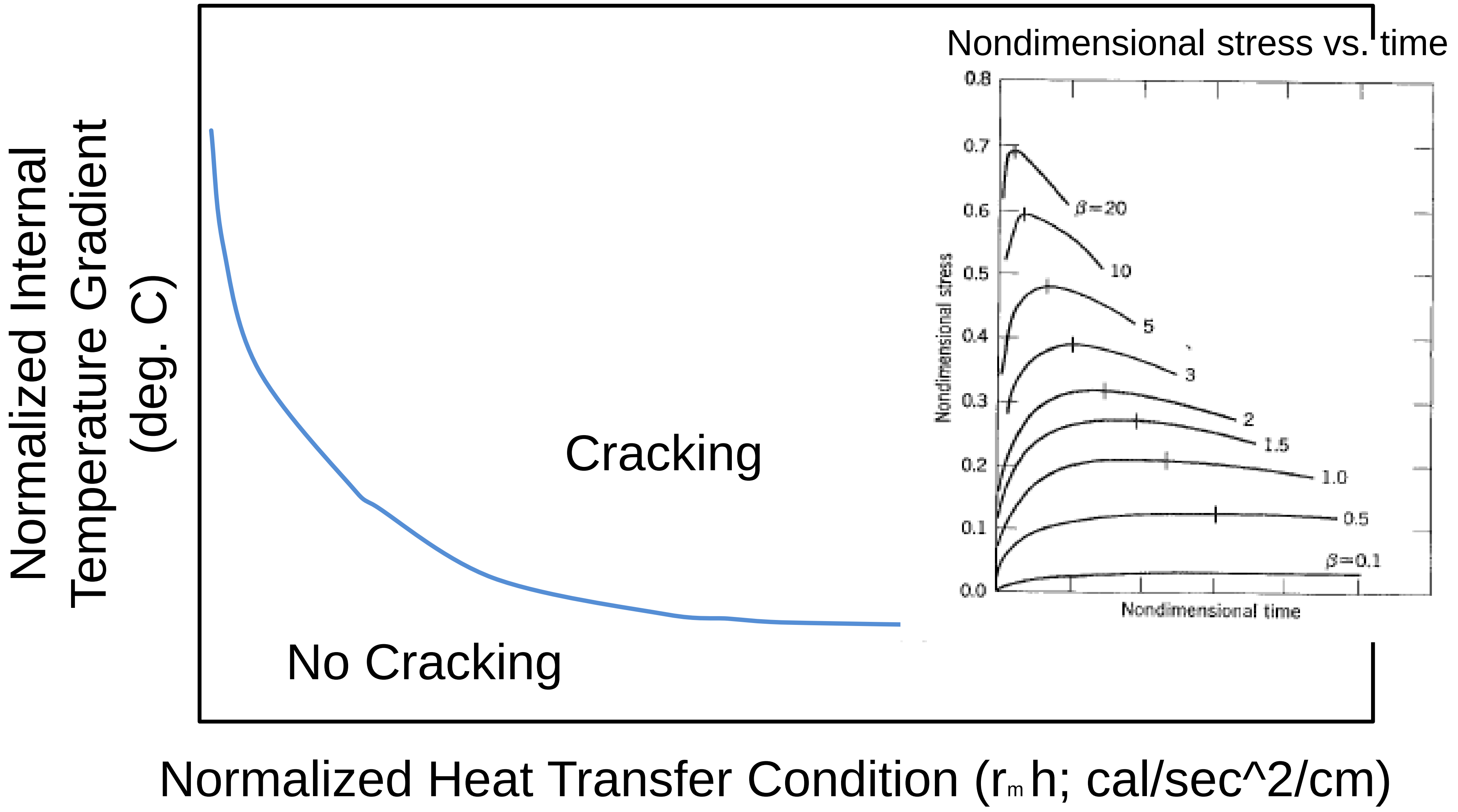


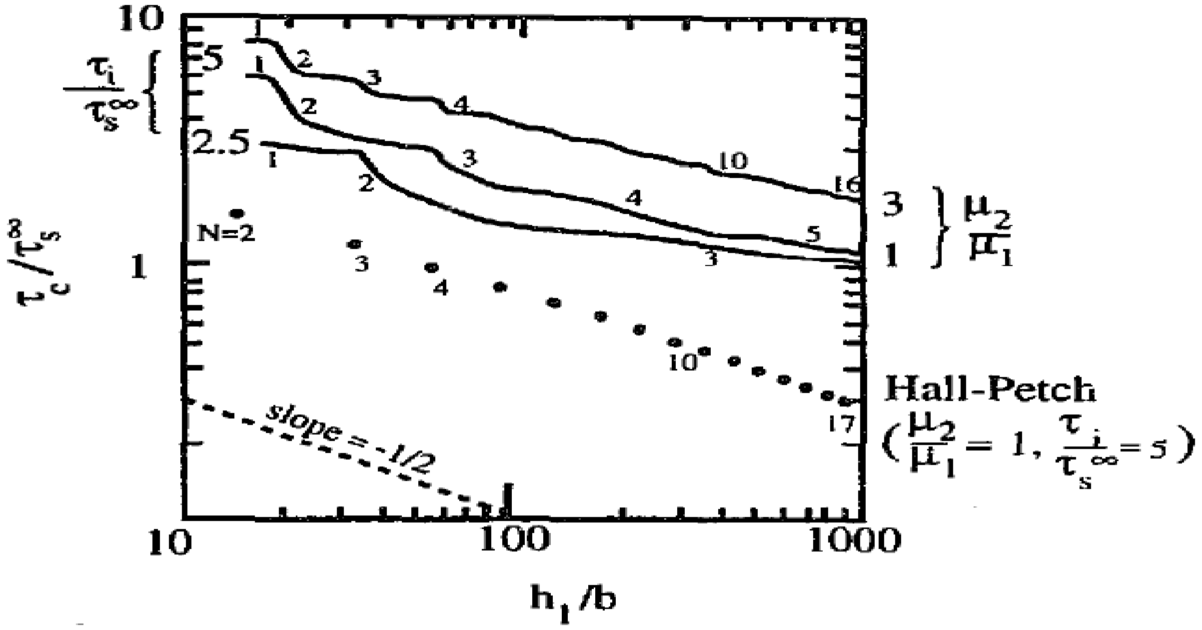


D. Scheiman, Testing of Solar Cells for Solar Probe Plus Mission

Understanding solid state transport mechanism used to reduce bonding time
Spinel formation properties linked to transport mechanism
Looking to see if cells can survive more aggressive bonding temperature

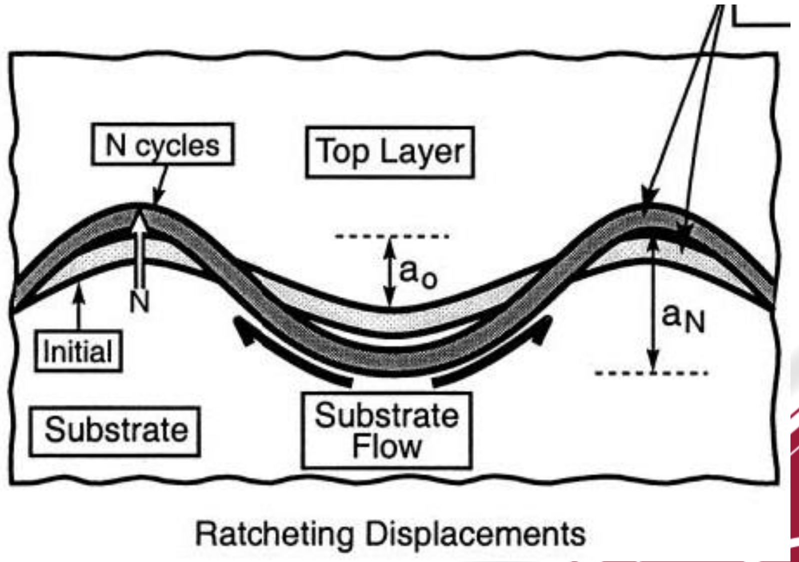
Fracture Mechanism (Thermal, Mechanical Considerations)





Variation in critical shear stress with thickness (Anderson P., 1992)

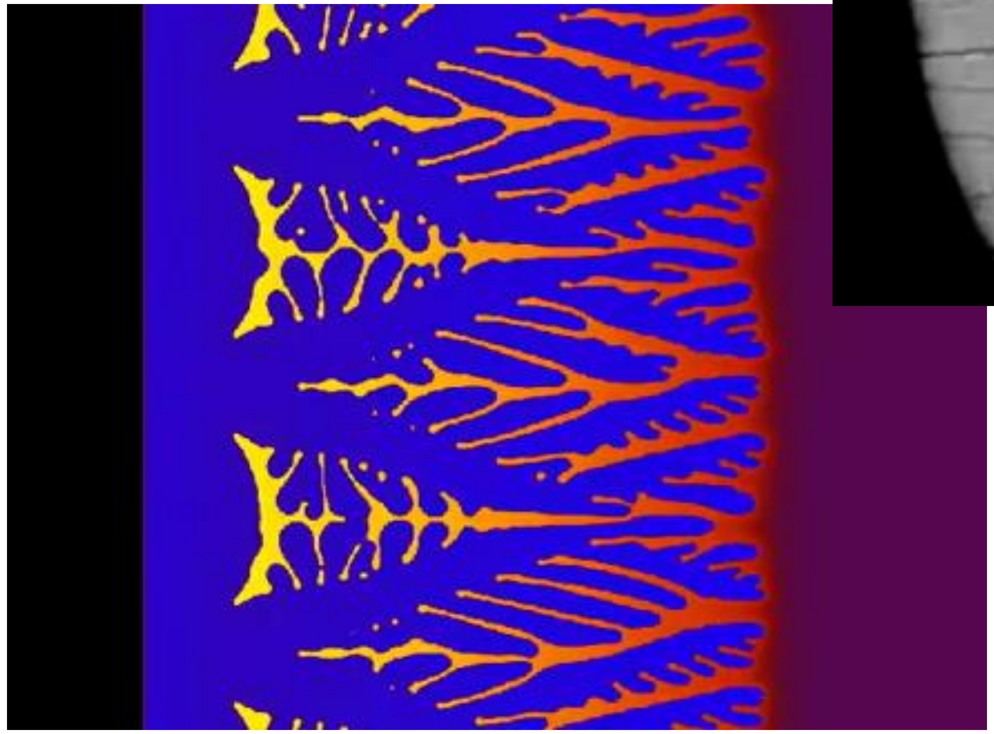
Ratcheting Model (He Y., 1999)

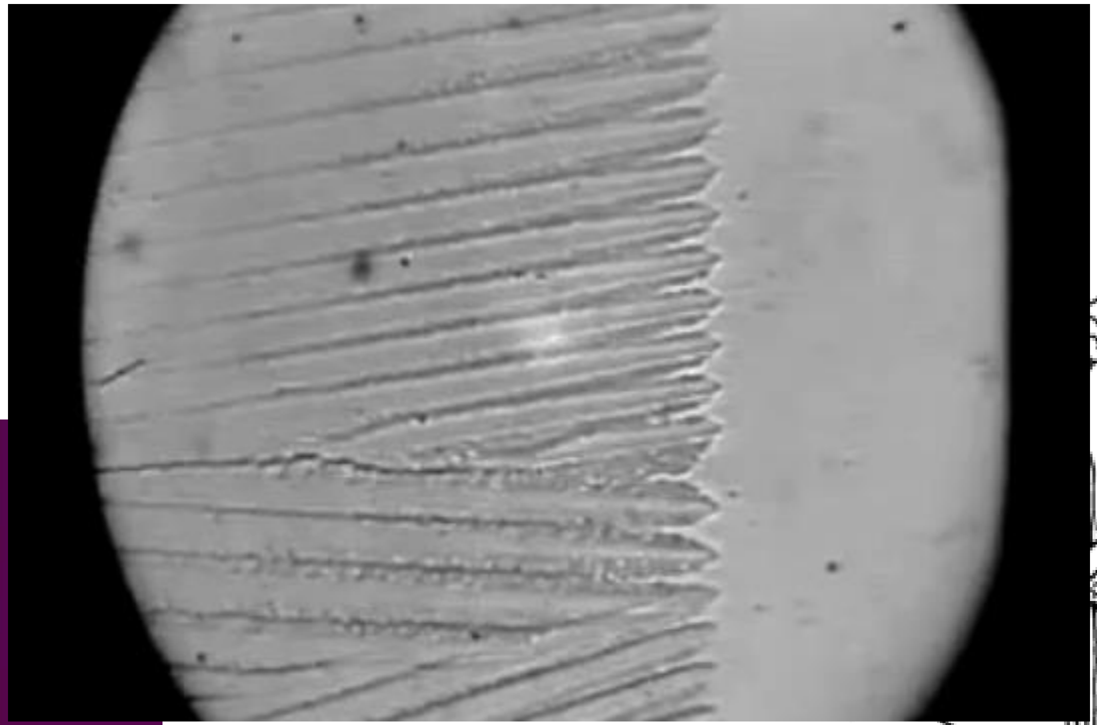


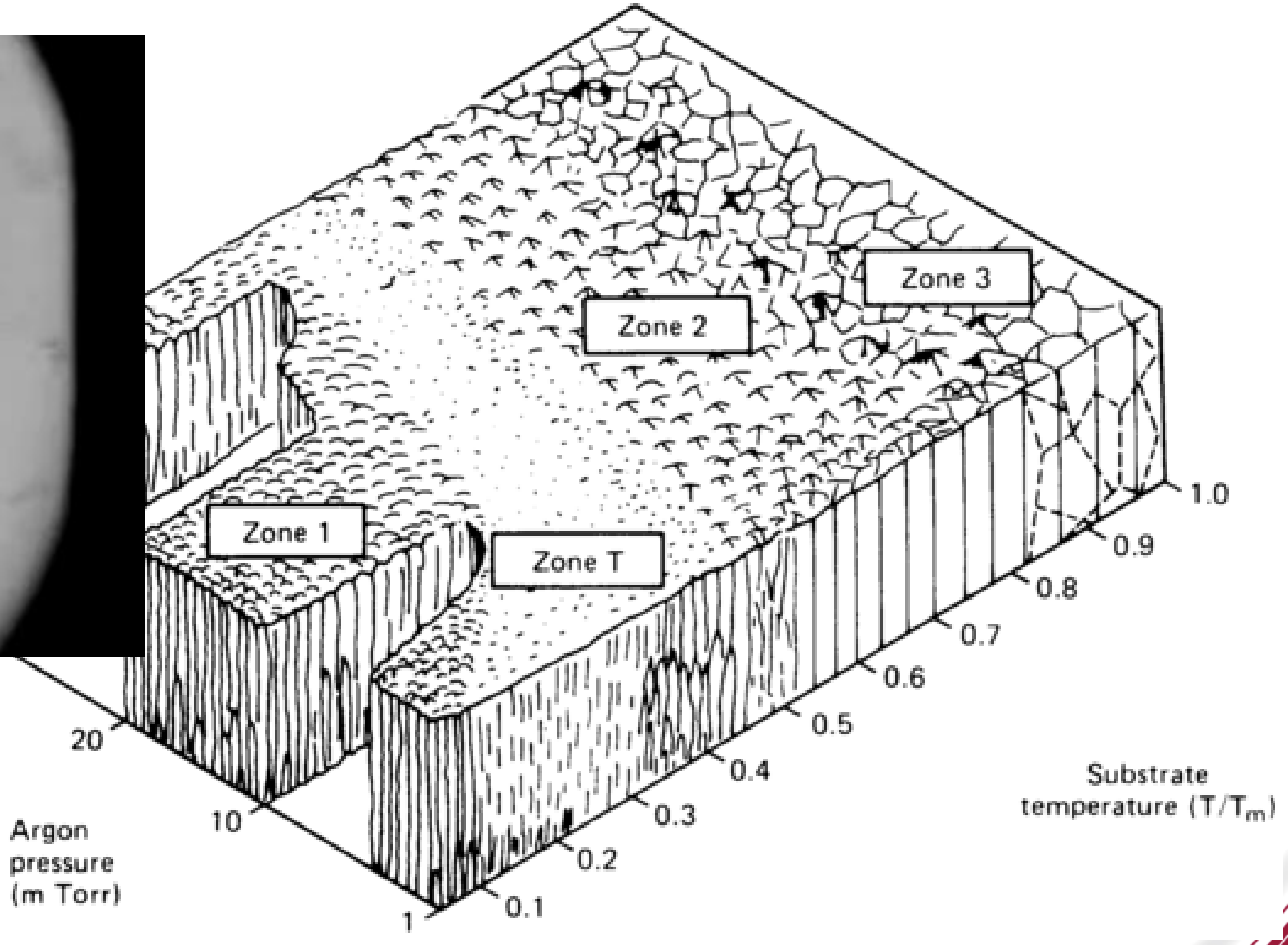
- Bonding IMM with this process alters the heat transfer characteristics from SOP
- Potential to tolerate higher thermal gradient within thin graded interlayers
- First order thermal cycling conducted with out cracking
  - *Necessary but maybe not sufficient depending on fracture mechanics*
  - *Introduction of flaws to evaluate growth vs. combined event*

Solidification mode

- Believe optical performance linked to solidification
  - *Dendritic*
  - *Cellular*
  - *Sputtered*







Summary

- Results to date
  - *Liquid–solid boundary*
  - *Diffusion time*
  - *Optical transmission*
  - *Electrical properties*
- Pending data and analysis
  - *Ficks law investigation under various boundary conditions*
  - *Understanding of reaction processes and kinetics*
  - *Additional thermal cycling coupons*
  - *Detailed optical performance*
- Additional testing planned
  - *Thermal, mechanical behavior*
  - *Solidification phenomena*